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The Economic Commission for Latin America and the Caribbean (ECLAC) was right: scale-free complex networks and core-periphery patterns in world trade

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Abstract

The main purpose of this paper is to apply big-data and scale-free complex network techniques to the study of world trade, with a specific focus on the investigation of ECLAC and structuralist ideas. A secondary objective is to illustrate the potentialities of the use of the new science of complex networks in economics, in what has been recently referred to as an econophysics research agenda. We work with a trade network of 101 countries and 762 products (SITC-4) which generated 1,756,224 trade links in 2013. The empirical results based on network analysis and computational methods reported here point in the direction of what ECLAC economists used to argue; countries with higher income per capita concentrate in producing and exporting manufactured and complex goods at the center of the trade network; countries with lower income per capita specialize in producing and exporting non-complex commodities at the network's periphery.

Keywords: Complex networks, Core-periphery, Economic development, International trade, ECLAC

JEL: D85 - Network Formation and Analysis: Theory, B20 - General, F10 - General

Issue Section: Article

1. Introduction

One of the keys to understanding the models and ideas of the Economic Commission for Latin America and the Caribbean (ECLAC) and structuralist economists in general lies in realizing that the disaggregation of economic analyses by product types is crucial; one cannot understand the economic development of countries without studying the specific technological and productive traits of each type or class of goods produced in a given nation. For ECLAC and structuralists, economic development is nothing more than a productive sophistication from simple products towards more complex ones. For these economists, increased productivity springs precisely from climbing the technology ladder, migrating from low- to high-quality activities and achieving technological sophistication of the economy (Bresser-Pereira, 2016). To this end, building a complex and diversified industrial system, subject to increasing returns to scale, high synergies and linkages between activities is crucial (Reinert, 2010). Specialization in agriculture and commodity extraction alone does not allow for this kind of technological evolution.

How does one empirically measure these propositions? Ideally one could study the structure of world markets as reflected in the world trade web. If the propositions of these authors are correct, one would then find that countries with higher income per capita would specialize in the production of manufactured goods, while poor countries would specialize in activities more closely connected with commodities production and extraction, which is indeed easily seen from a superficial analysis of today's world trade patterns, but difficult to demonstrate in a more robust way. This is the path that this paper will follow. We use complex networks and big-data computational techniques to study the world's trade network. We apply here econophysics' techniques to test classical structuralist ideas. As we will show, the concentration of commodities trade in the hands of emerging countries and of manufactured goods trade in those of rich countries is an important indication of core-periphery patterns in the world trade web.

Other works on econophysics have used scale-free complex networks to study international trade as well (Fagiolo *et al.*, 2008; Deguchi *et al.*, 2014), but not with the focus adopted here: using structuralist ideas and a database focused on productive complexity of countries and products in the world trade web. Serrano and Boguñá (2003) arrived at similar conclusions about the scale-free characteristics of the world trade network that we present in this paper. Our work here is different because we incorporate into the empirical investigations advances from Hidalgo *et al.* (2007), Hausmann *et al.* (2011) and Hidalgo and Hausmann (2011) regarding complexity measurements for the world trade network. This paper thus provides a new analysis for the topology of the world trade network, taking into account recent findings in economic complexity investigations. The empirical results that we report here based on computational and network-science methodologies point in the direction of ECLAC and structuralist economists' arguments.

This paper's main purpose is, therefore, to apply big-data and scale-free complex network techniques to the study of world trade, with a specific focus on investigating structuralist ideas. A secondary objective is to illustrate the potentialities of the use of approaches from the new science of complex networks in economics, in what has more recently become known as an econophysics research agenda (Sinha *et al.*, 2010). The paper is divided into five sections. The next section briefly introduces the connections that structuralist economists draw between economic development and international trade. Section 3 covers measurements of productive sophistication adopted in *The Atlas of Economic Complexity* and introduces the database that will be used for this paper's empirical analysis. Section 4 discusses key themes for the application of scale-free complex networks techniques and addresses the empirical methodology to be used in the paper. Section 5 studies the world trade web and the structure of several international product markets. The fifth and final section concludes the text.

2. Structuralism and economic development

Former development economists, also known as structuralist economists, were mainly divided into two main strands: the Anglo-Saxon and the Latin American. Both based their analyses of economic development on concepts such as productive linkages, poverty traps, core-periphery patterns and dualism in economic systems. The structuralist view defines economic development as a radical transformation of economic structures towards the sophistication of the productive fabric. Assuming that a country's industrial productive structure affects both the pace and the direction of economic development, the structuralist literature emphasizes the importance of industrialization in this growth trajectory. For structuralist economists, in the absence of a robust industrialization process a country cannot increase its employment, productivity and per capita income levels, and thereby reduce its poverty. For these authors the development process involves reallocating output from low- to high-productivity industries, where increasing returns to scale prevail.

Paul Rosenstein-Rodan, Ragnar Nurkse, Arthur Lewis, H. Singer, Albert Hirschman, Gunnar Myrdal and Hollis Chenery belong to the group of economists associated with the original structuralism or classical development economics. Their seminal contributions challenged the neoclassical view of market efficiency as a promoter of the structural change that economic development processes require. Another strand of contributions comes from the so-called Latin American structuralism, which is mainly associated with the Economic Commission for Latin America and the Caribbean (ECLAC), whose works coalesced into a coherent school of thought in the late 1950s. In light of historical experiences, the core thinking of the Latin American strand of structuralism is encapsulated in the works of Raul Prebisch and Celso Furtado, which focused on the specific challenges faced by developing countries in a world economy divided into two poles, the 'center' and the 'periphery', and their distinctive productive structures (Prebisch, 1949; Furtado, 1964). Problems relating to dualism in international trade, technology disparities, balance of payments constraints and state interventionism were all emphasized.

Broadly speaking, these authors emphasized that productive sectors are different in terms of their potential to generate growth and development. Manufacturing sectors, with high increasing returns, high incidence of technological change and innovations and high synergies and linkages arising from labor division, strongly induce economic development (Reinert, 2008). These are activities where imperfect competition rules, with all its typical features (learning curves, fast technical progress, high R&D spending, economies of scale and scope, high industrial concentration, entry barriers, product differentiation, etc.). This group of high value-added sectors are usually opposed to low value-added sectors typical of poor and middle-income countries and its perfect competition market structure (low R&D content, low technological innovation, perfect information, absence of learning curves, etc.).

Many studies associate the emergence of the early structuralism with the publication of Rosenstein-Rodan's 'Problems of industrialization of Eastern and South-Eastern Europe'. In this study, Paul Rosenstein-Rodan assigned particular emphasis to the transformative power of industrialization in the economic system (Rosenstein-Rodan, 1943). In a similar line of thinking, Nurkse (1953), Lewis (1954), Hirschman (1958), Myrdal (1957) and Chenery (1960, 1979) pointed out that the study of long-term economic growth is a 'sector-specific' process and consequently involves an increase of the industry share, which, in turn, provides the highest potential of productivity, spillover effects, forward and backward linkages, as well as technological and pecuniary externalities. Hence, their focuses were essentially on the internal special properties of manufacturing and on the way in which these properties spread to the economy as a whole, stimulating the process of economic growth. Although not always emphasized by the literature, the essence of these classical contributions relied especially on Allyn Young's ideas concerning long-term determinants of economic growth, which were further extended in their seminal studies. These pioneers of economic development also focused on the identification of bottlenecks and rigidities that block the industrialization process in underdeveloped economies (see Gala *et al.* [2016] for a longer discussion of these issues).

Latin American structuralism should be placed in a methodological tradition which has its origin in Raul Prebisch's (1949) study 'El desarrollo económico de la América Latina y algunos de sus principales problemas'. With Prebisch leading a group of outstanding economists, the Economic Commission for Latin America and the Caribbean (ECLAC) sparked remarkable insights and explanations regarding the causes of Latin American underdevelopment. Latin American structuralist writers challenged the neoclassical theory through a critique of the prevailing international trade and proposed a theory of peripheral capitalism incorporating core elements presented in the French tradition, and Anglo-Saxon structuralist traditions, as well as in Keynesian thinking (Furtado, 1967; Love, 1995, 1996; Sunkel, 1989, Palma, 1987, Blankenburg *et al.*, 2008). François Perroux (1939) defined structural economics as a science which analyses the relations characteristic of an economic system situated in time and space. According to him, economic analysis should incorporate institutions and structures over time (see Blankenburg *et al.*, 2008).

Based on this theoretical background, the basic analytical components of ECLAC and other Latin American structuralists were grounded in historical methodology, the study of domestic determinants of economic growth and technological progress, as well as an evaluation of arguments in favor and against state intervention (Bielschowsky, 1998). Many prominent works followed ECLAC thinking and provided important insights, criticisms and complementarities for the understanding of the Latin American underdevelopment. Through a sharp critique of neoclassical economics and its idea that specialization based on comparative advantages, whatever its nature, was a superior solution for economic growth, the Latin American Structuralist school gave life to an important interpretation where the productive structure matters to the pace and scope of the development process. Comparing commodity-producer economies and industrialized countries, Prebisch (1949) noted that productivity was essentially higher in the manufacturing sector than in primary activities. This dichotomy in levels of productivity between the productive structure of developed (center) and underdeveloped (periphery) countries was also analyzed by Furtado (1959, 1961).

For Furtado (1961), the mainspring of capitalist development is technological progress through a process of incorporation and diffusion of new techniques with a consequent increase in production and productivity. Therefore, underdevelopment is seen as a partial and blocked version of development, either because of the uneven spread of technical progress or the limited transmission of productivity gains to wages. In developed countries, dynamic growth is headed by technical progress, while in underdeveloped countries it is determined primarily by external demand for imports. While the center countries internalized new technology by developing an industrial capital goods sector and by spreading the improved technology to all economic sectors, the periphery remained dependent on imported technology which in turn was mainly confined to the primary export sector. Consequently, a sizeable low-productivity pre-capitalist sector continued to survive in the periphery, producing a continuous surplus of labor and consequently keeping wages low. Without the processes of industrialization, the asymmetry between the center and periphery would not only perpetuate but also deepen (see Gala *et al.*, 2016).

During the 1980s, Fernando Fajnzylber provided important contributions in relation to the underdevelopment theory emphasizing the Latin American bottlenecks, especially regarding technical progress and productivity. Fajnzylber (1983) explained the low technological dynamism that characterized Latin American industrialization through a convergence of structuralist thinking, the French regulation school and evolutionary economics. According to Fajnzylber, an economy which does not have an 'endogenous nucleus of technological dynamism' cannot overcome underdevelopment. Moreover, since the sector of capital goods materially incorporates technological progress, policies to strengthen this sector should be carried out to establish an endogenous nucleus of technological dynamism and stimulate the diffusion of technology to other sectors as well as reverse the Latin American structural deficit in the current account. According to Fajnzylber, in Latin America, the problem with transnational companies (TCs) was the establishment of productive structures based on technology transferred by headquarters which therefore did not contribute to the process of technological innovation. To clarify the understanding of how to overcome the inheritance of past mistakes, the author defended that Latin America should not only focus on macroeconomic stabilization and debt reduction, but also push the technological frontier, inducing TCs to adopt innovative domestic behavior.

While various writers contributed to the Latin American structuralist paradigm, Prebisch's original ideas were pivotal in launching a critical perspective on the neoclassical approach to the mutual profitability of free trade between developed and developing countries. In his thinking, a key structural economic characteristic of peripheral economies refers to the deterioration in their terms of trade over time due to different income-elasticity of demand—also known as 'dynamic disparity of demand'. Thus, contrary to what the comparative advantage theory suggested, prices of primary products produced and exported by peripheral countries, such as in

Latin America, tended to present an antagonistic evolution when compared to prices of manufactured products exported by industrialized countries. This means that the center's imports of primary products from periphery rise at a lower rate than its national income, while the periphery's imports of manufactured goods from the center grow at a faster rate than its income. Since demand for manufactured goods increases more rapidly than the demand for primary goods, the well-known Engel's law, there is a tendency to deteriorate the terms of trade of those economies specialized in the production and export of primary goods in comparison to central industrialized economies.

In other words, prices of manufactured goods would be structurally higher in relation to primary products. This meant that peripheral economies would have to export more to achieve the same value of industrial exports over time. In central economies, adjustments along the global economic cycle are made through export quantities, due to the high level of industrialization. On the other hand, in peripheral economies, adjustments occur through export prices due to the primary specialization. In contrast to the free trade doctrine, these movements would be gradually accentuated in the absence of a dynamic industry. Thus, overcoming underdevelopment would not be possible through the international division of labor, in which peripheral countries would be doomed to a specialization in primary products. In this sense, industrialization was seen as a way to modify this process. Through productivity increases, the deterioration of the terms of trade could be reduced, the technological progress incorporated and a process of income distribution promoted. These dynamics were also pointed out by Furtado (1959). In this sense, Furtado's works are closely connected to Prebisch, especially regarding the endogenous dimensions of underdevelopment and its determinants (see Gala *et al.*, [2016] for a longer discussion of Prebisch and Furtado's ideas).

Broadly speaking, the idea expressed by Latin American Structuralism was that, despite the spread of modernity, backwardness and wide differences in labor productivity between economic sectors and subsectors, and between regions and segments of the population, tended to be maintained and sometimes expanded. According to these authors, developing countries could be characterized by a dual structure where a late agricultural sector and a sophisticated industrial sector would coexist. The manufacturing importance *vis-à-vis* a concentration in primary commodity exports was a central concern of the structuralist approach associated with ECLAC. Industrialization based on productive sophistication was seen as the only way for developing countries to catch up. Kaldorian theory (1966), which concentrated on the demand-supply relationships in the manufacturing sector, complements this view, giving further elements to explore the importance of the industrialization process, more specifically the manufacturing sector (Taylor, 2004; Ocampo *et al.*, 2009).

3. Economic complexity and patterns of international trade

Hausmann *et al.* (2011) use computational, network and complexity techniques to create an ingenious method for comparison of productive sophistication, or 'economic complexity', across countries. Starting from an analysis of a given country's exports basket, they are able to indirectly measure its productive technological sophistication. The methodology devised to build economic complexity indexes culminated in an *Atlas* (http://atlas.media.mit.edu) that collects extensive analyses on countless products and countries over 50 years, starting in the 1960s. The two basic concepts used to measure whether a country is 'economically complex' are the ubiquity and diversity of the products found in its exports. If a given economy is capable of producing and exporting several non-ubiquitous goods, this indicates the presence of a sophisticated productive fabric.

This measure obviously involves a scarcity problem, particularly of natural resources. Non-ubiquitous goods can be divided into those with high technological content, which are therefore difficult to produce (airplanes), and those that are highly scarce in nature, such as diamonds, which are therefore naturally non-ubiquitous. To control for this issue of scarce natural resources in complexity measurements, the authors of the *Atlas* use an ingenious technique: they compare the ubiquity of the product made in a given country with the diversity of the exports of countries that also produce and export this good. To illustrate: Botswana and Sierra Leone produce and export something that is rare and therefore non-ubiquitous, rough diamonds. On the other hand, their exports are extremely limited and undiversified. These, then, are instances of non-ubiquity without complexity.

At the opposite end of the ubiquity spectrum we could mention image-processing medical devices (X-ray equipment), which practically Japan, Germany and the USA (complex countries) alone can manufacture and export; these are non-ubiquitous complex products. In this case, the export composition of Japan, USA and Germany is extremely diversified, indicating that these countries are highly capable of making many different things. In other worlds, non-ubiquity with diversity means 'economic complexity'. On the other hand, countries with highly diverse export composition made up of ubiquitous goods (fish, meat, fruits, ores, etc.) do not show high economic complexity; they produce and export what all others can do. Diversity without non-ubiquity means lack of economic complexity.

One of the main virtues of such economic (ECI) and product complexity (PCI) indicators is the fact that they operate based on quantitative measures obtained from linear algebra calculations. There is no account of qualitative issues relating to the production and exports of those goods. That is, no judgment is made as to what is regarded as complex or non-complex. Along these lines, the authors rate several countries and arrive at robust correlations between income per capita levels, inequality and economic complexity (Hausmann *et al.*, 2011; Hartmann *et al.*, 2015). Japan, Germany, Switzerland and Sweden are always ranked among the top ten countries in terms of complexity. Economic development may be treated as the mastery of more sophisticated production techniques, which usually lead to higher value-added per worker as argued by structuralist authors. This is what economic complexity indicators ingeniously capture from measures of ubiquity and diversity of exports from various countries. The *Atlas*'s results are in line with predictions from structuralist economists regarding specialization patterns in world trade: rich countries tend to specialize in producing manufactured goods, poor countries in commodities; an aspect we will explore in greater depth ahead.

The *Atlas of Economic Complexity* offers yet another important empirical contribution: by calculating the probability of products being jointly exported by several countries, the *Atlas* also creates an interesting measure of productive knowledge embedded in products and of local capabilities needed for their production; the 'product space' (Hidalgo *et al.*, 2007). The greater the probability of two products being co-exported, the greater their 'proximity' and the more indication that they contain similar characteristics and therefore require similar productive capabilities; they are 'siblings' or 'cousin' products. The co-exportation indicator ultimately serves as a measure of each product's 'connections', that is, an indication of the productive ties linking various goods as a result of their shared requirements for production. Highly connected goods are therefore loaded with knowledge and technological potential; they are 'hubs of knowledge', whereas those with low connectivity have low knowledge multiplication potential. For example: countries that make advanced combustion engines probably have engineers and knowledge that enable them to produce a series of similar and sophisticated things. Countries that only produce bananas or other fruit have limited knowledge and are probably incapable of making more complex goods. It is important to emphasize that the difficulty in observing these differences arises from our inability to directly measure and capture such local productive skills. What one observes in international trade are the products, not countries' ability to produce them.

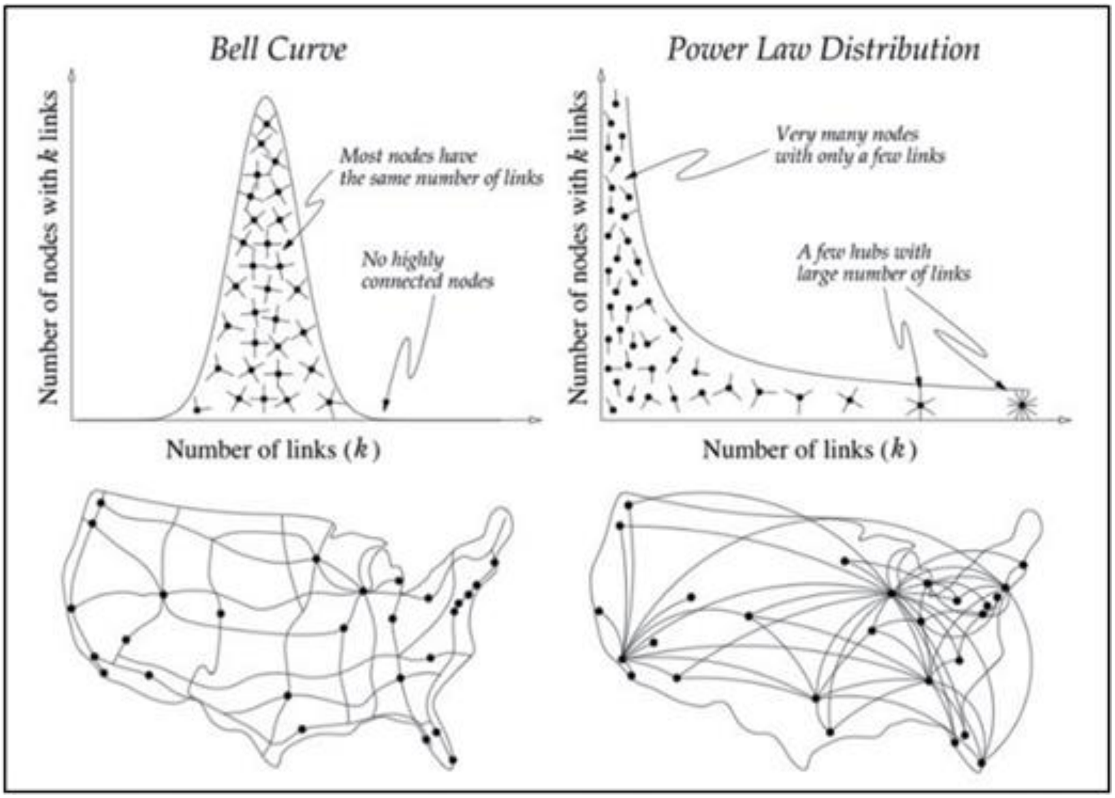
Some examples from the *Atlas of Complexity* illustrate the point: machinery in general and cars are highly 'connective' and complex in terms of knowledge content and are therefore 'hubs of knowledge'; iron ore and soybeans have very low connectivity and are non-complex. Manufactured goods stand out from other kinds of goods in terms of complexity and 'connectivity'. Commodities in general lack these characteristics. Empirically, the *Atlas* shows that manufactured goods are generally characterized as more complex and connected, whereas commodities emerge as non-complex and non-connected goods. Out of the 34 main communities of goods in the *Atlas* calculated by their network compression algorithm (Rosvall and Bergstrom, 2008), one finds that machinery, chemicals, airplanes, ships and electronics stand out as the more complex and connected goods. On the other hand, precious stones, oil, minerals, fish and shellfish, fruit, flowers and tropical agriculture show very low complexity and connectivity. Vegetable oils, textiles, construction material and equipment and processed food occupy an intermediate position between more and less complex and connected goods.

4. Big data, scale-free complex networks, power laws and hubs

Studies in complexity gained momentum in economics after Brian Arthur's work (Arthur, 2015; Foster, 2005) as the head of New Mexico's Santa Fe Institute in the late 1980s. With applications on various fronts, complexity approaches have been applied to different fields of research in economics and other sciences. Applications are used, for example, in game theory, political science, biology and physics. Original applications in economics were on modeling of financial markets, individual decision-making rules in various contexts and studies on path-dependence and technological dynamics with increasing returns. The *Atlas* presented in the previous section advances the discussion of complexity combining it with Big Data techniques to create what is perhaps one of today's most relevant economic databases for world trade analysis. The term 'Big Data' has been widely used in various contexts to describe the explosive growth of data available from the digital world. At its roots, Big Data deals with a large volume and variety of high-velocity data.

In a compilation of his works on scale-free complex networks, Barabasi (2002) provides a detailed explanation of the concepts and recent contributions to network science within the context of Big Data in different fields of knowledge, some practical examples of which include the Internet itself, the network of Hollywood actors and films, and biological and linguistic networks, among many more. The simple case of the US airlines network (see Fig. 1 below) as presented by Barabasi (2002) explains in a clear manner the concept of scale-free complex networks that we will use in our empirical analysis below. The first network is that of the US highway system with many connection nodes (each city is a node) and no relevant hubs. The airlines network in the same graph is the opposite case: a complex network with hubs (that is, large nodes with many connections), therefore a non-random network. A few hubs exist that concentrate the majority of connections (Chicago, New York, Houston, LA, etc.). In such complex, non-random networks, a few hubs hold the majority of connections and many other nodes have very few connections. A new city that tries to compete in terms of receiving and sending flights will face great difficulty when competing with the mega hubs. Its status as an 'ordinary hub' in the network makes entry into this 'space' far too difficult. The network is considered to be scale-free because the number of links connecting to the nodes does not follow a well-behaved pattern, but rather a power-law distribution.

Fig. 1.



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Complex scale-free and random networks Source: Barabasi (2002)

Nodes in a random network have a random number of links. In a scale-free complex network, a few nodes have the majority of the links (the hubs) and the great majority of other nodes have very few links. A Gaussian distribution characterizes the former kind of network, while the latter is characterized by a power-law distribution. Non-random networks show a hierarchy where the hubs prevail because they have far more access to links than ordinary nodes: a 'topocracy' reigns (Borondo *et al.*, 2014). Competition inside these networks is uneven in the sense that, over time, certain nodes collect large numbers of links to become hubs with greater access to other nodes of the network. An 'ordinary' node faces great difficulty when competing with a hub because it starts out from a poor position in terms of its stock of accumulated links. Barabasi (2002) and his team created a simplified model that reproduces with remarkable accuracy this kind of real-world network dynamics; the model has three pillars: i) a network that grows with new nodes being incorporated to other nodes by means of links at every point in time; ii) a preferential attachment rule according to which each new node prefers to connect to an existing node with lots of links; and iii) fitness: some nodes are more competent link-accumulators than others, which may help a new node to overcome the difficulty of lacking links when it enters the network.

Barabasi (2002) uses these three simple rules to formally replicate the characteristics of such networks in the real world, including the appearances of power-law distributions as indicated above in the case of the US airlines network. Barabasi's 'preferential attachment' mechanism is nothing more than the familiar dynamics of increasing returns illustrated in the well-known single urn Polya-process or in a generalized several urns Yules-process. H. Simon showed that power laws may emerge as consequences of Yule-type processes (Newman, 2010). These findings are crucially important for economists because they formalize and add analytical content for already known insights and empirical regularities; particularly for discussions of the new economic geography and trade theory. This kind of Barabasi network dynamics clearly illustrates the increasing returns and path-dependent processes that Myrdal (1957) and Arthur (2015) demonstrated in their works.

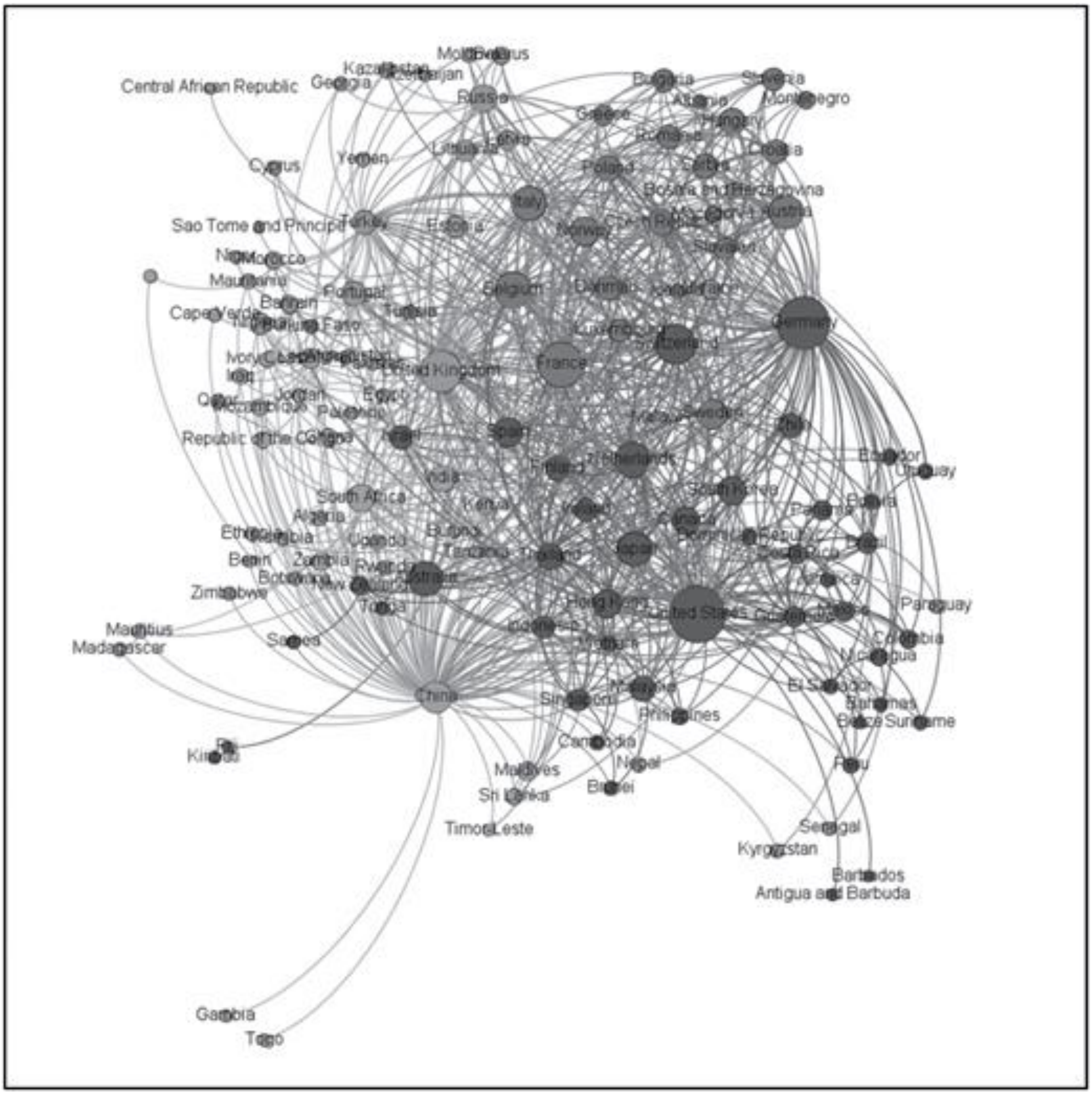
5. The scale-free complex network of international trade

The first step of our empirical approach was to study the structure of the international world trade web for the year 2013 (last complete data set available at the *Observatory of Economic Complexity* for SITC-4 products). To do so, we began by investigating the number of links for each node (countries) in the world trade web; one link represents one product that goes from one country to another. Our final database, after several filtering procedures to eliminate countries with missing data, resulted in a trade network with 101 countries, 762 products classified according to the Standard International

Trade Classification (SITC Revision 2 with 4 digits) and 1,756,224 links between nodes. Each node in the network represents a country that trades an SITC-4 product, and each link represents a trade connection between two countries. The more links a country has in a given market, the greater its relevance is according to our methodology; many links mean that a country is able to achieve several other countries in that specific market. The economic idea we follow using this kind of approach is that a country with many links for a given product reveals comparative advantages proven to be important in this market. Many factors exist that can explain these comparative advantages: i) locational advantages in terms of low freight cost; ii) relatively abundant natural resources; iii) cheap or specialized labor in the production of certain goods; iv) technological advantages; and so forth.

The network below (Fig. 2) exemplifies the methodology for the world market of blown glass (top 1 SITC-4 product from the *Observatory of Economic Complexity* in 2013). This network has 133 nodes (countries) and 962 links which represent products going from country A to country B, measured by the presence or absence of exports from A to B. The bigger hubs dominate this market, while peripheral nodes have little relevance and are usually mere recipients of products. The network plotted below represents a single market for the purposes of enabling a visualization of our methodology. To get a sense of the world trade network of our complete database, one could multiply the network below by the other 761 products.

Fig. 2.



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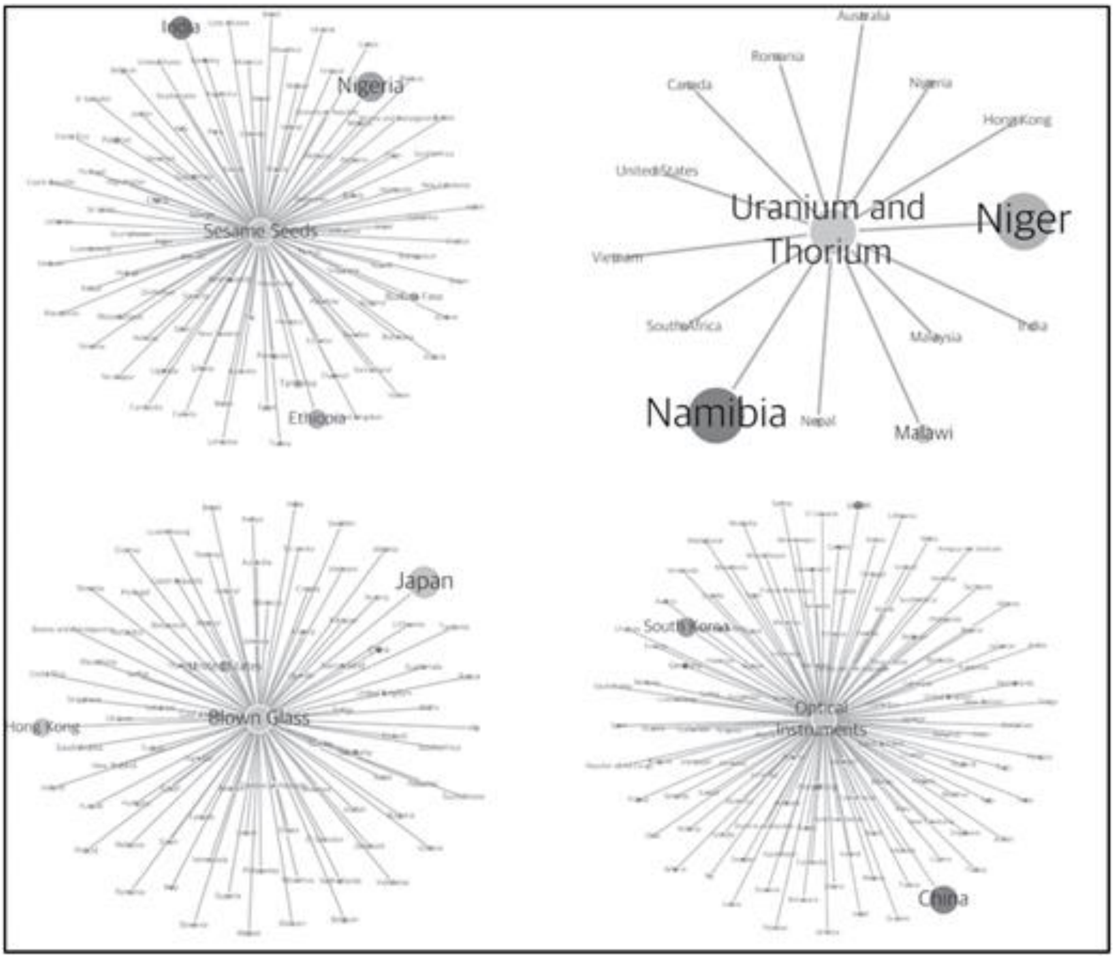
World market of blown glass in 2013 Source: Elaborated by authors.

Identifying trade hubs based on the number of country links brought us newer results when compared to other works in the literature that measure country's participation in markets as the total value of their exports in current dollars relative to total market values (Hausmann *et al.*, 2011). This approach also enabled us to run an algorithm to detect the presence of power laws and hubs in the main global trade network (including all countries and all SITC-4 products) and in the various SITC-specific markets. A country with an excessive number of links is considered to be a hub, as discussed previously. As an example, Fig. 3 below describes the commercial networks for sesame seeds, uranium and thorium, blown glass and optical instruments, the two less complex and the two more complex products, respectively, as measured by the *Atlas of Complexity*. The graphs indicate which countries export each product, where the size of the country nodes represent the share of each country in the exports of each product and the color intensity of the nodes indicates the number of links that the country has on the trade of this product. Uranium and thorium and sesame seeds, the less complex products, are exported from less diversified countries. India, Nigeria, Ethiopia, Namibia and Niger are the main exporters of these products (higher node size). On the other hand, blown glass and optical instruments, the two more complex products, are exported by very diversified countries. Once again, the size and intensity of the nodes' color highlight these characteristics: Japan, Hong Kong, the USA, South Korea and China are the main exporters of these products (higher node size and color intensity).

Fig. 3.



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Four SITC markets and their countries in 2013 Source: Elaborated by authors.

One can see above that there are several relevant nodes in those markets and some larger hubs. The uranium and thorium markets seem to be dominated by Niger and Namibia; the sesame seeds market has as its most important players India, Nigeria and Ethiopia. In our methodology, India has the biggest number of links in this market; optical instruments are dominated by China and South Korea, and blown glass by Japan and Hong Kong. The algorithm for the detection of power laws in terms of numbers of country links in all markets found a positive result for some of the SITC-4 products and for the network as a whole (coefficient 2,58). The procedure captures the distributions of links across markets and calculates power-law coefficients using the 'Maximum Likelihood Fitting' method described by Newman (2010):

$$\widehat{\alpha} \simeq 1 + n\left[\sum_{i=1}^{n} \log\left(\frac{x_i}{x_{min}-0{,}5}\right)\right]^{-1}$$

where $\widehat{\alpha}$ is the power-law parameter, n is the number of elements in the array where the data is contained, x_i is the value of the variable i in the vector x and x_{min} is the minimum value of x which starts the power law. The Table 1 below shows the results in terms of distributions of these power laws for the 762 SITC-4 products analyzed. Power laws are characterized when 2<a>3. When a>3, networks are characterized as indistinguishable from random ones according to Barabasi (2016).

Table 1

Power Laws distributions in the sample

Alpha Coeficient	Percentage
Alpha = a< 1	0%
Alpha = 1<a> 2	25%
Alpha = 2<a>3	34%
Alpha = a>3	41%
Total	100%

Source: elaborated by authors

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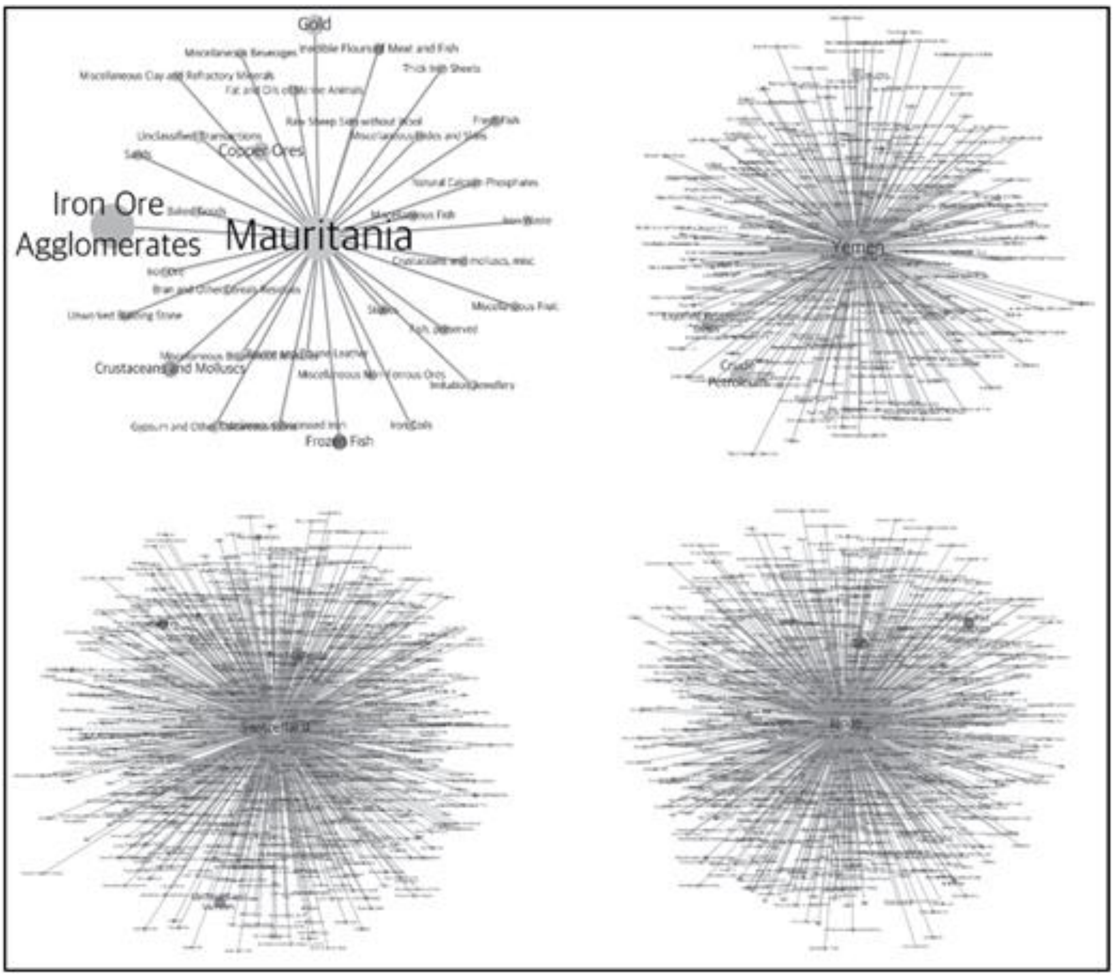
According to the Table 1 above, no SITC market shows linearity or sub-linearity in the power-law coefficient, meaning that as long as the number of country links increases in this market, the growth rate in the number of links is less than proportional or proportional to growth. Twenty-five percent of the products show super-linearity, that is, when the number of country links grows, they increase more than proportionally. For power laws with values of the alpha parameter between 2 and 3, results are positive for 34% of the markets in the sample. This shows that for one-third of SITC markets studied here, we found relevant hubs in world trade and a scale-free pattern. For all these products and for the network as a whole, we find a few countries dominating world trade in terms of number of links or countries accessed, a result that approaches HHI concentration measurements for world markets. As an exercise, we found very similar results in terms of the methodology followed here and HHI kind of measures for markets of soya beans, wheat and coffee made, for example, by Oladi and Gilbert (2012); further research here seems to be promising.

Based on the idea of product complexity indexes (PCI), we also made an analysis of the total number of country links weighted by the 'quality' of the product. The purpose in this case was to capture the quality of links of various countries in terms of complexity of products exported. Thus, if country A has many links in a low-complexity market as measured by a low PCI (sesame seeds market, for example), its productive capabilities will probably be worse than those of country B with fewer links but in a highly complex market as measured by a high PCI (say, optical instruments). For the purpose of visualization, Fig. 4 below shows the total trade links of Switzerland and Japan (the top two ranking countries in complexity) and Mauritania and Yemen (the ranking's bottom two) in terms of exported SITC products. The graphs indicate which products were exported by each of the countries, where the size of the product nodes represents the share of each product in the exports of that country. Mauritania and Yemen, the least complex countries, are poorly diversified exporters with fewer connections. On the other hand, Switzerland and Japan, more complex countries, are very diversified exporters with many connections to more complex products.

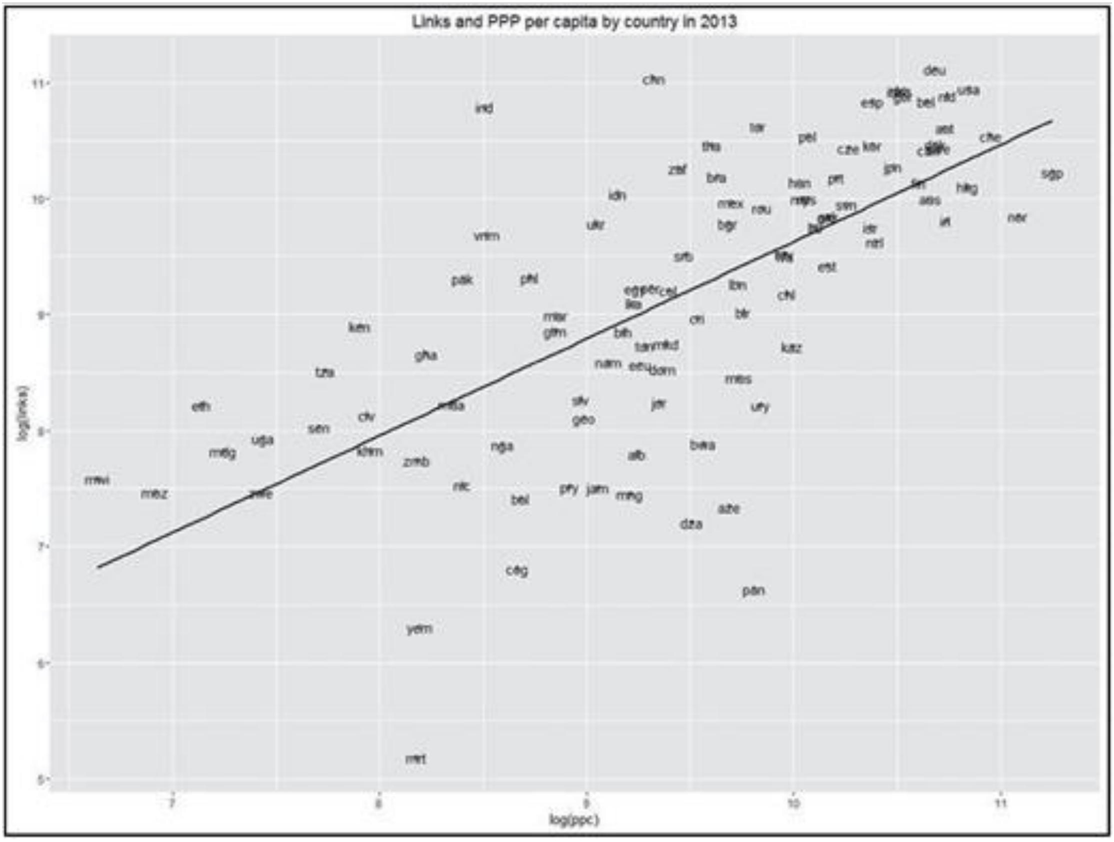
Fig. 4.



Four countries and their products in 2013 Source: Elaborated by authors.

After studying links and hubs, we moved on to a second step in our empirical efforts: regression analysis to better understand the network of 101 countries, 762 products and 1.756.224 links. Our objective in this second stage of the empirical analysis was to detect potential productive patterns in terms of income per capita levels, quantity and quality of trade links and complexity levels of exported products. The regression plotted below (Fig. 5) shows our main results for the complete network. The regression reveals an important correlation between countries' total links and their per capita incomes (PPP). The closer to the center of the world trade network a country lies, the greater its per capita income is; both per capita incomes and the total number of links per country increase in a non-linear fashion (log-log) across countries. We use here the total number of links per country as a measurement of network centrality (see degree centrality in Newman [2010]).

Fig. 5.

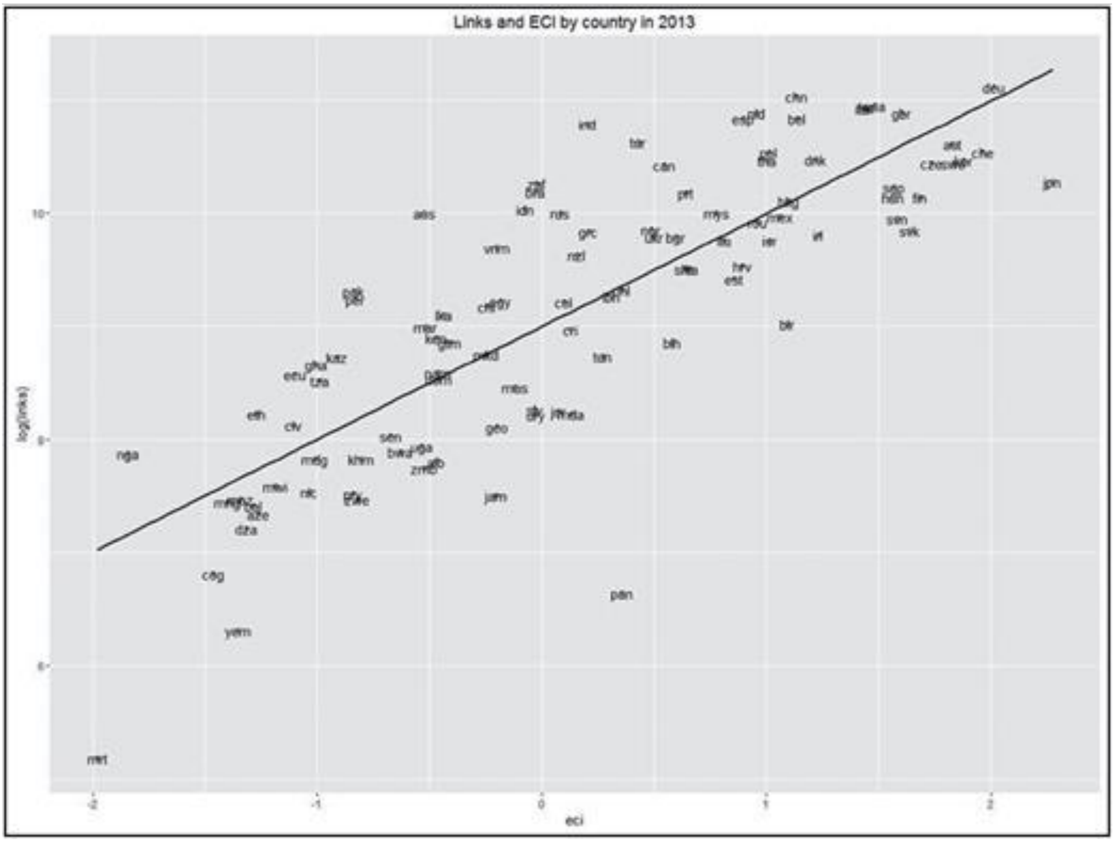


Regression of number of links on per capita income (PPP) Source: Elaborated by authors.

We also ran regressions with the transformation in the number of product links from non-weighted to weighted according to product complexity (PCIs) ratings of SITC products, as mentioned before. In this second exercise, we assigned a greater weight to complex products and a lower weight to non-complex ones (see appendix). The results were the same in terms of R-squared and significance, showing that a country's proximity to the center of the network persists regardless of whether the analysis is done with qualified or non-qualified links. That is, central countries are hubs both in terms of the total range of products traded and of the more qualified range of trades represented by more complex products.

The total number of links is also strongly correlated with each country's economic complexity, as the regression below (Fig. 6) shows, one more indication that sophisticated countries conquered many markets and were able to develop productive capabilities for countless complex products. This applies to countries with large and small populations according to the regression analysis that we did (see appendix; Fig. 7). Additional empirical steps for subsequent studies could analyze the relations between per capita income, total number of links per country and the traditional control variables of the economic growth literature (average years of schooling, quality of the institutions, etc.), an effort that could explore the connections between the networks-based approach presented here and the traditional literature on the determinants of growth.

Fig. 6.



Regression of number of links on economic complexity (ECI) Source: Elaborated by authors.

Fig. 7.

	Dependent variable:					
	log(link_p) (1)	link_p (2)	links (3)	log(links) (4)	links (5)	log(links) (6)
log(population)	0.345***	27,822.040***	5,612.974***	0.344***		
	(0.040)	(2,899.779)	(582.245)	(0.038)		
eci	0.722***	41,215.740***	7,993.698***	0.692***		
	(0.085)	(6,235.320)	(1,251.965)	(0.082)		
log(ppc)	0.395***	26,952.250***	5,342.364***	0.384***		0.835***
	(0.085)	(6,264.717)	(1,257.889)	(0.082)		(0.089)
ppc					0.681***	
					(0.080)	
Constant	1.160	-637,669.100***	-127,885.400***	-0.308	4,265.066**	1.279
	(1.155)	(84,733.040)	(17,013.500)	(1.114)	(2,080.827)	(0.844)
Observations	101	101	101	101	101	101
R2	0.822	0.781	0.774	0.823	0.423	0.472
Adjusted R2	0.816	0.774	0.767	0.818	0.417	0.467
Residual Std. Error	0.550 (df = 97)	40,362.570 (df = 97)	8,104.375 (df = 97)	0.531 (df = 97)	12,829.480 (df = 99)	0.908 (df = 99)
F Statistic	149.268*** (df = 3; 97)	115.125*** (df = 3; 97)	110.972*** (df = 3; 97)	150.829*** (df = 3; 97)	72.556*** (df = 1; 99)	88.495*** (df = 1; 99)
Note:						*p<0.1; **p<0.05; ***p<0.01

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Regressions of numbers of links on economic complexity and per capita income Source: Elaborated by authors.

The overall data presented in this section indicates that countries with most links, both in terms of PCI-qualified and non-PCI-qualified products, are rich, the main hubs of world trade. Simple nodes of the network are poor countries. China and India stand out in the world network shown above. Even with relatively lower per capita incomes as a result of their enormous populations, they were still able to accumulate a vast number of links; both are also still somewhat behind in terms of economic complexity in 2013 as compared to rich countries, particularly in the case of India. The USA, Germany, Japan and South Korea, the 'usual suspects', appear at the center of the network. They have thousands of highly complex links. These results are in line with what ECLAC authors argued: countries with higher per capita incomes concentrate in producing and exporting manufactured and complex goods at the center of the network, whereas those with lower per capita incomes concentrate in producing and exporting non-complex commodities at the periphery. Rich countries in Europe, North America and Asia are at the center of the world trade network. Poor countries in Africa, Latin America and Asia are at the periphery.

As for a criticism and potential problems with our methodology, its main failure probably lies in using only export data as a proxy for the productive structures of countries. This is, indeed, a weakness, as we know that certain countries do produce goods that they do not export for a variety of reasons. Our entire analysis is based on what can be 'seen' from world trade data, a broad, disaggregated, standardized database that goes back to the 1960s. The main advantage of these trade databases (SITC, HS) rests precisely in the standardization, capillarity and longevity of the data; their disadvantage lies in not capturing all of each country's domestic idiosyncratic features. On the other hand, national account databases that include some of those idiosyncratic aspects have not yet been able to capture the same kind of information with the granularity level required for the kind of analysis that we perform here; these databases usually have fewer productive disaggregation layers. Another problem with the database we use is the fact that it does not identify countries that are mere 'maquilas': those that simply import and then export complex products, Mexico being the most notorious case. Schteingart (2014) has an interesting perspective on qualifying countries' complexity based on the number of patents per country and ratios of R&D spending to GDP as an attempt to identify 'truly complex' countries, a path that could be used in the future to improve the network-based methodology proposed here.

6. Conclusions

To a certain extent the results presented here for the analysis of markets, countries, hubs and their relation to economic and product complexity were expected; the empirical analysis of the *Atlas of Complexity* already pointed in this direction, though not using a scale-free network approach. The *Atlas* basic regressions are on countries' per capita income and complexity, using the literature's traditional control variables. Here we followed the path of detecting hubs and scale-free properties in each market's network and in the overall world trade network. The results are significant in the sense of demonstrating new and important empirical content for old economic ideas. This paper's novelty lies in specifically analyzing market structures for each SITC-4 product and for the global trade web using network science techniques.

From the complex networks perspective adopted here, we may now argue that each country's ability to collect trade links depends on its productive capabilities. The more complex countries were able to collect many higher-quality links (as measured by PCI) as time went by. The historical process that led to the picture of the world trade network in 2013 that we present here took place in an environment full of increasing returns, a world of power laws. In such an environment, countries that have already collected many links can easily collect more on the margin. Countries that have collected few links face greater difficulty getting ahead. Breakthroughs from the few low-quality links status to a many high-quality links situation are feasible, but extremely difficult to accomplish. A potential topic for further research based on the approach presented here might involve dynamic analyses of the world trade network using complexity measures.

The hub and links analysis performed here indicates that the 'rich center' of the world trade network features a productive structure that specializes in producing and exporting complex, sophisticated and industrialized goods whereas the 'poor periphery' of the scale-free complex world trade network has a productive structure focused on producing and exporting less complex goods (commodities). This kind of topology of the world trade network can be seen in the correlations found between economic complexity levels (ECI) and total links per country. Following ECLAC, therefore, we could conclude that economic development will continue to be a very difficult task for poorer countries unless they are able to transform their productive structure in the direction of producing and exporting more complex goods.

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Appendix

Regressions

Source: Elaborated by authors.

ppc – per capita income PPP (2013)

eci – economic complexity index (2013)

link_p – adjusted total links

link – non-adjusted total links

Database

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