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Network Configuration as a Measure of Power in Global Production Networks

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Abstract

Power is one of the key components in understanding and analyzing global production and is central to the analytical frameworks of both GVCs and GPNs. By focusing on firms' power within GPNs, we are able to draw a novel analytical link between the governance structures of GVCs and network configuration presented in recent versions of GPNs. Using global input-output data, we show that the network structure of global production helps determine the distribution of power among firms in different economic sectors and, consequently, it influences the governance structures of supply networks. More specifically, we find a very high correlation between the distribution of profits and a sector's position in global production, captured by its (total strength) centrality. Based on this, we are able to provide a quantitative measure of power within global production and its governance structures.

Keywords: global production networks, global value chains, power relations, network theory

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1 Introduction

Since the early 1990s the frameworks of *Global Commodity Chains* (GCCs), *Global Value Chains* (GVCs) and *Global Production Networks* (GPNs) have dominated the analysis of global production and circulation. Sometimes conflicting and divergent, and at other times complementary and synthesizing, these approaches highlight the inner mechanisms that allow multinational corporations to coordinate, and eventually, dominate a geographically dispersed, and functionally specialized, global supply system. Following an interdisciplinary methodology, the aforementioned frameworks have managed to form their own analytical locus within international political economy and to promote a distinctive literature for the analysis of world capitalism (Gereffi 1994; Gereffi, Humphrey, and Sturgeon 2005; Henderson et al. 2002; Coe and Yeung 2015).

In these analyses the concept of power is central. Power translates into the ability of lead firms to shape governance structures in order to dominate in their respective value-chains and/or production-networks, and consequently capture the highest possible amounts of value (Hopkins and Wallerstein 1994; Gereffi, Humphrey, and Sturgeon 2005; Coe and Yeung 2015;

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Henderson et al. 2002). Each analytical approach places emphases on different aspects (dimensions) of power relations established in a commodity-chain, value-chain or production-network. For example, the GCC framework, sheds light on the technological differences between production processes, in order to explain the birth and evolution of global commodity chains, driven by large and powerful producers (Producer-Driven) or buyers (Buyer-Driven) (Gereffi 1994). On the other hand, several contributions using or extending the GPN framework stress the bidimensionality of power, which acts as both a topological characteristic of the position (positionality) each actor holds in the production network, as well as, a relational attribute of the exchange relations between network participants (Henderson et al. 2002; Coe and Yeung 2015)[5]. Specifically, the more recent version of the GPN framework, known as GPN 2.0, goes one step further, implying that power relations and asymmetries are latently embedded into specific configurations of global production networks. In their innovative extension of the previous - so-called - GPN 1.0 framework, Coe and Yeung (2015) introduced a causal mechanism that links the dynamic competitive environment in which economic and non-economic actors interact, with actor-specific strategies formed and implemented, by those same actors. The result of this causal mechanism is the generation of specific configurations of production networks depicting the topological and relational power position of every actor in the network. Despite its strengths, GPN 2.0 remains a theoretical framework which has not been used for quantitative policy analysis (Yeung 2016). However, as our paper argues, by accounting for the dynamic nature of global production, GPN 2.0 opens up a space towards analysis that contributes to policy prescriptions. Indeed, the links between GPN 2.0 and the policy friendly governance structures of GVCs have not been made. Herein lie two important overlapping gaps in the literature. The aim of our paper is to fill these gaps by linking the global governance structures with network configuration and providing a quantitative measure of power through the structure of global production.

Building on and extending Mahutga (2014a, 2014b, 2014c), we show that the structural and statistical properties of the network relationships in the world economy have the ability to reflect patterns of governance structures. This allows us to draw a set of conclusions on the power asymmetries between economic actors. This is accomplished by an analysis of the topological (positional) dimension of power in production networks, captured by the concept of node centrality, borrowed from the discipline of Network Theory. More specifically, we depict the global economy in the form of an economic interdependent network and show that the centrality of economic sectors within GPNs is highly related to the results of profit distribution. We demonstrate this by applying correlation tests on the relationship between measures of node centrality and sector-specific shares of total profits using data from global Input-Output Tables (IOTs), taken from the World Input-Output Database (Timmer et al. 2015) and the OECD Inter-Country Input-Output Tables (ICIO) database (OECD 2018). The policy implications of such an approach are extremely important, since the GPN framework becomes less abstract and complex, compared to GVCs, and thus more easily applicable for policy-making purposes.

The structure of the paper is as follows. Section 2 discusses the concept of power in general and positional power, in particular within the relevant literature. In Section 3 we introduce the relevant concepts from network theory and IOTs that we use in our empirical analysis. We specifically focus on the notion of centrality in networks and how it can identify the key players, the most significant economic actors in a multilayered and complex global production system. Section 4 describes the data we use and methodology that we follow in our empirical analysis. Section 5 presents the empirical results of the correlation tests regarding the relationship between positional power and actual, realized, sectoral shares of profits. Section 6 concludes and proposes possible directions for future research.

[5] This literature sparked a vibrant discussion around the issues of power under transnational capitalism, each stage identified important limitations which paved the way for the next theoretical and empirical development (Dallas, Ponte, and Sturgeon 2019; Rutherford and Holmes 2008; Tonts, Plummer, and Taylor 2012; Grabs and Ponte 2019; Mahutga 2014a, 2014b, 2014c).

2 Power in Value-Chains and Production-Networks

The concept of power is central in the analyses of the 'chain' and 'network' frameworks. Indeed, the governance structure is defined as the "authority and power relationships that determine how financial, material and human resources are allocated and flow within a chain" (Gereffi 1994, 97). Gereffi, along with others in the GCC tradition, provided the first conceptualization of power relations between firms in the commodity chain. His categorization of producer-driven (PD) and buyer-driven (BD) was based on the level of manufacturing activity that takes place in-house compared to the activity that is outsourced to suppliers. For the GCC framework, power becomes the "ability of lead firms to 'drive' the organization of international production networks" (Dallas, Ponte, and Sturgeon 2019, 669), based on the level of capital intensity of the activities they develop (Sturgeon 2008).

While Gereffi's dichotomy between PD and BD governance structures broke new ground by constructing a framework to analyse the global production process, it was also critiqued for treating the process as too static. Critics maintained that the Gereffi binary left little room for analyzing the transformation of governance structures (Gibbon, Bair, and Ponte 2008). Additionally, the simultaneous existence of varieties of governance linkages reflect that "formerly producer-driven industries were taking on some of the characteristics of buyer-driven chains" (Dallas, Ponte, and Sturgeon 2019, 669). As a result, a new framework was initiated by Gereffi, Humphrey and Sturgeon (Gereffi, Humphrey, and Sturgeon 2005) – global value chains – which attempted to overcome the limitations of GCCs while simultaneously expanding its analytical scope. As far as power relations are concerned, Gereffi et al. (2005) propose a fivefold typology of governance structures dependent upon three factors: complexity of transactions, codifiability of information, and supply-base capabilities. These factors, in turn, are influenced by the technological characteristics of the production process and the strategies designed and implemented by the chain actors, regarding "the effectiveness of industry actors and the social processes surrounding the development, dissemination, and adoption of standards and other codification schemes" (Gereffi, Humphrey, and Sturgeon 2005, 98). The five types of governance structure that we observe in GVCs are Market, Modular, Relative, Captive and Hierarchical (see Table 1). As we can see from Table 1, which was used in the original paper of Gereffi et al. (2005), the fivefold governance typology corresponds to a range of degrees of explicit coordination and power asymmetry, spanning from low values characterizing the market governance structure, to higher and higher values, as the structures move from market towards hierarchical governance structures.

Despite the Gereffi et al. (2005) governance typology improving on the previous GCC framework, it generated hot debate. Some maintained that it remained still too static and homogenized in nature, with geographical, social and institutional specificities unaccounted for. Another important area of criticism was the way it treated and analyzed the concept of power (Gibbon, Bair, and Ponte 2008; Henderson et al. 2002; Coe, Dicken, and Hess 2008; Dicken et al. 2001).

According to a new framework of analysis - the global production networks - the GCCs and GVCs frameworks suffer analytically in that they conceptualize global production in linear and vertical terms, instead of incorporating "highly complex network structures in which there are intricate links – horizontal, diagonal, as well as vertical – forming multi-dimensional, multi-layered lattices of economic activity" (Henderson et al. 2002, 442). More recently, Dallas, Ponte and Sturgeon (2019) underlined that the concept of power within the framework of global value chains is "rarely explicitly defined, is not systematically analyzed, and is most often applied as a unitary concept rather than having multiple dimensions" (Dallas, Ponte, and Sturgeon 2019, 667).

Table 1 Governance Structures of Global Value Chains

Governance Structure	Transactions Complexity	Transactions Codifiability	Supply-base Capabilities	Degree of: -Explicit Coordination -Power Asymmetry

Market	Low	High	High	Low
Modular	High	High	High	
Relational	High	Low	High	
Captive	High	High	Low	
Hierarchy	High	Low	Low	High

Source: Adopted from Gereffi et al. (2005, 117)

The GPN literature added much-needed complexity by understanding global governance as a multifactorial and contingent process. Building upon Actor-Network Theory and Varieties of Capitalism literatures, the GPN analysis proposes a "relational framework which conceptualizes the networking nature of the global economy as a tangled web of production circuits and networks of interconnected economic processes that are grounded and embedded in specific locations" (Yeung 2016, 266). A GPN is defined as "the nexus of interconnected functions, operations and transactions through which a specific product or service is produced, distributed and consumed" (Coe, Dicken, and Hess 2008, 272). That said, the GPN approach is able to transcend global-regional-local dichotomies found in the GCC/GVC methodology, since the network methodology that it utilizes, transforms topological characteristic into comparable measurements (Dicken et al. 2001). The architecture of the GPN model focuses on three conceptual categories expressed through four conceptual dimensions. The conceptual categories around which the GPN research is applied are the creation, enhancement and capturing of Value, the corporate, institutional and collective forms of Power and the territorial and network-like Embeddedness of linkages. In turn, these categories are expressed through the conceptual dimensions of Firms, Sectors, Networks and Institutions, forming, in that way, the GPN methodological architecture, necessary for the analysis of modern world economy (Henderson et al. 2002).

The conceptualization of the global capitalist economy as a network that connects, in a multidimensional way, different economic and non-economic actors, allows the GPN scholars to develop a more thorough and concise discussion around the notion of power. According to Dicken, et al. (2001), power in a global production network is the ability of actors to "drive networks and make things happen" (2001, 93), based on the "control of key resources" (2001, 93), expressed in a bi-dimensional way, as both structural and relational power. In particular, we observe power as both reflecting the topological-positional characteristics of network actors (structural dimension), usually quantified by node centrality, and the qualitative characteristics of the linkages in a production network (relational dimension). Hence, the power that an actor renders from the possession of a particular asset, reveals, not only its position in a global production network, but also the normalization and legitimization processes that allow the holder of such a position to exert its power upon the other actors of the network.

A succeeding version of the GPN framework - GPN 2.0 - proposes a dynamic model of governance structures, attempting to overcome the limitations of the previous methodology, which failed to capture the ever-changing nature of the global economy and to provide with a causation mechanism of how configurations of production networks emerge from the interactions of their determining factors. Introduced in the literature by Coe and Yeung (Coe and Yeung 2015), the new methodology highlights the importance of actor-specific strategies, shaped by the confrontation of network actors against certain competitive dynamics, in the creation and evolution of global production network configurations. In particular, they identify three competitive dynamics (cost-capabilities ratio, market development, financial discipline) and four actor-specific strategies (intra-firm coordination, inter-firm control, inter-firm partnerships and extra-firm bargaining), the combination of which will eventually determine the characteristics of the global production network under question, specifically the network configuration.

The GPN 2.0 approach incorporates the same conceptualization of power as the previous version of GPNs (GPN 1.0), with its bi-dimensionality reflecting both the position of an actor in a production network, as well as, the "relational practice embedded in the structural position within a network" (Coe and Yeung 2015, 65). However, contrary to GPN 1.0, in which the conceptual categories of value, power and embeddedness, materialize through the conceptual dimensions of firms, sectors, networks and institutions, the GPN 2.0 puts more emphasis on the analytical role played by network configurations, as the reflection of the actor-specific strategies.

The aforementioned approaches initiated a new discourse around the issues of power, both in conceptual and theoretical (what power consists of), as well as, empirical (how power is measured) terms. Recently, Dallas, et al. (2019) summarized the discussion of power relations in the extended literature of value-chains and production-networks, proposing a new power typology. This new typology incorporates the diverse multidimensionalities that have been found in the literature and proposes a 'systematic framework that draws from the varied implicit usages of power in GVC and GVC-adjacent literatures' (Dallas, Ponte, and Sturgeon 2019, 667). The new typology consists of four types of power relations (bargaining, demonstrative, institutional, constitutive) and it is based on the combination of direct or diffuse 'transmission mechanisms' and dyadic or collective actor-specific 'arena of actors'. For instance, the bargaining type of power is consistent with dyadic and directly transmitted power relations established between actors in value-chain and production-networks, while the demonstrative type of power reflects situations of dyadic diffused relationships. Likewise, the institutional and constitutive types of power correspond to power relations that are transmitted in collectively direct and collectively diffuse ways, respectively.

Notwithstanding the considerable expansion of the view of power relations in value-chain and production-networks that Dallas et al. managed to achieve with their new typology, there is still a noteworthy gap in the respective literature, regarding the topological dimension of power in inter-firm relationships. This gap, in our opinion, has been partially addressed by Mahutga, who in a series of papers (2012, 2014a, 2014b, 2014c) synthesizes the GCCs, GVCs and GPNs approaches, in order to focus on the positional conceptualization of power, already found in the GPN 1.0 and later in GPN 2.0 frameworks, as structural power.

Mahutga (2012) combines the BD-PD chains with the fivefold typology of GVCs, stressing that the determining factor of governance structures in a value-chain is the height of entry barriers to manufacturing. In particular, he underlines that capital-intensive industries with high entry barriers, which constitute the lead firms in producer-driven chains, will tend to establish either modular/relational governance structures in the global north or captive/hierarchical structures in the global south.

Later, Mahutga (2014a, 2014b, 2014c) unifies the GCC/GVC and the GPN frameworks, building upon Power-Dependence Theory (Emerson 1962; Cook and Emerson 1978). More specifically, he introduces the concept of positionality, to depict the power attributes of firm actors in an economic network. In the GCCs/GVCs frameworks the power of lead firms stems from their possession of tangible (technologies for PD) or intangible (brand names for BD) resources to erect entry barriers in their respective industries. The existence, in turn, of such resource-based entry barriers, is decisive for the generation of power asymmetries, since lead firms in PD and BD industries have the ability to restrain the number of competitors in their markets and thus become the irreplaceable producers/buyers for their dependent partners.

Allowing for inter-firm relations to take the form of an economic network, Mahutga (2014a, 2014c) shows that PD and BD lead firms that erect entry barriers tend to hold more central positions in the production network they control. Therefore, firms possessing valuable and important resources (dependency-power theory), have the ability to raise entry barriers to their competitors (GCC/GVC framework), hold central positions in the production network (GPN framework), and consequently, dominate over their partners.

In Mahutga (2014a, 2014b, 2014c) the world economy is expressed in the form of a global trade network, where each node represents a country and each link its trade relations. Assuming that country-specific trade patterns rightly reflect the economic behavior of the lead firms in BD and PD networks, he measures the positional power of countries participating in the most characteristic examples of buyer- and producer-driven networks (garment and transportation equipment industries respectively).

Table 2 Power Relations in GCCs, GVCs and GPNs

Framework	Power Determinants	Power Forms	Literature
GCCs	Capital Intensity	Producer-Driven Buyer-Driven	(Gereffi 1994)
GVCs	Product Technologies Corporate Strategies	Market, Modular, Relational, Captive, Hierarchy	(Gereffi, Humphrey, and Sturgeon 2005)
GPN 1.0	Structural (Position) Relational (Norms)	Corporate Institutional Collective	(Dicken et al. 2001) (Henderson et al. 2002)
GPN 2.0	Structural (Position) Relational (Norms)	Network Configurations (Actor Strategies)	(Coe and Yeung 2015)
Dallas, Ponte, Sturgeon GVC/GPN	Transmission Mechanisms (Direct-Diffuse) Arena of Actors (Dyadic-Collective)	Bargaining Demonstrative Institutional Constitutive	(Dallas, Ponte, and Sturgeon 2019)
Mahutga GCC/GVC	Entry Barriers (Resources)	BD/PD Chains & GVC-typology	(Mahutga 2012)
Mahutga GCC/GVC/GPN	Entry Barriers (Resources) Position in Trade Network	Import/Export Ratios Export/Import Ratios	(Mahutga 2014a) (Mahutga 2014c)

Source: Own Illustration.

In this way, the positional power of a country in a BD trade network will depend on the import content of its exports, implying that the higher the share of its imports to the exports of its trading partners, the higher the number of business relationships with many "dependent import partners" (Mahutga 2014a, 167). The exact opposite is expected for countries in a PD trade network.

Methodologically, the calculation of countries' positional power is a modified version of the techniques which have been used for the quantification and measurement of labor bargaining power in an interdependent national economy (Wallace, Griffin, and Rubin 1989; Perrone, Wright, and Griffin 1984). Perrone (1984) was the first to explicitly link the concept of market power with that of positionality through analyzing the potential damage inflicted to employers, by workers' mobilizations in important industries. More specifically, he argues that labor employed in industries that play a key role for the production processes of other industries and thus holding a central position in the interdependent economic system of a country will have greater bargaining power compared to labor employed in an industrial sector in the periphery of the national economy. Later, Wallace, Griffin and Rubin (Wallace, Griffin, and Rubin 1989) refined Perrone's theories and introduced a more advanced, and analytically exploitable notion of labor positional power, on which Mahutga has erected his approach to the analysis of power relations in a GVC/GPN framework.

Table 2 summarizes the above-mentioned literatures vis-à-vis power relations and governance structures. Each analytical framework is defined according to the factors that determine the power asymmetries in the world economy, as well as, the form that assumes in the commodity/value chain or production network. The ‘chain’ framework with their linear, vertical and unidimensional understanding of power in global supply systems, has limited application in the thorough analysis of power relations and asymmetries in a dynamic world economy. On the contrary, a GPN approach, and especially the focus on network structures of GPN 2.0, provides the appropriate theoretical bedrock upon which a multi-dimensional and multi-layered theorization of power can be constructed.

3 Production, Network Centrality and Power

A common theme in the frameworks of GCCs, GVCs and GPNs, is the analysis of geographically dispersed, but functionally integrated, production processes. Production lines that previously demanded the meticulous articulation of detailed processes within the premises of an industrial complex, can now be performed in the most distant places of the world, and through international trade are assembled in industrial hubs close to the final markets of the products or services where they produce. In other words, globalization has affected the way goods and services are being produced, distributed and consumed, changing the nature of production processes into an interdependent network of distinct production processes. An emergent characteristic of the aforementioned phenomenon is the positioning of each economic actor to a particular location in the global, interdependent and complex production system. For example, the global auto-industry production network is composed by thousands of suppliers and buyers, scattered around the world, each concentrating on the production of specific part of the vehicle, with the end result being the distribution of vehicles to regional markets, from strategically located assembly plants.

Informed by Mahutga (2014a, 2014b, 2014c), we assume that the position each actor holds in a production-system is co-constitutive of the power it accumulated. Mahutga argues that powerful firms that are able to lead and shape a production-network have managed not only to erect barriers to entry for their immediate competitors, but also to become attractive with respect to their partners and thus become important buyers and/or suppliers. Indeed, a firm’s power position leads to more power (via capital accumulation) which leads to mergers, acquisitions, and self-investment into technology, which further cements the firm’s power position. However, while GCC/GVC/GPN analysis remains squarely at the level of the firm using qualitative case study methods, Mahutga’s analysis at the level of the country, assumes that country-specific trade patterns reflect the behavior of lead firms in the production-network. To Mahutga, power is conceptualized as the position of each country in a trade network. However, whereas Mahutga underlines the topological-geographical characteristics of power, we propose a more direct and systematic analysis of the topological dimension of power relations in value-chains and production-networks. We focus not only on the geography of power asymmetries, but also on their functional topologies. Crucially, the basis of the theories of various strands of analysis of the production process outlined so far are based on firm-level relational analysis. They have never been demonstrated quantitatively at the level of the firm or even at the sectoral level, as an aggregating unit of analysis, combining many firms with similar technological characteristics. This is the primary aim and original contribution of our paper.

We understand the global economy as shaped by the composition within and interaction between different production networks. Thus, the world economy is express as an economic network, with each node representing economic sectors and their links representing the value of the respective transactions. In order to understand the world economy, we must analyze power in the network(s). Indeed, we use information from IOTs, which is the best measure of the interdependence of networks, to quantitatively undergird theories of the production process. Ultimately, borrowing from the analytical corpus of network theory, we calculate the centrality of each node-sector, in order to quantify the topological, geographical and functional, characteristics of the global production and global industries.

3.1 GPNs and Network Theory

A network is defined as "a collection of points joined together in pairs by lines" (Newman 2010, 1), where each point, also known as a node, represents an object of interest, and each line, also known as a link, expresses the relationship that 'joins together' the respective points. Hence, we can express the production processes of a GPN as a network where the nodes represent economic sectors and links the transactions between them. Networks can be distinguished between directed and undirected, with the former having links that point to a direction, and the latter having links that connect nodes, without any directional characteristic. In the case of a GPN, the direction of linkages connecting economic sectors is crucial, since it denotes the buying (of inputs) and/or selling (of outputs) behavior of the sectors under investigation. Another analytical distinction, which is especially important when discussing GPNs, is between weighted and unweighted networks. In weighted networks, the links connecting the various sectors of a GPN are characterized by their relative importance (weight), given by the monetary value of transactions conducted between these sectors. In the case of unweighted or binary economic networks, on the other hand, the links connecting the various sectors-nodes, simply represent the presence of a business connection between them.

The necessary information which can fully describe a network is expressed through an Adjacency Matrix. In the case of a GPN comprised by n sectors, the adjacency matrix is a square, non-negative, matrix with n rows and n columns, such that each element A_{ij} of the matrix, with $0 \leq i \leq n,\ 0 \leq j \leq n$, takes the value of 1, whenever a link exists connecting node i with node j, and the value 0, otherwise. It follows that an adjacency matrix of a binary form represents an unweighted network, where the elements of the matrix take only the values of 1 and 0, depending on the presence of a link connecting the respective nodes. In the case of a weighted network, however, where links represent the relative importance of the connection between two nodes, the elements of the adjacency matrix reflect exactly that relative importance. In the context of production networks, the unweighted adjacency matrix aggregates the information of the number of buyer-seller relationships formed between sectors. In contrast, in the case of a weighted adjacency matrix, their relative importance in terms of the value content of the respective transactions is underlined. Consequently, the information contained in an adjacency matrix allows for the analysis of the properties of economic and production networks constructed by thousands of nodes (economic sectors) and millions of links (economic transactions).

The data structure that captures the production activities of a GPN (or a production network in general) takes the form of an IOT, which includes the basic information regarding the production (output) and consumption (inputs) of goods and services in a specific geographic unit (Miller and Blair 2009). As in the adjacency matrix, each row of an IOT shows the amount of goods and services produced by each sector in an economy and how much of these commodities have been used, either as an input for the production of other goods and services or as final products for consumption. Likewise, each column of an IOT expresses the amount of inputs demanded from all the other sectors of an economy, as well as the amount of labor and capital used for the production of goods/services. So, it is evident to conclude that the intermediate demand matrix of an IOT acts, by definition, as an adjacency matrix of an economic and production network and that combining network theory and IOTs gives us the ability to analyze the properties of the structure of an economy, consisting of multiple interdependent production processes.

3.2 Production Centrality and Power

As it is discussed above, the position of firms in the production process, is the key ingredient of their power in relation to their competitors, partners and employees. Within a network, the position of a node can be captured by different measures of centrality and over time new measures are being developed (Jackson 2008). Hence the centrality of a firm, or in our case an economic sector, is a key component regarding the topological-positional dimension of power relations. Here we consider the centrality measures of *Degree*, *Strength* and *PageRank*, as we believe these are the most appropriate for our analysis.

The most direct centrality measure is that of degree. Degree centrality measures the number of links (connections) a node has with the rest of the nodes. For directed networks, we have to distinguish between incoming and outgoing economic transactions and thus introduce two types of degree centralities, the In-Degree, that counts all the transactions that point to sector *i*, and Out-Degree, which counts the outgoing transactions originated from sector *i*. Then Total-Degree is simply the sum of the two-directional measures of the number of links. So, in our GPN context, degree centrality measures the number of relationships that have been built between economic sectors. For example, if an economic sector purchases inputs from 100 other sectors and sells its products to 200 other sectors, then the in-degree of that sectors will be 100, its out-degree 200 and the total-degree the sum of the two, namely 300.

Moving to the weighted version of the network, strength centrality, measures inflows and outflows of inputs and output, and hence volumes instead of simple linkages (partnerships). As in the case of degree centrality, we can distinguish between in-strength, measuring the volume of inflows to an economic sector, and out-strength, measuring the volume of outflows from a sector. The sum of two will give the total strength. For example, if a sector purchases 500 million $ of inputs from other sectors and sells products valued at 400 million $, then the in-strength of that sector will be 500, the out-strength 400, and the total-strength 900.

In our GPN context, degree and strength centralities capture the number and weight of the business relationships established among the various sectors of the world economy. However, degree and strength centralities are primarily local centrality measures. They take into account only the direct production links of an economic sector, its nearest neighbors in other words, irrespective of those neighbors' position in the overall structure of the economic network. Considering this shortcoming and the need to uncover the effects of the rest of the sectors within a network, global centrality measures have been proposed, such as Eigenvector and PageRank centralities (Jackson 2008).

Eigenvector centrality is defined as the sum of the links connecting a sector with its neighbors. However, in eigenvector centrality each link connecting the node under consideration with the neighboring nodes, has a different weight, based on the centrality of the latter. That is, the centrality of a node depends, not only on the number of links it has established with other nodes, but also on the number of links those other nodes have established with their neighbors, as well. Thus, for example, sector i gains more centrality if it is connected to more connected sectors. Connected sectors are those that have themselves higher centralities. A variant of the eigenvector centrality measure was introduced by the founders of Google search engine, Larry Page and Sergey Brin, who developed, along with Rajeev Motwani and Terry Winograd, a computer algorithm for rating and ranking webpages based on their importance (Page et al. 1999). PageRank centrality instead of calculating a centrality score proportional to the centrality of neighboring nodes, it scales the effect of those nodes that have a large number of outgoing links.

In our context, an economic sector of a GPN will be highly central in terms of the PageRank centrality measure, if it is connected to highly connected sectors that have gained their importance, notwithstanding the fact that they have a large number of out-going links. In that way, PageRank centrality controls for those cases of economic sectors, which under the eigenvector centrality measure, would have accumulated high scores of centralities, merely due to the fact that they have established business relationships with large input providers, for example, energy, transportation and financial intermediation, services. More details about the mathematical formulation of the centrality measures are found in the Empirical Appendix.

4 Data and Methodology

The methodology that we follow in order to address our research question is interdisciplinary. As we pointed out in the previous section, our contribution to the literature of GCCs/GVCs and GPNs is, through a large-scale analysis at the sectoral level, we attempt to quantify power in the global economy. To accomplish this, we use input-output data for global economic sectors, and employ the tools of network theory, especially the notion of node centrality, to quantify the topological dimension of power, accumulated by economic actors. In particular, we express the world economy as an interdependent production network, based on the transactions information of global IOTs, and then calculate the centralities of each economic sector. In that way, we have managed to obtain a measurement of the topological-geographical and topological-functional dimensions of the power of economic actors. Afterwards, we test the association between the calculated measures of centrality and the distribution of profits among economic sectors, assuming that more powerful sectors will have the ability to accumulate higher profits.

In Figure 1 we present an exemplified version of an IOT, underlining a further sub-division of an IOT into four sub-matrices: the *Intermediate Demand*, which consists of the inter-industry transactions between sectors, the *Final Demand*, which records the sales of products and services to final markets, breaking the respective amounts into the final demand components of *Consumption*, *Investment*, *Government Expenses* and *Net Exports*; the *Value-Added*, which accounts for the non-industrial inputs of the production process, such as, *Employees' Compensation*, *Capital's Income*, usually in the form of *Gross Operating Surplus* and *Taxes*; and *Gross Output* vector, which expresses the total output of the economy, produced and consumed.

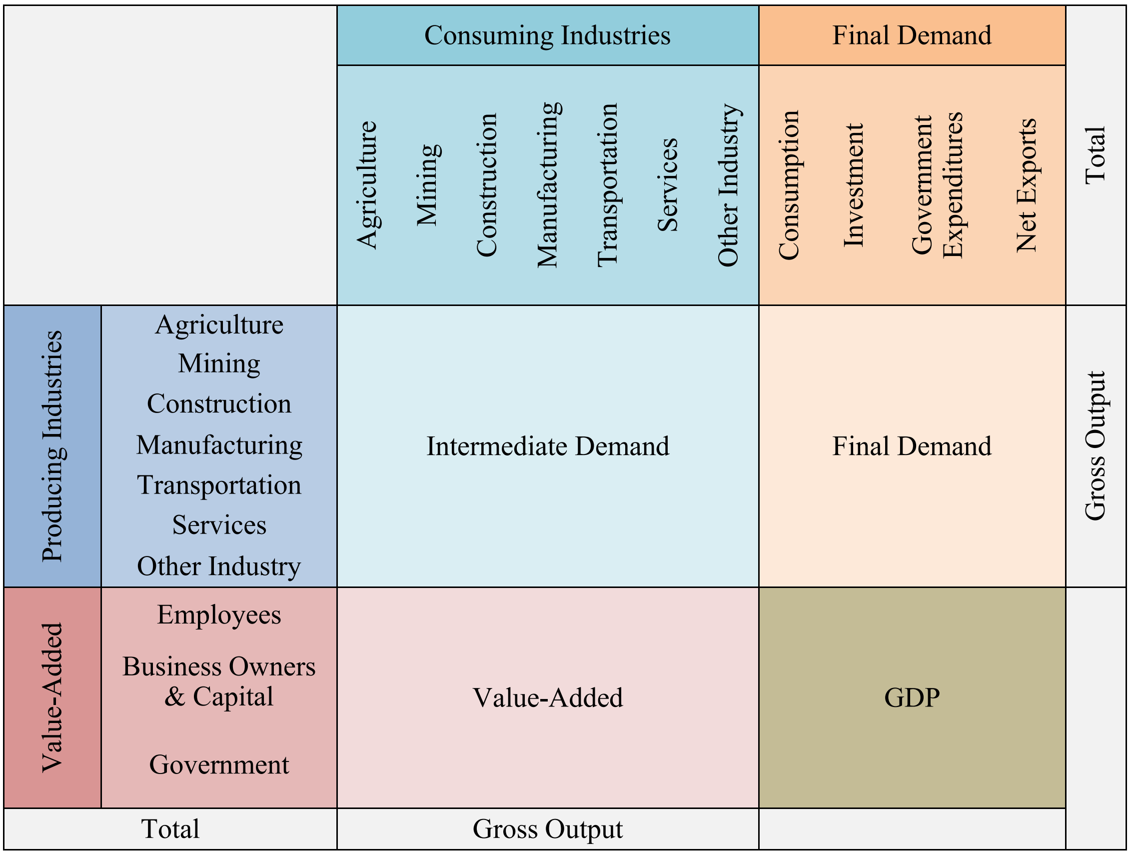

Figure 1 Schematization of an Input-Output Table
Source: Adopted from Miller and Blair, (2009, 3)

For example, the row entitled 'construction' on the IOT (Figure 1) indicates how much of the product of the construction sector has been purchased and used in the production processes of all the other buyer-sectors in the hypothesized economy. In addition, we can see how much of this product has been sold to the final market, either to private consumers (households and firms), to the government, or exported to foreign markets. Likewise, reading the columns of

the IOT, we can see how much of inputs, each production process demands from the seller-sectors, and how much of value, the primary inputs have been added to the final product.
In this paper, we take into account four sources offering global databases of IOTs. In particular, we make use of the WIOD and the collection of ICIO Tables, offered by OECD, for different industry classifications and time ranges. The WIOD (Timmer et al. 2015) is the result of an international project aiming to combine, harmonize and reconcile economic data from national accounts, national IOTs and international trade statistics. More specifically, the WIOD project provides time-series for global IOTs giving detailed information about the production processes of national economic sectors in a global scale, as well as, data on the incomes of the value-added components. All data have been obtained by official national statistics and are structured as a unified global IOT, with the block diagonal reflecting the national IOTs.
The WIOD comes into two versions, at basic prices in millions of US dollars. The 2013 version covers 35 economic sectors (ISIC Rev.3), for 40 countries and a proxy for the Rest-of-the-World (RoW), from 1995 to 2011. The 2016 version of the WIOD, on the other hand, covers 56 economic sectors (ISIC Rev.4) for 44 countries (including an estimate the RoW), from 2000 to 2014. The OECD database (OECD 2018) provides time-series global IOTs in two versions, as well. The first version covers 34 industries (ISIC Rev.3) for 64 OECD and non-OECD countries, including an estimate of the RoW from 1995 to 2011, while the second version covers 36 industries (ISIC Rev.4) for 65 countries (plus RoW), from 2005-2015. Table 3 summarizes[6] the basic information for the four economic network configurations. The number of country-sector nodes is less by one country because we had to exclude the RoW from all network configurations, due to the unavailability of data regarding value-added components (labor and capital income).

Table 3 Summary Statistics of Economic Network Configurations

Database	Years Covered	Industrial Classification	Sectors	Countries	Nodes	Average Links
WIOD	1995-2011	ISIC-Rev.3	35	40	1400	1763906
WIOD	2000-2014	ISIC-Rev.4	56	43	2408	5039876
OECD	1995-2011	ISIC-Rev.3	34	63	2142	2287321
OECD	2005-2015	ISIC-Rev.4	36	64	2304	4408763

Source: Own Calculation

Taking into account these four global production networks we capture the positional power of each sector, by calculating the degree, strength and PageRank centralities and explore their behavior against sector-specific shares of profit distribution. Profit distribution shares are computed by dividing the Gross Operating Surplus (GOS) component of the Value-Added of each sector over the total amount of GOS generated in the global economy. OECD database provides direct estimates of the GOS. The WIOD IOTs, however, have been constructed in terms of Gross Value-Added (GVA) and thus, in order to compute the GOS, we had to subtract from GVA the amount of employees' compensation for each sector and for the total global IOTs.
For the analysis of the relationship between sector-specific positional power, measured by centrality, and GOS, in log-scales, we apply both parametric (Pearson) and non-parametric (Spearman and Kendall) correlation tests over the whole period covered by each database. Pearson correlation coefficient, r, expresses the linear association between two variables, x and y, and is defined as the ratio of their covariance over the product of their standard deviations:

[6] Details for the countries and sectors can be found, for the WIOD, here: http://www.wiod.org/home and for the OECD, here: https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

$$r = \frac{cov(x, y)}{s_x s_y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} \tag{1}$$

where, s_x and s_y, denote the standard deviations, and $\bar{x}$ and $\bar{y}$, the sample means of variables, x and y, respectively. A correlation coefficient close to 1 implies that centrality and profit distribution, move together, in an almost perfectly linear fashion. Likewise, a negative correlation coefficient that tends towards -1 signals the fact that the variables of centrality and profit distribution, although moving strongly together, they do so in an antithetical direction. Whenever one variable takes higher values, the other takes lower ones. On the contrary, the co-movement relationship between centrality and profit distribution becomes weak, as correlation coefficients take values that tend towards zero.

Whereas Pearson correlation measures the linear nature of the relationship between two variables, Spearman and Kendall correlations focus on their monotonic relationship. Spearman correlation method is computationally similar to Pearson statistic. Instead of computing the linear relationship between variables x and y, Spearman ρ estimates the ordinal relationship between them. In other words, for the calculation of Spearman correlation we have to rank our data points from the highest to the lowest value and then substitute the rank scores into Pearson's formula, according to (1):

$$\rho = \frac{cov(rank(x), rank(y))}{s_{rank(x)} s_{rank(y)}} \tag{2}$$

Likewise, Kendall τ employs a method that measures the association between ranked pairs of data, based on the following formula:

$$\tau = \frac{1}{n(n-1)} \sum_{i \neq j}^{n} sign(x_i - x_j) sign(y_i - y_j) \tag{3}$$

with the sign function taking values according to the sign of the difference of each argument. If the difference is positive, then sign becomes +1, if the difference is zero, then sign function takes the value of zero, and in case the difference is negative, the sign becomes -1.

The parametric nature of Pearson test dictates for the samples to follow a normal distribution, in order for the coefficients to be valid and the estimates to produce significant results. For sample data that do not follow a normal distribution, it is more appropriate to use non-parametric correlation statistics, especially if we are dealing with heavy-tailed distributions, as is the cases with centralities and sector-specific shares of GOS (de Winter, Gosling, and Potter 2016). In particular, Spearman ρ and Kendall τ, seem to have better statistical properties with non-normal distributions compared to Pearson's r, and furthermore are invariant to monotonic transformations, like the log-transformation that we have applied on the data (Li et al. 2012). The distributional characteristics of the three centrality measures that we have focused on this paper are gathered in the Empirical Appendix, showing a clear non-normal distribution and thus justifying our decision to consider, additional to the Pearson correlation test, the non-parametric choices of Spearman and Kendall.

5 Empirical Results

Figure 2 captures the behavior of the three correlation coefficients, for all years and network configurations. Each row of the figure corresponds to an economic network configuration based on the four databases. Equally, each column of the figure corresponds to one of the three correlation measurements that we have used in our analysis, the Pearson, the Spearman and the Kendall. Lastly, each line corresponds to one of the three centrality measures, namely total-

degree, total-strength and PageRank. In the Empirical Appendix (Table 4) we have gathered all the results for the three correlation tests applied over the relationship between positional power, measured by three alternative measures of node centrality, and sectoral-specific shares of profit distribution, in log-log scales.
For the application of the log-log transformation, we had to exclude those values of centralities and shares of profitability, that were equal to zero since the natural logarithm of zero is undetermined. Excluding the zero values from the data eventually reduced the size of each dataset, by 10% for the WIOD (ISIC3), 8% for WIOD (ISIC4), 17% for OECD (ISIC3) and 8% for OECD (ISIC4). However, the impact on the co-movement conclusions is minor, because country-sectors with zero centralities imply that they are positioned at the most disconnected component of the global economic network, with no ties to the most connected part of the world economy. According to Table 4 (see Empirical Appendix) all correlation tests, parametric and non-parametric, are statistically significant, for at least 0.1% level of statistical significance. The only exceptions are the correlation tests applied to the relationship between total-degree and profitability for the economic network based on WIOD (ISIC3) for six years between 2005 and 2011.

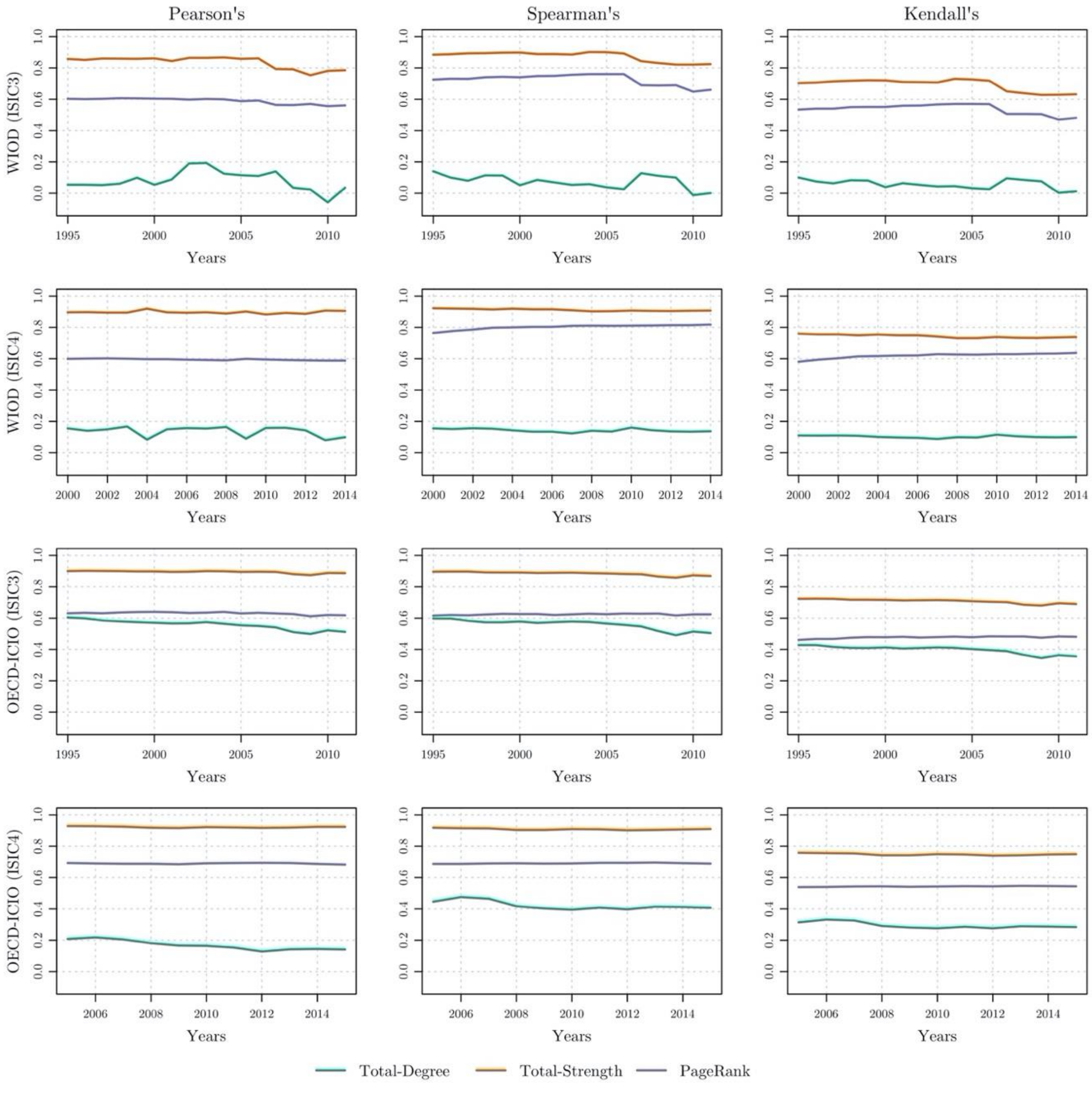

Figure 2 Correlation Coefficients of Centralities and sectoral shares of GOS
Source: Own Calculation. *Data*: WIOD, OECD

From Figure 2, we can easily conclude the existence of a roughly stable co-movement between centrality measures and profit distribution for strength and PageRank centralities. For degree centrality, on the other hand, all correlation tests show a low association, with the exception of the OECD (ISIC3) economic network, in which case the dataset gives us Pearson and Spearman coefficients in the area of 0.5 – 0.6 and in the area of 0.4 for the case of Kendall correlations. A stronger association, though, is given by PageRank for all correlation types and network configurations. In particular, the Pearson linear correlation for PageRank versus profitability, varies between 0.55 and 0.69 for all years and configurations, while Spearman's rank correlation varies between 0.6 and 0.81 and Kendall's, much lower, between 0.46 and 0.61. However, the strongest association between profit distribution and centrality, is captured by strength centrality. Pearson correlation for strength-profitability varies between 0.75 and 0.92, with Spearman and Kendall rank correlations, varying between 0.82 and 0.92 and 0.62 and 0.75, respectively. A 'snapshot' of the relationships between degree, strength and PageRank centralities and sectoral profit-distribution, for the year 2014, is given by Figure 3, where we clearly observe the higher correlations with respect to strength centrality, compared to PageRank and degree.

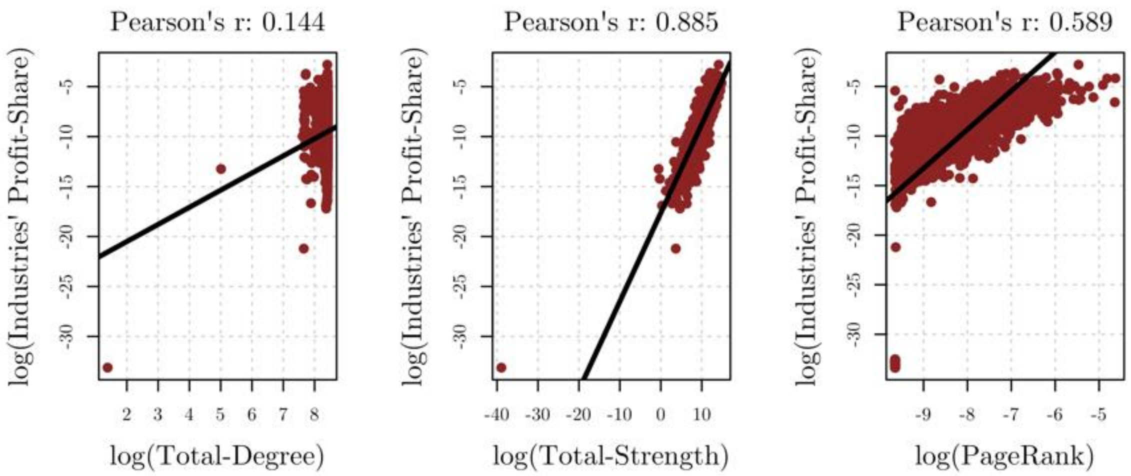

Figure 3 Correlation Coefficients of Centralities and sectoral shares of GOS, 2014
Source: Own Calculation. *Data*: WIOD IOT, 2014

The aforementioned results imply that the concept of centrality has the ability to reflect the topological dimension of power in an interdependent, global production system. In other words, those economic sectors that manage to hold central positions, both geographically and functionally, in a GPN, will eventually capture more profits from the total pool of profitability. Moreover, we conclude that from the variety of centrality measures offered by network theory, it is strength centrality that shows the highest degree of association with respect to profit-distribution, highlighting that both the volume of transactions, as well as, the number of linkages in a global production network, matter for the topological dimension of power relations.

Thus, we prove quantitatively at the sectoral-level what scholars of GCC/GVN/GPNs have maintained qualitatively at the firm level (or quantitatively at a country-level (Mahutga 2014a, 2014b, 2014c)). That, it is those sectors that manage to become large buyers and/or suppliers in the global economy who receive the lion's share of the realized profitability. The lower values of correlation coefficients measuring the relationship between PageRank and profitability, on the other hand, highlight the intricacies of the centrality measure, which takes into account the topological power effects of functionally and geographically remote economic sectors. As we underlined in the previous section, PageRank centrality takes into account, not only the centralities of the immediate (first tier) partners (either suppliers or buyers) of a particular economic sector, but also the centralities of the partners of those partners (second tier), and so on. For example, whereas a global sector might be characterized by very high strength centrality, due to the fact that is a large buyer and/or supplier, with PageRank centrality we will in general have a lower measurement, since we have incorporated the centrality information of 2nd-, 3rd-, 4th-, until the last, -tier suppliers and buyers. Finally, by taking into account merely the number of relationships established between economic sectors, irrespective of their relative weight (degree centrality), we get a very weak association with respect to the distribution of power, which in our case is assumed to be measured by the distribution of profits between global industries.

6 Conclusions

Even though the analysis of power relations between economic actors is a crucial component of the GPN framework, the concrete conceptualization of power has been limited (Mahutga 2012, 2014a; Dallas, Ponte, and Sturgeon 2019). In this paper, we proposed a novel analytical link between firms' power and the centrality of their position with respect to the production process within a GPN. As such, we were able to express the geographical, as well as, the functional interdependences of global production processes.

Focusing on the network structure and, specifically, on different forms of network centrality allowed us to draw a concrete conclusion regarding the power topologies of economic actors. In this way, our proposed re-conceptualization of the multidimensionality of power relations in value-chains and production-networks, provides a link between GVC and GPN analytical frameworks through the governance-power-network configuration nexus. Moreover we take a significant step towards constructing a quantitative empirical approach for GPN 2.0, based on the analytical foundations of network theory, and thus overcoming relevant critiques (Yeung 2016; Dallas, Ponte, and Sturgeon 2019; Tonts, Plummer, and Taylor 2012). In that way, we make the GPN framework even more relevant for policy-making purposes.

This paper can be extended towards three different research paths. The first directs towards the empirical decomposition of the various quantifiable dimensions of power in a global production network. For instance, other variables such as capital-intensity, access to finance, productivity etc. can be considered on top of the topological-geographical and the topological-functional characteristic of each sector, in order to have a more complete picture of the determining factors of profit distribution. The literature on international trade and the effects of globalization provides a wide-array of theoretical approaches and empirical econometric techniques that allow for a thorough analysis of these issues (Feenstra 1998; Milberg and Winkler 2013; Stockhammer 2017). The second path looks towards labor and questions regarding the relationship between the workers' bargaining power and global production structures. The third path combines the other two paths and sheds light on the functional distribution of income between labor and capital, on the basis of the centrality of each actor in the complex economic and production network of the global economy.

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Empirical Appendix

Degree centrality, d_i, is defined as:

$$d_i = \sum_{i=1}^{N} A_{ij} = \sum_{j=1}^{N} A_{ij} \tag{4}$$

where A_{ij} the unweighted adjacency matrix and N the number of economic sectors. For directed networks we distinguish between In-Degree and Out-Degree centralities, defined as following:

$$d_i^{in} = \sum_{j=1}^{N} A_{ij}\,, \qquad d_j^{out} = \sum_{i=1}^{N} A_{ij}\,, \qquad d_i^{total} = d_i^{in} + d_j^{out} \tag{5}$$

In weighted networks, the corresponding measure of degree, is strength centrality, and the adjacency matrix represents the value of each link.

Eigenvector centrality is defined as:

$$eg_i = \frac{1}{\lambda_{max}} \sum_{j=1}^{N} A_{ij} eg_j \tag{6}$$

where, eg_i is centrality for sector i and eg_j the centrality of sector j that sells goods and services to sector i, while λ_{max} is the maximum eigenvalue of A_{ij}, the weighted adjacency matrix.

PageRank centrality is a modified version of the eigenvector centrality measure, which instead of calculating a centrality score proportional to the centrality of neighboring nodes, it scales the effect of those nodes that have a large number of outgoing links. Formally is defined as:

$$pr_i = \alpha \sum_j A_{ij} \frac{pr_j}{deg_j^{out}} + \beta \tag{7}$$

with pr_i and pr_j being the centralities of sectors i and j and α and β the constant parameters.

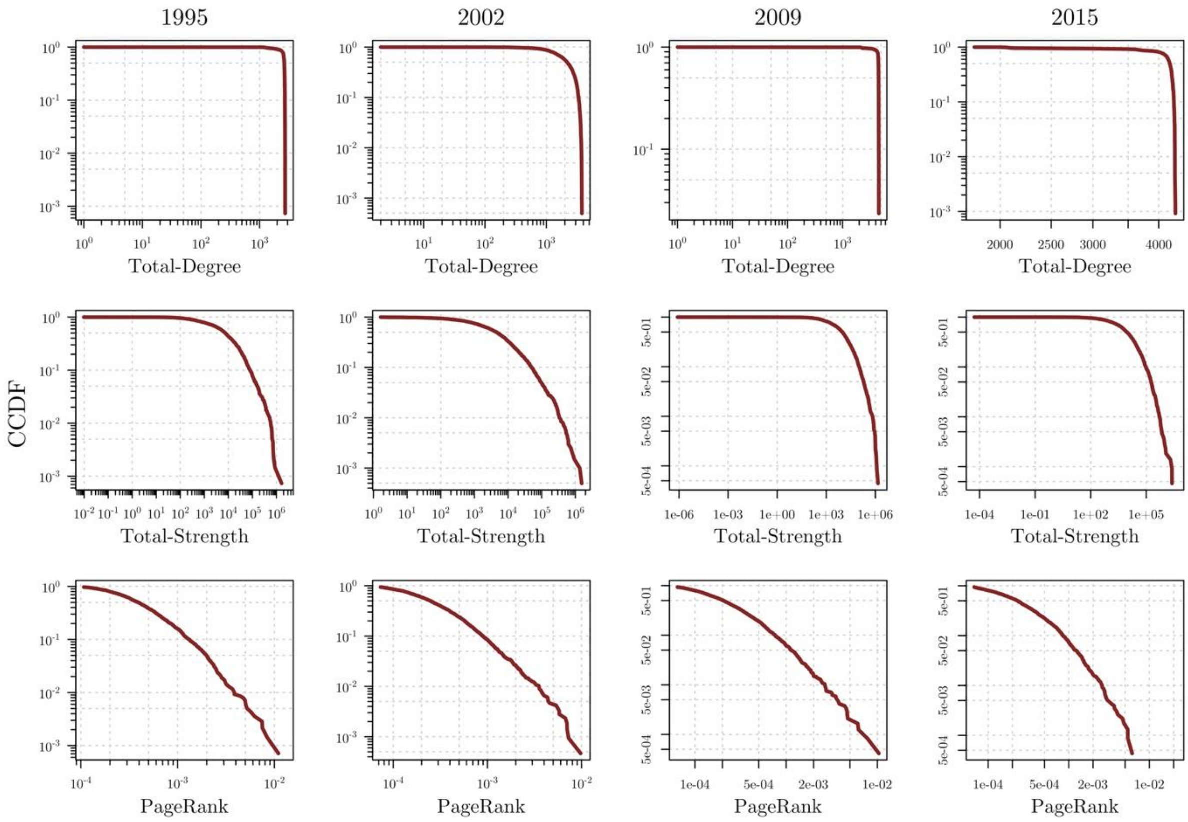

Figure 4 Distributions of Degree, Strength and PageRank Centralities, Selected Years

Source: Own Calculation. Data: WIOD-ISIC3 for 1995, OECD-ISIC3 for 2002, WIOD-ISIC4 for 2009, OECD-ISIC4 for 2015. *Note*: Plots in log-log scales.

Figure 4 shows the distributions of centralities for representative years from all reference databases. Both strength and PageRank centrality measures seem to follow some type of a heavy-tail distribution, with the exception of the degree centralities, where the linear part of the CCDF[7] plot becomes almost vertical at the right-tail region, implying an exponential distribution (Cirillo 2013). The distributions are consistent with those found in other economic networks (Cerina et al. 2015). In Table 4 we have gathered the results of the correlation tests we have applied over the relationship between centralities and sector-specific profit distribution, in log-log scales.

[7] A complementary cumulative distribution function measures the probability of a variable taking values higher than a particular level and is formally defined as $\overline{F}_x = P(X > x) = 1 - P(X \leq x)$.

Table 4 Correlation Tests for Centralities against sectoral shares of GOS

		WIOD(ISIC3)			OECD(ISIC3)				WIOD(ISIC4)			OECD(ISIC4)		
Year		TD	TS	PR	TD	TS	PR	Year	TD	TS	PR	TD	TS	PR
1995	r	0.054*	0.857***	0.603***	0.604***	0.900***	0.631***	2000	0.155***	0.896***	0.599***			
		n:1270	n:1270	n:1293	n:1776	n:1776	n:1843		n:2196	n:2196	n:2339			
	ρ	0.140***	0.884***	0.725***	0.598***	0.896***	0.616***		0.155***	0.922***	0.764***			
		n:1270	n:1270	n:1293	n:1776	n:1776	n:1843		n:2196	n:2196	n:2339			
	τ	0.100***	0.703***	0.534***	0.428***	0.723***	0.461***		0.110***	0.759***	0.581***			
		n: 1270	n:1270	n:1293	n:1776	n:1776	n:1843		n:2196	n:2196	n:2339			
1996	r	0.054*	0.851***	0.601***	0.599***	0.902***	0.634***	2001	0.140***	0.897***	0.601***			
		n:1267	n:1267	n:1289	n:1777	n:1777	n:1844		n:2215	n:2215	n:2357			
	ρ	0.100***	0.887***	0.731***	0.598***	0.897***	0.620***		0.151***	0.920***	0.777***			
		n:1267	n:1267	n:1289	n:1777	n:1777	n:1844		n:2215	n:2215	n:2357			
	τ	0.075***	0.706***	0.540***	0.428***	0.724***	0.467***		0.109***	0.755***	0.594***			
		n:1267	n:1267	n:1289	n:1777	n:1777	n:1844		n:2215	n:2215	n:2357			
1997	r	0.052*	0.860***	0.603***	0.585***	0.901***	0.631***	2002	0.149***	0.894***	0.602***			
		n:1271	n:1271	n:1293	n:1780	n:1780	n:1847		n:2215	n:2215	n:2357			
	ρ	0.080***	0.893***	0.730***	0.583***	0.897***	0.618***		0.156***	0.918***	0.786***			
		n:1271	n:1271	n:1293	n:1780	n:1780	n:1847		n:2215	n:2215	n:2357			
	τ	0.063***	0.714***	0.540***	0.416***	0.723***	0.467***		0.110***	0.755***	0.603***			
		n:1271	n:1271	n:1293	n:1780	n:1780	n:1847		n:2215	n:2215	n:2357			
1998	r	0.061**	0.859***	0.607***	0.579***	0.900***	0.636***	2003	0.167***	0.894***	0.600***			
		n:1271	n:1271	n:1293	n:1805	n:1805	n:1872		n:2214	n:2214	n:2356			
	ρ	0.114***	0.894***	0.740***	0.573***	0.892***	0.623***		0.153***	0.914***	0.798***			
		n:1271	n:1271	n:1293	n:1805	n:1805	n:1872		n:2214	n:2214	n:2356			
	τ	0.083***	0.718***	0.550***	0.410***	0.717***	0.475***		0.108***	0.749***	0.615***			
		n:1271	n:1271	n:1293	n:1805	n:1805	n:1872		n:2214	n:2214	n:2356			
1999	r	0.099***	0.858***	0.606***	0.574***	0.898***	0.639***	2004	0.084***	0.919***	0.597***			
		n:1276	n:1276	n:1297	n:1819	n:1819	n:1886		n:2220	n:2220	n:2362			
	ρ	0.113***	0.897***	0.743***	0.573***	0.891***	0.627***		0.143***	0.919***	0.800***			
		n:1276	n:1276	n:1297	n:1819	n:1819	n:1886		n:2220	n:2220	n:2362			
	τ	0.081***	0.721***	0.551***	0.409***	0.717***	0.479***		0.101***	0.754***	0.617***			
		n:1276	n:1276	n:1297	n:1819	n:1819	n:1886		n:2220	n:2220	n:2362			

(continued)

Table 4 (continued)

Year		WIOD(ISIC3) TD	WIOD(ISIC3) TS	WIOD(ISIC3) PR	OECD(ISIC3) TD	OECD(ISIC3) TS	OECD(ISIC3) PR	Year	WIOD(ISIC4) TD	WIOD(ISIC4) TS	WIOD(ISIC4) PR	OECD(ISIC4) TD	OECD(ISIC4) TS	OECD(ISIC4) PR
2000	r	0.054*	0.861***	0.604***	0.570***	0.898***	0.640***	2005	0.149***	0.896***	0.597***	0.208***	0.929***	0.693***
		n:1274	n:1274	n:1298	n:1814	n:1814	n:1881		n:2215	n:2215	n:2358	n:2149	n:2149	n:2219
	ρ	0.051*	0.898***	0.740***	0.578***	0.891***	0.626***		0.134***	0.915***	0.803***	0.446***	0.918***	0.687***
		n:1274	n:1274	n:1298	n:1814	n:1814	n:1881		n:2215	n:2215	n:2358	n:2149	n:2149	n:2219
	τ	0.039**	0.720***	0.551***	0.413***	0.716***	0.478***		0.097***	0.749***	0.620***	0.314***	0.758***	0.539***
		n:1274	n:1274	n:1298	n:1814	n:1814	n:1881		n:2215	n:2215	n:2358	n:2149	n:2149	n:2219
2001	r	0.088***	0.844***	0.603***	0.566***	0.895***	0.638***	2006	0.157***	0.893***	0.594***	0.218***	0.928***	0.690***
		n:1275	n:1275	n:1298	n:1814	n:1814	n:1881		n:2224	n:2224	n:2367	n:2152	n:2152	n:2222
	ρ	0.085***	0.888***	0.748***	0.569***	0.888***	0.626***		0.134***	0.915***	0.803***	0.475***	0.915***	0.687***
		n:1275	n:1275	n:1298	n:1814	n:1814	n:1881		n:2224	n:2224	n:2367	n:2152	n:2152	n:2222
	τ	0.064***	0.710***	0.559***	0.406***	0.713***	0.481***		0.095***	0.749***	0.621***	0.332***	0.756***	0.540***
		n:1275	n:1275	n:1298	n:1814	n:1814	n:1881		n:2224	n:2224	n:2367	n:2152	n:2152	n:2222
2002	r	0.190***	0.864***	0.598***	0.567***	0.896***	0.633***	2007	0.154***	0.896***	0.592***	0.205***	0.925***	0.688***
		n:1269	n:1269	n:1292	n:1814	n:1814	n:1881		n:2227	n:2227	n:2370	n:2153	n:2153	n:2223
	ρ	0.069**	0.888***	0.749***	0.574***	0.889***	0.620***		0.123***	0.909***	0.810***	0.465***	0.914***	0.690***
		n:1269	n:1269	n:1292	n:1814	n:1814	n:1881		n:2227	n:2227	n:2370	n:2153	n:2153	n:2223
	τ	0.053***	0.709***	0.560***	0.409***	0.714***	0.476***		0.088***	0.741***	0.629***	0.326***	0.754***	0.543***
		n:1269	n:1269	n:1292	n:1814	n:1814	n:1881		n:2227	n:2227	n:2370	n:2153	n:2153	n:2223
2003	r	0.193***	0.864***	0.602***	0.574***	0.900***	0.635***	2008	0.164***	0.888***	0.590***	0.181***	0.918***	0.688***
		n:1279	n:1279	n:1300	n:1818	n:1818	n:1885		n:2213	n:2213	n:2355	n:2151	n:2151	n:2221
	ρ	0.053*	0.885***	0.756***	0.578***	0.890***	0.624***		0.140***	0.902***	0.811***	0.417***	0.904***	0.691***
		n:1279	n:1279	n:1300	n:1818	n:1818	n:1885		n:2213	n:2213	n:2355	n:2151	n:2151	n:2221
	τ	0.043**	0.707***	0.567***	0.413***	0.715***	0.479***		0.099***	0.731***	0.627***	0.291***	0.742***	0.544***
		n:1279	n:1279	n:1300	n:1818	n:1818	n:1885		n:2213	n:2213	n:2355	n:2151	n:2151	n:2221
2004	r	0.125***	0.867***	0.600***	0.564***	0.899***	0.640***	2009	0.090***	0.901***	0.599***	0.166***	0.916***	0.685***
		n:1278	n:1278	n:1301	n:1818	n:1818	n:1885		n:2204	n:2204	n:2347	n:2135	n:2135	n:2205
	ρ	0.058**	0.901***	0.760***	0.575***	0.887***	0.628***		0.135***	0.903***	0.810***	0.403***	0.904***	0.689***
		n:1278	n:1278	n:1301	n:1818	n:1818	n:1885		n:2204	n:2204	n:2347	n:2135	n:2135	n:2205
	τ	0.045**	0.730***	0.570***	0.410***	0.713***	0.482***		0.097***	0.731***	0.626***	0.281***	0.742***	0.541***
		n:1278	n:1278	n:1301	n:1818	n:1818	n:1885		n:2204	n:2204	n:2347	n:2135	n:2135	n:2205

(continued)

Table 4 (continued)

WIOD(ISIC3)	OECD(ISIC3)	WIOD(ISIC4)	OECD(ISIC4)

Year		TD	TS	PR	TD	TS	PR	Year	TD	TS	PR	TD	TS	PR
2005	r	0.115***	0.858***	0.588***	0.554***	0.895***	0.630***	2010	0.158***	0.882***	0.595***	0.164***	0.922***	0.691***
		n:1275	n:1275	n:1298	n:1817	n:1817	n:1883		n:2214	n:2214	n:2358	n:2146	n:2146	n:2216
	ρ	0.038	0.900***	0.760***	0.565***	0.885***	0.625***		0.160***	0.907***	0.811***	0.395***	0.909***	0.690***
		n:1275	n:1275	n:1298	n:1817	n:1817	n:1883		n:2214	n:2214	n:2358	n:2146	n:2146	n:2216
	τ	0.032*	0.726***	0.570***	0.402***	0.708***	0.478***		0.115***	0.738***	0.629***	0.276***	0.749***	0.543***
		n:1275	n:1275	n:1298	n:1817	n:1817	n:1883		n:2214	n:2214	n:2358	n:2146	n:2146	n:2216
2006	r	0.110***	0.861***	0.592***	0.550***	0.896***	0.634***	2011	0.159***	0.892***	0.592***	0.153***	0.920***	0.693***
		n:1279	n:1279	n:1302	n:1822	n:1822	n:1888		n:2208	n:2208	n:2351	n:2144	n:2144	n:2214
	ρ	0.026	0.892***	0.760***	0.557***	0.882***	0.629***		0.144***	0.905***	0.812***	0.408***	0.908***	0.694***
		n:1279	n:1279	n:1302	n:1822	n:1822	n:1888		n:2208	n:2208	n:2351	n:2144	n:2144	n:2214
	τ	0.026	0.718***	0.569***	0.396***	0.704***	0.484***		0.105***	0.733***	0.629***	0.286***	0.747***	0.545***
		n:1279	n:1279	n:1302	n:1822	n:1822	n:1888		n:2208	n:2208	n:2351	n:2144	n:2144	n:2214
2007	r	0.139***	0.793***	0.564***	0.541***	0.895***	0.630***	2012	0.143***	0.886***	0.590***	0.128***	0.917***	0.694***
		n:1276	n:1276	n:1299	n:1824	n:1824	n:1890		n:2217	n:2217	n:2359	n:2147	n:2147	n:2216
	ρ	0.128***	0.843***	0.690***	0.547***	0.880***	0.628***		0.136***	0.904***	0.814***	0.397***	0.902***	0.694***
		n:1276	n:1276	n:1299	n:1824	n:1824	n:1890		n:2217	n:2217	n:2359	n:2147	n:2147	n:2216
	τ	0.095***	0.651***	0.506***	0.389***	0.702***	0.483***		0.100***	0.732***	0.632***	0.276***	0.740***	0.544***
		n:1276	n:1276	n:1299	n:1824	n:1824	n:1890		n:2217	n:2217	n:2359	n:2147	n:2147	n:2216
2008	r	0.035	0.791***	0.563***	0.511***	0.881***	0.626***	2013	0.080***	0.907***	0.588***	0.142***	0.919***	0.693***
		n:1272	n:1272	n:1297	n:1816	n:1816	n:1882		n:2213	n:2213	n:2355	n:2147	n:2147	n:2217
	ρ	0.111***	0.831***	0.688***	0.517***	0.865***	0.629***		0.134***	0.906***	0.814***	0.414***	0.904***	0.696***
		n:1272	n:1272	n:1297	n:1816	n:1816	n:1882		n:2213	n:2213	n:2355	n:2147	n:2147	n:2217
	τ	0.085***	0.639***	0.506***	0.365***	0.685***	0.483***		0.098***	0.735***	0.633***	0.289***	0.742***	0.547***
		n:1272	n:1272	n:1297	n:1816	n:1816	n:1882		n:2213	n:2213	n:2355	n:2147	n:2147	n:2217
2009	r	0.024	0.753***	0.570***	0.499***	0.874***	0.612***	2014	0.099***	0.905***	0.588***	0.144***	0.924***	0.687***
		n:1258	n:1258	n:1282	n:1805	n:1805	n:1871		n:2213	n:2213	n:2357	n:2146	n:2146	n:2216
	ρ	0.100***	0.821***	0.690***	0.491***	0.858***	0.617***		0.137***	0.907***	0.818***	0.412***	0.907***	0.692***
		n:1258	n:1258	n:1282	n:1805	n:1805	n:1871		n:2213	n:2213	n:2357	n:2146	n:2146	n:2216
	τ	0.076***	0.628***	0.505***	0.345***	0.680***	0.475***		0.100***	0.738***	0.637***	0.287***	0.747***	0.546***
		n:1258	n:1258	n:1282	n:1805	n:1805	n:1871		n:2213	n:2213	n:2357	n:2146	n:2146	n:2216

(continued)

Table 4 (continued)

	WIOD-ISIC3	OECD-ISIC3	WIOD-ISIC4	OECD-ISIC4

Year		TD	TS	PR	TD	TS	PR	Year	TD	TS	PR	TD	TS	PR
2010	r	-0.058**	0.781***	0.556***	0.522***	0.888***	0.620***	2015				0.141***	0.924***	0.683***
		n:1270	n:1270	n:1295	n:1819	n:1819	n:1885					n:2149	n:2149	n:2219
	ρ	-0.012	0.821***	0.649***	0.514***	0.873***	0.624***					0.407***	0.910***	0.689***
		n:1270	n:1270	n:1295	n:1819	n:1819	n:1885					n:2149	n:2149	n:2219
	τ	0.003	0.629***	0.470***	0.363***	0.695***	0.483***					0.284***	0.749***	0.544***
		n:1270	n:1270	n:1295	n:1819	n:1819	n:1885					n:2149	n:2149	n:2219
2011	r	0.035	0.785***	0.561***	0.512***	0.887***	0.618***							
		n:1269	n:1269	n:1293	n:1815	n:1815	n:1881							
	ρ	0.001	0.824***	0.661***	0.505***	0.869***	0.624***							
		n:1269	n:1269	n:1293	n:1815	n:1815	n:1881							
	τ	0.012	0.632***	0.481***	0.356***	0.690***	0.481***							
		n:1269	n:1269	n:1293	n:1815	n:1815	n:1881							

Source: Own Calculation. Data: WIOD, OECD. p*<0.1, p**<0.05, p***<0.01. *Notes*: r: Pearson Correlation, ρ: Spearman Correlation, τ: Kendall Correlation, n: number of industries, TD: Total-Degree, TS: Total-Strength, PR: PageRank. The total number of industries in WIOD-ISIC3, WIOD-ISIC4, OECD-ISIC3, OECD-ISIC4, is 1400, 2408, 2142 and 2304, respectively.