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The structure of inter-industry systems and the diffusion of innovations: The case of Spain

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ABSTRACT

This paper focuses on the role of inter-industrial structures and the position of economic sectors in them for the diffusion of knowledge and innovation. Network Theory and Social Network Analysis have been applied to analyze the structure of the Spanish Input–output system and its evolution over a thirty-five-year period. The structural analysis conducted tests the existence of a Scale-free topology and also includes the identification of sectors acting as hubs or super-spreaders, which make up the core of the system. Scale-free networks correspond to structures that allow for faster and more efficient diffusion processes that are enhanced when initiated in hubs. As a concluding remark, this paper puts forward a proposal for interventions to attain a higher incidence in the national innovative capacity and in the development process.

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1. Introduction

Even if Network Theory (NT) is still a novel methodology in economics [1,2], it is increasingly accepted that the economy is a complex system that requires deep systemic analyses, starting from its topological characteristics [3–5]. More precisely, understanding the structure and dynamics of economic networks requires the study of the structural properties of the underlying interaction networks and their dynamics [6]. This paper analyzes the structure and evolution of inter-industry systems in Spain, from NT and Social Network Analysis (SNA). It adopts a systemic approach and the structural change definition stated in Saviotti and Gaffard [7]: "In the past, the concept of structural change has been interpreted in the economics literature as a change in the weights of different sectors. However, today it is increasingly evident that a broader concept of structural change is required. In a systemic framework, structural change can be defined as a change in the structure of the economic system, that is, in its components and their interactions".

When this structural view is applied to innovation processes, it is assumed that actors acquire and develop overlapping and diverse knowledge resources through interactions with other actors, and that the newly acquired knowledge can be converted into new products, patents and other tangible forms [8]. Knowledge is more likely to be transferred between organizations that make chains or systems than through independent organizations [9]. In general terms, knowledge flows between two actors are made easier when the actors are embedded in a dense network of third-party connections.

This is the case of economic sectors embedded in dense production networks and exchanging knowledge and innovation. Although the processes of production and of innovation differ in important respects "they are also mutually interdependent" [10]. In accordance with Hauknes "At the firm level, it should be evident that for most firms, their relations with customers, competitors and suppliers are the most significant links to their environment, to the extent that these agents constitute the major dimensions of this environment. It is not unlikely that these immediate relations shape the major learning modes for a majority of firms" [11]. In many innovation surveys, as in OECD surveys [12], firms indicate that suppliers, customers and competitors are

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'highly important' sources of knowledge for innovation. User–producer interactions, joined through inter-industry linkages, play a fundamental role providing embodied knowledge flows in incremental innovation and in the learning process [10,13,14]. In the same line, Schmookler [15] points out that "the best way to improve an industry's technology is often to improve the inputs it buys from other industries".

Even if not all user–producer relationships promote innovative activities [10], all of them constitute opportunities to increase the efficiency of policy interventions. The ability to take advantage of those opportunities depends on the structure of production networks. Structure matters, but there is a diversity of them that shapes dense networks, and Scale-free is outstanding among them. The role of topology in the study of the diffusion of innovations and of the effectiveness of innovation strategies is emphasized by the picture emerging from the system of economic interactions. At the same time, an innovation flow may die out on the same network immediately or persist for a considerable time, depending on the sector where it was originated. We know that our knowledge about the interactions that allow and promote innovation flows will improve by going in depth into inter-industrial structures, with its policy implications. The availability of a considerably long time series of Input–output Tables (IOT) should not be passed by. A structural analysis of inter-industry networks would contribute to the understanding of how innovation flows, to identifying highly connected sectors, named hubs or super-spreaders, that speed up the process, and to improving the design of interventions. In the case of Spain this is particularly relevant because of its innovation backwardness, its efficiency problems and the lack of effectiveness of its innovation policies.

Research on the impact of innovation on productivity growth and on other economic variables, by Input–Output (IO) analysis, was initiated by Terleckyj and Scherer, who assume that R&D is indirectly incorporated by purchasing intermediate inputs [16–18]. For DeBresson [19] IOT can serve as economic maps that indicate which are the paths of least resistance for the industrial diffusion of the technologies when the analysis is focused on market relationships and on the accumulation of technological knowledge, through experience based on the circulation of goods and services and on the process of learning by doing. "In order for a new technology already adopted by industry *i* to be subsequently adopted by industry *j*, it is preferable that industry *j* be in *direct contact*, as a client or as a supplier, with industry *i*. In other words, the two industries must be directly linked in an input–output table by a supply–demand relationship". DeBresson remarks that the information embodied in IO interactions is particularly useful for the analysis of the productive structure of the whole economy [19–21].

A new research line was opened up by Leoncini et al. [22] with the identification and study of Technological Systems by combining IO and R&D data and applying NA [23–26]. According to Montresor and Vittucci [25], IO coefficients crucially affect learning by interacting and the entailed knowledge networks that firms establish in innovating. More specifically, IO matrices map inter-sector flows of goods and services which shape the inter-sector diffusion of innovation by channeling and driving both embodied and disembodied innovation flows and the knowledge embedded in the exchanged goods and services. Their work fits into a wider field that considers that organizations acquire knowledge through interactions with other actors, making chains and systems and explaining that knowledge and innovation spread through intermediate trade linkages [8,9,25,27–29].

Our argument is also in line with other relevant pieces of research. This is the case of the literature of systems of innovation studying system failures, with the focus on missing connections to support knowledge processes through interactive learning [30–33]. A system failure policy implies that the framework conditions for a better diffusion and adoption process taking place across the structure of economic activities should be set. Actors supplying knowledge and innovation through sales and also users and consumers of goods, receiving information and probably adopting innovations through them should be taken into account.

The present paper is placed in the above literature both for its objective and its methodology. However, its focus differs as it is the structure of inter-industrial systems. We do not focus on direct relationships between two particular sectors but on the chains and sub-systems that are making up the whole inter-industrial structure. The structure and evolution of intermediate trade relationships in Spain in the period 1970–2005 using IOT are analyzed because the constituting networks that represent inter-industrial systems push production systems into the open [34,35] and act as a platform for interactions that ease learning and the processes of knowledge and innovation diffusion. The study of its structure implies a first necessary step, not addressed in the literature, before studying more specific topics affected by it. It is valuable not only for scholars but also for policy makers because its results relate to productivity and the national innovative capacity, and hence to the enhancement of development [36].

This paper raises the following questions: Does the inter-industry network in Spain show a Scale-free topology where a core and a periphery can be identified? How has it evolved in the period 1970–2005? Can hubs, or super-spreaders, sectors be identified? Are there specific strategies that can be proposed from a relational analysis to improve the diffusion of ideas, knowledge and innovation? By answering these questions this paper aims to fill a void in the literature by studying the relevance of structures for diffusion processes, particularly for the diffusion of innovations through inter-sectoral interactions. In doing so, this paper is methodologically coherent, as the economy is viewed as a complex system, and systemic methodologies are applied (SNA and NT). Following this structural view, the Scale-free topology of inter-industry networks has been analyzed and a core and a periphery have been identified; results also indicate that the core–periphery structure is consolidated and that there is a set of sectors in the core with a permanent character in the period considered. Hubs have also been identified, opening up a discussion on the suitability of the sectors which innovation policies are being directed at. Through these results, this paper offers novel contributions to the methods of identifying core–periphery networks, the analysis of innovation flows between economic sectors by using IO data, the design of public and private interventions that would enhance a more efficient diffusion of knowledge and innovation, and the methods to verify whether the selected sectors in innovation programs are the most appropriate in terms of scope and speed when a systemic effect is intended.

The paper is organized as follows: Section 2 explains the most relevant theoretical matters and the methodology followed; Section 3 presents the Spanish context in the period analyzed and the data used; Section 4 contains the empirical analysis conducted to examine the structural evolution and the core–periphery structure of IO networks; the final section gives the conclusions.

2. Theoretical matters and methodology

2.1. The structure of networks and the diffusion processes

The sum of individual interactions forms systems and systems of systems, so creating complex networks that can be studied structurally from NT [37]. In studying the diffusion of innovations Rogers has emphasized that "the study of networks helps illuminate communication structure" [38]. According to Jackson [28], network structure has an impact on behavior, and ultimately on the wealth of society, through two mechanisms that are particularly relevant in the study of innovations: 1) there is a mechanical impact, acting mainly as a conduit, like in understanding the diffusion of an idea or information and 2) the trade of goods and services and the adoption of a technology imply strategic interactions between networked agents. Following the same author, network structure is the primary determinant of whether diffusion occurs for a significant fraction of the society, how quickly it occurs and what fraction is finally affected. In fact, only flows whose spread rate exceeds a critical threshold can reach the whole network. That threshold is determined by the topology of the network over which knowledge and innovations spread [3].

The empirical evidence offered by NT indicates the existence of a very few topologies present in many networks (social, economic, ecological, biological, etc.), among which Scale-free distribution stands out. This distribution has common features with a very relevant structure in economic networks, the core–periphery structure, which comes from SNA [3,6,39–51]. Recent research has shown that in Scale-free networks there is a vanishing threshold, leading to the spread of exchanges through the whole system. The Scale-free networks imply, according to Pastor-Satorras and Vespignani, "a extreme heterogeneity in the pattern of connectivity" because each node "has a statistically significant probability of having a very large number of connections compared to the average connectivity of the network" [52]. Barabási and Bonabeau [40] indicate the potential implications of Scale-free networks for business: "Understanding how companies, industries and economies are interlinked could help researchers monitor and avoid cascading financial failures. Studying the spread of a contagion on a Scale-free network could offer new ways for marketers to propagate consumer buzz about their products". As already discussed in the Introduction of this paper, Scale-free structures are very important for a systemic diffusion of knowledge and innovation. Regardless of the origins of the influence process, there is a wide range of social phenomena, such as diffusion of innovations, which share this logic of contagion, implying that spread is almost instantaneous in networks with such a structure [53]. Scale-free networks can also present communities, defined as high density groups. Sun and Gao [54] have proved that the clearer the community structure of networks, the weaker the robustness of the system, so facilitating the diffusion processes. This implies that Modular Scale-free network topology facilitates the diffusion of innovations most.[1] This feature is associated with a propagation process that follows a hierarchical dynamics from higher to lower degree classes, going from the core to the network periphery. When the lowest degree sectors are reached, the whole system is implied in the propagation process. The connectivity pattern of networks underlines the relevance of highly connected nodes, labeled as hubs, super-spreaders, 'boosters' or 'networkers' [56–59]. If the propagation starts at those nodes, the dynamical structure of the spreading is characterized by a hierarchical cascade from hubs (core) to intermediate degree nodes (semi-periphery) and, finally, to small degree classes (periphery). The starting point is, then, very important, because it can either stop the diffusion process or facilitate its spreading. Following Hai-Feng et al. [60], any effective interventions in Scale-free networks should imply a targeted activation of: 1) highly connected individuals and 2) significant edges, as they connect high degree nodes. Moreover, when communities can be identified in the network, diffusion is higher through acting in hubs than through acting in a sector of each community [59].

In SNA terms, highly connected nodes also play a leading role in core–periphery structures, by forming the core of the system. They hold the structure up, allowing any diffusion process to reach most of the system. There are numerous research works showing the strong capacity of core–periphery structures to represent different relationships between various kinds of actors (individuals, organizations or countries) [42–51]. Among the most recent research works, Giuliani and Bell [61] apply SNA to analyze the inter-firm links in a wine cluster and identify a core–peripheral knowledge structure where core firms transfer knowledge between themselves and are sources of knowledge for peripheral firms. Rank et al. [62] also identify a core–periphery structure when examining a regional network of interfirm cooperation in biotechnology. Hidalgo and Hausmann [63,64] propose, in a wider context, that development processes are related to the complexity that emerges from the interactions between the individual activities that comprise an economy. Their conclusions are important in theoretical and political terms: "A network view of development does not require a unique definition of a link: rather it requires accepting as a reasonable assumption that

[1] This deduction is in disagreement with Soofi and Ghazinoory [55], who assert that hierarchical systems are more resistant to innovation diffusion when compared to dense and evenly distributed systems. The research work mentioned does not consider that systems with the same density can correspond to diverse structures and that the impact of the diffusion processes depends on its starting point.

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there are links connecting some products and not others, links through which knowledge, inputs and workers can flow; links that may be traversed by endeavor or serendipity" [64]. In their work, and in Hidalgo et al. [43], networks of related products are analyzed using international trade data to focus on the relationship between development and economic specialization. The authors identify a hierarchically clustered structure in the 'product space' with a core and a periphery. According to them, a network view to describe product relatedness illuminates aspects of development processes that, ultimately, depend on how nations develop different industries and products. Hojman and Szeidl [44] have asserted that many economic and social networks share their core–periphery structure as a common organizing feature. The authors conduct pure theoretical research to show that, under certain restrictive assumptions, there is a unique equilibrium architecture exhibiting a core–periphery structure and that there is a positive correlation between centrality and payoffs. Finally, Lovejoy and Sinha [65] try to answer the following question: "What social network structure is the most efficient for the ideation phase of innovation?" Their study simulates several topologies and concludes that "the idealized core–periphery graphs emerge as an important family on the time–cost efficient frontier." In general terms, the core–periphery duality describes the conflict between two groups of actors, with the core capturing the dominant, or power, position and the periphery corresponding to the dependent position. This structural analysis stresses the asymmetric interdependence characterizing the links between two or more categories in a particular system.

These results are extremely useful in understanding the diffusion processes taking place in economic systems. They also stress the need to know the topology of inter-industry networks to understand the processes that allow or impede the spread of ideas, knowledge and innovation and to propose appropriate interventions to achieve an impact on the whole system. Thus, both SNA and NT are applied in this paper to analyze the structural evolution of IO systems, assuming that the highly connected nodes in the core in SNA terms act as hubs in Scale-free and Modular Scale-free distributions in NT terms. A hub-and-spoke type of network emerges when a hierarchy of hubs can be established [66]. In an ideal hub-and-spoke network there is a hub, the largest in relational terms, in contact with a large fraction of all nodes. This corresponds to a core–periphery structure with a core made up of the most central node, or the central hub, consisting of a fully connected component with maximum density [66–68]. Both structures are analyzed here to approach the questions posed in the Introduction and therefore, the results are more robust.

2.2. Modular Scale-free networks and core–periphery structures

This section includes NT and SNA definitions of the network concepts and measures used in the empirical analysis conducted in this paper to identify Modular Scale-free and core–periphery topologies.

Degree, k, is the number of links that a node has to other nodes. In directed networks, like IO, incoming degrees, k_{in}, and outgoing degrees, k_{out}, can be distinguished for each node and interpreted as centrality measures (Indegree and Outdegree Centrality).

Density is the ratio between the number of links, edges, or arrows, in a graph and the number of arrows if the graph is complete. It is the number of effective connections related to the number of possible connections.

Degree distribution, $P(k)$, gives the probability that a selected node has exactly k links. It allows us to distinguish between different structures, such as random and Scale-free networks [69].

A *Scale-free network* presents a degree distribution that approximates a Power-law tail, $P(k) \sim k^{-\gamma}$ [39]. In a Scale-free network there are a few highly connected nodes, known as hubs, holding together numerous low degree nodes.

The *clustering coefficient* quantifies the tendency to cluster or form high density groups in a network. The clustering coefficient for node i, where n_i is the number of links between the k_i neighbors of i, is measured as in Eq. (1) and implies the local network property of modularity [70].

$$C_i = \frac{2n_i}{k_i(k_i - 1)} \tag{1}$$

Modular Scale-free network accounts for the coexistence of modularity and Scale-freeness. At the extreme, a perfect simulation presents a clustering coefficient following $C(k) \sim k^{-1}$. In general, it shows a Power-law degree distribution with an inverse relationship between degree and clustering. This structure implies that sparsely connected nodes are part of highly clustered areas, with the links between the different highly clustered neighborhoods being maintained by a few hubs [70].

A *core–periphery structure can be identified in a network* with a two-class partition of nodes with 1-blocks and 0-blocks in blockmodelling terminology [71,72]. In an ideal core–periphery structure there are just those two groups of nodes. The 1-block group is the core, integrated by nodes linked to all the nodes in the system. The 0-block group is the periphery, made up of nodes linked only to the core, and the ties between the core and the periphery can be either 1-blocks or 0-blocks.

In socio-economic systems, idealized structures are difficult to find, but structures that come close to the theoretical one can be estimated. In many situations it is possible, and even convenient, to identify a semiperiphery, i.e. an intermediate group of nodes placed between the core and the periphery. This structure is generally analyzed by applying the core–periphery algorithm

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proposed in Borgatti and Everett [71] to maximize the correlation between the matrix with the original data and the postulated idealized matrix (Eq. (2)).

$$\rho = \sum_{ij} a_{ij}\delta_{ij} \; with \; \delta_{ij} = \begin{cases} 1 & \text{if } c_i = \text{core or } c_j = \text{core} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

Coreness, c_i, quantifies the strength of nodes membership in the core group by measuring the degree of closeness to the core. The position of nodes in the core–periphery structure is thus determined [71].

The *concentration index* (Eq. (3)), where the first *j* nodes comprise the membership to the core, is applied to select the sectors making up the core [73]. The number of nodes maximizing the concentration index is selected as being the core. In general terms, the higher the differences between the corenesses of core and periphery, the higher the concentration index. It distinguishes different areas (like core, strong semi-periphery, weak semi-periphery and periphery) from the hierarchical order established by the coreness scores.

$$\frac{\sum_{i=1}^{j}\left(c_i - max\left(c_{j+1}, c_{j+2}, \ldots, c_n\right)\right)}{2j} + \frac{\sum_{k=j+1}^{n}\left(min\left(c_1, c_2, \ldots, c_j\right) - c_k\right)}{2(n-j)} \tag{3}$$

2.3. Proposed methodology

In this paper, IO networks are analyzed assuming that development processes imply an evolution of intermediate trade exchanges. IO links constitute a relevant system working within the more complex economic system, and their structural characteristics must be studied in order to understand development processes. Some inter-sectoral linkages emerge or increase their presence in the economic activity, while other technical relationships lose importance or even disappear. As a consequence, sectors change their position in the system, becoming more central, more peripheral, more interlinked or more isolated, so determining the structural evolution of the network. This evolution originates at firm level and shows its effects in sectors, in production systems and in the economy as a whole. Production systems are sub-systems formed by sectors linked by technical relationships and are embedded in the whole IO network. Their evolution reflects the innovation strategies being continuously adopted by firms and shapes the structure of IO networks [34]. In this regard, the strategies adopted by firms in terms of organizational innovation and market integration promote a general increase of connections among sectors. Therefore, an increasing density of intersectoral networks is expected to be found, assuming that the number of zero entries in intermediate matrices decreases.

The position of each sector in inter-industry systems is ascertained by analyzing it and applying NT and SNA. In this way, the structure of IO systems is identified and a core and a periphery are looked for. The core would be made up of a group of highly linked sectors, or hubs, occupying a central position, holding the whole IO structure together, and acting as super-spreaders. A tendency to form clusters, or production systems can also be sought in the IO structure if there are modules connected by the hubs.

Two procedures will be followed in this paper to test if the core–periphery model can represent the inter-sector relationships taking place in a particular economy. The core–periphery algorithm proposed in Borgatti and Everett [71] is applied in SNA. The same research work is used to identify sectors making up the core and the periphery. Their position in the IO structure is determined through the 'coreness' score of each node, computed with UCINET [74]. Using NT, the core–periphery model is analyzed as a type of Modular Scale-free network and, therefore, the degree distribution, the clustering coefficient and the modules' densities are studied.

From an intervention perspective, we already know that it is possible to drive a systemic innovation policy by focusing on hub sectors and their trade linkages. The spread will be more effective when networks show a Scale-free topology and the innovation process is initiated in hubs. We propose that if IO systems in Spain can be identified as Scale-free networks with a core–periphery structure, an effective innovation policy should be directed at: 1) sectors acting as hubs, identified as strategic diffusers, and 2) sectoral and institutional linkages with sectors acting as hubs. In particular, diffusion can be promoted by increasing the contact between hubs and highly innovative sectors. If it is not initiated in hubs, the flow has to find other routes to spread the innovation and knowledge, which can slow down the spread considerably. If the selection of sectors is merely random there is a very little effect, even when selecting the same number of sectors. In those cases the spread is slowed down and reaches fewer sectors. The systemic inefficiencies of periphery sectors can also be studied when, owing to the country's specialization or for any other reason, they are selected by policy makers as target sectors. Their embeddedness in the networks can be improved by acting on their linkages. The objective would be to foster them in terms of competitiveness an innovation.

Research using IO data to analyze the core–periphery structure of IO systems is very scarce [34,35]. There are recent studies that use SNA to analyze some structural properties of technological systems from IO matrices [24,26], to analyze redundant relations and structural holes in IO data [27], while others apply NT to study relationships between prices [75], or to identify core sectors from their degree centrality [55], but none focuses on the structural evolution of inter-industry systems.

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Table 1
Development indicators of Spain, 1970–2005.

	1970	1980	1990	2000	2005
GDP*pc*[a]	10,488	13,604	17,553	22,312	24,361
HDI[b]	0.820	0.863	0.896	0.932	0.949
Agriculture Value Added (%)[c]	13.46	7.20	5.60	4.40	3.30
Infant mortality rate (‰)[d,e]	21.40	10.65	6.65	4.10	3.91
Life expectancy at birth[e]	72.20	75.75	77.44	79.75	80.85

Note: Data from [95–97].
[a] Gross Domestic Product *per capita* in US dollars, at constant 2000 prices. GDP*pc* in 1970 is an estimated value.
[b] Human Development Index.
[c] Agriculture includes cultivation of crops, livestock production, forestry, hunting and fishing.
[d] Deaths per thousand births as the probability of dying between birth and exact age 1.
[e] Infant mortality rate and life expectancy at birth are a 5-year average.

3. Context and data

3.1. Context

In spite of the economic crisis in the 1970s, the period analyzed (1970–2005) is characterized by intense economic growth and development in Spain (Table 1). The GDP *per capita* multiplied by 2.3 over 1970–2005, and in 2005 its position in the HDI ranking was 13, out of 177 countries. The intense reduction in the contribution of agriculture to the GDP indicates the structural change the Spanish economy underwent. The selected social indicators also show a development process: there is a big reduction in infant mortality rate (−17.5 percentage points), and Spain figures among the ten countries with the highest life expectancy in the world.

Despite the strong economic growth and the advances observed in social indicators, labor productivity growth has been modest and competitiveness still has a lot of room for improvement. The OECD Spanish report on science and technology for 2008 recalls that the government's National Reform Programme aims to boost productivity through reforms in product and labor markets, higher education and human capital, investment in infrastructure and R&D. The report highlights the need for additional efforts in research and innovation and summarizes the situation as follows: “Spain spent 1.2% of GDP on R&D in 2006, significantly below the EU27 (1.76%) and OECD (2.26%) averages. However, there is a substantial increase on the levels of the mid-1990s. The business sector finances 47% of gross domestic expenditure on R&D; the government finances 42.5%; 5.9% is financed from abroad and 4.5% from other national sources. Boosting R&D and innovation in the business sector is a challenge, as most industries are relatively low-technology and most firms are small or medium-sized” [76]. The Global Competitiveness Report shows that Spain occupies the 33rd place in a ranking of 133 countries in the Global Competitiveness Index corresponding to 2009–2010, and it had dropped four positions on the previous year [77]. The index is made up of 11 pillars, and the one where Spain has the worst score is ‘Labor market efficiency’ (97th). ‘Innovation’ is one of the pillars, measured by several variables, and the worst score corresponds to the Government procurement decisions to foster technological innovations (66th). The World Economic Forum also publishes a Global Information Technology Report and Spain occupies 34th place out of 133 countries, in technology terms, in the 2010 report [78]. The calculated index includes 68 components and the success of the Spanish government in promoting the use of information and communication technologies is among the worst (ranked 102nd). The national INNO-Policy TrendChart-Innovation Policy Progress Report elaborated in 2009 by the European Commission describes Spain as a moderate innovator and shows its Summary Innovation Index with a marked negative evolution in the indicators ‘Linkages & entrepreneurship’ and ‘Innovators’, and concludes: “this data reflects the negative appreciation of the experts, showing a severe worry about the behavior of the Spanish RDI system in an immediate future” [79].[2] An effort is therefore needed to enhance innovation, and the opportunity to make use of new methodologies for a better understanding of innovation processes and to design innovation strategies should be of general interest.

3.2. Data

The information used in this paper corresponds to the IOT constituting squared $n \times n$ matrices made by the x_{ij} inter-sectoral domestic trade linkages in a system including n sectors in Spain for the period 1970–2005.[3]

[2] RDI stands for Research, Development and Innovation. The ‘Linkage & entrepreneurship’ indicator includes: SMEs innovating in-house; innovative SMEs collaborating with others; firm renewal (SMEs entries + exits) and public–private co-publications (2-year average). The ‘Innovators’ group includes the following indicators: product/process innovators (SMEs); marketing/organizational innovators (SMEs); reduced labor costs and reduced use of materials and energy.

[3] Data for 1970 have been obtained from Instituto de Estudios de Planificación [80], for 1975 the source is FIES [81] and for years 1980 to 2005, data are taken from the Spanish Statistics Bureau web page (http://www.ine.es). All matrices, from 1970 to 2005, apply entirely the methodology proposed by the European Commission Statistical Office (EUROSTAT). x_{ij} is the intermediate consumption that sector j makes from sector i. According to the European System of Accounts [82] intermediate consumption “consists of the value of the goods and services consumed as inputs by a process of production, excluding fixed assets whose consumption is recorded as consumption of fixed capital. The goods and services may be either transformed or used up by the production process.” Although the information selected corresponds to domestic, or inside, values, the analysis has also been conducted for total transactions and the section on the empirical analysis includes results for the total data in selected cases. Data are analyzed using the original IOT to avoid losing information when trying to understand the complexity of the networks studied. The classifications of sectors have also been homogenized in time to include the same sectors in the selected years to corroborate the results; this information has been shown in the present paper only in Fig. 5. Intra-sectoral transactions have not been considered (main diagonal). The names of all sectors and their corresponding abbreviations are given in the Appendices.

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Each IOT has been transformed to obtain three different versions of relative domestic inter-industry linkages. The Intermediate Sales Matrix, **S**, considers the weight of each intermediate transaction in the total intermediate sales of a selling sector (Eq. (4)). The Intermediate Purchasing Matrix, **P**, considers the importance of each intermediate transaction in the total intermediate purchases of the purchasing sector (Eq. (5)). The Intermediate Global Matrix, **G**, considers each intermediate transaction in relation to the total number of exchanges (Eq. (6)).

$$s_{ij} = \frac{x_{ij}}{\sum_j x_{ij}} \tag{4}$$

$$p_{ij} = \frac{x_{ij}}{\sum_i x_{ij}} \tag{5}$$

$$g_{ij} = \frac{x_{ij}}{\sum_{ij} x_{ij}} \tag{6}$$

The analysis was also conducted after the application of selected threshold values, or filters, to the three matrices. The use of filters allows the emergence of the system's skeleton, so its structure can be ascertained and analyzed. An adjacency matrix is then obtained by following the usual procedure of SNA and Qualitative Input Output Analysis (QIOA) [83,84]. If we consider a generic **I** matrix collecting the relative intermediate transactions with i_{ij}elements representing s_{ij}, p_{ij} and g_{ij}, its binary transformation, on applying a filter, leads to the adjacency matrix made up of the i_{ij}^F filtered elements:

$$i_{ij}^F = \begin{cases} 1 & \text{if } i_{ij} \geq \text{filter} \\ 0 & \text{if } i_{ij} < \text{filter} \end{cases} \forall i, j = 1, \ldots, n. \tag{7}$$

The filter applied to dichotomize **P** and **S** is $1/(n-1)$ and it corresponds to a structural value where transactions are equally distributed by each sector to eliminate the matrix size effect. After filtering, both binary matrices have been added together in Boolean terms. Therefore, the transactions considered surpass the threshold value from the selling or buying perspective of each sector. The new summed and filtered matrix that considers the two way transactions is $\mathbf{T}^F$, and it limits the size effect, emphasizing pure relational aspects and focusing on the production system to which each sector belongs [25,26,85]. $\mathbf{G}^F$ is the binary version of **G**, when the filter $1/n \times (n-1)$ is applied. In this case the filter considers the whole network, implying that the selected links are important for the whole inter-industrial system and, therefore, the size effect is not eliminated, so the links of the smaller sectors will be penalized and the larger sectors will be overweighted.[4]

4. Empirical analysis: the network structure of IO systems

A first approach to the structural analysis of the IO system shows an increase in its density, as expected from the previous sections. This change is captured in a period of growth and development, with densities reaching high levels (0.7 in 2005). In general terms, the increase in the number of IO links occurs with and without imposition of a filter in domestic and total terms (Table 2).[5] Variations range from 29% to 176% and are very similar for the domestic and total data, with the highest increase corresponding to the domestic information when a high global filter is imposed.[6]

The relationships between density and economic growth and between density and development have received scarce consideration in the literature. Research works have focused on intra-organizational networks and on informal links, showing a positive relationship between density and productivity [86] and between density and performance [87]. Other authors focus on information flows at firm level, and underline the importance of dense networks for the transfer of knowledge [88–90]. At

[4] Montresor and Vittucci [26] discuss the need to relativize IO data to avoid scale effects. After comparing various techniques, the authors propose a method similar to the one we have applied in order to emphasize pure relational aspects. The same paper examines the advantages of using binary data by applying threshold values instead of using the relative valued matrices when the aim of the research is to identify and map relational structures.

[5] Tables hereinafter will show results for all the years analyzed (1970, 1975, 1980, 1985, 1990, 1995, 2000 and 2005) and the two types of selected filters. Figures will only show results for the years 1970, 1980, 1990, 2000 and 2005 and $\mathbf{T}^F$.

[6] Montresor and Vittucci [26] compare the IOT of six countries (Japan, Korea, Netherlands, Poland, Spain and the USA), with a sixteen sector disaggregation for the year 2005, concluding that Spain appears as the most systemic (high density according to the authors), though least innovation intensive country (R&D expenditures in GDP terms).

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Table 2
Density values in Spain, 1970–2005.

Domestic	1970	1975	1980	1985	1990	1995	2000	2005	VR (%)[a]
$\mathbf{T}$	0.453	0.466	0.482	0.653	0.638	0.764	0.734	0.688	51.899
$\mathbf{G}^F$	0.083	0.091	0.115	0.147	0.135	0.147	0.151	0.141	68.585
$\mathbf{G}^{2F}$	0.054	0.057	0.074	0.090	0.082	0.092	0.090	0.089	66.355
$\mathbf{G}^{4F}$	0.033	0.036	0.043	0.053	0.045	0.051	0.051	0.090	175.610
$\mathbf{T}^F$	0.170	0.168	0.192	0.257	0.255	0.264	0.261	0.259	52.235
$\mathbf{T}^{2F}$	0.114	0.113	0.133	0.162	0.161	0.164	0.163	0.162	42.379
$\mathbf{T}^{4F}$	0.070	0.069	0.081	0.084	0.085	0.085	0.086	0.090	28.592
Total									
$\mathbf{T}$	0.454	0.467	0.482	0.653	0.638	0.766	0.736	0.696	53.361
$\mathbf{G}^F$	0.080	0.086	0.113	0.143	0.134	0.142	0.142	0.140	74.938
$\mathbf{G}^{2F}$	0.052	0.054	0.073	0.086	0.083	0.089	0.092	0.086	66.151
$\mathbf{G}^{4F}$	0.031	0.034	0.042	0.049	0.047	0.049	0.051	0.051	62.739
$\mathbf{T}^F$	0.162	0.163	0.185	0.253	0.248	0.249	0.248	0.248	52.774
$\mathbf{T}^{2F}$	0.108	0.109	0.130	0.157	0.155	0.156	0.157	0.154	42.486
$\mathbf{T}^{4F}$	0.066	0.068	0.075	0.079	0.079	0.081	0.083	0.086	31.250

Note: $\mathbf{G}^{2F}$ and $\mathbf{T}^{2F}$ are two times each filter, $\mathbf{G}^{4F}$ and $\mathbf{T}^{4F}$ are four times the corresponding filter. **T** is the dichotomized intermediate transaction matrix, where all positive entries get the value 1. The values of **T** coincide when binarized from **S** and **P** or from **G**.

[a] Variation rate of density values between 1970 and 2005.

Table 3
Main core–periphery indicators, Spain, 1979–2005.

	1970	1975	1980	1985	1990	1995	2000	2005
Correlations[a]								
$\mathbf{T}$	0.594	0.599	0.528	0.568	0.595	0.618	0.597	0.562
$\mathbf{G}^F$	0.468	0.459	0.477	0.545	0.555	0.566	0.557	0.556
$\mathbf{G}^{2F}$	0.431	0.422	0.447	0.516	0.508	0.517	0.535	0.538
$\mathbf{G}^{4F}$	0.382	0.362	0.409	0.421	0.421	0.488	0.495	0.510
$\mathbf{T}^F$	0.426	0.439	0.446	0.457	0.462	0.454	0.470	0.460
$\mathbf{T}^{2F}$	0.383	0.379	0.399	0.382	0.408	0.409	0.420	0.425
$\mathbf{T}^{4F}$	0.318	0.287	0.311	0.292	0.313	0.357	0.377	0.369
Concentration[a]								
$\mathbf{T}$	0.918	0.919	0.926	0.890	0.885	0.934	0.881	0.867
$\mathbf{G}^F$	0.838	0.835	0.849	0.857	0.854	0.854	0.837	0.837
$\mathbf{G}^{2F}$	0.833	0.835	0.866	0.867	0.858	0.848	0.830	0.796
$\mathbf{G}^{4F}$	0.848	0.828	0.888	0.839	0.851	0.850	0.770	0.800
$\mathbf{T}^F$	0.837	0.834	0.843	0.840	0.816	0.846	0.854	0.842
$\mathbf{T}^{2F}$	0.828	0.801	0.827	0.858	0.813	0.820	0.820	0.826
$\mathbf{T}^{4F}$	0.799	0.817	0.790	0.844	0.817	0.817	0.781	0.783
Number[b]								
$\mathbf{T}$	52	54	34	37	38	52	56	45
$\mathbf{G}^F$	26	30	17	21	23	22	16	19
$\mathbf{G}^{2F}$	24	25	18	18	22	21	18	15
$\mathbf{G}^{4F}$	17	18	17	21	20	20	12	12
$\mathbf{T}^F$	21	26	12	13	13	18	16	12
$\mathbf{T}^{2F}$	15	23	8	9	7	12	12	7
$\mathbf{T}^{4F}$	19	15	8	8	11	6	1	6

[a] Correlations and the concentration index have been explained in Section 2.
[b] Number of sectors in the core.

sectoral level, DeBresson and Soofi and Ghazinoory [19,55] establish a relationship between density in IOT and innovation diffusion. There are denser circulation channels in IOT, indicating the best possibilities for a new technology to move from one industry to another [19].

In any case, levels and variations of densities allow only a first approach to understanding the systems under analysis and to obtaining initial information about their complexity. Indeed, different networks with identical densities can present very different patterns in their relationships, with consequences for performance terms. The main question we intend to answer in this section is if we can identify a core–periphery structure in the Spanish IO system. The SNA algorithm applied to check a core–periphery

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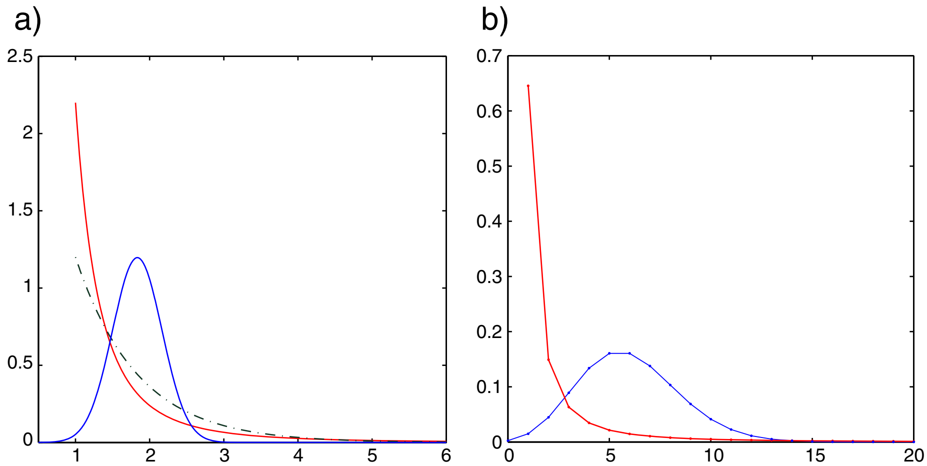

Fig. 1. Continuous and discrete distributions. Note: (a) Continuous case, density functions; Power-law, Exponential and Normal distributions; (b) discrete case, probability mass functions; Power-law and Poisson; same mean values.

structure (presented in Section 2) indicates that correlations generally show a strong fit with the ideal structure.[7] The core–periphery model has a high capacity to represent the inter-sector structure of Spain. Moreover, when comparing the beginning and the end of the period analyzed with filtered data, the registered adjustment improves, thus indicating the increasing representation capacity of the core–periphery structure. As the most recent case, in 2005 there are twelve sectors in the core for $\mathbf{T}^F$ and nineteen for $\mathbf{G}^F$, corresponding to 0.5 and 0.6 correlation values, and to 0.8 concentration indices (Table 3).[8]

NT offers an additional methodology to get a more robust result. Here, the imposition of filters allows the network skeleton to emerge and the base inter-industrial structure can therefore be analyzed in network terms. This is done by studying the distributions of sectors' degrees and of clustering coefficients. Fig. 1 compares the continuous Power-law, Normal and Exponential distributions (a), and the discrete Power-law and Poisson distributions (b). The intention is to recall the general shape of these distributions for comparative purposes.

Fig. 2 suggests that the degree distribution in the IO Spanish inter-industrial structure is far from representative of a Normal continuous distribution or a Poisson distribution, because inter-sectoral relationships present an unequal distribution. As deduced from the SNA analysis conducted, the Spanish inter-industry networks contain hub sectors with a very high number of links.

The procedure proposed in Clauset et al. [91] has been followed to identify a Power-law distribution[9]: 1) the best fit of the observed data to a Power-law model was determined according to a goodness-of-fit based method, i.e. the maximum likelihood estimate of the scaling parameter, γ, is calculated for each possible choice of the cutoff parameter, x_{min}, and the estimate of x_{min} is then given by the value that minimizes the Kolmogorov–Smirnov (KS) statistic over all values of x_{min} considered; 2) the Power-law hypothesis was tested using a goodness-of-fit test: a large number of synthetic data sets were generated from the best fit Power-law obtained under point 1[10]; the KS statistic was calculated for each set relative to its own Power-law best fit; finally, the *p-value* was taken as the fraction of the synthetic data KS statistic whose value exceeds the observed data KS statistic.

Table 4 summarizes the basic statistical parameters obtained with the above methodology. The filtered matrix that avoids the size bias ($\mathbf{T}^F$) enables the Scale-free structure to come out, because the *p-value* is sufficiently large (above 0.1) as to fit a Power-law distribution.[11] According to the results obtained, the probability that a sector can connect to k other sectors decays as a Power-law with $2.8 \leq \gamma \leq 3.5$.

Checking a Modular Scale-free topology also requires analyzing the modularity of the system. Fig. 3 shows the clustering coefficient distributions for 1970–2005, without imposing any filter and when applying the same filters as in Fig. 2. The clustering distribution indicates that the clustering coefficients of IO data decrease as $k^{-0.4}$ for $\mathbf{T}^F$. Its distributions always show a negative slope ranging from 0.33 to 0.41.[12] There is, then, a hierarchy of modules which are groups of sectors with high density. One of the modules, or a group of modules, would be the core in the core–periphery structure.

[7] Those correlations can be considered strong even if they are far from the perfect fit with the ideal model. This assertion is in agreement with [71], who report similar correlation values.
[8] The only sector in the core in 2000 for $\mathbf{T}^{4F}$ is Business services.
[9] The authors explain the correct procedure to identify a Power-law distribution. According to them, the tool most often used, the simple histogram, shows significant biases under relatively common conditions. As a consequence, the results are often incorrect and should not be trusted.
[10] In fact, what is used is a semi-parametric approach which involves the best fit Power-law above the cut-off and a distribution similar to the data observed below this value.
[11] According to Clauset et al. [91] many authors use the rule *p-value* ≤ 0.05, although they recommend ruling out the Power-law if *p-value* ≤ 0.1.
[12] This is the slope after adjusting a potential function to the distribution data, with an $R^2 = 0.8$. In a typical Scale-free network, without modularity, the clustering coefficient is independent of the node degree.

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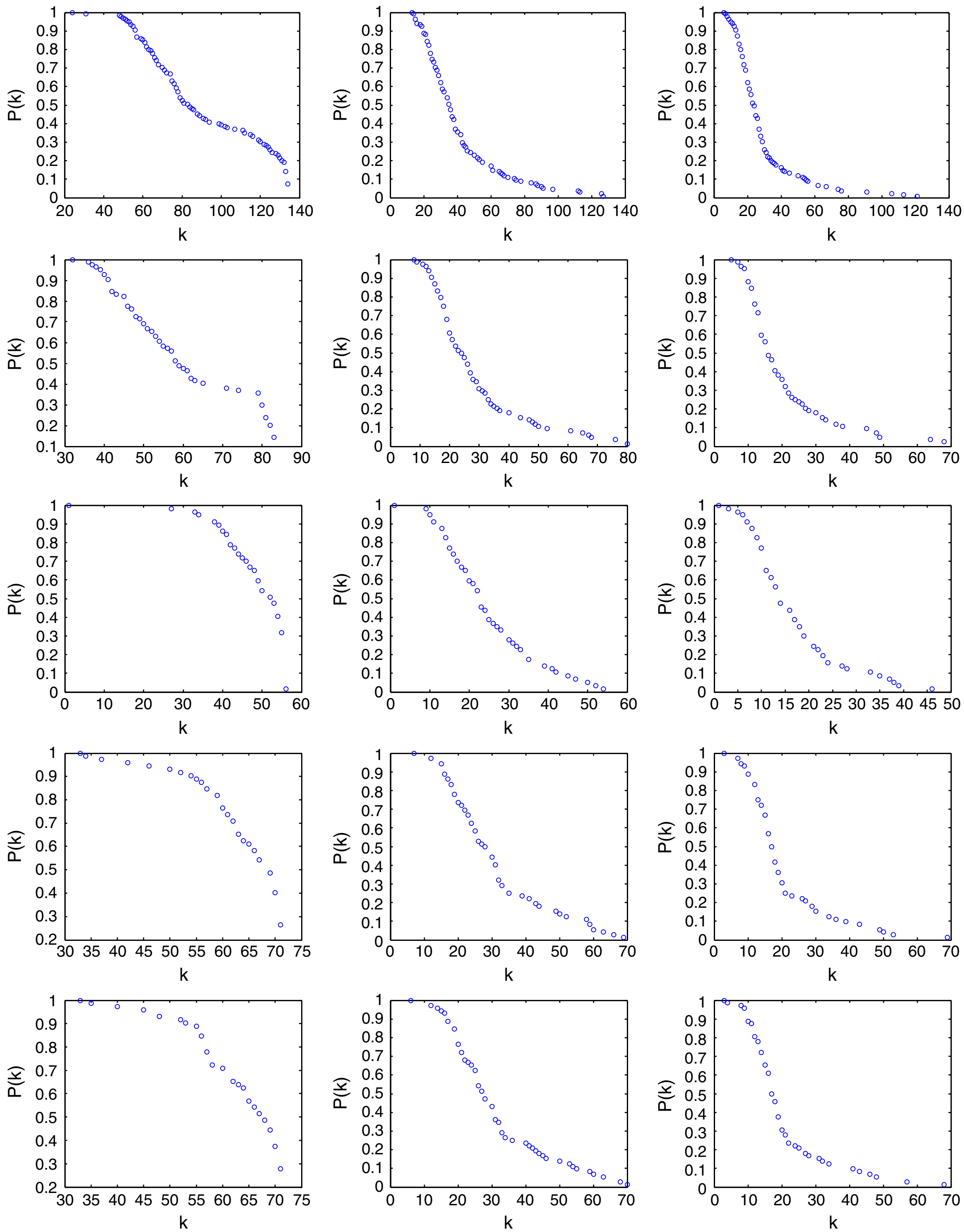

Fig. 2. Degree distributions, Spain, 1970–2005. Note: Every raw corresponds to a different year: 1970, 1980, 1990, 2000 and 2005. Cumulative Degree Distributions, **T** first column; $\mathbf{T}^F$ second column; $\mathbf{T}^{2F}$ third column. All parameters corresponding to these distributions are offered in Table 4.

Sectors in the core make up a component, or module, of much larger density than the whole network density: 0.66 versus 0.09 in 1970 and 0.7 versus 0.15 in 2005 ($\mathbf{T}^F$) (Table 5). As expected, the periphery component is a low density group that can be divided into smaller groups. Table 5 shows the densities of the core and periphery sets and of two subgroups making up the periphery. The new partition corroborates the high relative density of the core group and the existence of a very low density

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Table 4
Power-law distributions, basic parameters, Spain, 1970–2005.

	$\hat{\gamma}$	$\hat{x}min$	*p-value*		$\hat{\gamma}$	$\hat{x}min$	*p-value*
1970				1975			
$\mathbf{G}^F$	2.830	19	0.272		2.320	11	0.010
$\mathbf{G}^{2F}$	2.720	13	0.405		2.520	11	0.137
$\mathbf{G}^{4F}$	2.550	7	0.812		2.260	5	0.131
$\mathbf{T}^F$	3.390	34	0.539		3.250	33	0.232
$\mathbf{T}^{2F}$	3.320	24	0.326		3.210	24	0.446
$\mathbf{T}^{4F}$	3.020	13	0.457		3.160	14	0.752
1980				1985			
$\mathbf{G}^F$	2.210	8	0.000		2.010	6	0.000
$\mathbf{G}^{2F}$	2.320	7	0.066		3.500	14	0.148
$\mathbf{G}^{4F}$	2.030	3	0.079		1.830	2	0.003
$\mathbf{T}^F$	3.250	24	0.599		3.500	21	0.348
$\mathbf{T}^{2F}$	2.820	13	0.710		3.330	14	0.449
$\mathbf{T}^{4F}$	2.840	8	0.194		2.880	6	0.476
1990				1995			
$\mathbf{G}^F$	2.660	11	0.044		3.500	24	0.043
$\mathbf{G}^{2F}$	2.370	7	0.001		3.500	19	0.321
$\mathbf{G}^{4F}$	3.480	8	0.184		3.300	11	0.373
$\mathbf{T}^F$	3.500	21	0.441		3.500	24	0.636
$\mathbf{T}^{2F}$	3.490	16	0.799		3.170	15	0.574
$\mathbf{T}^{4F}$	3.200	8	0.320		3.010	8	0.172
2000				2005			
$\mathbf{G}^F$	3.210	19	0.288		3.500	23	0.430
$\mathbf{G}^{2F}$	1.750	3	0.001		3.500	20	0.891
$\mathbf{G}^{4F}$	2.910	8	0.734		2.680	7	0.247
$\mathbf{T}^F$	3.500	27	0.202		3.500	25	0.614
$\mathbf{T}^{2F}$	3.150	14	0.618		3.470	16	0.687
$\mathbf{T}^{4F}$	3.280	16	0.678		3.020	8	0.097

periphery group (periphery 2).[13] This differentiation helps understand the dynamical structure of an innovation spread because, as stated in Section 2, the most efficient propagation process would be initiated in the core to spread hierarchically, first to sectors in Periphery 1 and then to sectors in Periphery 2.

The intermediate domestic network of Spain in 2005 (for $\mathbf{T}^F$) is represented in Fig. 4, where sectors have been ordered according to their coreness value.[14] It offers a visual approach to the core–periphery structure, with black cells (relationships present) and white cells (absent relationships) and with solid lines delimiting the core, periphery 1 and periphery 2. The first set of sectors includes the 12 core sectors of 2005, from Other businesses to Restaurants, that make up the dense group of hubs, with a notably higher number of selling links when compared to buying relationships. The last set of sectors, periphery 2, shows many white cells and, therefore, a very low density. The intermediate links maintained between core and periphery, and particularly periphery 2, differ when distinguishing between purchasing and selling relationships. The number of links from the core to the periphery 2 is much higher than in the opposite direction. For this reason, the core–periphery2 density is greater than the periphery 2–core density (Table 5). Core sectors have a key character, as they act as 'superspreaders' and, in this particular case, because they are technically needed by almost all the sectors in the system.

The graphs in Fig. 5 have been elaborated by implementing the Fruchterman–Reingold algorithm in Pajek [92,93]. This algorithm brings the most interconnected sectors nearer and moves unconnected sectors further away when considering distances. Thus, the most central nodes are located in the core and sectors move further away as they become more peripheral. The color scheme shows the three groups: core (darker), semi-periphery (medium) and periphery (lighter). The node size indicates the average relative weight of each sector in intermediate sales and purchases terms.

The group of hub sectors constituting the core presents a significant evolution in the thirty-five-year period analyzed. Table 6 shows the core with a structural character, as it includes the eight sectors that are in the core in all the years analyzed. It also summarizes the dynamism of the core, as there are three sectors that join it during the period, and four sectors that leave it.

The evolution of the core also indicates that Chemical industry, Telecommunications and Real estate show a clear advance in terms of coreness over the whole period. The economic activities occupying the first two positions in the core are the same in most years:

[13] In Table 2, densities have been calculated for the whole system, without making any distinction. In Table 5, three sub-systems have been differentiated in order to calculate densities between their sector members (Core–Core, Periphery–Periphery, Periphery 1–Periphery 1 and Periphery 2–Periphery 2) and between the sub-systems (Core–Periphery, Core–Periphery 1, and so on).

[14] An important characteristic of the SNA core–periphery model is that the position of each sector in the core–periphery structure depends on its own degree and also on the degree level of its transacting sectors [71].

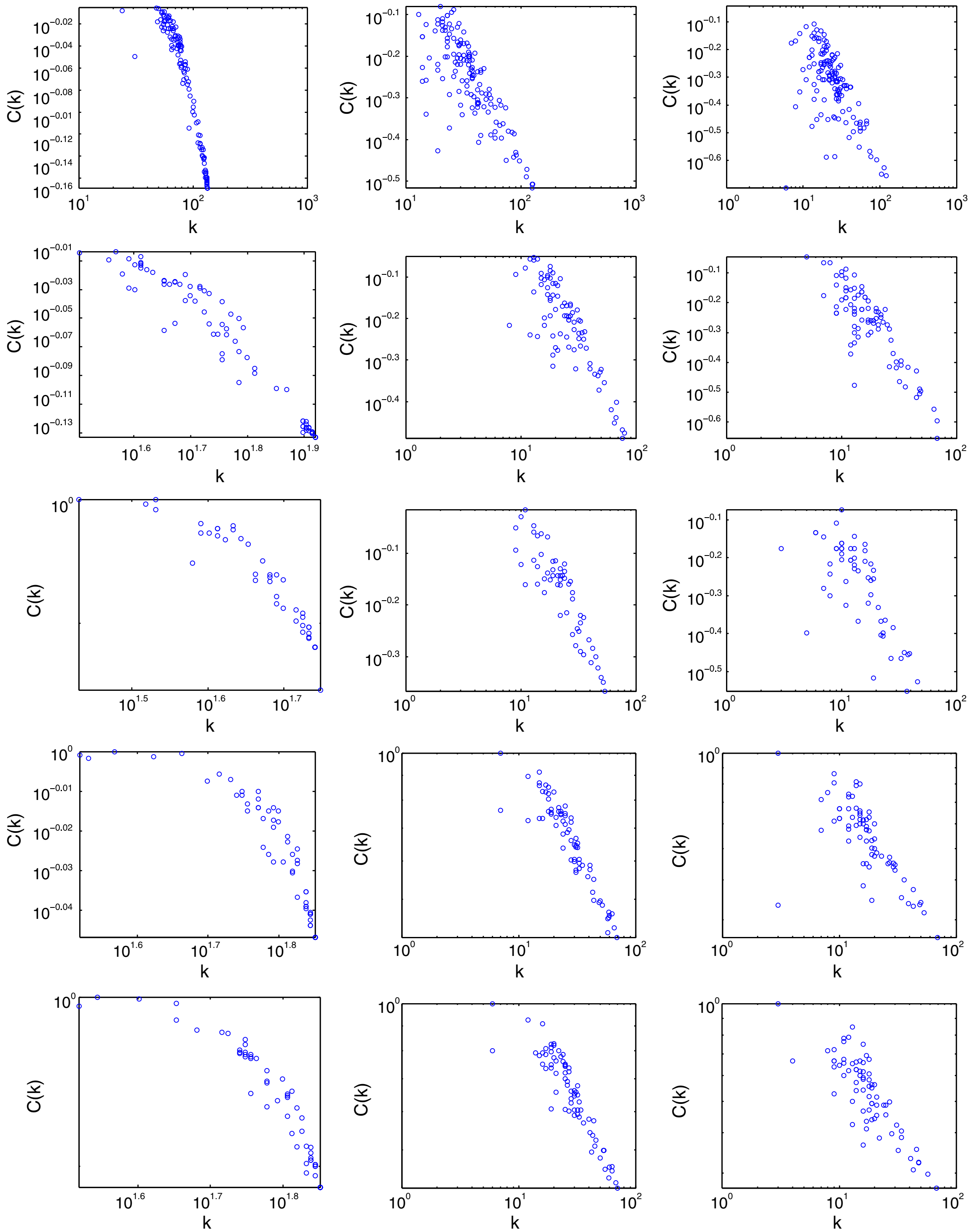

Fig. 3. Clustering coefficient distributions, Spain, 1970–2005. Note: Log–log scale; every row is a year data: 1970, 1980, 1990, 2000 and 2005; **T** first column; $\mathbf{T}^F$ second column and $\mathbf{T}^{2F}$ third column.

Trade in the first part of the period and Business services from 1995. Business services is referred to as Other businesses in 2005 and includes several kinds of business services such as legal, accountancy, auditing, consultancy, marketing, management, tests, analyses, advertising, headhunting, research, security, cleaning, photography, packaging, secretary, translation, decoration, fair and congresses organization, call center, activities of business and employer organizations and activities of professional organizations. The extensive core (eleven sectors considering the first two groups in Table 6) includes three sectors with high technology content (Business

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Table 5
Inter and intra group densities, Spain, 1970–2005.

	Core	Periphery	Periphery 1	Periphery 2
1970				
Core	0.660	0.521	0.598	0.444
Periphery	0.162	0.090		
Periphery 1	0.250		0.163	0.102
Periphery 2	0.075		0.058	0.037
1975				
Core	0.635	0.436	0.539	0.333
Periphery	0.128	0.078		
Periphery 1	0.199		0.140	0.087
Periphery 2	0.057		0.042	0.041
1980				
Core	0.682	0.642	0.711	0.574
Periphery	0.186	0.103		
Periphery 1	0.285		0.217	0.101
Periphery 2	0.088		0.048	0.049
1985				
Core	0.686	0.580	0.640	0.516
Periphery	0.243	0.124		
Periphery 1	0.346		0.251	0.130
Periphery 2	0.136		0.056	0.052
1990				
Core	0.673	0.589	0.654	0.524
Periphery	0.234	0.126		
Periphery 1	0.357		0.255	0.134
Periphery 2	0.112		0.072	0.043
1995				
Core	0.644	0.557	0.573	0.540
Periphery	0.252	0.117		
Periphery 1	0.391		0.218	0.160
Periphery 2	0.107		0.048	0.035
2000				
Core	0.700	0.588	0.623	0.554
Periphery	0.289	0.124		
Periphery 1	0.411		0.218	0.161
Periphery 2	0.167		0.084	0.033
2005				
Core	0.697	0.674	0.697	0.650
Periphery	0.315	0.147		
Periphery 1	0.444		0.274	0.159
Periphery 2	0.186		0.098	0.057

Note: The Periphery submatrix has been divided into two groups: Periphery 1 (or semiperiphery) and Periphery 2.

services, Chemical industry and Telecommunications).[15] Chemical industry, including Chemicals and Pharmaceuticals, also stands out, as it is the sector in the core with the highest R&D in terms of production (2.22%) and added value (7.72%) [94]. According to Jensen et al. [29], the role of Business service firms in the diffusion of innovation is highlighted, as they deliver disembodied general knowledge to customers as standard solutions. This sector may become strategic as it diffuses knowledge widely in the economy through learning by interacting. It is, therefore, identified as a main 'superspreader', on which systemic policies should focus.

5. Discussion and conclusions

In Barabási [3] it is asserted that "interconnectivity is so fundamental to the behavior of complex systems that networks are here to stay". Interconnectivity among different actors (persons, countries, firms, etc.) generally implies multiple and overlapping linkages making up complex networks and allowing for a wide range of flows (ideas, affects, goods, technology, etc.). Among the several disciplines that have demonstrated the relevance of interactions and networks, Sociology and Economics have

[15] According to OECD STAN and INE Technology classifications, Business services can be partially classified as high technology content as it includes Information services and Programming, consultancy and other computing activities. According to the same classification, Pharmaceuticals is a high technology activity and Chemicals, excluding pharmaceuticals, has medium–high technology content.

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Fig. 4. Inter-industry matrix and core–periphery model, Spain, 2005.

emphasized the case of firms. Firms interact with other business and non business institutions, implying learning processes and also material and immaterial flows making up networks. This paper focuses on the structural analysis of the network made by the intermediate exchanges maintained by economic sectors. This constitutes a main relational dimension for firms as it generally implies repeated and also frequent and intense interactions.

Considering an IOT as a map of relevant economic flows [19], this study examines the potential role of the Spanish inter-industrial structures in the diffusion of knowledge and innovation. Two complementary methodologies, SNA and NT, have been applied and novel contributions are offered to the methods of identifying core–periphery networks. The algorithm proposed in Borgatti and Everett [71] has been applied and a high correlation coefficient is obtained. Also a rigorous NT method has been used to analyze MSF structures and the existence of hub nodes has been tested. These nodes make a core sub-system of high density maintaining the whole network connected.

This paper also adds to the literature on the analysis of innovation flows between economic sectors by using IO data. National IO matrices have been studied as interaction platforms where knowledge and innovation flows take place. Depending on these

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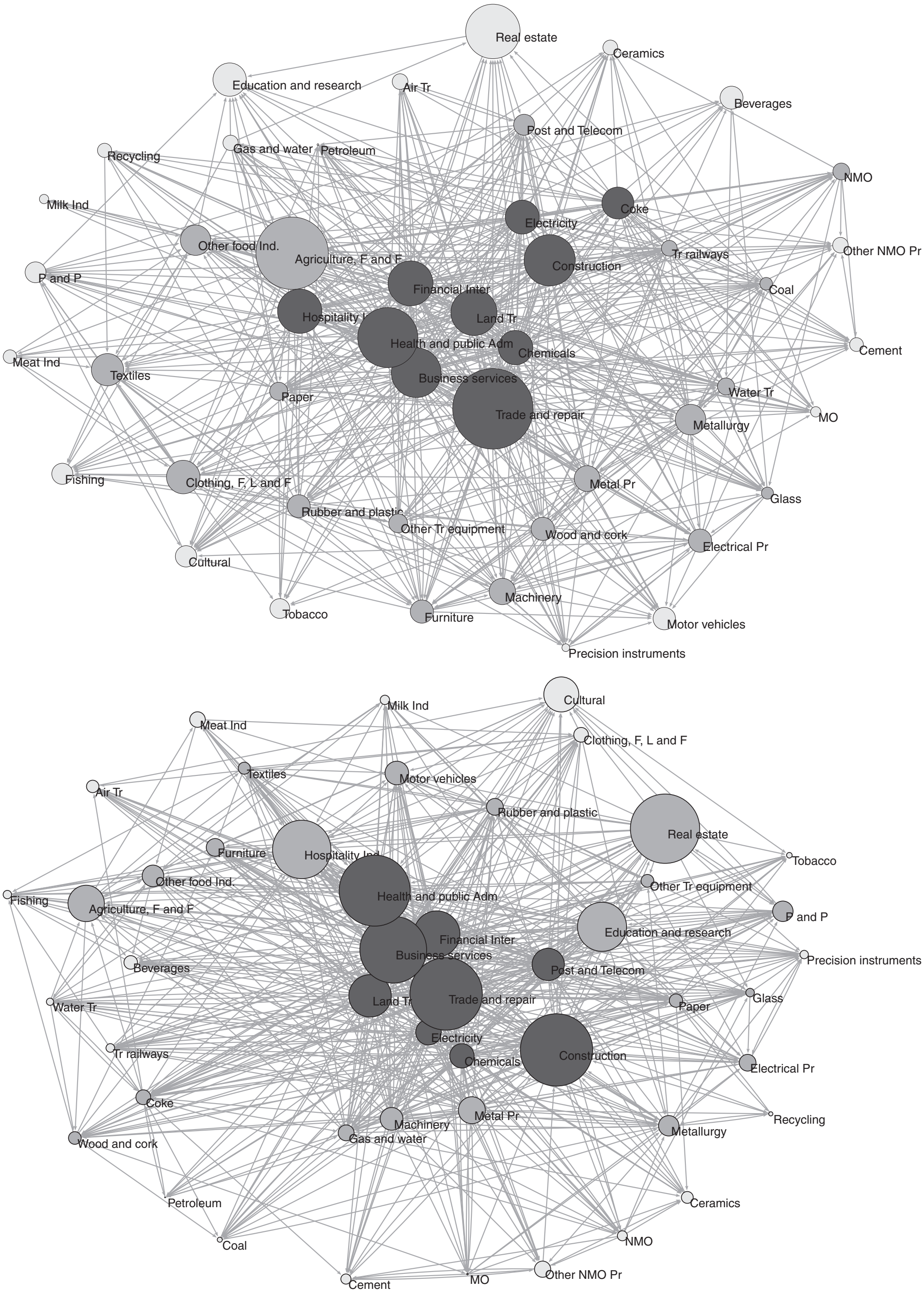

Fig. 5. Core–periphery network, Spain, 1970 and 2005. Note: The first network corresponds to 1970 and the second to 2005. Unlike previous figures and tables, Fig. 5 corresponds to the homogeneous classification mentioned in footnote 3 to facilitate the comparison (see Appendix A).

inter-industrial structures, innovation flow processes could be very different. In Spain, the inter-industry network shows a core–periphery structure with Scale-free properties. This implies that different sectors play quite diverse roles in diffusion processes. The evolution of the analyzed network also indicates that the core–periphery structure is consolidated in the period considered (1970–2005) and that there is a set of sectors in the core with a permanent character: Metal products, Electricity, Construction, Trade, Hotels and restaurants, Land transport, Financial intermediation and Business services. An in-depth view indicates that the core, where hubs or 'superspreaders' can be identified, is mainly made up by service sectors and, in2005, it comprised Business services,

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Table 6
The core sectors in the Spanish inter-industry system.

Structural core
Metal products
Electricity
Construction
Trade
Hotels and restaurants
Land transport and auxiliary transport activities
Business services
Financial intermediation
Core dynamics
Sectors getting into the core
Chemical industry (1975)
Post and telecommunications (1995)[a]
Real estate activities (1995)
Sectors leaving the core
Petroleum and natural gas (2005)
Rubber and plastic industry (2005)[b]
Machinery and mechanical equipment (2005)
Metallurgy (1990)[b]

Note: Year in brackets indicates when sectors join or leave the core.
[a] Also in the core in 1975.
[b] Not in the core in 1980.

Wholesale trade, Post and telecommunications, Financial intermediation, Real estate, Land and auxiliary transport, Restaurants, Electricity, Construction, Chemicals and Metal products.

This relational analysis offers valuable information when trying to promote innovation by considering the system's structural characteristics. Our results imply an advance in our understanding of how the design of public and private interventions would enhance a more efficient diffusion of knowledge and innovation. This includes methods to give priority to selected sectors in innovation programs when a systemic effect is intended and when the purpose is to increase its scope and speed. Interventions trying to foster innovation should, from this perspective, take into account the heterogeneity of economic sectors, in terms of their linkages and of their position in the inter-industry system. Certain linkages are more relevant than others for the diffusion process and the position of sectors conditions the final effect of innovation diffusions. This systemic information can be incorporated into the design and implementation of sectoral and innovation strategies, adding a criterion of rationality to the assignment of resources. Innovation fostered in the core sectors, when taking these as 'superspreaders', can flow faster and reach most of the sectors in the inter-industry system with more certainty. Owing to Spain's inter-industrial structure, special attention should be paid to the sectors identified in its core, particularly to Business services, because this appears as the main core sector and because of its capacity to transfer knowledge and innovation through its trade linkages. If this information is taken into consideration, the efficiency of national innovation policies could improve.

The targeted sectors of the Spanish innovation policies, according to the European Commission [79], are food, agriculture and fisheries, in the first place, followed by biotechnology activities. Moreover, the several programs designed to foster innovation in Spain direct resources mainly to high technology sectors, measured generally in terms of R&D. The lack of a systemic view, detected in Spain, to select sectors for intervention, seems to be general, according to Jensen et al. [29]: "The tendency among policy makers to think in terms of the linear model of innovation and give priority to supporting R&D-activities in high technology sectors to the neglect of organizational learning and user-driven innovation is problematic. Equally, problematic are policies that give little attention to the strengthening of linkages to sources of codified knowledge for firms operating in traditional manufacturing sectors and services".

A systemic innovation strategy, when combined with the more generalized interventions, would imply considering the relevance of the linkages supported by core sectors with high technology sectors and also with knowledge and innovation institutions. In the case of Spain, this kind of strategy would lead to selecting the Chemical industry as a receiver of particular attention, because it has become increasingly relevant in the core group, it is a high technology content sector with high R&D expenditures and it is closely linked to biotechnology. The proposals raised in this paper could be considered in the selection of sectors and linkages that would receive preferential attention from public innovation policies and, in general, also in the processes of innovation decision making. The present analysis specifically suggests directing efforts towards:

1) The sectors identified in the core and, primarily, towards Business services and Chemical industry. We already know that product innovations, knowledge and learning, and efficiency increases taking place in the most central sectors reach further and faster, in the whole economic system.
2) The linkages that core sectors, and particularly Business services and Chemical industry maintain with other economic activities and with innovation and knowledge institutions. We are aware that policies specifically designed to increase connectivity, particularly with the most central and the most innovative sectors, clearly contribute to the improvement of competitiveness.

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3) Sectors with competitive and also innovation problems not located in the core. Those sectors would require acting on their linkages with other sectors and coordinated interventions. As an example, this could be the case of Agriculture and its linkages with the sectors making up the Agro-food system (e.g. Vegetables industries) and with sectors located in the core of the whole system (e.g. Hotels and restaurants and also Chemical industry).

The generalizability of our conclusions should be taken cautiously as we used data only for the case of Spain. Nevertheless, those results, and others offered by the network analysis literature, indicate that the core–periphery structure shows a high representative capacity of inter-industrial networks. Presumably, locations in a similar development situation to the Spanish one will show a similar structure. Then, the policy implications we have discussed could be widely useful. With regard to future research, we are already testing those statements and also the existence of a positive relationship between the core–periphery and Modular Scale-free topologies and economic development levels and their dynamics.

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Appendix A. Whole sector's names and abbreviations, Spain, homogeneous classification for 1970 and 2005

Agriculture, F. and F.	Agriculture, farming, hunting and forestry
Fishing	Fishing and aquaculture
Coal	Anthracite, coal, lignite and peat
Petroleum	Petroleum and natural gas
MO	Metal ores
NMO	Non-metal ores
Coke	Coke works, refine an nuclear fuels
Electricity	Electric power
Gas and water	Gas, water and vapor
Meat Ind.	Meat industry
Milk Ind.	Milk industry
Other food Ind.	Other food industry
Beverages	Beverages
Tobacco	Tobacco industry
Textiles	Textile industry
Clothing, F., L. and F.	Clothing, fur, leather and footwear industry
Wood and cork	Wood and cork industry
Paper	Paper industry
P. and P.	Printing and edition
Chemicals	Chemical industry
Rubber and plastic	Rubber and plastic industry
Cement	Cement, lime and plaster
Glass	Glass industry
Ceramics	Ceramic industry
Other NMO Pr.	Other non-metal ore products
Metallurgy	Metallurgy
Metal Pr.	Metal products
Machinery	Machinery and mechanical equipment
Electrical Pr.	Machinery, electrical and electronic goods
Precision instruments	Surgical and precision instruments
Motor vehicles	Motor vehicles and trailers
Other Tr. equipment	Other transport equipment
Furniture	Furniture and other manufacturing products
Recycling	Recycling
Construction	Construction
Trade and repair	Trade and repair
Hospitality Ind.	Hospitality industry
Tr. railways	Transport via railways
Land Tr.	Land transport
Water Tr.	Sea and river transport
Air Tr.	Transport by air and space transport
Post and Telecom.	Post and telecommunications
Financial Inter.	Financial intermediation and private insurances
Real estate	Real estate activities
Business services	Business services and other personal services
Education and research	Education and research
Health and public Adm.	Health and public administration
Cultural	Recreational, cultural and sports activities

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Appendix B. Whole sector's names and abbreviations, Spain, 2005

Agriculture and F.	Agriculture, farming and hunting
Forestry	Forestry
Fishing	Fishing and aquaculture
Coal Extr.	Anthracite, coal, lignite and peat extraction
Petroleum	Crude petroleum and natural gas extraction, Uranium.
MO	Metal ores extraction
NMO	Non-metal ores extraction
Coke	Coke works, refine and nuclear fuel
Electricity	Electric power
Gas	Gas
Water	Water
Meat Ind.	Meat industry
Milk Ind.	Milk industry
Other food Ind.	Other food industry
Beverages	Beverages
Tobacco	Tobacco industry
Textiles	Textile industry
Clothing and fur	Clothing and fur trade industry
Leather and footwear	Leather and footwear industry
Wood and cork	Wood and cork industry
Paper	Paper industry
P. and P.	Printing and edition
Chemicals	Chemical industry
Rubber and plastic	Rubber and plastic industry
Cement	Cement, lime and plaster
Glass	Glass industry
Ceramics	Ceramic industry
Other ore Pr.	Other ore products
Metallurgy	Metallurgy
Metal Pr.	Metal products
Machinery	Machinery and mechanical equipment
Office machinery	Office machinery, accounting and computing machinery
Electric Mat.	Manufacture of machinery and electrical goods
Electronic goods	Manufacture of electronic goods
Precision instruments	Surgical and precision instruments
Motor vehicles	Manufacture of motor vehicles and trailers
Other Tr. equipment	Manufacture of other transport equipment
Furniture	Manufacture of furniture and other manufacturing products
Recycling	Recycling
Construction	Construction
Repair and sale vehicles	Repair and sale of motor vehicles; fuel trade
Wholesale trade	Wholesale trade and intermediaries
Retail trade	Retail trade, repairing of personal effects
Hotels	Accommodation
Restaurants	Hotels and restaurants
Tr. railways	Transport via railways
Land Tr.	Land and pipe transport
Water Tr.	Sea transport
Air Tr.	Transport by air and space transport
Auxiliary Tr.	Supporting and auxiliary transport activities
Travel agencies	Travel agencies
Post and Telecom.	Post and telecommunications
Financial Inter.	Financial intermediation
Insurances	Insurances and pension plans
Auxiliary Act.	Auxiliary activities
Real estate	Real estate activities
Machinery renting	Renting of machinery and domestic belongings
Computer Act.	Computer activities
Research	Research and development
Other businesses	Other business activities
Health	Health and social services for sale
Drainage fs	Drainage for sale
Associative fs	Associative activities
Educ fs	Education for sale
Culture fs	For sale recreational, cultural and sports activities
Personal ss	Personal services activities
Public Adm.	Public administration

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Appendix B (*continued*)

Health nfs	Not for sale health and social services
Educ. nfs	Not for sale education
Drainage nfs	Not for sale drainage from Public Administration
Associative nfs	Not for sale associative activities
Cultural nfs	Not for sale recreational and cultural activities

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