Network analysis of the economic structure and environmental flows in Spain

Cazcarro, Ignacio [a]*

[a] Department of Economic Analysis, University of Zaragoza

C/ Gran Vía 2, 50005 Zaragoza (Spain)

Phone: +34 876 554621 Fax: +34 976 761996 Email: icazcarr@unizar.es

*Corresponding author

Abstract

The analysis of the economic structure and its change, importance of sectors regarding its position with respect to others and the study of environmental impacts associated has a long tradition in input-output studies. Especially in recent years, insights from network analysis have been introduced in the field by studying key, power-of-pull sectors, centrality,..., and other characteristics of the clusters and networks (e.g. Montresor and Vittuci, 2009 [34], McNerney, 2009 [33], Luo, 2010 [32]). The network analysis, boolean graphs, information theory, etc. has been applied with the Spanish input-output framework among others in García Muñiz et al. (2008) [21] and García Muñiz et al. (2010) [22] analyzing it in comparison (and finding common patterns) with the European Union. The aim, determining the key sectors with multilevel indicators, and from the standpoint of the core-periphery models (core formed by a group of densely connected actors) derived from the social networks theory (e.g. Borgatti and Everett, 1999 [9]).

All in all, both fields provide powerful tools to examine the environmental flows, both directly and in terms of its embodied contents, which let us observe, e.g. that not only the process of food requires high embodied water contents but also some other such as the transport sector. The purpose of the paper is precisely analyzing and representing those relations, with a special focus on the flows of consumed water. This means examining key paths and blocks of production and environmental impact, to see e.g. whether the sectors conforming them (usually considered *a priori*), truly would form clusters (with no predefined disposition at the start) given their position and similarities in its relation with other sectors.

In the study of the clustering or blockmodeling we discover relevant differences between the obtained clusters (with analogies among them given the used definitions of equivalences) and those groupings usually considered by the national classifications and researchers, which should lead us to re-think the traditional blocks or classifications of activities and their strong relations or linkages frequently taken as given. In this sense, it might be relevant to discuss the importance of being the only sector connecting commercial relations between other two (betweeness), the effects of the chosen number of sectors forming a cluster, or the way to consider how modifications in the impacts and pressure on the resources are transferred through the production processes, with supply, demand, technological or sectors weights alterations.

Key words: Environmental Input-output, Key sectors, Network analysis, Virtual water, SAM, Spain.

Topic: 5.- Analysis of monetary and physical flows.

1 Introduction

The economic transformation taken place in Spain in the last decades has modified the patterns of transactions and resources use, and particularly of water consumption, both in terms of direct and embodied contents. The role of each sector and group of them as blocks has also been altered, and in this way in recent years the rise in the size e.g. of specific sectors lead to the debate of whether they were key, or a deformation of the economy with symptoms of economic and environmental risks. In the same fashion, the widening of knowledge regarding the chains of processes through which more embodied consumption or impact is carried out becomes a must in order to make a better use of the resources. Despite we know that the importance of the sectors can be examined from different viewpoints and with different measures, and that once identified it is still questioned whether knowing the position and characteristics of a sector in the net matrix of transactions generalizations can be extracted regarding its risks or real role in the processes, our special concern on the agri-food transactions and the processes of embodied water flows, guide us then to examine them with a wide approach, looking also for procedures from other fields concerned with the relation among nodes and clusters.

The works of Rasmussen (1956) [42], Hirschman (1958) [25] and Chenery and Watanabe (1958) [12] on the simple approach of linkages we will briefly present in the following section, led to a lively discussion on key sectors and many approaches such as this one were proposed afterwards (see, for example, Schultz, 1976 [43]; Oostherhaven, 1988 [37], Clements, 1990 [13]; Dietzenbacher and van der Linden, 1997 [17]). Issues discussed were the use of weighting factors and indexes with dispersion (Diamond, 1974 [15], Laumas, 1975 [30]), aggregation problems (Hewings, 1974 [23]), inconclusive evidence of the importance of key sector in development policy and growth (Jones, 1976 [26]).
As explained in García Muñiz et al. (2008 [21]), several alternative means have been proposed to identify key sectors, such as triangularization (Aujac, 1960 [3]), the Leontief output inverse (Augustinovics, 1970 [2]), the so-called hypothetical extraction method (Strassert, 1968 [44]; Dietzenbacher, 1997 [16]), the measure of total linkage (Cella, 1984 [11]), the fields of influence (Hewings et al., 1988 [24]) or the multivariate approach (Csamanski, 1974 [14]). However, we will not deal with these subjects here, given our preference for comparing this type of results with those usually studied from the network and graph theory, which has been already introduced in the field by studying key (keystone sectors), power-of-pull sectors, centrality,. . . , and other characteristics of the clusters and networks (e.g. Morillas, 1983 [35], Aroche-Reyes, 1996 [1], Kilkenny and Nalbarte, 2002 [28], Montresor and Vittuci, 2009 [34], McNerney, 2009 [33], Luo, 2010 [32]).
The terminology that prevails in the following subsections devoted to the network analysis and the software used comes from some textbooks on graph theory, for example, Wilsons (1972) [47] introduction to graph theory. In any case, we will try to connect them with the more well known terms in our input-output (IO) discipline.

In the following section the Material and Methods are presented, starting by introducing the backward and forward linkages first formulations that will enable us to compare the methods from the network theory to stress centrality, and in general the importance of the sectors. The models and tools of the networks and the nodes are then introduced, comprising density, length of (shortest) paths, geodesics matrices, degree distribution, closeness, betweeness or the classification of hubs and authorities. In a paragraph is pointed out that we use a Social Accounting Matrix (SAM) for Spain (in 2004) with environmental extensions and a disaggregation of the agri-food activities, in different forms/sizes, to study in the section of results the explained measures for the relations of monetary transactions among activities, and of direct and embodied water consumption flows. In the last section a summary of comparison of approaches and final comments of the article are presented.

2 Material and Methods

2.1 Traditional definition of key sectors in Input-output

The backward and forward linkages obtained with generalized multipliers, global and unitary, allow a good description of the links between accounts, but describe poorly the succession of the different effects. To obtain those type of results, often two techniques, graphs and decomposition of multipliers, are used. Those techniques may be applied to the analysis with IOTs, but we find them more explanatory to represent all transactions in the economy with the SAMs, because it gathers the relations among institutions, the productive factors and the external sector.

The backward linkage of sector j quantifies the change in economy wide income, relative to the average change in the economy, caused by a unitary injection in the final demand of sector j. The backward linkage coefficients or simple output multipliers (B_j) are described as the column sum of the Leontief inverse, and the forward linkage coefficients or input multipliers (F_j) as the row sum of the Leontief inverse,

$$B_j = \sum_{i=1}^{n} L_{ij} \qquad \bar{F_i} = \sum_{j=1}^{n} L_{ij}$$

The backward and forward linkages can be measured mathematically as an index, which is what we will use to obtain the results:

$$U_B = \frac{\frac{1}{N} B_j}{\frac{1}{N^2}\sum_{j=1}^{n} B_j} = \frac{B_j}{\frac{1}{N}\sum_{j=1}^{n} B_j} \qquad U_F = \frac{\frac{1}{N} F_i}{\frac{1}{N^2}\sum_{i=1}^{n} F_i} = \frac{F_i}{\frac{1}{N}\sum_{i=1}^{n} F_i}$$

If U_B is greater than 1, it means that one unit change in a final demand in sector j, will result in an above-average increase in the water consumption of all of the sectors in the entire economy. In contrast, if $U_F$is greater than 1, a unit change in all sectors' final demand will lead to an above-average increase in the water consumption of sector i in the entire economy. Then a sector with backward (forward) linkages greater than 1, and forward (backward) linkages less than 1, is called backward (forward) oriented. When the backward and/or forward linkage indexes are greater than 1, we define those sectors as key/leading sectors. If none of the linkages is greater than 1, the sector is called weak.

The above Hirschman-Rasmussen indices do not take into account the relative importance of each sector in terms of GDP, final demand, or total production. We use then *total production shares* to compute weighted linkages indices. Let σ_i be sector is total production share; the weighted sums of the $i - th$ row and column of the inverse matrix are given, respectively, by

$$WB_j = \sum_{i=1}^{n} \sigma_i L_{ij} \qquad W\bar{F}_i = \sum_{j=1}^{n} \sigma_j L_{ij}$$

Again the weighted backward and forward linkages can be measured mathematically as an index, which is what we will show in the results:

$$U_{WB} = \frac{\frac{1}{N} WB_j}{\frac{1}{N^2}\sum_{j=1}^{n} WB_j} = \frac{WB_j}{\frac{1}{N}\sum_{j=1}^{n} WB_j} \qquad U_{WF} = \frac{\frac{1}{N} WF_i}{\frac{1}{N^2}\sum_{i=1}^{n} WF_i} = \frac{WF_i}{\frac{1}{N}\sum_{i=1}^{n} WF_i}$$

2.2 Models and tools of network analysis

In most of the measures used in network analysis, the elementary definitions have been mostly constructed for undirected networks, or then for directed but binary ones (with connection or not), but no so much for weighted networks. However, for those cases, as it occurs in the relations among sectors shown by the IOTs or SAM (with the weights being the purchases and sales among them), it is key to redefine them. There have been several attempts to identify them, for example the shortest paths in weighted networks (e.g. Katz, 1953 [27]; Peay, 1980 [41]; Yang and Knoke, 2001 [48]). Dijkstra (1959) [18] proposed an algorithm that finds the path of least resistance, and was defined for networks where the weights represented costs of transmitting (opposite to strength of ties), and hence weights need to be reversed before directly applying the algorithm for networks such as IO, e.g., to identify the shortest paths in these networks (and the BellmanFord algorithm dealt with negative edge weights). Both Newman (2001) [36] and Brandes (2001) [10] separately proposed to invert the tie weights while extending closeness and betweenness centrality, respectively. Taking tie weights into account e.g. when calculating distance leads us to:
$d^w(i,j) = min(\frac{1}{w_{ih}} + ... + \frac{1}{w_{hj}})$

But still, with this formulation the distance between node A and node B is not affected by the number of nodes on the shortest path between two nodes. Opsahl et al. (2010) [39] extend the shortest path algorithm by taking into consideration the number of intermediary nodes. Considering this solution superior for the type of data we are having with the IOT, we will follow this implementation and the same reasoning for all measures considered in the next subsections.

In this sense, instead of considering a connected weighted undirected graph $G = (V, E)$ with n vertices (or nodes or vertex, which will serve us to represent sectors) and m edges ($|V| = n, |E| = m$), which are nothing but the ties or relations among nodes (when we care about the direction of the tie, as it is the case when working with input-output matrices, we refer to arcs instead of the bidirectional edge).

2.2.1 Net analysis

The net analysis refers to the characteristics of the whole network, such as size (nodes and links), density (existing links among all the possible links), the connection (number of connected components), diameter (the length of the longest shortest path in network and corresponding two vertices), average length of (shortest) paths, geodesics matrices (the shortest path length matrix and the geodesics count matrix), etc. Since here we will not compare many nets, those measures will be analyzed less in depth than the specific nodes (sectors).

Then $d(v, u)$ is commonly used to denote the length of a shortest-path between v and u, Δ denotes the diameter of graph G, i.e., $\Delta = max_{v,u \in V} d(v, u)$, etc. A weighted network can be represented mathematically by an adjacency matrix $\mathbf{W}$ with entries that are not simply zero or one, but are equal instead to the weights on the edges, or what is the same, the transactions among sectors represented by the matrix of (intermediate, if only considered those activities) transactions.

Geodesic distance and its mean value

The geodesic distance is the length of the shortest path between two nodes. To perform the estimation of the geodesics matrix though, given that the traditional measures give most importance to weak connections (as in Dijkstra, 1959 [18]), I inverse the values of the weights, and then normalize the values with the average weight in the network, so that the highest values of weights (most important transactions) have the lowest value. Then the shortest path length among sectors is calculated summing their values, and we can highlight the sectors with shortest paths to other sectors (for the nodes analysis) and obtain the mean value for the whole network.

2.2.2 Nodes analysis

Regarding the nodes, one can examine the centrality (average distance to another node), degree centrality, closeness, betweenness (how many paths among nodes necessarily need to pass by the node), eccentricity (the longest distance to another node), or its position as hubs or authority.

Degree and degree distribution

The degree or connectivity s_i of a node i is the number of its neighbors, and is a basic indicator and often used as a first step when studying networks (Wasserman and Faust, 1994 [46]), $k_i = C_D(i) = \sum_{j=1}^{N} x_{ij}$, where i is the focal node, j represents all other nodes, N is the total number of nodes, and $\mathbf{X}$ is the adjacency matrix, in which the cell x_{ij} is defined as 1 if node i is connected to node j, and 0 otherwise.

Degree was extended to weighted networks by Barrat et al. (2004) [4] and defined as the sum of the weights attached to the ties connected to a node. An outcome of 10 could either be a result of 10 ties with a weight of 1, one tie with a weight of 10, or a combination between those two extremes: $s_i = C_D^w(i) = \sum_{j=1}^{N} w_{ij}$ where $\mathbf{W}$ is the weighted adjacency matrix, in which w_{ij} is greater than 0 if the node i is connected to node j, and the value represents the weight of the tie. However, node strength is a blunt measure as it only takes into consideration a nodes total level of involvement in the network, and not the number of other nodes to which it connected. In an attempt to combine both degree and strength, we use a tuning parameter, α, which determines the relative importance of the number of ties compared to tie weights. More specifically, Opsahl et al. (2010) [39] propose a degree centrality measure, which is the product of the number of nodes that a focal node is connected to, and the average weight to these nodes adjusted by the tuning parameter

$$C_D^{w\alpha}(i) = k_i \left(\frac{s_i}{k_i}\right)^{\alpha} = k_i^{(1-\alpha)} s_i^{\alpha} \tag{1}$$

where α is a positive tuning parameter that can set according to the research setting and data. If this parameter is between 0 and 1, then having a high degree is taken as favorable, whereas if it is set above 1, a low degree is favorable.

Closeness centrality

For a weighted network, this definition changes slightly. Within the adjacency matrix, for any two nodes, i and j, if δ_{ij} is the shortest distance from i to j, then the closeness centrality of node j is defined as $x_j = \frac{n-1}{\delta_{1j}+\delta_{2j}+...+\delta_{nj}}$, where n is the total number of nodes.

In its simplest form of an undirected graph $G = (V, E)$, the closeness centrality c_v of vertex v is defined as $c_v = \frac{n-1}{\sum_{u \in V} d(v,u)}$
In other words, the closeness centrality of v is the inverse of the average (shortest-path) distance from v to any other vertex in the graph. The higher the c_v, the shorter the average distance from v to other vertices, and v is more important by this measure.

Closeness centrality relies on the length of the paths from a node to all other nodes in the network, and is defined as the inverse total length. Freeman (1978) [20] asserted that closeness was:

$$C_C(i) = [\sum_{j=1}^{N} d(i,j)]^{-1} \tag{2}$$

But as we have explained, we want to take into consideration the number of intermediary nodes and hence we transform the inverted weights by a similar tuning parameter used in the proposed degree measure, 1, before using Dijkstra's algorithm to find the least costly path. This ensures that both the tie weights and the number of intermediary nodes affect the identification and length of paths:

$$d^{w\alpha}(i,j) = min\left(\frac{1}{(w_{ih})^{\alpha}} + \cdots + \frac{1}{(w_{hj})^{\alpha}}\right) \tag{3}$$

where α is a positive tuning parameter. When $\alpha = 0$, the proposed measure produces the same outcome as the binary distance measure, whereas when $\alpha = 1$, the outcome is the same as the one obtained with Dijkstra's algorithm. When Dijkstra's algorithm produces the same distance score for paths with different number of intermediary nodes, a value for $\alpha < 1$ assigns the path with the greatest number of intermediary nodes the longest distance. Hence, for $\alpha < 1$, a shorter path composed of weak ties (e.g., A,B) is favored over a longer path with strong ties (e.g., A,D,E,B). Conversely, when $\alpha > 1$, the impact of additional intermediary nodes is relatively unimportant compared to the strength of the ties and paths with more intermediaries are favored.

The shortest path algorithm is used to allow the closeness centrality measure to take into account both the number of intermediary nodes and the tie weights. By combining Eqs. 2 and 3, we get the following measure:

$$C_C^{w\alpha}(i) = [\sum_{j=1} N d^{w\alpha}(i,j)]^{-1} \tag{4}$$

Betweenness centrality

Betweenness relies on the identification of the shortest paths, and measures the number of them that passes through a node. Freeman (1978) [20] asserted that betweenness was: $C_B(i) = \frac{g_{jk}(i)}{g_{jk}}$ where g_{jk} is the number of binary shortest paths between two nodes, and $g_{jk}(i)$ is the number of those paths that go through node i. A complication arises when the ties in a network are differentiated (i.e. have a weight attached to them). However, again following Opsahl et al. (2010) [39] we take advantage of the proposed shortest path algorithm to extend betweenness centrality, based on a combination of the number of intermediary nodes and tie weights [1]: $C_B^{w\alpha}(i) = \frac{g_{jk}^{w\alpha}(i)}{g_{jk}^{w\alpha}}$

Clustering or Blockmodeling

The choice of groups or blocks of sectors to be treated together or as a "cluster" is common in the IO analysis; in that case the selection of sectors for a cluster is usually done by the researcher. With popular network analysis software, apart from being possible to analyze the net with that predefined "clustering", also we may study the problem of establishing a partition of a network in terms of a considered equivalence, which is a special case of clustering problem. Structural equivalence and regular equivalence are available as options, and we choose the first one, which in its first formulation emphasized the cluster of nodes (sectors) that are connected to the rest of the network in identical ways (Lorrain and White, 1971 [31]). An appropriate generalization of the equivalence idea is one where each block, of a particular partition, is free to conform to a different equivalence idea. This led Batagelj (1997) [5] and Doreian, Batagelj, and Ferligoj (1994) [19] to the definition of several types of connection inside and between the clusters, or in another words, different types of ideal blocks. In this sense, instead of grouping the sectors according to a predefined classification such as the National Classification (NACE) codes, which in fact reflects a similitude in the type of activity carried out, we may ask ourselves, how clusters would be formed (setting the number desired of them, from random starts), so that clear-cut relations within each cluster and between clusters are obtained?. The clustering problem then can be formulated as an optimization problem: determine the clustering $C*$. for which

$$P(C*) = \min_{C \in \Phi} P(C) \tag{5}$$

where C is a clustering of a given set of units or units U, Φ is the set of all possible clusterings and $P : \Phi \to \mathbb{R}$ the criterion function. The criterion function must reflect the considered equivalence.

This can be done indirectly, i.e. as a function of a compatible (dis)similarity measure between pairs of units, or directly, i.e. as a function measuring the fit of real blocks induced by a given clustering to the corresponding ideal blocks with perfect relations within each cluster and between clusters according to the considered types of connections (equivalence). With the direct approach, which is the one we will present in the results, we get the predefined clusters (by us, from 2 to 20 to observe all optimal clustering for a given number) by an initial partition randomly generated by Pajek as further explained in Batagelj et al., (2004) [8])[2].

Hubs and authorities

In directed networks we can usually identify two types of important vertices: hubs and authorities (see Kleinberg (1998) [29]). A vertex is a good hub, if it points to many good authorities, and it is a good authority, if it is pointed to by many good hubs. In the obtained partition in Table 3, value 1 means, that the vertex is a good authority (an analogous measure to the strong forward linkages), value 2 means, that the vertex is a good authority and a good hub (an analogous measure to the consideration of key sector), and value 3 means, that the vertex is a good hub (an analogous measure to the strong backward linkages); making use again of the adjacency matrix **W** (transactions matrix) with inverted

[1] We apply it as a directed network, so that a path from one node to another can only follow the direction of present ties, e.g., information cannot be passed from node to node if the first one is not connected to the second node, irrespective of whether the second is connected to the first.

[2] Using *Operations-Blockmodeling-Random start*

weights.

2.3 Data

The data used is s Social Accounting Matrix for Spain in 2004 with environmental extensions and a disaggregation of the agri-food activities (meaning the most connected accounts with food, ie, agriculture, livestock, food sector, food commerce and hotels and restaurants). The analysis then will be performed with the whole matrix (78 sectors), omitting the institutional accounts (68 sectors) and even with only the agri-food accounts considered (40 sectors). Apart from those relations of monetary transactions among activities, also the pure water consumption flows are analyzed and represented, in order to examine the main direct and embodied paths.

3 Results

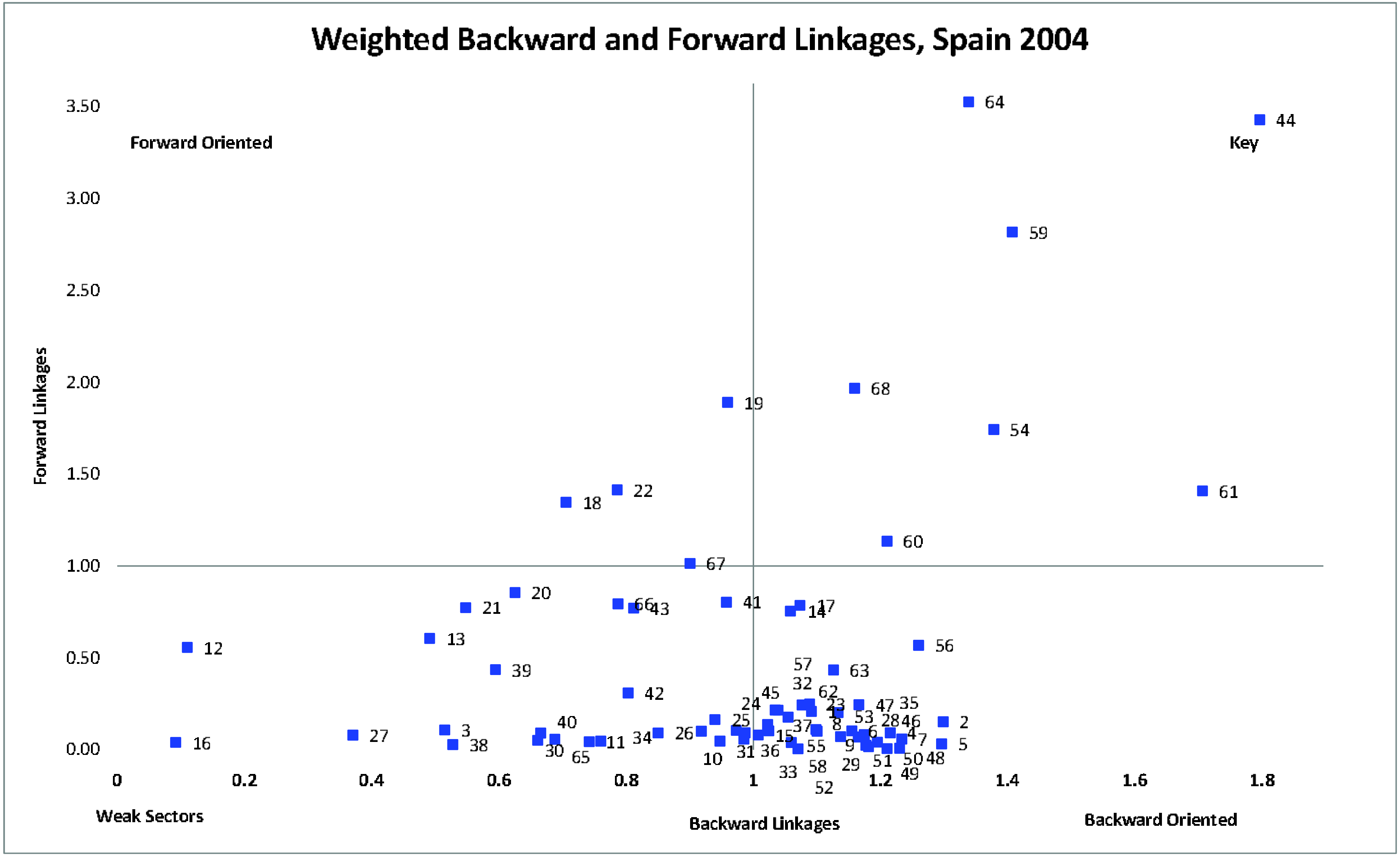
3.1 Traditional Input-output analysis of key sectors

In Figure 1 we show the weighted (using aggregate income shares as weights) backward and forward linkages for Spain in 2004 with 68 productive activities, for a visualization of the relative position of sectors. The key sectors are 44-Construction and engineering, 64-Other services for sale, 59-Transport and communications, 61-Real estate, 68-Public Services and 60-Credit and insurance. In Figure 2 we observe (without weights) the backward and forward linkages, where we observe that the most clear key sector in the previous figure, 44-Construction and engineering, is in this way less marked since its leading role in the forward linkage is reduced. In an analogous way the sector 64 Other services for sale has now a less important backward linkage, strictly disappearing from being key, and the same occurs with the sector 68 Public Services, which indeed has a much less important role in both backward and forward linkages. The sectors 59, 61 and 60-Credit and insurance keep on being key ones, and are also included now the sectors 41-Paper industry and 19-Metallurgy and manufacture of metal products.

In Table 1 we also can observe that with the disaggregation of 68 productive activities the main backward linkages (BL) are of agrarian subaccounts (porcine, poultry,...) and food industry ones (meat industry, industry of bread cakes and biscuits, industry of wines and ciders,...). Those accounts are however not important in terms of forward linkages (FL), ordering in which also stand out Metallurgy and manufacture of metal products, 18-Chemicals and 54- Non-food trade, being the only agri-food subsectors with relevant FL (among the 11 main subaccounts) Cereals and leguminous plants and the industry of feed. Only in the first positions of both types we find accounts such as Construction and engineering (the 9^{th} and 6^{th} respectively) and Real State (the 14^{th} and 8^{th} respectively). Noticing that those two accounts are also important in terms of size (and much more than the aforementioned subaccounts), as we can see in 1 the weighted BL and FL situate them in the first orderings, together with the accounts of Transport and communications, Non-food trade, Other services for sale.

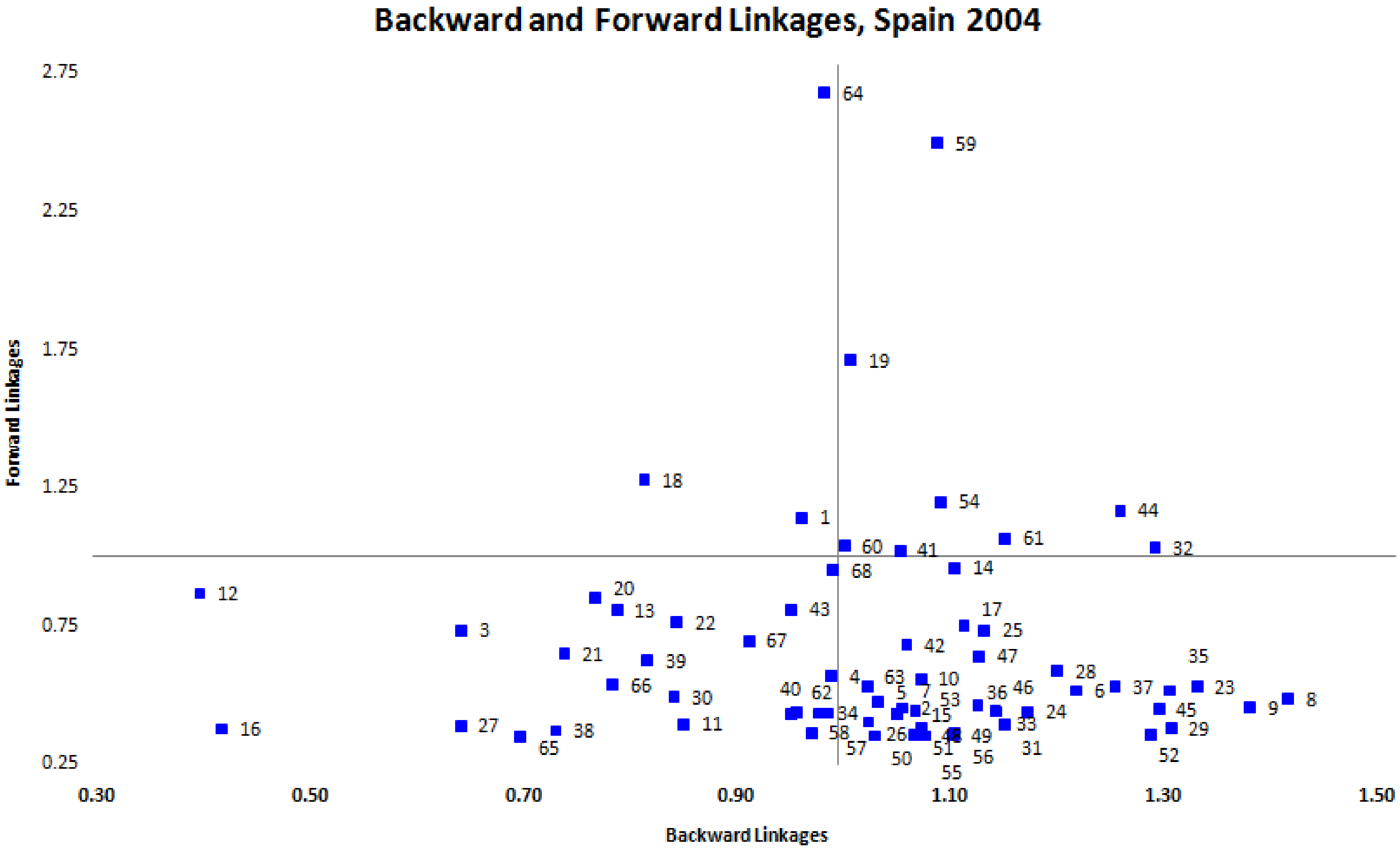
The accounts of the agri-food system, Vegetables and fruits, Grapewine, Coffees, bars and similar, Ovine and caprine, Retail trade of fruit and vegetables and Olive tree, are important in terms of BL, but not in terms of FL except for Cereals and leguminous plants.

Figure 1: Weighted Backward and Forward Linkages for Spain in 2004



Source: Own elaboration based on the SimSIP SAM tool (Parra and Wodon, 2009 [40])

Figure 2: Backward and Forward Linkages for Spain in 2004



Source: Own elaboration based on the SimSIP SAM tool (Parra and Wodon, 2009 [40])

Table 1: (Weighted and non weighted) Backward and forward linkages

Code Figures	Classification	Code	Backward Linkages	Order of BL	Forward Linkages	Order of FL	Weighted Backward Linkages	Weighted Forward Linkages
8	Porcine	AP1B3	1.422	1	0.484	37	1.098	0.110
9	Poultry	AP1B4	1.386	2	0.453	40	1.137	0.071
23	Meat industry	AP9A	1.336	3	0.529	31	1.088	0.249
29	Ind. bread cakes and biscuits	AP9C5	1.312	4	0.378	58	1.100	0.100
35	Ind. wines and ciders	AP9D2	1.311	5	0.514	35	1.165	0.069
45	Recovery and Repair	AP15	1.301	6	0.446	42	1.022	0.137
32	Ind. feed	AP9C8	1.297	7	1.031	10	1.039	0.215
52	Retail wine and other beverages	AP16G	1.293	8	0.352	64	1.070	0.005
44	Construction and engineering	AP14	1.264	9	1.165	6	1.796	3.429
37	Ind. non-alcoholic beverages	AP9D4	1.259	10	0.529	33	1.024	0.103
6	Bovine	AP1B1	1.223	11	0.515	34	1.155	0.103
28	Ind. milling	AP9C4	1.205	12	0.586	27	1.174	0.082
24	Dairies	AP9B	1.178	13	0.437	47	0.973	0.105
61	Real estate	AP20	1.156	14	1.066	8	1.706	1.409
31	Cocoa and confectionery ind	AP9C7	1.156	15	0.390	55	0.947	0.047
46	Wholesale of agricultural raw materials	AP16A	1.147	16	0.439	45	1.195	0.041
33	Other food industries	AP9C9	1.147	17	0.446	43	0.987	0.092
25	Industrial oils and greases	AP9C1	1.137	18	0.732	21	0.940	0.164
47	Wholesale food	AP16B	1.132	19	0.640	25	1.166	0.245
36	Ind. beer	AP9D3	1.131	20	0.463	39	0.985	0.058
17	Minerals and non-metallic mineral products	AP5	1.118	21	0.749	19	1.073	0.786
14	Production & distribution of electricity & gas	AP2C	1.109	22	0.959	12	1.058	0.755
56	Coffees, bars and similar	AP17B	1.109	23	0.362	61	1.260	0.568
49	Retail meat and charcuterie	AP16D	1.107	24	0.352	65	1.181	0.016
54	Non-food trade	AP16I	1.096	25	1.199	5	1.378	1.743
59	Transport and communications	AP18	1.093	26	2.495	2	1.407	2.818
48	Retail trade of fruit and vegetables	AP16C	1.081	27	0.352	66	1.230	0.008
55	Restaurants	AP17A	1.078	28	0.379	57	1.055	0.178
10	Other agricultural and Forestry activities	AP1C	1.077	29	0.557	29	0.918	0.101
53	Trade in large surfaces	AP16H	1.072	30	0.444	44	1.133	0.202
51	Other retail food	AP16F	1.071	31	0.352	63	1.177	0.024
42	Wood, cork and wood furniture	AP12	1.064	32	0.680	23	0.803	0.309
2	Vegetables and fruits	AP1A2	1.060	33	0.452	41	1.299	0.152
41	Paper industry	AP11A	1.058	34	1.022	11	0.958	0.803
15	Water	AP3	1.054	35	0.429	51	1.008	0.080
7	Ovine and caprine	AP1B2	1.054	36	0.429	52	1.233	0.058
5	Grapewine	AP1A5	1.038	37	0.473	38	1.296	0.032
50	Retailing Fish	AP16E	1.033	38	0.351	67	1.210	0.006
26	Ind. vegetables	AP9C2	1.028	39	0.402	53	0.850	0.092
63	Private healthcare	AP22	1.027	40	0.529	32	1.126	0.434
19	Metallurgy & manufacture of metal products	AP7A	1.011	41	1.711	3	0.959	1.891
60	Credit and insurance	AP19	1.006	42	1.038	9	1.210	1.135
68	Public Services	AP27	0.995	43	0.949	13	1.159	1.968
4	Olive tree	AP1A4	0.993	44	0.566	28	1.215	0.092
57	Hotels, pensions and similar	AP17C	0.991	45	0.433	49	1.034	0.216
64	Other services for sale	AP23	0.986	46	2.677	1	1.338	3.526
34	Ind. alcohols and liquors	AP9D1	0.981	47	0.433	48	0.760	0.047
58	Other catering services	AP17D	0.975	48	0.361	62	1.060	0.040
1	Cereals and leguminous plants	AP1A1	0.966	49	1.141	7	1.091	0.209
62	Private Education	AP21	0.961	50	0.438	46	1.077	0.243
43	Rubber, plastics and other manufactures	AP13	0.956	51	0.808	16	0.812	0.771
40	Manufacture of leather and footwear	AP10C	0.956	52	0.431	50	0.665	0.091
67	Public health	AP26	0.916	53	0.695	22	0.900	1.014
11	Fishing and aquaculture	AP1D	0.855	54	0.394	54	0.742	0.044
22	Transport equipment	AP8	0.848	55	0.762	18	0.786	1.414
30	Ind. sugar	AP9C6	0.846	56	0.492	36	0.661	0.051
39	Textiles, clothing and fur	AP10A	0.821	57	0.623	26	0.594	0.436
18	Chemicals	AP6	0.818	58	1.277	4	0.705	1.347
13	Coking, refining and nuclear fuels	AP2B	0.792	59	0.806	17	0.491	0.606
66	Public education	AP25	0.788	60	0.536	30	0.787	0.794
20	Machinery and equipment	AP7B	0.771	61	0.850	15	0.625	0.855
21	Manufacture of machinery and equipment	AP7C	0.743	62	0.648	24	0.547	0.773
38	Tobacco industry	AP9E	0.735	63	0.370	60	0.527	0.028
65	Domestic Service	AP24	0.701	64	0.351	68	0.688	0.057
3	Industrial crops	AP1A3	0.646	65	0.734	20	0.515	0.108
27	Ind. canned fish	AP9C3	0.645	66	0.387	56	0.370	0.080
16	Minerals and metals	AP4	0.422	67	0.377	59	0.091	0.040
12	Extraction of energy products	AP2A	0.401	68	0.867	14	0.110	0.557

Source: Own elaboration.

On the contrary, other accounts not mentioned yet with a primary position as pusher or supplier of other sectors, with a high rank in FL, are the Public Services, Metallurgy and manufacture of metal products, Transport equipment and Chemicals. Finally, the account of Credit and insurance, became noticeably with the analysis of the SAM in a balanced and relevant pull and push position (the 12^{th} in BL ordering and 10^{th} in FL).

3.2 Structural analysis from Network Analysis

3.2.1 Net analysis

The structure of the Spanish economy, which as it is usually available, we have in monetary terms, can be represented making use of the network theory, as it was described by García Muñiz et al. (2008 [21], 2010 [22])[3], being a useful tool to visually observe and compute key sectors and changes in purchases among them, that may lead to evaluate the technological change. This global structural analysis is not

[3] Precisely using the graph theory for the water analysis, Velázquez (2006) [45] found that the food industry in the Spanish region of Andalusia acquires most of its purchases (89%) from the agricultural sectors, while the Hotels and restaurants sector does it mainly from the Food sector (24%) and from the agricultural sectors (76%).

essential in this work, focused on the water flows, but we are interested in the links between agriculture, livestock, food industry and the rest of activities because the agrarian activities are the main direct water consumers, and they are the key to understand the integrated water flows.

Taking as first example one of the nets to be studied, the global SAM, which has a size of 78 nodes (68 sectors and 10 institutional accounts), we get that the number of lines (transactions) with non-zero value is 3,609, having 59 loops (reuse or transactions within the sector or institutional account). The density (allowing loops) is of 0.59, and the average degree of 92.54. The diameter of the whole net is 4, since the longest shortest path occurs from the activity of longest shortest path from Recovery & Repair (45) to Domestic Service (65). Regarding the geodesics matrices, computing the shortest path length matrix with the inverse value ($1/w_{ij}$) of each weight (or transaction) from i to j, the mean value of the geodesic distances is 1.86.

In this case we note in Figure 3[4] the high importance of exchanges among institutions and of them with other sectors that the SAM reflects (black arrows in Fig. 3). Those are the only links remaining when leaving the purchases among accounts of more than 20,000 million Euros, apart from the commerce between the activity of transport material and the Foreign sector (in both directions with the EU, vertice 77). On the bottom-right image we may observe that those transactions take place among those activities with higher total production, represented by the size of the balls[5].

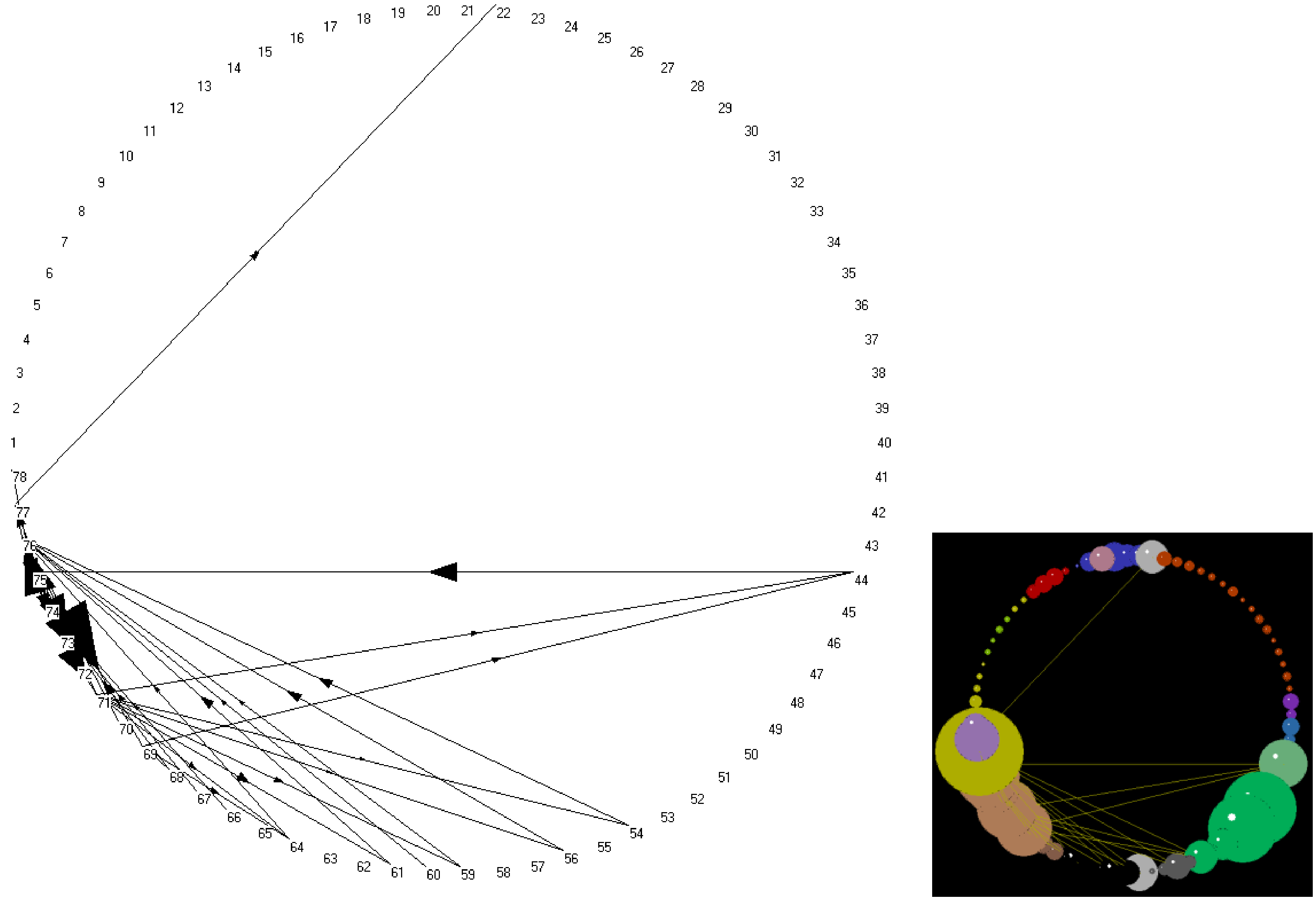
Regarding the relations among the 68 productive activities (red arrows in Fig. 4), it is remarkable, apart from the high quantities of self-purchases within sectors such as Construction & engineering not appearing in the graph, the strong links among the activities of Metallurgy & metallic products, Machinery & equipment, Transport Material and Construction & engineering, being obvious that the bigger arrows are the one going from the activity of 17-Minerals and non-metallic products to 44-Construction & engineering, the one from this sector to this activity to Real State, and the flow from the extraction of energetic products to refining. Nevertheless, the central position of most of those sectors, together with activities such as Transport and communications, although is manifestly indicating that Spain is not situated in a leading position in the high technology industries, is not the essential point in this work, specially given the slow down that has recently taken place in Spain in what had been the driving force activities.

The sector that is central (in spite of not seeming so in the graph because of the high disaggregation used) and has been more stable is the Food industry, that we will show in relation with the agrarian activities and services (Commercial and Hotels & restaurants). Leaving just the flows of the activities in the agro-industry system (higher than 400 million Euros in the direction that follow the products represented by the blue arrows in Figure 5), interesting chains of flows are observed. In that sense, in the Food sector there are included the industries transforming grains into feed, which will be sold to the Livestock activities. The industries of meat transformation and Dairies incorporate also high contents of primary livestock products, which as it can be already guessed, will be crucial when computing the embodied water contents in this framework coherent with the exchanges among the economy. The same will be observed for the other agrarian products with clear destination, the Vegetables and fruit activity, going mainly to the industries of Vegetables and Oils & greases, obviously without forgetting

[4] With the numbers (1-76 activities, plus 77 of the European Union and 78 of the Rest of the World)

[5] The colors represent the different clusters (15) we consider *a priori* from the NACE classifications.

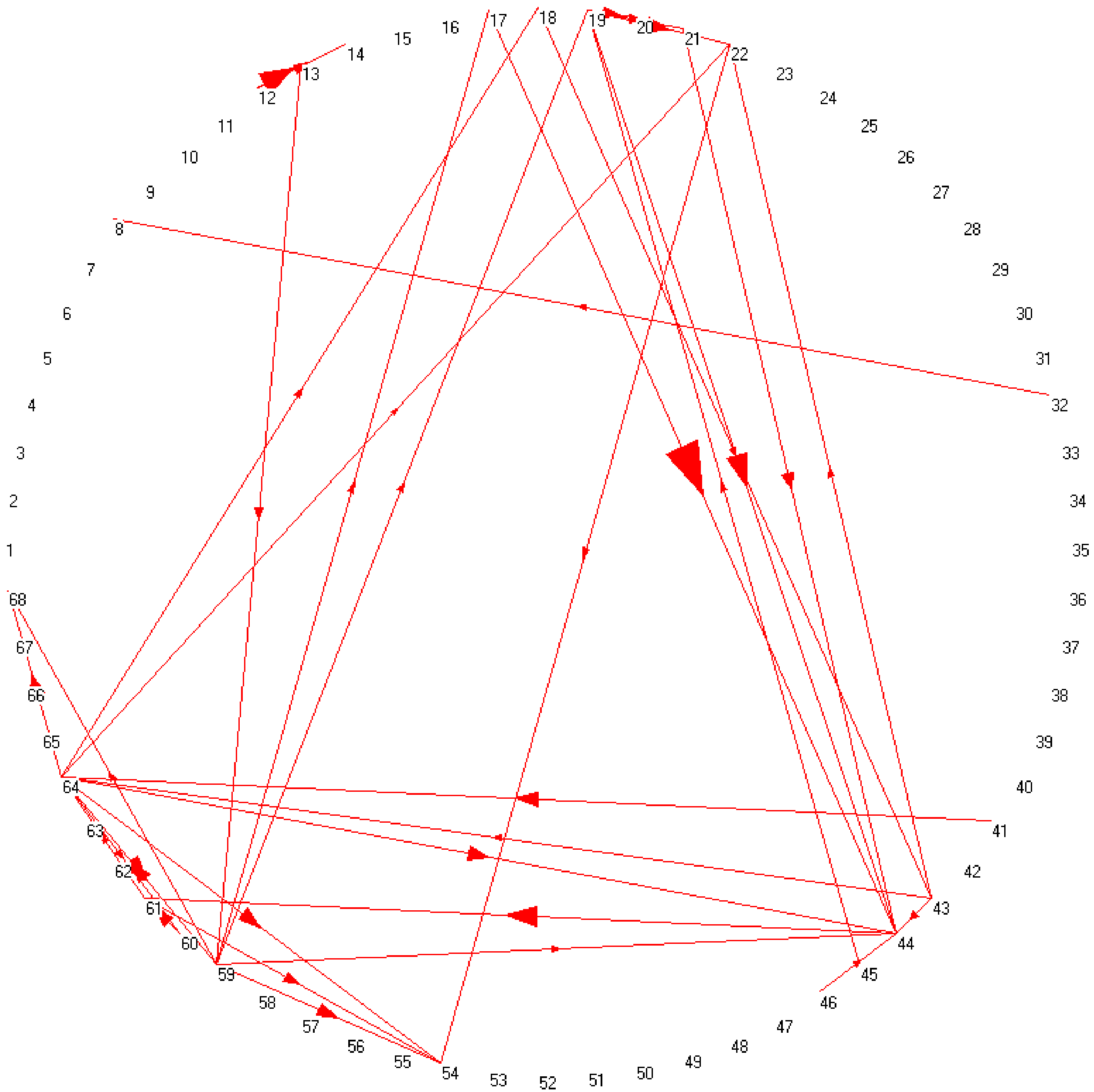
FIGURE 3: All productive activities and institutions in the economic system (more than 20,000 million Euros)*



* On the bottom-right image we may observe that those transactions take place among those activities with higher total production, represented by the size of the balls. The colors represent the different clusters (15) we consider *a priori* from the NACE classifications.

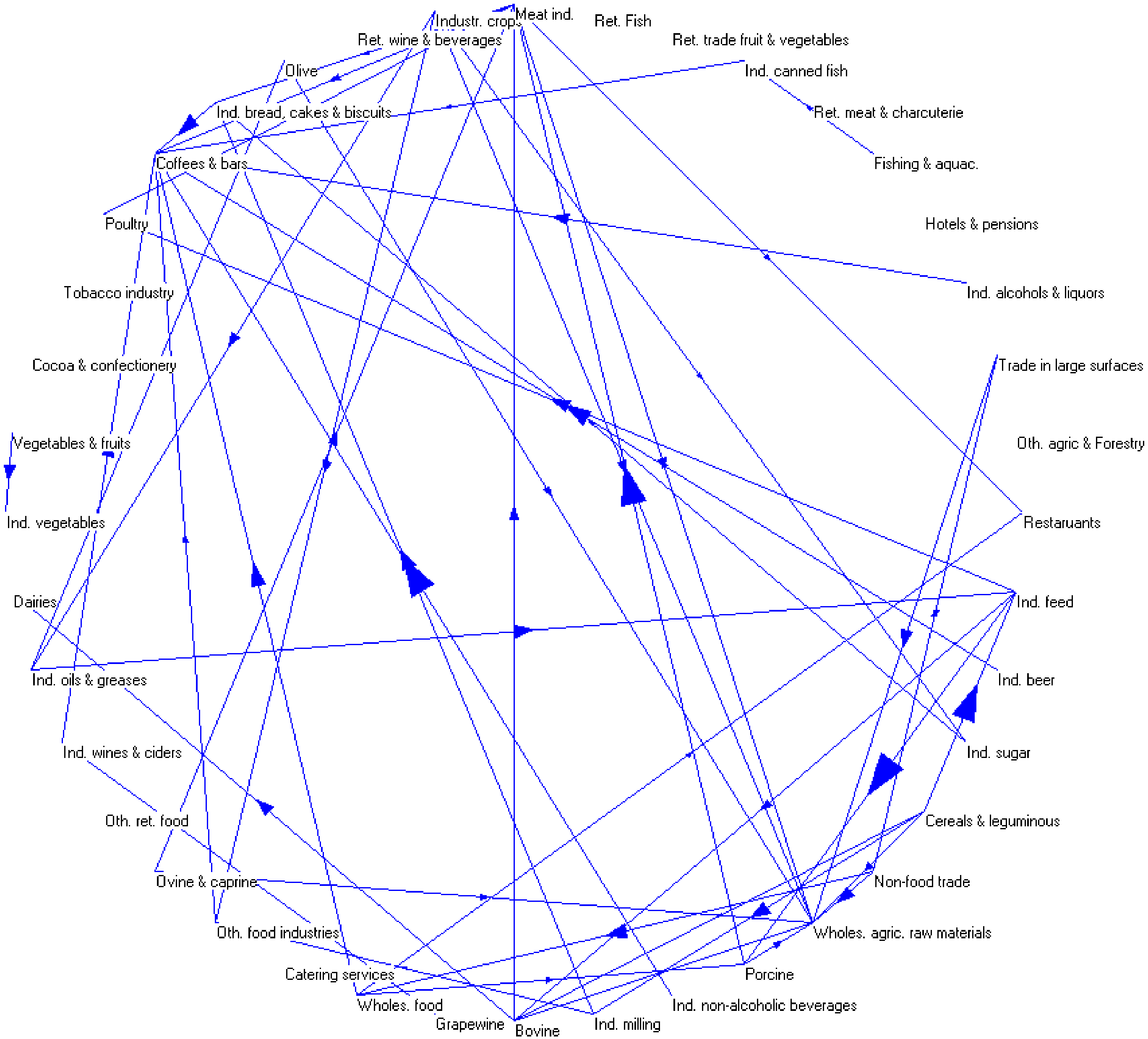
Source: Own elaboration

Figure 4: 68 productive activities in the economic system



Source: Own elaboration.

Figure 5: Structure of the flows of goods: SAMS04, with 68 activities, and representing the agro-industry system (higher than 400 million Euros)



Source: Own elaboration.

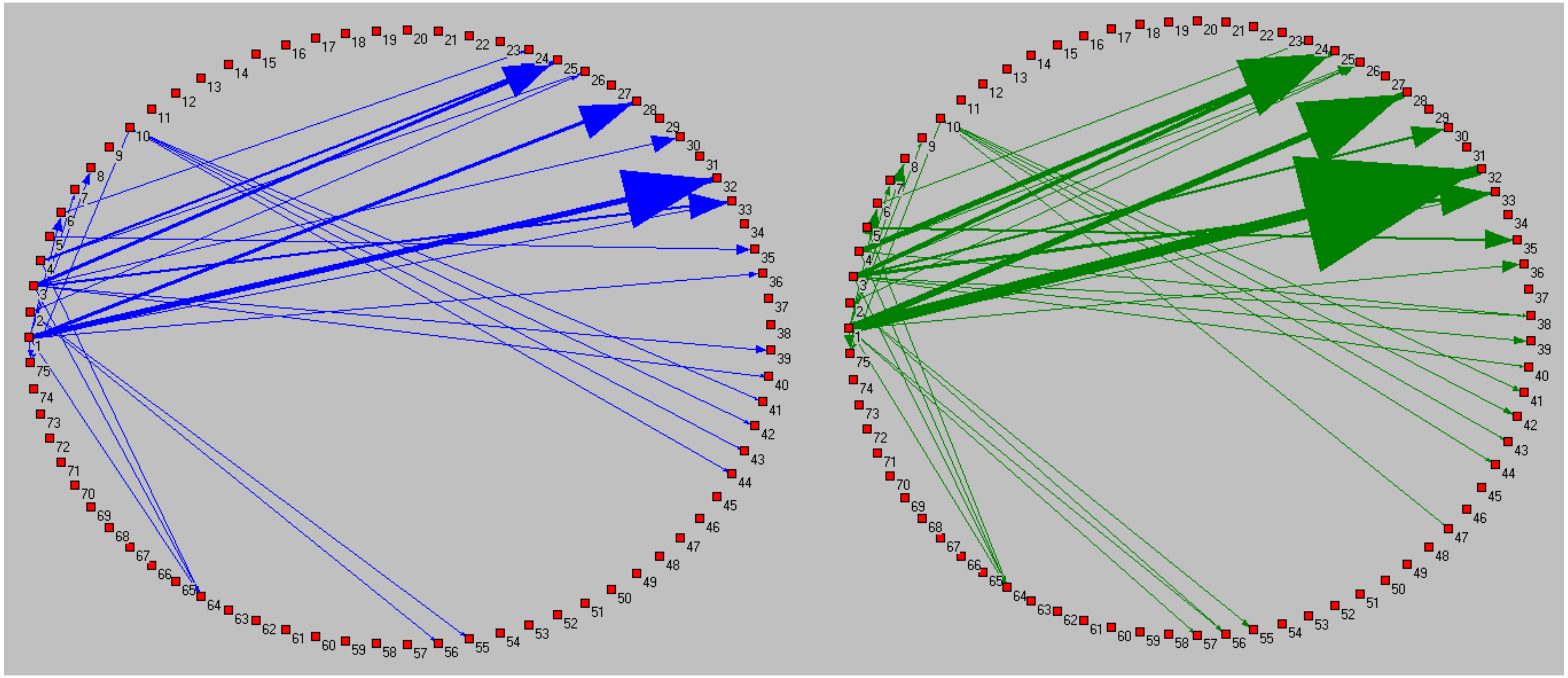
the high quantities that are sold directly to the Households and are not represented in the Figure to make it less dense. Compared to the former decade, the activities of Vegetables and Fruits have become more relevant in terms of production, acquiring a more central role in the agro-industry system, and reflecting changes in specialization and technologies. Finally, it is also noticeable the diverse origins from which the activities of Hotel & restaurants get their products (especially that of Coffees and bars), as it is not just food from the transformation industry but also beverages, that are being provided by intermediate activities of commercial services too.

Water flows representation

In an analogous way to the drawings of flows of goods and services presented in subsection 3.2, in this one we present the direct water consumption in Figure 6 and use the expression $\mathbf{w} * (\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{y}}$ to represent the embodied water (physical consumption) flows among all productive activities and institutions in the economic system (we simply show those above). In the first of the two we observe that the direct flows (and especially both blue and green water flows) are basically those from the agricultural activities to the Food industry, especially from Cereals to the industry of feed, which has been the most clear water flow and increase in water flows in recent years, due to the need to feed livestock. Also the direct water flows from Cereals to the Milling industry and from Olives to the Industry of oils and greases stand out as clear second and third major water flows (unless representing in the graph the water flows from Vegetables and fruits to Households and to the Rest of the World, which would be then the second and third major water flows). The figure also reveals that together with livestock consumption (with high water contents coming from feed), very high embodied water contents are found through the final demand of the goods and services provided by the Hotels and restaurants, and through exports of agrarian goods, especially of Vegetables and fruits, which were phenomena much less marked when we look at tables and water data of 2 decades before.

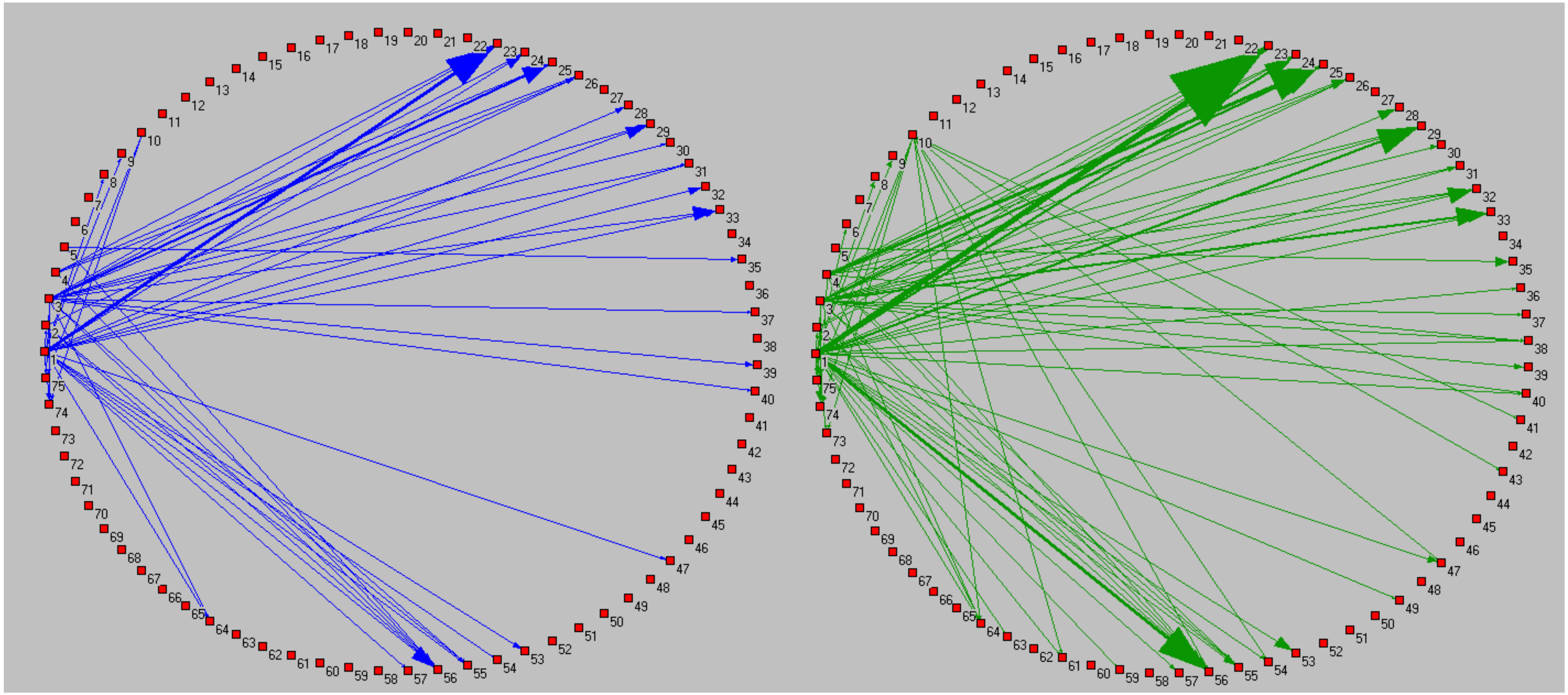
If in Figure 3 we basically observed that the most relevant connections in monetary terms (more than 20,000 million Euros) were taking place among institutional sectors, in Figure 7 we observe that despite of that fact, the most important (more than 50 hm^3) embodied blue and green physical (only blue in the left, and both blue and green in the right hand side) water flows occur in the Spanish economy obviously from agriculture to many other ones. The graph seems to be a quite clear cut figure (we have kept the circular order of accounts, starting in the number 1, Cereals and leguminous and ending in the number 75, S/I, as we present them in tables by code order), with the arrows of embodied blue physical water consumption pointing to the transport sector, the food industry, and the hotels and restaurants activities (on the left hand side). This figure is complemented with the circle and relations of the right hand in which also green water is considered (keeping the proportion of the size of the lines and arrows) and hence all the physical water flows of embodied consumed water are represented. Some new important flows appear (above 50 hm^3, such as those ending in the activities 41 of Paper industry, 43 of Rubbers and plastic, 59 Transport and communication and 61 Real State, or the increasing presence of the activities 47 Wholesale food.

FIGURE 6: Direct blue and blue and green (physical) water flows among all productive activities and institutions in the economic system (more than 50 hm^3)



Source: Own elaboration.

Figure 7: Embodied blue and blue and green (physical) water flows among all productive activities and institutions in the economic system (more than 50 hm^3)



Source: Own elaboration.

3.2.2 Nodes analysis

Degree and degree distribution

In Table 2 we observe the generalised measure proposed in Opsahl et al. (2010) [38]. The intput degree and output degree (and output value), with big differences in the connections (and weight). Differential behaviour is found for the activities have a high number of input ties (inputs from many sectors) such as the sector 66-Public education (59 input degree, 3 output degree), 67-Public health (58 in, 3 out), 68-Public Services (58, 3) and 76- Households (72, 9). Also in a smaller degree it occurs the same with sector 3-Industrial crops (41, 27), sector 4-Olive (42, 22), sector 5-Grapewine (41, 21), sector 11-Fishing & aquaculture (56, 37), sector 38-Tobacco industry (53, 16), 48-Ret. trade fruit & vegetables (40, 15), 49-Retail meat & charcuterie (43, 15), 50-Retail Fish (40, 15), sector 51-Other retail food (46, 15), 52-Retail wine & beverages (35, 15) and sector 75-S/I (48, 4).
On the contrary, the accounts with few inputs or ties in columns, but high in rows, such as the sector 69-Wages & salaries (3 in, 70 out), sector 70-Social contribution of employers (4, 70) and sector 71-K (4-67), and in a smaller degree, 12-Extraction energy products (34, 12), 22-Transport equipment (44, 71) and 54-Non-food trade (39, 72).

Table 2: Degree and strength of a node* with the generalised measure for weighted networks.

node	input degree	output degree	output	node	input degree	output degree	output	node	input degree	output degree	output
1	42	34	7,167	**27**	45	36	5,118	**53**	52	69	16,672
2	42	44	14,382	**28**	36	44	3,625	**54**	**39**	**71**	107,959
3	**41**	**25**	4,167	**29**	54	34	8,299	**55**	59	68	16,903
4	**42**	**21**	2,959	**30**	36	43	2,515	**56**	60	67	65,539
5	**41**	**20**	1,247	**31**	45	35	2,544	**57**	59	68	14,836
6	**44**	**29**	3,906	**32**	45	31	6,653	**58**	59	67	3,407
7	42	29	1,962	**33**	56	44	6,894	**59**	55	71	103,974
8	42	26	4,508	**34**	47	35	2,441	**60**	51	69	49,664
9	41	38	3,031	**35**	42	35	3,831	**61**	62	71	103,220
10	47	47	2,838	**36**	42	29	2,983	**62**	57	68	13,818
11	**56**	**36**	3,635	**37**	43	27	5,594	**63**	57	68	23,894
12	34	53	18,545	**38**	53	**14**	2,651	**64**	62	72	150,127
13	62	70	26,658	**39**	50	69	21,520	**65**	2	1	6,752
14	62	70	25,849	**40**	42	61	6,886	**66**	59	3	28,775
15	60	70	4,398	**41**	58	69	25,327	**67**	58	3	36,384
16	25	26	1,293	**42**	53	67	8,897	**68**	58	3	70,128
17	63	66	30,554	**43**	52	70	37,827	**69**	3	70	312,838
18	51	71	51,950	**44**	53	67	155,904	**70**	4	70	89,194
19	61	70	61,463	**45**	33	27	4,248	**71**	4	67	352,121
20	63	70	47,179	**46**	45	63	1,651	**72**	11	7	8,867
21	61	70	40,368	**47**	52	46	18,061	**73**	7	6	222,469
22	**44**	**70**	81,809	**48**	**40**	**15**	551	**74**	28	47	315,184
23	51	57	18,111	**49**	**43**	**15**	1,523	**75**	**48**	**4**	188,325
24	53	42	8,542	**50**	**40**	**15**	477	**76**	**72**	**8**	748,708
25	43	43	7,038	**51**	**46**	**15**	2,406	**77**	67	67	203,733
26	50	39	4,957	**52**	**35**	**15**	101	**78**	67	67	102,972

Source: Own elaboration.

Closeness and Betweenness

In Figure 8 closeness scores for nodes in a weighted network based on the weighted distance [6], as explained in the methodology, by inverting the score so that it shows closeness instead of farness. This means that the highest the value obtained, the highest is the proximity of the sector studied to other ones in the network. The measure of betweeness defined studies the number (and weight) of shortest paths between any two nodes in the network that pass through the node studied. Determining the fraction of shortest paths that pass through the vertex in question, then the sectors with non-zero numbers shows nodes that fall on the geodesic paths between other pairs of sectors in the network. Intuitively then, it shows their presence (and the higher the value the higher importance in the paths) as inter-

[6] Setting the α parameter (here is presented by default equal to 1, but the robustness is tested looking at the sensitivity towards favouring the number of nodes or of strong ties), and removing self-loops (reuse).

mediate nodes (sectors) in paths were other sectors depend on it to make connections with other sectors.

In Figure 8, it stands out the leading role in terms of closeness and betweenness of the institutional accounts: Households, PP.AA., Capital Factor, Societies, Savings/Investment, European Union, Gross wages and salaries,. . . , but then also of the sector Coffees, bars and similar, Public Services, Construction and engineering, Transport and communications, Other services for sale and Real estate (this last one more in terms of closeness than betweenness). We also find activities with low closeness but with positive values of betweenness, which have to do mostly with the agri-food accounts, [7]Meat industry, Ind. bread cakes and biscuits, Industrial oils and greases, Porcine, Ind. wines and ciders, Ind. feed, Olive tree and Cereals and leguminous plants (with low values of closeness). This activities are in the middle of some supply-chains of goods and services, as purchasers and sellers with other sectors that do not have transactions in that direction. This fact that gives us the idea (further studying those paths) of the essentialness of the sector as intermediary (lets think in the break of those chains with the disappearances or sectoral crises), is applicable also to the sector of Metallurgy and manufacture of metal products, Coking, refining and nuclear fuels and the Extraction of energy products.

FIGURE 8: Closeness scores for nodes * with the generalised measure for weighted networks**.

node	closeness	betweenness	node	closeness	betweenness	node	closeness	betweenness
52	0.0008351	0	51	0.00776	0	21	0.010257	0
46	0.0026026	0	42	0.007869	76	19	0.010426	227
50	0.0029602	0	27	0.007948	0	23	0.010454	368
48	0.0034992	0	38	0.008035	0	53	0.010486	0
30	0.0036951	0	8	0.008241	142	20	0.010496	0
10	0.0037146	0	37	0.008291	0	55	0.010515	0
5	0.0040623	0	45	0.0084	0	17	0.010571	0
7	0.0049214	0	33	0.008535	0	63	0.010591	0
3	0.0053663	0	12	0.009095	71	60	0.01077	0
1	0.0054323	221	40	0.0091	0	66	0.010851	0
4	0.0057005	75	72	0.0094	0	22	0.010912	53
16	0.0057862	0	57	0.009551	0	67	0.010919	0
34	0.0059699	0	13	0.009678	75	59	0.011008	692
28	0.006062	2	2	0.009698	0	64	0.011043	596
32	0.0064481	151	29	0.00975	149	69	0.011065	2007
49	0.0064531	0	14	0.009779	0	54	0.011079	75
9	0.0064705	0	65	0.00982	0	44	0.011092	543
6	0.0065488	2	24	0.009826	75	68	0.011093	77
35	0.0066384	76	43	0.009887	0	77	0.011101	883
31	0.0067443	0	41	0.009893	0	56	0.011106	379
26	0.0073903	0	62	0.009955	0	61	0.011106	17
36	0.0075433	0	78	0.010129	373	75	0.011173	681
15	0.0075463	0	39	0.010185	0	73	0.011195	681
58	0.0076005	0	18	0.010223	0	71	0.011235	2950
25	0.0076125	150	47	0.010228	0	74	0.011251	317
11	0.0077568	0	70	0.01025	0	76	0.011304	4614

** Running the "weighted one-mode tnet". There were self-loops in the edgelist, which were removed.
*** Betweenness means in this titles betweenness.
Source: Own elaboration.

[7] It is worth signaling though that a higher disaggregation of the agri-food accounts (although not always leading to the smallest accounts in terms of production, see total size) likely leads to that highlighted importance of the node due to being to specific, and being intermediary of specific activities too, see Hewings, 1974 [23].

Clustering

In Figure 9 we show the results of clustering (from a random start) for each chosen number of clusters (from 2 to 20) of the transactions network of Spain with 78 nodes (in Figure 11 in the Appendix they are shown as ordered by cluster when we search to obtain 15 of them).The colors in the first column, showing the name of node, represent the default groups or clusters we would consider as distinguished from the NACE codes and the original breakdowns. The colours of the following columns distinguish (grade) clusters (given by number) within the same column (and hence no comparisons should be made by color or number from one color to other, apart from observing whether the same accounts belong to each cluster or not). Vegetables and fruits has a different behaviour with respect to most of other agrarian activities (less sells to the transformed food industry in proportion, having much more production directed to the final demand of households and foreign countries (exports).

When we distinguish 5 clusters or less, the agrarian activities are grouped in the same cluster with the food industry accounts; the accounts of the Energy and water sectors, it is worth noting that the behavior of the Extraction of energy products results more different than Coking, refining and nuclear fuels, Production and distribution of electricity and gas, and the Distribution of water, which are grouped always together in the same cluster. In the industry sectors, we find differential a separate clustering of Chemicals, and especially of Minerals and metals and Transport equipment, with respect to the activities of Metallurgy and manufacture of metal products, Machinery and equipment (and its manufacture), Minerals and non-metallic mineral products and Paper industry.

The (3) industrial activities of Wood, cork and wood furniture, Rubber, plastics and other manufactures and Construction and engineering, at least until we distinguish 6 clusters or more are grouped together with the previous ones. Interestingly, the last three of these sectors belong always (up to the studied 20 clusters) to the same cluster, and if looking carefully to the Chemical sector and the services activity of Transport and communications, they become always grouped with the (3) cited industrial activities. In a similar way (3) livestock accounts, Bovine, Ovine and caprine and Porcine, are mostly clustered with the industry of feed when 13 or less clusters are searched. On the contrary, the account of Poultry is often clustered in a different group, mostly (considering 13 or less clusters) with Food industry activities (e.g. Industry of milling). Also Minerals and metals, and Recovery and repair are for almost any chosen number of clusters grouped together.

Textiles, clothing and fur and Manufacture of leather and footwear grouped mostly together (with 15 or less clusters), and in the case of the second one always together with the account of Non-food trade. As this account, the account of Trade in large surfaces shows a different behavior from all the other commerce activities. Grouped in the same cluster we always (up to the analysis of 20 clusters) we find all the accounts from the Hotels and Restaurants sector (Restaurants, Coffees, bars and similar, Hotels, pensions and similar and Other catering services). Interestingly it occurs the same with (5) accounts of Services, Credit and insurance, Real estate, Private Education, Private healthcare and Other services for sale, and in the same fashion, it occurs within the public sector activities (only with less than 5-6 clusters the account of Domestic Service and the Commerce activities are grouped with them). Although indeed the account is not very relevant in the whole economy, the Tobacco industry (and frequently the Industry of bread cakes and biscuits) is always in a different from that of the food industry, and indeed mostly with the public sector activities.

Figure 9: Clustering for each chosen number of them (from 2 to 20), Spain, 78 nodes

Number of clusters		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Short Name of node	Node	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.
Cereals & leguminous plants	1	1	3	3	1	1	1	2	8	7	9	3	5	13	6	1	4	2	3	13
Vegetables and fruits	2	2	3	4	5	5	6	5	4	6	4	1	9	12	8	1	4	2	3	13
Industrial crops	3	1	3	3	1	1	1	2	8	7	9	3	5	13	6	13	17	11	8	12
Olive tree	4	1	2	3	1	1	1	2	8	7	9	3	5	13	6	13	17	11	8	12
Grapewine	5	1	2	3	1	1	1	2	8	7	9	3	5	13	6	13	17	11	8	12
Bovine	6	1	3	3	1	1	1	2	8	7	9	3	5	3	14	4	7	6	18	16
Ovine and caprine	7	1	3	3	1	1	1	2	8	7	9	3	5	3	14	4	7	6	18	16
Porcine	8	1	2	3	1	1	1	2	8	7	9	3	5	3	14	4	7	6	18	16
Poultry	9	2	3	3	1	5	6	5	4	6	4	1	9	3	14	4	7	6	18	16
Other agricultural & Forest	10	2	3	4	5	5	6	4	4	2	6	5	11	12	15	14	2	10	11	19
Fishing and aquaculture	11	1	3	3	1	5	7	5	2	8	5	4	10	11	7	8	15	13	9	7
Extraction of energy products	12	2	3	4	5	5	6	4	9	2	6	8	2	4	11	9	8	18	5	8
Coking, refining and nuclear fuels	13	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Prod. & distrib. of electricity & gas	14	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Water	15	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	16	6	1
Minerals and metals	16	1	3	3	1	1	1	2	8	7	9	3	12	7	12	15	10	15	16	6
Minerals & non-metallic mineral	17	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Chemicals	18	2	1	1	3	6	2	8	3	9	1	7	3	6	9	12	5	7	4	17
Metallurgy & manuf. of metal prod.	19	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Machinery and equipment	20	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Manuf. of machinery & equipment	21	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Transport equipment	22	2	1	4	5	6	2	4	9	2	6	8	2	4	11	16	13	18	14	10
Meat industry	23	2	1	4	5	6	2	8	3	9	1	7	7	12	15	14	11	10	14	4
Dairies	24	2	1	3	1	6	7	5	2	8	3	4	10	11	7	7	11	13	12	4
Industrial oils and greases	25	2	3	3	1	5	6	5	4	6	4	1	9	2	8	5	9	1	7	9
Ind. vegetables	26	2	3	3	1	5	7	5	4	6	4	1	9	2	2	5	9	3	7	11
Ind. canned fish	27	1	3	3	1	5	6	5	4	6	3	1	9	2	2	7	9	3	7	11
Ind. milling	28	2	3	3	1	5	6	5	4	6	4	1	9	2	8	5	9	1	7	9
Ind. bread cakes and biscuits	29	1	3	3	1	5	7	5	2	8	5	4	10	11	2	8	15	3	9	7
Ind. sugar	30	2	3	3	1	5	6	5	4	6	4	1	9	2	8	5	9	1	7	9
Cocoa and confectionery ind	31	1	3	3	1	5	7	5	4	6	3	1	9	2	2	7	9	3	7	11
Ind. feed	32	1	3	3	1	1	1	2	8	7	3	3	5	2	13	7	14	3	12	11
Other food industries	33	2	3	3	1	5	7	5	2	8	5	4	10	11	7	8	15	13	9	7
Ind. alcohols and liquors	34	1	3	3	1	5	7	5	4	6	3	1	9	2	2	7	9	3	2	14
Ind. wines and ciders	35	1	3	3	1	5	6	5	4	6	4	1	9	2	2	5	9	1	2	14

Continues on the next page...

FIGURE 10: ... continues from the previous page

Number of clusters		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Short Name of node	Node	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.	Clu.
Ind. alcohols and liquors	34	1	3	3	1	5	7	5	4	6	3	1	9	2	2	7	9	3	2	14
Ind. wines and ciders	35	1	3	3	1	5	6	5	4	6	4	1	9	2	2	5	9	1	2	14
Ind. beer	36	1	3	3	1	5	6	5	4	6	3	1	9	2	2	7	9	3	2	14
Ind. non-alcoholic beverages	37	1	3	3	1	5	1	5	4	6	3	1	9	2	2	7	9	3	2	14
Tobacco industry	38	1	2	2	2	4	3	3	5	4	10	10	6	8	3	10	3	17	10	3
Textiles, clothing and fur	39	2	1	4	5	6	2	8	3	2	6	7	3	6	11	12	5	7	4	17
Manuf. of leather & footwear	40	2	1	4	5	6	2	4	9	2	6	8	2	4	11	16	13	18	5	8
Paper industry	41	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Wood, cork and wood furniture	42	2	1	1	3	6	2	8	3	9	1	7	3	6	9	12	5	7	4	17
Rubber, plastics & other manuf.	43	2	1	1	3	6	2	8	3	9	1	7	3	6	9	12	5	7	4	17
Construction and engineering	44	2	1	1	3	6	2	8	3	9	1	7	3	6	9	12	5	7	4	17
Recovery and repair	45	1	3	3	1	5	1	5	8	7	9	3	12	7	12	15	10	15	16	6
Wholesale of agric. raw materials	46	2	1	4	5	3	4	4	9	2	6	8	2	4	11	16	13	18	5	8
Wholesale food	47	2	1	1	3	3	4	6	6	1	11	2	7	12	15	1	11	12	17	5
Retail trade of fruit & vegetables	48	1	2	2	2	2	5	1	1	3	8	12	1	5	4	2	16	14	1	2
Retail meat and charcuterie	49	1	2	2	2	2	5	1	1	3	8	12	1	5	4	2	16	14	1	2
Retailing Fish	50	1	2	2	2	2	5	1	1	3	8	12	1	5	4	2	16	14	1	2
Other retail food	51	1	2	2	2	2	5	1	1	3	8	12	1	5	4	2	16	14	1	2
Retail wine & other beverages	52	1	2	2	2	2	5	1	1	3	8	12	1	5	4	2	16	14	1	2
Trade in large surfaces	53	2	1	1	3	6	2	8	6	1	11	9	3	6	1	12	5	7	4	15
Non-food trade	54	2	1	4	5	6	2	4	9	2	6	8	2	4	11	16	13	18	5	8
Restaurants	55	2	1	1	3	6	2	8	3	5	2	11	13	14	5	11	12	9	19	18
Coffees, bars and similar	56	2	1	1	3	6	2	8	3	5	2	11	13	14	5	11	12	9	19	18
Hotels, pensions and similar	57	2	1	1	3	6	2	8	3	5	2	11	13	14	5	11	12	9	19	18
Other catering services	58	2	1	1	3	6	2	8	3	5	2	11	13	14	5	11	12	9	19	18
Transport & communications	59	2	1	1	3	6	2	8	3	9	1	7	3	6	9	12	5	7	4	17
Credit and insurance	60	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	16	14	10
Real estate	61	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	15
Private Education	62	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	16	6	15
Private healthcare	63	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	16	6	15
Other services for sale	64	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	15
Domestic Service	65	1	2	2	4	2	5	7	7	10	7	6	8	9	10	3	6	5	13	20
Public education	66	1	2	2	2	4	3	3	5	4	10	10	6	1	3	10	3	8	15	3
Public health	67	1	2	2	2	4	3	3	5	4	10	10	6	1	3	10	3	8	15	3
Public Services	68	1	2	2	2	4	3	3	5	4	10	10	6	1	3	10	3	8	15	3

* The number of clusters considered are presented in the first row, while the number of the corresponding cluster to which each activity belongs to is shown by columns. Dark lines are intended to show differences of groups created with the 15 clusters blockmodeling.

Source: Own elaboration.

Finally after this ordered analysis, we pay attention to probably less expected connections (accounts not generally classified together in the IOTs), of common created clusters formed by more different activities in the processes performed, but probably tied as providers and demanders of products of services. The aforementioned (5) accounts of Services are clustered with a big industrial group, the activities of Coking, refining and nuclear fuels, Production and distribution of electricity and gas, and the Distribution of water; Metallurgy and manufacture of metal products, Machinery and equipment (and its manufacture), Minerals and non-metallic mineral products; and (up to 15 clusters) with the Wholesale food.

Hubs and authorities

According to the analysis of the network of 78 sectors (the whole SAM, and choosing 10 hubs and 10 authorities), the sectors classified as authority (analogous measure to the strong FL), i.e. with value 1, are the Olive tree, Grapewine, Dairies, Manufacture of leather and footwear, and all the Retail food products. Sectors classified as hubs (analogous measure to the strong BL), i.e. with value 3, are Manufacture of machinery and equipment, Tobacco industry, Textiles, clothing and fur, Wood, cork and wood furniture, Restaurants, Hotels, pensions and similar, Private Education, Private healthcare, and the account of the European Union; while the Rest of world account appears as a good authority and hub (value 2).

Somehow surprisingly, the picture taking into account only the net of 68 sectors is radically different, with no hubs and authorites sectors (analogous to the key classification), and highlighted as authorities activities that were not in the 78 nodes analysis: Coking, refining and nuclear fuels, Water, Minerals and non-metallic mineral products, Metallurgy and manufacture of metal products, Manufacture of machinery and equipment and Textiles, clothing and fur (those last 2 being hubs in the 78 nodes analysis), Transport equipment and Wood, cork and wood furniture and Rubber, plastics and other manufactures.

When omitting then the role of most sectors, especially some as the Food Industry, with the institutional accounts (especially of the final demand of those productions), the emphasis on their capacity of demand from other sectors (i.e. agrarian) is increased, and hence the hubs are the industry of oils and greases, the industry (Ind.) of vegetables, Ind. canned fish, Ind. milling, Ind. sugar, the industries of beverages and other food industries. Otherwise said, all the food industry except the Ind. bread cakes and biscuits, Cocoa and confectionery ind., Tobacco industry, and Meat industry, Dairies and the Ind. of feed, which are not classified there contrary to what it might be expected (given their high pull from the livestock accounts), due to their intermediary role as strong providers to the retail trade, hotels and restaurants activities, and the agrarian accounts in the case of the last one. In any case if considered 15 hubs and 15 authorities, together the Wholesale of agricultural raw materials and Fishing and aquaculture, they also become hubs; except the Tobacco industry, which appears as authority, together with Paper industry, Retailing Fish, Credit and insurance and Public education.

Table 3: Hubs and authorities

node	H&A 78 sectors	H&A 68 sectors	node	H&A 78 sectors	H&A 68 sectors	node	H&A 78 sectors	H&A 68 sectors
1	0	0	**27**	0	3	**53**	0	0
2	0	0	**28**	0	3	**54**	0	0
3	0	0	**29**	0	0	**55**	3	0
4	1	0	**30**	0	3	**56**	0	0
5	1	0	**31**	0	0	**57**	3	0
6	0	0	**32**	0	0	**58**	0	0
7	0	0	**33**	0	3	**59**	0	0
8	0	0	**34**	0	3	**60**	0	0
9	0	0	**35**	0	3	**61**	0	0
10	0	0	**36**	0	3	**62**	3	0
11	0	0	**37**	0	3	**63**	3	0
12	0	0	**38**	3	0	**64**	0	0
13	0	1	**39**	3	1	**65**	0	0
14	0	0	**40**	1	1	**66**	0	0
15	0	1	**41**	0	0	**67**	0	0
16	0	0	**42**	3	1	**68**	0	0
17	0	1	**43**	0	1	**69**	0	-
18	0	0	**44**	0	0	**70**	0	-
19	0	1	**45**	0	0	**71**	0	-
20	0	0	**46**	0	0	**72**	0	-
21	3	1	**47**	0	0	**73**	0	-
22	0	1	**48**	1	0	**74**	0	-
23	0	0	**49**	1	0	**75**	0	-
24	1	0	**50**	1	0	**76**	0	-
25	0	3	**51**	1	0	**77**	3	-
26	0	3	**52**	1	0	**78**	2	-

* Prod. & dis.: Production and distribution, transp.: transport, manuf.: manufactures, veg.*: vegetables, contr.: contributions, agr.: agrarian.
Source: Own elaboration from the program Pajek.

4 Comparison of approaches and final comments

One of the main goals of the study has been analyzing the agri-food transactions (framed in a better understanding of the structure of the economy) and the processes of embodied water flows (which from previous studies we knew that run mostly through those cited activities), obtaining insights from the input-output analysis (IOA) but also from fields with important analogies to it, which provide us with measures and interpretations to links and clusters, such as the network and graph theories. The common measures of the approaches that firstly appeared in the network theory, become especially relevant for us in our study of IO or SAM matrices when redefined for weighted networks, where in essence the importance of the flows (the higher the higher, contrary to the first measures as Dijkstras, based on costs) is the key concept to introduce (frequently this can be done by inverting each value, and hence interpreting inversely the importance of the ties).

The characterization of the construction sector lead in the past years to the debate of whether it was becoming a key sector with capacity to pull and push the economy (and how a block was created tied closed with the Real State activities), or a deformation of the economy with symptoms of economic and environmental risks. Here what it is confirmed is that with the traditional Hirschman-Rasmussen indices to obtain key sectors (when looking at the 68 productive activities) is that the activities of Construction and engineering and the Real estate belonged in 2004 to that group, together with the Public Services, Transport and communications, Credit and insurance, and Other services for sale. Looking more carefully, we observe that backward capacity of the Construction sector was much stronger (in relative terms with respect to others) than its forward. The clustering analysis though revealed new strong linkages among (3) industrial activities, the cited sector of Construction and engineering, Wood, cork and wood furniture, Rubber, plastics and other manufactures, which belong always (up to the studied 20 clusters) to the same cluster, also almost always to the Chemical sector and the services activity of Transport and communications, and until we distinguish 6 clusters or more are grouped together with other industrial sectors.

Although again it is conditioned on the disaggregation used (and number of sectors studied, 68), the main backward linkages (BL) are of agrarian subaccounts (porcine, poultry,...) and food industry ones (meat industry, industry of bread cakes and biscuits, industry of wines and ciders,...), but they are not important in terms of forward linkages (FL), ordering in which also stand out Metallurgy and manufacture of metal products, Chemicals and Non-food trade, being the only agri-food subsectors with relevant FL (among the 11 main subaccounts) Cereals and leguminous plants and the industry of feed. Looking at the weighted values, the agri-food system, Vegetables and fruits, Grapewine, Coffees, bars and similar, Ovine and caprine, Retail trade of fruit and vegetables and Olive tree are important in terms of BL, but not in terms of FL except for Cereals and leguminous plants.

The hubs and authorities analysis provides us with many differences. When considering only those 68 sectors, and hence omitting the role of most sectors, especially some as the Food Industry, with the institutional accounts (especially of the final demand of those productions), the emphasis on their capacity of demand from other sectors (i.e. agrarian) is increased. The hubs obtained are the industry of oils and greases, the industry (Ind.) of vegetables, Ind. canned fish, Ind. milling, Ind. sugar, the industries of beverages and other food industries. Otherwise said, all the food industry except the Ind. bread cakes and biscuits, Cocoa and confectionery ind., Tobacco industry, and Meat industry, Dairies and the Ind. of feed, which are not classified there contrary to what it might be expected (given their high pull from the livestock accounts), due to their intermediary role as strong providers to the retail trade, hotels and restaurants activities, and the agrarian accounts in the case of the last one.

Surprisingly, this result is very different from the analysis of the network of 78 sectors (the whole SAM), which situates in the classification as authorities (analogous measure to the strong FL) the Olive tree, Grapewine, Dairies, Manufacture of leather and footwear, and all the Retail food products. Sectors classified as hubs (analogous measure to the strong BL), are Manufacture of machinery and equipment, Tobacco industry, Textiles, clothing and fur, Wood, cork and wood furniture, Restaurants, Hotels, pensions and similar, Private Education, Private healthcare, and the account of the European Union; while the Rest of world account appears as a good authority and hub. In any case if considered 15 hubs and 15 authorities, together the Wholesale of agricultural raw materials and Fishing and aquaculture, they also become hubs; except the Tobacco industry, which appears as authority, together with Paper industry, Retailing Fish, Credit and insurance and Public education.

Complementary information for the whole SAM (78 accounts) was obtained from the closeness and betweeness information, were the special role of the institutional extensions was emphasized by observing that those accounts connect some sectors that have no other connection in terms of transactions in any other way. In this sense the detail of some accounts of the agri-food system (meaning the most connected accounts with food, ie, agriculture, livestock, food sector, food commerce and hotels and restaurants) reveals accounts which that position in between of nodes, but their smaller size and strength of ties shows their low closenesses values.

Looking at the water flows, the direct ones are basically those from the agricultural activities to the Food industry, especially from Cereals and leguminous to the industry of feed, which has been the most clear water flow and increase in water flows in recent years, due to the need to feed livestock. The direct water flows from Cereals to the Milling industry and from Olives to the Industry of oils and greases stand out as clear second and third major water flows (unless representing in the graph the water flows from Vegetables and fruits to Households and to the Rest of the World, which would be then the second and third major water flows). The chart reveals then that together with livestock consumption (with high water contents coming from feed), very high embodied water contents are found through the final demand of the goods and services provided by the Hotels and restaurants, and through exports of agrarian goods, especially of Vegetables and fruits, which were phenomena much less marked when we look at tables and water data of 2 decades before.
Also interesting insights were obtained from the study of the clustering or blockmodeling, by discovering clusters (with analogies among them given the used definitions of equivalences), which have more to do with its similarities in the ties they have with other sectors, and among them, which should lead us to re-think the traditional blocks or classifications of activities frequently taken as given.

In parallel with some expected recurrent groupings, i.e. Textiles, clothing and fur with Manufacture of leather and footwear, less known results appear such as the permanent cluster of this last sector with the account of Non-food trade (and hence with more common ties than with the first). Interestingly it occurs the same with (5) accounts of Services, Credit and insurance, Real estate, Private Education, Private healthcare and Other services for sale, and in the same fashion, it occurs within the public sector activities (only with less than 5-6 clusters the account of Domestic Service and the Commerce activities are grouped with them). Also the activities of Minerals and metals and Recovery and repair are for almost any chosen number of clusters grouped together. Furthermore, putting all together in relation with former results, we observe that the studied clusters do not tend to group sectors with the same characterization in strength of backward and forward linkages, but more on the contrary, having complementarities, or being in the sequence of the upstream and downstream chains as in the cases of the Manufacture of leather and footwear, and Non-food trade, and the nexus between the Chemical products and the Rubber, plastics and other manufactures (an exception to this is represented by the Construction and engineering and Transport and communications, often grouped together).

Together with the knowledge of the modernization processes influencing the direct consumption of water, and of the role that we play as consumers, understanding the full processes of production, i.e., the chains of the goods and services through which more embodied water consumption takes place, is crucial to make a better use of the water resources.

Acknowledgements

The author acknowledges the availability, guidance or/and help with the code of applications such as SimSIP SAM (see Parra and Wodon, 2009 [40]), Pajek (see Batagelj and Mrvar, 1998, 2003 [6] [7], and Mage for visualization), "tnet" (Opsahl (2009) [38]), runned in R, and Matlab/Octave code. The author wants to thank the financial support of the Regional Government of Aragon-CAIXA through the project GA-LC-029/2009 and the Spanish Ministry of Science and Innovation through the project ECO2010-14929 and through a FPU grant (AP2007-03816).

References

[1] Aroche-Reyes, F. (1996) Important coefficients and structural change: a multi-layer approach, **Economic Systems Research** 8, 235246. 2

[2] Augustinovics, M. (1970) Methods of international and intertemporal comparisons of structure. In Carter, A. P. and Brody, A. (Eds) Contributions to InputOutput Analysis. North-Holland, Amsterdam. 2

[3] Aujac, H. (1960) La hirarchie des industries dans un tableau des echanges interindustriels, **Revue Economique** 2, 169238. 2

[4] Barrat, A., Barthélémy, M., Pastor-Satorras, R. and Vespignani, A. (2004). The architecture of complex weighted networks". Proceedings of the National Academy of Sciences 101 (11), 37473752. 5

[5] Batagelj, V. (1997). Notes on blockmodeling. **Social Networks** 19, 143-155. 7

[6] Batagelj, V. and Mrvar, A. (1998). Pajek - Program for Large Network Analysis. **Connections** 21, pp. 47-57. 28

[7] Batagelj, V. and Mrvar, A. (2003). Pajek. Analysis and Visualization of Large Networks. En: Graph Drawing Software. (Eds.: Juenger, M., Mutzel, P.). placeStateBerlin, Springer (series Mathematics and Visualization), pp. 77-103. 28

[8] Batagelj, V., Mrvar, A., Ferligoj, A. and Doreian, P. (2004) Generalized Blockmodeling with Pajek. **Metodoloski zvezki** 1(2), 455-467. 7

[9] Borgatti, S.P., Everett, M.G. (1999) Models of core/periphery structures". **Social Networks** 21: 375395. 1

[10] Brandes, U. (2001) A faster algorithm for betweenness centrality. **Journal of Mathematical Sociology** 25, 163177. 4

[11] Cella G, (1984) The input-output measurement of interindustry linkages, **Oxford Bulletin of Economics and Statistics** 46, 73-84. 2

[12] Chenery, H. and Watanabe, T. (1958) International comparisons of the structure of production, **Econometrica** 26, 487521. 2

[13] Clements, B.J. (1990) On the decomposition and normalization of interindustry linkages", **Economic Letters** 33, 337-340. 2

[14] Csamanski, S. (1974) Study of Clustering of Industries. Institute of Public Affairs, Dalhousie University, Halifax, Canada. 2

[15] Diamond, J. (1974) The analysis of structural constraints in developing economies: a case study, **Oxford Bulletin of Economics and Statistics** 36, 95108. 2

[16] Dietzenbacher, E. (1997) In vindication of the Ghosh model: a reinterpretation as a price model, **Journal of Regional Science** 37, 629651. 2

[17] Dietzenbacher, E. and van der Linden, J.A., (1997) Sectoral and spatial linkages in the EC production structure, **Journal of Regional Science** 37, 235-257. 2

[18] Dijkstra, E.W. (1959) A note on two problems in connexion with graphs. **Numerische Mathematik** 1, 269271. 4, 5

[19] Doreian, P., Batagelj, V. and Ferligoj, A. (1994) Partitioning networks on generalized concepts of equivalence. **Journal of Mathematical Sociology**, 19, 1-27. 7

[20] Freeman, L.C. (1978) Centrality in social networks: conceptual clarification. **Social Networks** 1, 215239. 6

[21] García Muñiz, A.S., Morillas, A. and Carvajal, C.R. (2008) 'Key Sectors: A New Proposal from Network Theory', **Regional Studies** 42(7), 1013–1030. 1, 2, 11

[22] García Muñiz, A.S., Morillas, A. and Carvajal, C.R. (2010). Core periphery valued models in input-output field. A scope from network theory. **Regional Science** (forthcoming). 1, 11

[23] Hewings, G. J. D. (1974) The effect of aggregation on the empirical identification of key sectors in a regional economy: a partial evaluation of alternative techniques, **Environment and Planning A** 6, 439453. 2, 20

[24] Hewings, G. J. D., Merrifield, J. and Schneider, J. C. (1984) Regional tests of the linkage hypothesis, **Revue dEconomie Régionale et Urbaine** 2, 275289. 2

[25] Hirschman, A.O. (1958) **The Strategy of Economic Development**, Yale University Press, New Haven,CT. 2

[26] Jones, L. P. (1976) The measurement of Hirschmanian linkages, **Quarterly Journal of Economics** 90, 323333. 2

[27] Katz, L. (1953) A new status index derived from sociometric analysis, **Psychometrika** 18, 3943. 4

[28] Kilkenny, M. and Nalbarte, L. (2002) Keystone sector identification. In Hewings G. J., Sonis, M. and Boyce D. (Eds) **Trade, Networks and Hierarchies: Modeling Regional and Interregional Economies**. Springer, New York. 2

[29] Kleinberg, J. (1998) Authoritative sources in a hyperlinked environment. Proceedings of the 9th ACM-SIAM Symposium on Discrete Algorithms, edited by Howard Karloff (SIAM/ACM-SIGACT), 668–677. 7

[30] Laumas, P. S. (1975a) Key sectors in some underdeveloped countries, **Kyklos** 28, 6279. 2

[31] Lorrain, F. and White, H. C. (1971) Structural equivalence of individuals in social networks. **Journal of Mathematical Sociology** 1, 49-80. 7

[32] Luo, J. (2011) Which Industries to Bail out First in Economic Recession? Ranking Industrial Sectors by the Power-of-Pull. Working paper. 1, 2

[33] McNerney, J. (2009) Network Properties of Economic Input-Output Networks. Interim Report of the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria 1, 2

[34] Montresor, S. and Marzetti, G. V. (2009) Applying Social Network Analysis to Input-Output Based Innovation Matrices: An Illustrative Application to Six OECD Technological Systems for the Middle 1990s, **Economic Systems Research** 21 (2): 129 149. 1, 2

[35] Morillas, A. (1983) La teoría de grafos en el análisis inputoutput. La estructura productiva andaluza. Editorial Universidad de Málaga, Málaga. 2

[36] Newman, M.E.J. (2001) Scientific collaboration networks. II. Shortest paths, weighted networks, and centrality. **Physical Review E** E 64, 016132. 4

[37] Oosterhaven, J. (1988) On the plausibility of the supply-driven inputoutput model, **Journal of Regional Science** 28, 203217. 2

[38] Opsahl, T. (2009) **Structure and Evolution of Weighted Networks**. University of London, London, UK, pp. 104-122. 19, 28

[39] Opsahl, T.; Agneessens, F. and Skvoretz, J. (2010) Node centrality in weighted networks: Generalizing degree and shortest paths. **Social Networks** 32: 245. 4, 5, 6

[40] Parra, J.C. and Wodon, Q. (2009) **SimSIP SAM: A Tool for the Analysis of Input-Output Tables and Social Accounting Matrices**. The World Bank. 9, 10, 28

[41] Peay, E.R. (1980) Connectedness in a general model for valued networks. **Social Networks** 2, 385410. 4

[42] Rasmussen, P.N. (1956) **Studies in Inter-sectoral Relations**, North-Holland, Amsterdam. 2

[43] Schultz, S. (1976) Intersectoral comparisons as an approach to the identification of key sectors. In **Advances in Input-Output Analysis**, (Eds) Polenske, K.R. and Skolka, J.V., Ballinger, Cambridge, MA, 137–159. 2

[44] Strassert, G. (1968) Zur Bestimmung strategischer Sektoren mit Hilfe von InputOutput Modellen, **Jachrbucher fur Nationaloekonomie und Statistik** 182, 211215. 2

[45] Velázquez, E. (2006) An input-output model of water consumption: Analysing intersectoral water relationships in Andalusia. **Ecological Economics**, 56(2), pp. 226–240. 11

[46] Wasserman, S. and Faust, K. (1994) **Social Network Analysis**. Cambridge University Press, Cambridge, MA. 5

[47] Wilson, R. J. (1972) **Introduction to Graph Theory** (Edinburgh, Oliver and Boyd; published later by Wiley, New York. 2

[48] Yang, S. and Knoke, D. (2001) Optimal connections: strength and distance in valued graphs. **Social Networks** 23, 285295. 4

5 Appendix

FIGURE 11: Clustering ordered choosing 15 of them, for each chosen number of them (from 2 to 20), Spain, 78 nodes

Number of clusters		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Short Name of node	Node	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.
Coking, refining and nuclear fuels	13	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Prod. & distrib. of electricity & gas	14	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Water	15	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	16	6	1
Minerals & non-metallic mineral	17	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Metallurgy & manuf. of metal prod.	19	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Machinery and equipment	20	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Manuf. of machinery & equipment	21	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Paper industry	41	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	1
Trade in large surfaces	53	2	1	1	3	6	2	8	6	1	11	9	3	6	1	12	5	7	4	15
Credit and insurance	60	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	16	14	10
Real estate	61	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	15
Private Education	62	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	16	6	15
Private healthcare	63	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	16	6	15
Other services for sale	64	2	1	1	3	3	4	6	6	1	11	9	4	10	1	6	1	4	6	15
Ind. vegetables	26	2	3	3	1	5	7	5	4	6	4	1	9	2	2	5	9	3	7	11
Ind. canned fish	27	1	3	3	1	5	6	5	4	6	3	1	9	2	2	7	9	3	7	11
Ind. bread cakes and biscuits	29	1	3	3	1	5	7	5	2	8	5	4	10	11	2	8	15	3	9	7
Cocoa and confectionery ind	31	1	3	3	1	5	7	5	4	6	3	1	9	2	2	7	9	3	7	11
Ind. alcohols and liquors	34	1	3	3	1	5	7	5	4	6	3	1	9	2	2	7	9	3	2	14
Ind. wines and ciders	35	1	3	3	1	5	6	5	4	6	4	1	9	2	2	5	9	1	2	14
Ind. beer	36	1	3	3	1	5	6	5	4	6	3	1	9	2	2	7	9	3	2	14
Ind. non-alcoholic beverages	37	1	3	3	1	5	1	5	4	6	3	1	9	2	2	7	9	3	2	14
Tobacco industry	38	1	2	2	2	4	3	3	5	4	10	10	6	8	3	10	3	17	10	3
Public education	66	1	2	2	2	4	3	3	5	4	10	10	6	1	3	10	3	8	15	3
Public health	67	1	2	2	2	4	3	3	5	4	10	10	6	1	3	10	3	8	15	3
Public Services	68	1	2	2	2	4	3	3	5	4	10	10	6	1	3	10	3	8	15	3
Retail trade of fruit & vegetables	48	1	2	2	2	2	5	1	1	3	8	12	1	5	4	2	16	14	1	2
Retail meat and charcuterie	49	1	2	2	2	2	5	1	1	3	8	12	1	5	4	2	16	14	1	2
Retailing Fish	50	1	2	2	2	2	5	1	1	3	8	12	1	5	4	2	16	14	1	2
Other retail food	51	1	2	2	2	2	5	1	1	3	8	12	1	5	4	2	16	14	1	2
Retail wine & other beverages	52	1	2	2	2	2	5	1	1	3	8	12	1	5	4	2	16	14	1	2
Restaurants	55	2	1	1	3	6	2	8	3	5	2	11	13	14	5	11	12	9	19	18
Coffees, bars and similar	56	2	1	1	3	6	2	8	3	5	2	11	13	14	5	11	12	9	19	18
Hotels, pensions and similar	57	2	1	1	3	6	2	8	3	5	2	11	13	14	5	11	12	9	19	18
Other catering services	58	2	1	1	3	6	2	8	3	5	2	11	13	14	5	11	12	9	19	18

Continues on the next page...

FIGURE 12: ... continues from the previous page

Number of clusters		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Short Name of node	Node	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.	Clus.
Cereals & leguminous plants	1	1	3	3	1	1	1	2	8	7	9	3	5	13	6	1	4	2	3	13
Industrial crops	3	1	3	3	1	1	1	2	8	7	9	3	5	13	6	13	17	11	8	12
Olive tree	4	1	2	3	1	1	1	2	8	7	9	3	5	13	6	13	17	11	8	12
Grapewine	5	1	2	3	1	1	1	2	8	7	9	3	5	13	6	13	17	11	8	12
Fishing and aquaculture	11	1	3	3	1	5	7	5	2	8	5	4	10	11	7	8	15	13	9	7
Dairies	24	2	1	3	1	6	7	5	2	8	3	4	10	11	7	7	11	13	12	4
Other food industries	33	2	3	3	1	5	7	5	2	8	5	4	10	11	7	8	15	13	9	7
Vegetables and fruits	2	2	3	4	5	5	6	5	4	6	4	1	9	12	8	1	4	2	3	13
Industrial oils and greases	25	2	3	3	1	5	6	5	4	6	4	1	9	2	8	5	9	1	7	9
Ind. milling	28	2	3	3	1	5	6	5	4	6	4	1	9	2	8	5	9	1	7	9
Ind. sugar	30	2	3	3	1	5	6	5	4	6	4	1	9	2	8	5	9	1	7	9
Chemicals	18	2	1	1	3	6	2	8	3	9	1	7	3	6	9	12	5	7	4	17
Wood, cork and wood furniture	42	2	1	1	3	6	2	8	3	9	1	7	3	6	9	12	5	7	4	17
Rubber, plastics & other manuf.	43	2	1	1	3	6	2	8	3	9	1	7	3	6	9	12	5	7	4	17
Construction and engineering	44	2	1	1	3	6	2	8	3	9	1	7	3	6	9	12	5	7	4	17
Transport & communications	59	2	1	1	3	6	2	8	3	9	1	7	3	6	9	12	5	7	4	17
Domestic Service	65	1	2	2	4	2	5	7	7	10	7	6	8	9	10	3	6	5	13	20
Extraction of energy products	12	2	3	4	5	5	6	4	9	2	6	8	2	4	11	9	8	18	5	8
Transport equipment	22	2	1	4	5	6	2	4	9	2	6	8	2	4	11	16	13	18	14	10
Textiles, clothing and fur	39	2	1	4	5	6	2	8	3	2	6	7	3	6	11	12	5	7	4	17
Manuf. of leather & footwear	40	2	1	4	5	6	2	4	9	2	6	8	2	4	11	16	13	18	5	8
Wholesale of agric. raw materials	46	2	1	4	5	3	4	4	9	2	6	8	2	4	11	16	13	18	5	8
Non-food trade	54	2	1	4	5	6	2	4	9	2	6	8	2	4	11	16	13	18	5	8
Minerals and metals	16	1	3	3	1	1	1	2	8	7	9	3	12	7	12	15	10	15	16	6
Recovery and repair	45	1	3	3	1	5	1	5	8	7	9	3	12	7	12	15	10	15	16	6
Ind. feed	32	1	3	3	1	1	1	2	8	7	3	3	5	2	13	7	14	3	12	11
Bovine	6	1	3	3	1	1	1	2	8	7	9	3	5	3	14	4	7	6	18	16
Ovine and caprine	7	1	3	3	1	1	1	2	8	7	9	3	5	3	14	4	7	6	18	16
Porcine	8	1	2	3	1	1	1	2	8	7	9	3	5	3	14	4	7	6	18	16
Poultry	9	2	3	3	1	5	6	5	4	6	4	1	9	3	14	4	7	6	18	16
Other agricultural & Forest	10	2	3	4	5	5	6	4	4	2	6	5	11	12	15	14	2	10	11	19
Meat industry	23	2	1	4	5	6	2	8	3	9	1	7	7	12	15	14	11	10	14	4
Wholesale food	47	2	1	1	3	3	4	6	6	1	11	2	7	12	15	1	11	12	17	5

* The number of clusters considered are presented in the first row, while the number of the corresponding cluster to which each activity belongs to is shown by columns. Dark lines are intended to show differences of groups created with the 15 clusters blockmodeling.

Source: Own elaboration.