A network analysis of the Oil Linkages in the Mexican Economy using Input-Output Matrices from 1970, 1975, 1980, 1985, 1990, 1996 and 2000

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ABSTRACT

The oil sector has been the backbone of the Mexican economy for most of the twentieth century, albeit with different intensities and characteristics. Before 1976, oil production was mainly geared toward domestic demand; after the discovery and beginning of production from the country´s largest oil deposit –Cantarell- however, oil production continued to fulfill domestic demand while also bringing the national government with important fiscal revenues from exports. Many authors have proposed distinct impacts of these oil-related activities in the economic structure of the country, especially pertaining to the implications of an increase in the oil windfall. Some of these possible consequences of oil production can be analyzed through its linkages with other sectors. Therefore, the present article seeks to analyze, with the help of weighted graph theory, the relative importance of the oil industry to the rest of the Mexican economy for four different periods: 1970 and 1975 (before Cantarell), 1980 (during the oil boom after the discovery of Cantarell), 1985, 1990 (after the debt crisis) and 1996, 2000 (a period where Cantarell dwindles, Mexico´s main oil related activity is exports and the economy is liberalized). For each of these periods we will analyze the national matrix and the total matrix to highlight the importance of imports, as well as relate the visible linkages change to distinct oil policy configurations .

1. Introduction

The oil sector has been the backbone of the Mexican economy for most of the twentieth century, albeit with different intensities and characteristics. From the beginning of the century, oil exploration and perforation (E&P) started in Mexico in parallel (and by investments from) the rising American and British oil empires. The Mexican Revolution changed dramatically many of the country´s institutions and practices; oil policy was no exception, and from 1938 to the early 1970s, oil served the sole government mandate to serve the nation´s economic development in the way of lower oil derivative prices. This changed in 1971, however, when Mexico found itself amidst a radical transformation due to the State-led industrial development with the consequent rapidly increasing internal demand. The low rate of investment in the nationally owned oil company

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(Pemex) of the previous decades found the country importing oil, which years later became a strong vulnerability in energy security with rising international prices. Thus, oil policy began to gradually change toward rallying such oil price hike and strengthen national infrastructure speeding up E&P activities, albeit under the sole mandate of meeting domestic demand.

In the context of various discoveries of proven reserves at the highly productive fields of Samara and Reforma in the Mexican southeast, such conservative approach of oil policy radically changed under Jorge Diaz's Serrano and José Lopez Portillo´s leadership. On one hand, what began as a slow E&P effort to expand reserves that would guarantee future demand became a thorough mapping of resources to see the full oil potential of Mexico´s reserves. While investment on Pemex increased 183 percentage points from 1971 to 1976, already a huge rise, the five years between 1977 and 1982 saw an even higher 543 percentage points expansion, most of it dedicated to E&P activities[2]. On the other, with the keen potential of the marine fields off the newly discovered Campeche coast complex, the authorities saw it as not only possible, but necessary, to use the newly discovered oil abundance to promote economic growth, place Mexico in leading positions worldwide in terms, not only of reserves, but also of production and exports, and guarantee further investments and finance in Pemex, mainly through relatively unlimited access to international credit.

The debt crisis of 1982 found a highly indebted Mexico in a context of falling oil prices and a changing economic policy environment. Thus, the economy collapsed, the model of growth was sharply reformed away from State intervention and the vast oil export revenues, result from the previous administration´s ambitious oil industry investment program and vision, served mainly to steer Mexico away from further collapse by serving as countercyclical measures from the crisis and to pay the debt´s interest rate payments. From then on, oil would serve many purposes: to meet internal demand unsuccessfully (which brought back the need to import oil derivatives), to guarantee revenues from exports for internal social and economic purposes, including the source of an important part of fiscal income, and as a countercyclical measure, as in the 1994 crisis.

Public investment in Pemex, and in general, declined sharply from the crisis of 1982 on, due to the austerity programs implemented by the Mexican administrations, which included a sharp decrease in investment from the government. In 1982, gross fixed capital formation by the Mexican government reached a historic high of about ten percent of gross domestic product (GDP), while between 1983 and 2012 this indicator only reached a mean value of 5.5 percent of GDP[3]. However, the oil sector, and more specifically the E&P branch, continued to benefit from public investment, averaging over the same period close to half of all public investment.

What are the differentiated effects of these radical changes on the Mexican economy and oil policy that the country has undergone through most of the twentieth century? More specifically, what are the changes in the structure of the economy, especially as it pertains to the sectors

[2] Data from INEGI, (2009). Historical datasets.
[3] Data from World Bank (2015), World Development Indicators

related directly and indirectly to the oil branches? These questions will guide the Input-Output exercise done in the next sections.

Rasmussen (1956) and Hirschman (1958) are the forerunners in the study of the economy through the linkages between sectors. These studies have had many objectives, among which stands the identification of key sectors, the importance of a single sector as a function of how much it demands and offers other sectors, and key inter-sector relationships. Specifically, Hirschman was responsible for the idea of differentiating between backward and forward sectors. More recently, authors such as Sonis (1989; 2000) refined the previous authors´ methodologies.

More specifically for oil, various authors such as Adewuyi and Oyejide (2012), Lenzen (2003), Morrise et al. (2012), and Teka (2012) analyzed the linkages from oil in the economies of various countries. Although the work of these authors encompasses a wide range of oil related topics, the present article will complement the findings of more specific works. For example, the work of Adewuyi, on Nigeria finds that the linkages from the oil sector to other sectors in the economy are scarce, while Morris studies various countries from the Sub-Saharan African region and finds that although at first they had also scarce linkages from oil sectors to other sectors, several decades have witnessed a gradual increase in these inter-sector connections.

An explanation of such heterogeneity in the levels of linkages between the oil sector and the rest of the economy, as suggested by Morris, is the temporal dimension and its implications on distinct oil policies. Oil policy is indeed not a temporally homogeneous phenomenon for two main reasons: a) it pertains to three distinct economic activities (exploration of reserves, production and exports) that are not necessarily present simultaneously and on the same scale on any given year; and b) it is inextricably linked to a specific political economy and its national and international context, of which the international oil prices and the decisions of the main international supply actors are the two most important driving forces. Mexico is not relevant in the determination of the price of oil, and does not have excess oil production capacity to influence the production decisions of other suppliers; therefore, the country´s oil policy is explained in great part upon the determination of these factors that are beyond its control.

After these changes in oil policy throughout the country´s history, the question remains on the impacts of these changes over the structure of the economy as a whole, and with the linkages of other sectors. Thus, following is an analysis of the linkages from the oil sector to other sectors, especially in relation to the linkage structure of the economy as a whole. The next section describes the methodology of analysis.

2. - Methodology

The main way to study the linkages between sectors is the input-output matrix analysis developed by Leontief (1951). The author was a pioneer in the analysis of inter-sector linkages based on linear algebra manipulations of matrices, which are themselves constructed using technical coefficients (representing the direct linkages between sectors in the form of each of the sector´s percentage participation in each sector´s production for a given year) and coefficients obtained from the inverse of the Leontief matrix (which represent how much a sector demands from other sectors in first and higher order linkages). More recently, Miller and Blair (2009) have synthesized various decades of research of these topics.

The study of the matrices using linear algebra has recently found a booming alternative in the application of graph theory. Graph, or network, theory has been successfully applied to various social and economic problems (Wasserman, 1994; Wasserman & Galaskiewicz, 1994). Some advantages of this method over linear algebra calculations are its simpler manipulation using specialized software, the accessibility of presentation of its results, and a wider applicability to other related topics that promotes interdisciplinary cross-talk between various areas of research. However, by far the most important application of graph theory is the study of node centrality, as described by Faust (1997).

The flexibility of graph theory´s application to distinct areas of research resides in the fact that a node can represent just about any unit of research that has a link to other similar units of research. Graph study then, analyzes the way in which each node relates to all other nodes in the network, as well as different properties of their respective links. In the case of this article, each node represents a sector of the economy, as defined for the 72 sector input-output matrices gathered for Mexico by different institutions in the years of study: 1970, 1975, 1980, 1985, 1990, 1996 and 2000. Although oil policy for Mexico goes further back in time, these are the only comparable input-output matrices available for study, but do represent the moments in time of drastic changes in the nation´s oil policy. For each year, four matrices are analyzed: a) the national matrix of technical coefficients (matrix A); b) the national matrix of the coefficients obtained from the Leontief inverse matrix (matrix L); and the respective total matrices for each of these two types. Only the sectors that share between them one of these coefficients are considered in the study.

The main centrality measure calculated for each of these matrices is the degree, which is defined as the number of sectors linked to each node analyzed at a given time. A higher degree for each node implies higher connectivity of such sector with the rest of the economy. The degree is differentiated between out and in degree, which denote respectively the supply and the demand of this sector to other sectors in the economy, or the forward and backward linkages suggested by Hirschman. Since the Mexican matrices for all years are densely inter-connected, most nodes have a relatively high degree. Such homogeneity in the structure of the matrix does not allow for a rich structural analysis; therefore, a weighted degree is utilized for the analysis, which accounts not only for the number of neighboring nodes, but also for their “weights”, or the relative magnitude of the coefficient in turn. A higher weight implies higher connectivity ***and*** a higher coefficient, so that a node with a high weighted degree can have either many neighbors with small weights, few neighbors with large weights or many neighbors with large weights.

The network analysis is carried out by the specialized network software Cytoscape (Shannon et al. 2003), and the weighted degree is obtained with the Gephi (Bastian et al., 2009) software.

3. - Results

The results are presented in the three following sections: a) the first one includes the analysis of the national A and L matrices; b) the second one differentiates these last results with the analysis of the total A and L matrices; and c) the third one specifies the study for two main branches related to oil: Extraction of oil and gas and petrochemicals.

3.1 National matrices analysis

Table 3.1.1 presents the weighted degree for the national A matrix of only the most connected sectors, ordered by their 1970 value from highest to lowest. As seen in the comparison between the first row and the rest of the table, the average value of the weighted degree for all the sectors in all the years is lower than most of the values for each enlisted sector in Table 3.1.1. In fact, the weighted degree for the Construction, Iron and steel and Agriculture sectors is higher than the average value of the weighted connectivity of other sectors, at even up to two to five orders of magnitude. The oil related sectors also have higher than average connectivity for most years, except for the Oil and gas extraction sector, which has higher values only for 1975 (a weighted degree of 1.33 compared to an overall average of connectivity of 0.92) and 2000 (a weighted degree of 1.00 compared to an overall average of connectivity of 0.89), while the rest of the years witness values similar to or less than the average.

Table 3.1.1 Weighted degree for Matrix A; sectors with highest values

	1970	1975	1980	1985	1990	1996	2000
Average	0.92	0.93	0.91	0.86	0.77	0.86	0.89
Construction	4.34	4.54	5.36	4.31	3.61	3.53	4.37
Iron and Steel	2.87	2.75	2.92	2.82	2.79	2.52	2.46
Agriculture	2.05	1.87	1.82	1.97	1.77	1.66	1.65
Livestock	1.98	2.15	2.12	2.13	2.18	1.84	1.89
Oil refining	1.77	1.64	1.28	1.00	1.08	1.20	1.17
Commerce	1.63	1.56	2.36	2.43	2.11	1.51	1.57
Non metallic minerals	1.55	1.56	1.07	1.05	0.89	0.96	1.08
Other services	1.54	1.31	1.35	1.34	1.32	0.79	0.84
Paper and cardboard	1.47	1.42	1.34	1.29	1.19	1.25	1.21
Lumber mills, including triplay	1.45	1.40	1.59	1.52	1.41	1.54	1.63
Transport	1.44	1.57	1.53	1.37	1.35	1.67	1.54
Oil and gas extraction	1.33	0.93	0.77	0.83	0.71	0.72	1.00
Spinning and weaving, soft fibers	1.33	1.26	1.12	0.96	0.69	0.89	0.91
Other chemicals	1.26	1.34	1.26	1.28	1.19	0.89	0.95
Abonos y fertilizantes	1.26	1.23	1.22	1.31	1.15	1.30	1.02
Plastic resins	1.25	1.46	1.54	1.48	1.29	1.22	1.17
Food for animals	1.23	1.20	1.07	1.07	0.98	0.91	0.99
Basic petrochemicals	1.23	1.35	1.02	1.12	1.08	0.98	0.90
Automotive parts	1.23	1.21	1.21	0.77	0.69	1.68	1.76

Carbon	1.21	1.21	1.26	1.24	1.20	1.13	1.11
Non ferrous metal basic industries	1.20	1.19	1.21	1.11	0.98	1.34	1.28
Cement	1.15	1.14	1.17	1.06	1.00	1.04	1.14
Electricity	0.84	0.82	1.10	1.03	1.22	1.03	1.19

Table 3.1.2 shows the respective weighted degree values for the Matrix L. The first observation is the difference of scale between this table and table 3.1.1. Since the coefficients of the Leontief inverse account for direct and indirect influence in and from other sectors, their values are higher; hence, the weighted degree of each sector, as seen in the first row average in Table 3.1.2 is higher than that of the former table. Second, the Construction, Iron and Steel and Agriculture sectors remain those with highest degree values. The carbon sector, however, gains much more relative importance in Matrix L, as compared to its position in Matrix A. Again, most enlisted sectors have values of weighted degree above the average, but most importantly, so do the oil related sectors, for all years (as opposed to the previous table that included some exceptions to this rule).

Table 3.1.2.- Weighted degree for Matrix L; sectors with highest values

	1970	1975	1980	1985	1990	1996
Average	3.51	3.45	3.35	3.28	3.11	3.30
Construction	8.36	8.61	9.95	8.16	6.86	6.55
Iron and Steel	7.57	7.02	7.16	7.05	6.76	6.01
Agriculture	5.33	4.94	4.64	4.98	4.53	4.67
Carbon	5.07	4.97	5.23	5.02	4.74	4.35
Livestock	5.06	5.09	4.87	4.94	4.73	4.35
Oil refining	4.95	4.55	3.78	3.50	3.50	3.72
Paper and cardboard	4.87	4.69	4.25	4.14	3.92	4.15
Oil and gas extraction	4.82	4.02	3.69	3.65	3.54	3.46
Basic petrochemicals	4.73	5.20	4.12	4.29	3.98	3.89
Iron minerals	4.59	4.67	4.67	4.71	4.49	4.56
Meat and dairy products	4.56	5.06	4.47	4.69	4.33	4.15
Commerce	4.51	4.37	5.46	5.57	5.00	4.45
Transport	4.46	4.62	4.33	4.13	4.00	4.77
Other services	4.39	4.03	4.01	4.02	3.94	3.33
Non ferrous minerals	4.27	4.11	4.20	3.98	4.17	3.96
Fertilizers	4.27	4.03	3.93	4.18	3.69	4.05
Spinning and weaving, soft fibers	4.24	4.17	3.86	3.49	3.10	3.40
Non ferrous metal basic industries	4.17	4.03	3.91	3.70	3.45	4.05
Other chemical industries	4.07	4.23	4.01	4.09	3.88	3.40
Food for animals	4.06	4.15	3.87	3.94	3.67	3.68
Basic chemicals	4.03	3.93	3.77	3.86	3.62	3.56
Plastic resins	3.98	4.67	4.29	4.24	3.88	3.85
Other metallic	3.90	3.82	3.40	3.42	3.05	3.50

products							

Similar tables can be enlisted for the in and out degree. However, for the sake of brevity, Figures 3.1.3 and 3.1.4 present merely a final analysis of the histogram distribution of the in degree values, both for the Matrix A and Matrix L, respectively.

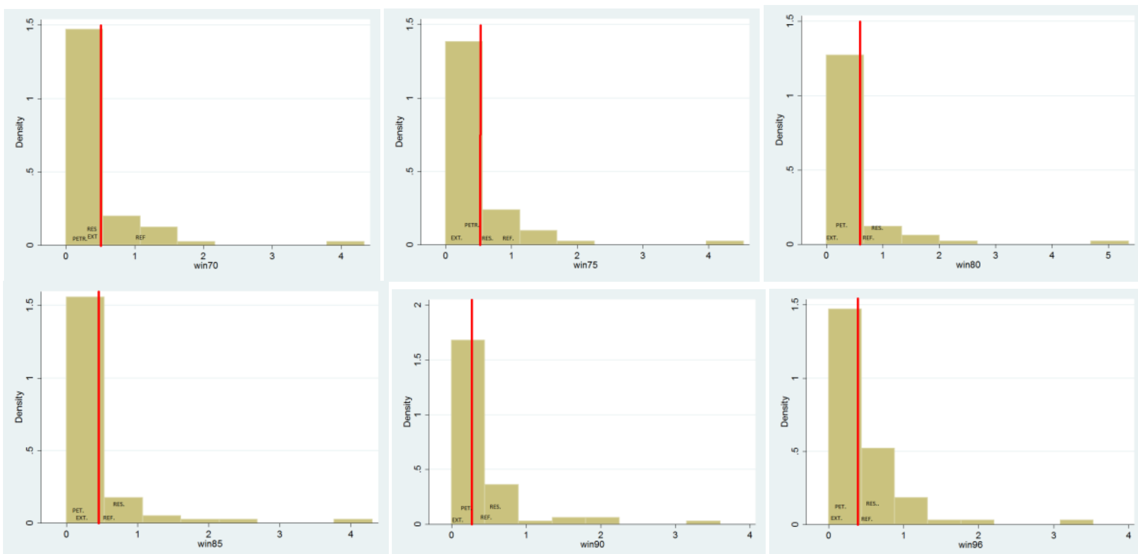

Figure 3.1.3 Histograms of weighted in-degree for each year under study (1970-1996), for Matrix A. The darker vertical line signals the average.

The histogram of the weighted in-degree of each of the A matrices shown in Figure 3.1.3 denotes little structural change of the Mexican economy, at least as far as the backward linkages of all the sectors goes. The distribution is highly skewed to the left, which implies that most sectors have very low backward linkage connectivity to other sectors (usually below 0.5). This low value is signaled by the average, which is always between 0 and 1. The oil related sectors have a weighted in-degree very close to the average for all years, even if some of the years the real value is above (and other years below) the average. This contrasts to the atypical in-degree weighted connectivity of sectors such as Construction and Iron and Steel, extreme values to the right of the distribution that are four to eight times higher than the average.

Figure 3.1.4 describes the equivalent histograms for the Matrix L. Compared to the previous figure, we can see that the distribution of weighted in-degree of the L Matrices becomes less skewed, although still far from normal. The average is higher, and gravitates around the value of 2, with a significant group of sectors having values much lower than the average, an extreme left group, especially for the L Matrix of 1980. This implies that even though the backward linkages count of most sectors is low, there is a further differentiation, as measured by the connectivity based on the Leontief inverse coefficients, in which there are sectors with extremely lower backward linkages. As previously discussed, the Construction and Iron and Steel sectors have the highest weighted in-degree, again four and eight times higher than the average. The oil related sectors continue to be very close to the average, suggesting they are as representative in terms of their backward linkages as the majority of other sectors of the Mexican economy.

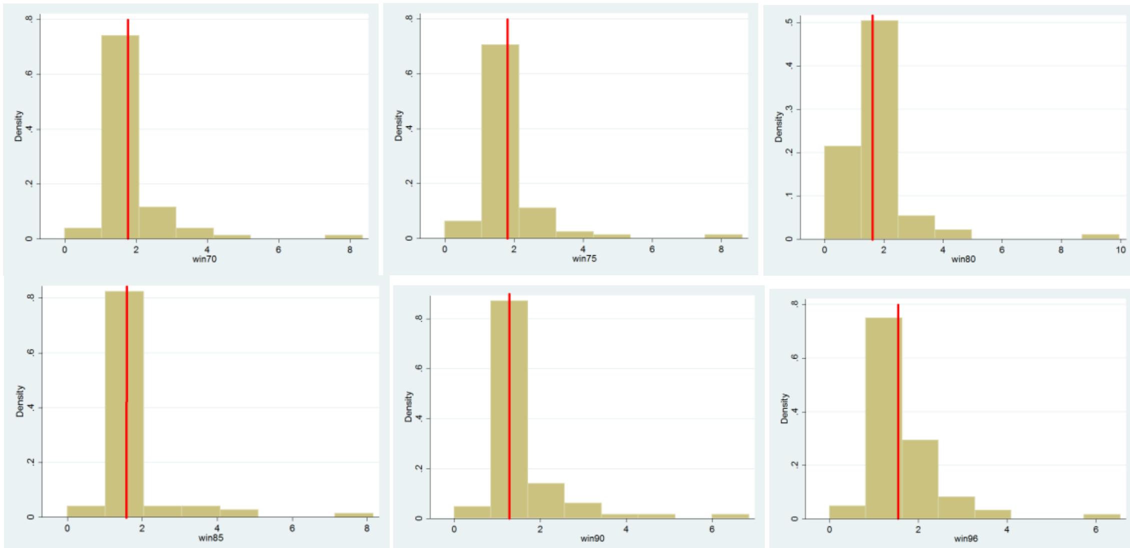

Figure 3.1.4 Histograms of weighted in-degree for each year under study (1970-1996), for Matrix L. The darker vertical line signals the average.

3.2 Total matrices analysis

The analysis of the total matrices implies the differentiation between the national A and L matrices and the respective matrices that include imports. Therefore, the difference between the total and the national matrices (as pertaining to the difference of their respective coefficients) can give an idea of the importance of imports in the production of each sector, as well as how much imports have an impact on the connectivity of each sector. We calculate such difference in each type of matrices, and then calculate the difference in connectivity of each sector. For brevity purposes, we do not present all results in this paper, but mainly highlight the most important changes.

The sectors whose connectivity changed more due to the impact of imports were different according to the year of study, although a pattern was evident: the automotive parts sector had usually the highest increase in weighted degree connectivity for most years, while the construction sector had the lowest, even negative, change. The same differences for the oil related sectors were smaller than for the automotive one, but positive for some years. Thus, imports do impact the connectivity of the oil related sectors, although in a less significant way than other sectors.

3.3 Oil related sectors analysis

The previous two sections have shown the panoramic results of a structural analysis of the entire Mexican economy in terms of each of the sectors´ weighted connectivity, in order to contextualize the following sector-specific analysis related to oil activities. There are three branches directly related to oil: “oil refineries”, “oil and gas extraction” and “basic petrochemicals”. A more thorough analysis of these three branches would require more space than this article can provide.

Therefore, the following analysis focuses mainly on the linkages of the sector that received the most public investment throughout the period of study: the “oil and gas extraction” (OGE) sector, related to the E & P activity described in the introduction to this article.

Figure 3.3.1 shows the linkages of this sector to other sectors, encoded in distinct shapes and shades according to their connectivity and permanence in time.

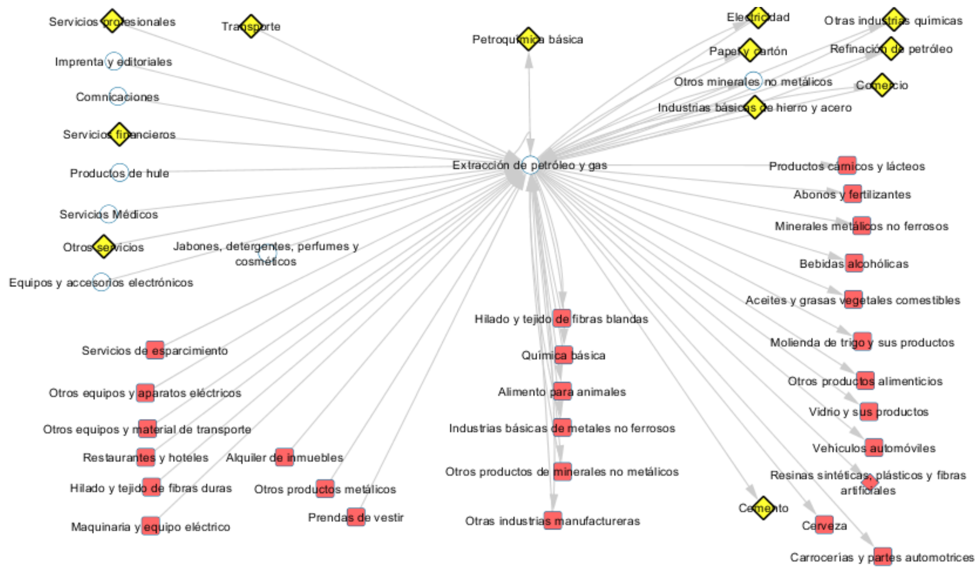

Figure 3.3.1 Linkages of the “Oil and gas extraction” sector, coded in terms of connectivity and permanence in time. See text for description.

As Figure 3.3.1 shows, the OGE sector has a total of 46 linkages to other sectors in 1970, the year in which this sector has such higher connectivity. For a better analysis, one can divide this figure in four quadrants. An imaginary diagonal axis that divides the figure in one top half and one bottom half encompasses two types of linkages: those that are permanent throughout the three decades of study (top half, or the 19 linkages with clear circles and most yellow diamonds) and those that connect intermittently with the OGE sector (bottom half, or the 27 linkages with shaded red squares). Another imaginary axis that divides the figure in left and right half describes the backward (19) and forward (13) linkages, respectively. Additional to these are linkages that go in both directions, which add up to 14.

The yellow shaded diamonds describe the sectors with high weighted connectivity that have direct linkages to the OGE sector, according to the analyses carried out in section 3.1. As is evident in the figure above, of those permanent linkages (19) that never lose their connectivity with the OGE sector, the majority (11) of these are sectors with high weighted degree, including the highest sector of Tables 3.1.1 and 3.1.2, the Iron and Steel industry. On the contrary, none of the sectors in red squares that loose the connectivity with the OGE sector are included in these two tables, which suggests that, even though the OGE sector looses much of its linkages, especially after 1980, most of these are minor sectors as measured by their weighted connectivity. The important exception is the sector of “cement”, which as we showed in these two tables, has a large weighted degree measure, but loses its connection to the OGE sector for some years.

4. - Discussion and conclusions

The previous analysis shows a Mexican economy with two clearly dominant sectors, or network hubs, in terms of their connectivity, or weighted degree, with other sectors: “Construction” and “Iron and Steel” (followed by two minor hubs: Agriculture and Livestock). The close relationship between these and the oil related sectors, especially through the permanent linkage between the Iron and Steel and the highly preferred in terms of investment, the Oil and Gas Exploration sector, suggest a central dynamic of the country´s economy that deserves further analysis. A second linkage between this latter sector and the Cement sector for most of the years of study also point to another central connection that may encompass a representative part of the Mexican economy, as the Cement sector is the foremost input of the Construction industry.

Aside from these hubs, the previous sections showed that the importance of oil in the national economy, at least in terms of the linkages of the three oil related sectors when compared to those of the rest of the economy, is indeed not as high as the aforementioned two sectors, but definitely not as low as the term “oil enclave” suggests. Throughout the three decades of study, the oil sectors remain very close to the average connectivity of the rest of the sectors, even when they lose an important part of their linkages, as seen in section 3.3.

Most importantly to the objective of the study, the privileged position of the Oil and Gas Exploration sector in terms of public investment discussed in the introduction section does not follow the changes in its linkages. When public investment in the seventies rose exponentially, mostly favoring this oil related sector, the overall connectivity of this sector decreases, from a value of 1.33 in 1970 to 0.77 in 1980, calculated based on its L matrix coefficient. During the eighties and nineties, even when public investment diminishes, the OGE sector receives still more than half of this total, accounting to nearly 2% of GDP. Even then, the connectivity of this sector, according to its L Matrix diminishes from its value of 0.82 in 1985 to a lower 0.71 in 1996. The exception is the highest value of the entire three decades, the 1.00 weighted connectivity resulted in 2000.

Thus, the implications of this article are threefold. First, the oil sector does not behave as an enclave in the Mexican economy, at least as far as the average backward linkages its three branches have throughout the four decades. Second, as central as the oil sector has been in the Mexican economy, as outlined in the introduction of this article, its main importance in terms of linkages is the relatively permanent connectivity of the three branches to the two hubs of the economic network: Iron and Steel and Construction. The three oil related branches studied do not attain levels of connectivity as these two hubs, and thus, cannot be entitled as “central”, at least as far as their connectivity is concerned. Lastly, the investment made by the Mexican government in one of these sectors has not translated into a higher connectivity, or a bigger impact of this sector to the production of other sectors. Further analysis in these three lines of research would enlighten more as to how much and in what manner oil has been central to the economy of

Mexico, and what have been the impacts to this centrality to the structure of the economy as a whole.

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