Alatriste-Contreras and Lugo
Journal of Economic Structures (2022) 11:23
https://doi.org/10.1186/s40008-022-00283-7

Journal of Economic Structures

RESEARCH

Open Access

Strategic sectors and the diffusion of the effect of a shock in Mexico for 2008 and 2012

Martha G. Alatriste-Contreras[1*] and Igor Lugo[2]

*Correspondence: marthaalatriste@gmail.com

[1] Facultad de Economía, Universidad Nacional Autónoma de México, Mexico City, México
[2] Centro Regional de Investigaciones Multidisciplinarias, Universidad Nacional Autónoma de México, Cuernavaca, Morelos, México

Abstract

We combine input–output analysis with a diffusion measure and complex network measures of centrality to propose a method to identify strategic or key sectors in an economy. We then apply our method to the case of Mexico for the years 2008 and 2012. Results for Mexico show that the ranking sectors according to the diffusion measure allows identifying strategic sectors with desirable properties such as high centrality and a high correlation to the aggregate effect of a shock. Furthermore, these sectors also have a good performance according to macroeconomic variables, such as exports and value-added. The disaggregation of the aggregate effect of a shock, together with our results on diffusion, suggests that one should focus on sectors with good diffusion to design policy recommendations.

Keywords: Diffusion through intersectoral linkages, Strategic sectors in the economy, Intersectoral linkages, Authority and hub scores, Ranking of sectors

1 Introduction

One of the most important issues to understand in economics is the relation between the macro economy and the structural properties of the economic system. Based on this understanding an economic growth policy may be successful or not. A key aspect of a successful policy intervention is the identification of strategic sectors that ought to be targeted. To be able to identify these strategic sectors we propose a method based on how the effect of a sectoral shock is diffused across the economy and the particular disaggregation of the effect of the shock. This method is based on a diffusion measure that complements centrality scores of sectors in the intersectoral input–output network.

Policy successfulness has many dimensions. Some of them can be measured through the performance of macroeconomic variables, such as exports, production, and value-added. Therefore, our method to identify strategic sectors considers the performances of these variables together with a good diffusion property.

The objective of the research is to propose a method to identify strategic sectors based on the diffusion and the disaggregation of the effect of a sectoral shock. For that purpose we complement impact analysis in the input–output literature with centrality measures of complex network analysis and a diffusion measure. The diffusion measure is based on the idea that the effect of a shock may be widely diffused to other sectors in the economy or may be concentrated on a few. Which one is more desirable depends on the objective of the policy to be implemented. However, we consider that identifying those sectors with the best diffusion properties will be more advantageous for a policy implementation.

Previous studies related to our investigation have applied impact analysis within input–output analysis to identify key sectors for a development strategy based on backward and forward linkages (Rasmussen 1956; Hirschman 1958; McGilvray and Leontief 1977; Dietzenbacher 1992; Humavindu and Stage 2013; Marconi et al. 2016). Other type of studies in the input–output literature have focused on the average propagation length as the average number of steps it takes for a shock in final demand of sector i to reach sector j and show that the average distance between these two sectors does not depend on whether the backward of forward perspective is adopted. Related to this literature, we find other studies that have addressed the identification of important sectors from the complex network perspective computing different centralities for input–output networks using different data bases, such as for OECD countries or European countries (Bl¨ochl et al.. 2011; McNerney et al. 2012; Alatriste-Contreras and Fagiolo 2014; Alatriste-Contreras 2015; Soyyigˇ, S., C¸irpici 2017; Tsekeris 2015). Finally, the diffusion index for the input–output network was first proposed in Alatriste-Contreras (2014), where it was applied to French data, and first applied to Mexican data in Alatriste-Contreras (2020). In this last study, the article limits to rank sectors according to the index. In a complementary fashion, our study goes beyond in two aspects. On one hand, we disaggregate the effect of a sectoral shock on final demand to observe how the effect distributes unevenly across the economy; we observe different patterns according to the sector that originally received the shock. On the other hand, we relate the ranking of sectors according to the diffusion measure to other variables, such as exports, valued added, and production. We present interesting scatterplots that show this relations and the specific non-linear relation between diffusion and aggregate effect of a shock. To our knowledge, the diffusion measure has not been applied to another study beyond the ones mentioned before.

Our results for the application to the Mexican economy show that the sectors that export the most do not necessarily generate high effects on production or value-added. Nevertheless, there are some sectors, which have a good performance on macroeconomic variables and a good diffusion of the effects of shocks. Therefore, results on the relation between diffusion, aggregate effect, centrality measures and macroeconomic variables, give insights on the role of strategic sectors with good diffusion in a successful performance of a country. By considering the different patterns in which the effects distribute across the network, our method to identify a strategic sector is capturing strategic interactions between sectors that form production chains (processes). Thus, we present a method that does not only focus on the macroeconomic variables or standard aggregate effect, but it focuses on the diffusion properties of the sectors in the input–output network.

Therefore, our contribution is to complement the identification of the most important sectors in the economy with the diffusion measure. This diffusion measure we compute builds a bridge between input–output analysis and complex network analysis to identify most strategic sectors in the intersectoral input–output network. Our findings have policy implications, since they suggest that our method to identify strategic sectors provides useful information to design the most effective industrial policy, because it will have the widest effect across the economy.

The paper is organized as follows. In Sect. 2, we present a more detail literature review of related studies. In Sect. 3, we present the materials and methods that includes the data we used. In Sect. 4, we report results for the application of our method to the Mexican economy for the years 2008 and 2012. Finally, in Sect. 4, we make a discussion about our main results and conclude providing some policy recommendations.

2 Review of related studies

Our analysis complements the impact analysis in the Input–output literature that identifies key sectors in a development strategy and the literature on the complex network analysis applied to economic systems to find the most central sectors in the input–output network according to different measures. Our work build a bridge between the two using a diffusion measure related to both aggregate effect (output multiplier) and hub score of sectors. We then apply our method to the case of Mexico to investigate about the poor performance of the export-driven model.

In particular the key sector identification and the impact analysis use as tools backward linkages, forward linkages and multipliers (Miller and Blair 2009). These tools identify key sectors as those with above average linkages (Rasmussen 1956; Hirschman 1958). These sectors should be targeted for selective promotion in a development strategy, because they will generate higher effects on economic growth (McGilvray and Leontief 1977). Backward and forward linkages can be computed using different methods including direct linkages, total linkages and forward linkages using the output matrix instead of the inputs matrix (Jones 1976), the eigenvector method (Dietzenbacher 1992) and the hypothetical extraction method (Dietzenbacher and Linden 1997). In Marconi et al. (2016) authors compute output multipliers, Hirschman–Rasmussen indices, pure backward linkages normalized (PBLN) indices, and pure forward linkages normalized (PFLN) indices to assess the performance of sectors in the Brazilian economy. The propagation of socks includes (Dietzenbacher and Romero 2007) that study average propagation length as the average number of steps it takes for a shock in final demand of sector i to reach sector j and show that the average distance between these two sectors does not depend on whether the backward of forward perspective is adopted. Nevertheless, the number of steps between a sector and another is different according to the wide set of alternatives there are following different production chains. They apply their analysis to the 1985 input–output table for six European countries. Finally, Temurshoev and Oosterhaven (2010) introduces environmental and resource factors to complement the computation of the linkages.

In the complex network analysis we find different measures of centrality that include degree centrality, weighted degree, closeness centrality, betweenness centrality, eigenvector centrality, and authority and hub scores (Newman 2010). Studies in the branch of literature that studies the properties of the input–output networks include (Bl¨ochl et al.. 2011; McNerney et al. 2012; Soyyigˇ, S., C¸irpici 2017; Slater 1978; Amaral et al. 2007).

In particular, (Soyyigˇ, S., C¸irpici 2017) studies the network structure of nine countries including Mexico using input–output data from the World Input–output database (WIOD). Authors calculate authority and hub scores and find that sectors are organize in core-periphery. Tsekeris (2015) identifies key sectors in the Greek economy based on measures of centrality and performs a cluster analysis. Finally, in Alatriste-Contreras (2020) author computes a diffusion measure based on the Leontief matrix and ranks sectors of the Mexican economy for the year 2012; however, this study does not link this ranking to other variables or compares findings to a previous year when the structure of the economy was different (before effects of the 2008 crisis). Comparably, in our study we complement the analysis and build a bride from input–output to complex network analysis and show interesting associations between variables that allow identifying the strategic sectors that could be targeted in the implementation of an industrial policy.

Another strand of literature related to our approach associates export performance with the capacity of a country to diversify their production and stimulate growth. Hausmann and Hidalgo (Hausmann and Hidalgo 2009) argue that the export specialization of countries relies on the capabilities they have to produce their products. Years later Hausmann and Hidalgo (Hausmann and Hidalgo 2011) argued that economic growth goes with a higher diversification of products that a country produces. To show this, they characterize the network connecting countries to the products they produce and export with a reveal comparative advantage, and fit the data to a model of the structure of the international trade network. To study the productive structure of countries they create a measure that, according to authors, infers the similarity between the capabilities required by a pair of goods. To do this, they look at the probability that two goods are co-exported. The measure is based on the conditional probability that a country that exports product p will also export product p^0. However, this literature has not analyzed the productive structure of an economy using detailed input–output data and the relation between sectors that are exporters, that generate value-added, and have high effects on production, thus on growth.

Regarding the application to the Mexican economy; it is interesting how our method shed lights on the limits of the export-driven model. The past performance of Mexico in terms of economic growth driven by exports has not been the desired one. Exports have been growing but the economy's GDP has not. Moreover, the country's past experiences have shown that exports do not necessarily have a great impact on value-added or qualified employment. The manufacturing sector in Mexico, and in particular products manufactured for exports, have not been playing a key role in promoting economic growth. This is because the maquiladora industry incorporates imported parts and components into final goods that are exported, and thus, backward and forward linkages of export products are weak in the Mexican economy. If we compare Mexico's, and Latin America's, experience with other countries, mostly in Asia, we may learn important lessons. In South Korea and Taiwan export orientation on its own did not account for the growth experienced and did not have a significant effect on aggregate performance. Instead," subsidizing and coordinating investment decisions" rendered government interventions effective (Rodrik 1995). The performance of some East Asian economies reinforces the idea that the way" countries achieve and sustain high rate of savings and investment" is what accounts for the success of these countries (Collins et al. 1996)[1]. In addition, evidence from three non-Asian countries shows the implementation of industrial policy in the specific circumstances of each country. El Salvador has implemented in recent years a special tax regime and trade preferences granted by the United States to the maquila sector; nevertheless" this has been insufficient to make up for the loss in traditional exports." Uruguay provides publicly key inputs to certain industries and tax incentives; moreover, the private sector is interested in investment opportunities in sectors, such as meat, rice, soy beans, forestry, pulp and paper, ports, tourism, software, and business services. Finally, South Africa" recently embarked on a new growth strategy" which places industrial policy at the center; this formulates policy initiatives for individual sectors, such as the auto industry (Rodrik 2008). As we may learn from these cases, we should recognize that each country deserves a policy design on its own. For Mexico, we propose that a successful industrial policy is about stimulating strategic sectors with both public and private funds. These strategic sectors should be targeted not only because they yield high aggregate effects but also because they interact with other strategic sectors, thus enhancing the effects of the policy in economic activity and diffusing the industrial policy objectives.

Different approaches have studied the successfulness of policies in Mexico in terms of economic growth. Fujii et al. (2005) mentions that Mexico and Central America have experienced a push for exports, but have also modified the pattern of exports in favor of industrial products intensive in low-qualified employment under the schema of international shared production. The objective of pushing forward exports was to energize economic growth. Nevertheless, in general, the economies' experience in terms of growth driven by exports has not been the desired one. In Mexico in particular, the determinants of the limited effects of the exports' expansion on growth are a maquila sector weakly linked with the rest of the economic system in terms of input supply, which instead are imported, because the export activities generate low value-added. Fujii and Cervantes-Martinez (2013) highlight the gap between the dynamism that have had the exports sectors and the economic growth. The growth of exports has stimulated the import of inputs, which has generated, in consequence, a low export multiplier effect. Fujii and Cervantes-Martinez (2017) show that the internal backward linkages of exports in the Mexican economy are weak. Authors also show that only a few sectors' products are used as inputs for exports, and that the forward linkages are weak as well, because the Mexican maquiladora industry incorporates imports parts and components into the final goods that are exported. Therefore, they show that the manufacturing sector does not play a key role in promoting economic growth. In (Ascárraga-Sejas 2012) the author applies vertical specialization and average propagation lengths. He finds that Mexico has weak linkages between the export sectors and the rest of the economy due to high import content. Author points out, in line with previous publications, that medium and high technology products' exports have weakly driven Mexico's economic growth, because they do not fulfill a productive integration or articulation between the export sectors and the rest of the economy, and that they add low domestic value-added.

[1] East Asian economies in the paper considers: Indonesia, Korea, Malaysia, Philippines, Singapore, Taiwan, and Thailand.

Consequently, there is a low productive integration between export sectors and the rest of the economy (Ascárraga-Sejas 2012). This is one of the reasons why productive linkages should be strengthen and increased to energize the Mexican internal market (Fujii and Gaona 2004). According to authors, the performance of the export maquila is one of the obstacles to overcome to increment employment and wages. This literature highlights the importance of productive linkages among sectors and the role that the exports have had in the growth performance of Mexico. Nevertheless, it has not shown what is behind this poor performance; why productive linkages, even though they are important, have not been playing the key role in the generation of growth and value-added?

Therefore, we apply our method for identifying strategic sectors to the case of Mexico using input–output data from the INEGI. We focus on the effects of a sectoral shock on final demand, and therefore, prices will remain unchanged. Our analysis will fill the gap by studying the detailed chain of effects triggered after a sector experiences a shock. These chains of effects will diffuse throughout the input–output network.

3 Data and methods

3.1 Data

Input–output tables are a natural source of information about the structure of interactions between the sectors in the economy. These tables also provide information to represent the economic system as a network and study its properties.

We use input-output tables for Mexico for the years 2008 and 2012 published by the Instituto Nacional de Estadística y Geografía (INEGI) in 2009 and 2013, respectively.[2] We use the domestic symmetric tables that classify the economy into 262 and 259 branches. This classification has a correspondence to the four-digit SCIAN classification. The three sectors that do not appeared at 2013 are: (1) foundations, prefabricated structure mounting and exterior work; (2) Installation and construction equipment; and (3) Finishing works on buildings. These branches are aggregated into Specialized works for construction in 2012 (de Estadística y Geografía (INEGI), I.N. 2013). These tables provide the information to compute the direct coefficients matrix, the Leontief inverse, and to represent the economy as a weighted directed network.

At the moment the research was conducted these two tables were the latest two periods available for the classification. These 2 years allowed us to study the Mexican economy the year the 2008 crisis triggered and 4 years later. This gave us the opportunity to observe if some of our main findings could give some insights into how the properties of the input–output network facilitated or enabled the diffusion of the effects of the crisis experienced by countries, in particular by Mexico.

For the statistical analysis we used the numpy, scipy, networkx and matplotlib libraries of Python 2.7. In specific, we used the numpy polyfit method and the stats methods of scipy for the calculation of the Spearman correlation coefficients (for details, see the methods section). We used the network library for the computation of centrality measures, in particular the authority and hub scores, and for the visualization of networks. Finally, we used the matplotlib library for the scatterplots.

[2] https://www.inegi.org.mx/temas/mip/.

4 Methods

Following the input–output model (Leontief 1936), production is computed as

$$x = (I - A)^{-1} f = Lf \tag{1}$$

where x is the $n \times 1$ column vector of output, $A = [a_{ij}]$ is the nxn matrix of direct input coefficients, f is the $nx1$ column vector of final demand, and $L = (I - A)^{-1}$ is an $n \times n$ matrix known as the Leontief inverse or the total requirements matrix.

We compute aggregate effect as in the impact analysis in the input–output literature. Aggregate effect is how much production is needed to compensate a change in final demand of sector i. This is also known as the output multiplier, which is computed as the ith column sum of the L matrix, and represent a sector-to-economy multiplier that relates final demand in sector i to economy-wide output (Miller and Blair 2009). To compute aggregate effect we calculate production before and after the shock. The effect of a shock is defined as the change in output that was needed to compensate the shock, this is production after the shock minus production before the shock:

$$\Delta x = L \Delta f \tag{2}$$

We clarify that this is not a calculation of a difference between 2012 and 2008. However, it is a calculation for each year; that is how much production is needed to compensate a change in final demand in 2008 for each sector and similarly, how much production is needed to compensate a change in final demand in 2012 for each sector.

How many other sectors, and by how much, will be affected? If only one or a few sectors are affected, then the effect is concentrated. However, on the contrary, if the effect is spread among several sectors with a skewed distribution of the magnitudes of the effects, then the effect is heterogeneously diffused. We focus on the individual effects in each case: supposed sector i experienced a shock on final demand, this will have an effect on production on the other sectors connected directly or indirectly to i: $j = 1,2,\ldots,n$. The aggregate effect is the output multiplier and is computed as the sum of the Δx_j. This aggregate effect can be disaggregated to observe the chain of effects that took place; for that we disaggregate $\Delta x_j = L \Delta f$ as

$$\Delta x_j = x_j^1 - x_j^0 = \sum_{k=1}^{n} l_{jk} f_k^0 \tag{3}$$

$$\Delta x_j = (l_{j\,1} f_1^1 + l_{j\,2} f_2^1 + \ldots + l_{j\,n} f_n^1) - (l_{j\,1} f_1^0 + l_{j\,2} f_2^0 + \ldots + l_{j\,n} f_n^0) \tag{4}$$

$$\Delta x_j = l_{j1} \Delta f_1 + l_{j2} \Delta f_2 + \ldots + l_{jn} \Delta f_n \tag{5}$$

We take each Δx_j and see its distribution. This gives the disaggregation of the effect on sector j's production when sector i received a shock. According to j, the distribution will be different. We perform this analysis for all sectors in the economy. This will give information on how the effect of a shock is distributed along the production process the shocked sector is embedded in.

To compute a measure of the diffusion of the effect of a shock we use the Leontief inverse. The diffusion measure is based on the Herfindahl concentration index (Herfindahl 1950).

It is defined as follows (Alatriste-Contreras 2014):

$$h_i = \sum_{i=1}^{n} s_i^2 = \sum_{j=1}^{n} \left(\frac{l_{ji}}{\sum_{j=1}^{n} l_{ji}}\right)^2 \tag{6}$$

where s_{i} is the fraction of the effect of the shock absorbed by sector j in each scenario (one for each sector in the input–output network), l_{ik} is the $jk-th$ element of the Leontief inverse, and n is the number of sectors in the economy.

To capture the diffusion properties of sectors, we compute the following

$$D_i = 1 - h_i \tag{7}$$

for each sector i, where a high $(1-h_i)$ means good diffusion properties or low concentration of the effect.

In contrast to the aggregate effect and the backward and forward linkages found in the input–output literature, the diffusion measure we propose disaggregates the effect and provides the different distributions of the effect of the shock according to the sector that was originally shocked.

A shock that experiences a final demand shock may diffuse widely or narrowly the effects of this shock. A wider diffusion means that the shock had effects on many sectors, even if these effects are small. On the other hand, a narrow diffusion means that the effects of the shock only reached one or a few sectors, even if these effects are big (the effects are concentrated). The diffusion of the effects is conducted through direct and indirect connections and these connections are weighted; therefore, the strength of the connection between sectors is considered.

The disaggregation of the aggregate effect complements this diffusion measure and provides information on the magnitude of the effects experienced by each of the sectors in the chain of effects triggered.

We then rank the sectors according to production, exports, value-added, aggregate effect and diffusion. We identify not only which sectors generated the highest aggregate effect and widest diffusion, but we study the chain of effects and the different sectors that were affected in each case.

To associate the strategic sectors according to the macroeconomic variables and the diffusion to the structural properties of the economic system, we represent the economy as a network and compute global centralities. A network is a graph $G\ (V,E)$, composed of a set nodes or vertices $v_{\mathrm{i}} \in V$ connected by a set of edges or links $e_{ij} \in E$. The direct input coefficients matrix, A, gives rise to a weighted directed graph with self-loops. The A matrix is the weighted adjacency matrix of the network. Every row of the input–output table is a node in the network and every cell represents a weighted link between nodes. Values on the diagonal of the A matrix represent self-loops and capture a sector using its own output as input.

We compute global centralities that rank the sectors considering the different direct and indirect linkages appropriately weighted according to their importance. The centrality measure we use generates an authority and a hub score for each sector corresponding to the directionality of the link. These scores are a generalization of the eigenvector centrality for directed networks.[3] The eigenvector centrality gives each node a centrality that depends both on the number and the quality of its connections, where a node with a smaller number of high-quality links may outrank one with a larger number of mediocre links (Newman 2010). Authority and hub scores were originally applied to study the link structure of web pages.[4] This algorithm assigns a hub score h_{i} and an authority score a_{i} to each node or web page. We thus have a circular definition of hubs and authorities which turns into a mutually reinforcing relation: good hubs point to good authorities and good authorities point to good hubs.[5] This is turned into an iterative computation, where initially $h(v) = a(v) = 1$. The core of the process is a pair of updates to the hub and authority scores of all nodes (Kleinberg 1999): $\tilde{\mathrm{h}} \leftarrow \mathrm{A}\tilde{\mathrm{a}}$ and $\tilde{\mathrm{a}} \leftarrow \mathrm{A}^{\mathrm{T}}\tilde{\mathrm{h}}$. Substituting we obtain: $\tilde{\mathrm{h}} \leftarrow \mathrm{AA}^{\mathrm{T}}\tilde{\mathrm{a}}$ and $\tilde{\mathrm{a}} \leftarrow \mathrm{A}^{\mathrm{T}}\mathrm{A}\tilde{\mathrm{h}}$. Iterating the process, the sequence of vectors converges to a limit or fixed point were a^* is the principal eigenvector of $\mathrm{A}^{\mathrm{T}}\mathrm{A}$, and h^* is the principal eigenvector of AA^{T}. The scores are given by the following equations:

$$\mathrm{a} = \left(\mathrm{I} - \lambda \mathrm{A}^{\mathrm{T}}\mathrm{A}\right)^{-1} 1 \tag{8}$$

$$\mathrm{h} = \left(\mathrm{I} - \lambda \mathrm{AA}^{\mathrm{T}}\right)^{-1} 1 \tag{9}$$

where 1 is a vector of ones.

A sector with a high hub score can be interpreted as a sector that is a good supplier of intermediate goods (outward connections), therefore, has connections to a wider range of buyers, and a high authority score as a sector that has connections to a wider range of suppliers, thus is a good buyer of intermediate goods (inward connections). Consequently, hub scores are related to diffusion properties of sectors, how a sector diffuses or distributes the effects of shocks in the network. The scores we obtain are used to rank the sectors, where the highest rank is for the most central sector.

To investigate the association between variables we calculated the Spearman correlation coefficient between pair of variables. This, together with scatterplots, help elucidating the relations between macroeconomic variables and properties of sectors. For certain relations, we also fitted the data to a polynomial to better understand the relation. For the fitting process we used the polyfit function of numpy (Python) which uses a polynomial to approximate the curve: $p(x_j) = y_j$, where $p(x_j)$ is the polynomial and y_j is the data. The function minimizes the squared error.

[3] Eigenvector centrality was first proposed in (Bonacich 1987) as a power measure in social networks.

[4] In this context, a good hub is a page that redirects to pages that are the most prominent sources of primary information (good authorities) and hubs assemble high-quality guides and resource lists directing the users of web pages to recommended authorities (Kleinberg 1999).

[5] A good hub is a sector with a high hub score and a good authority is a sector with a high authority score.

Table 1 Strongest connections in 2008 and 2012. Source: Results from authors calculations

Rank	2008	2012
1	Oil and gas extraction; oil and coal derivatives	Metallic minerals extraction; industries of nonferrous metals except aluminum
2	Oil and coal derivatives; other land passenger transport	Oil and gas extraction; oil and coal derivatives
3	Oil and coal derivatives; regular air transport	Oil and coal derivatives; other land passenger transport
4	Oil seeds, legumes, cereals, grinding grains seeds; oil and grease obtaining	Oil and gas extraction; regular air transport
5	Felling of trees, lumber; conservation of wood	Oils and gas extraction; school and staff transport

Table 2 Top ranked sectors according to macroeconomic variables (2008). Source: Results from authors calculations

Rank	Production	(Unit: million Mexican peso)	
		Exports	Value-added
1	Wholesale trade of food and groceries (2,332,613)	Oil and gas extraction (444,504)	Wholesale trade of food and groceries (1,785,940)
2	Renting without real-state intermediation (1,473,780)	Oil and coal derivatives products elaboration (63,468)	Renting without intermediation (1,367,962)
3	Oil and gas extraction (964,196)	Industry of non-ferrous metals except aluminum (64,270)	Oil and gas extraction (892,297)
4	Residential construction (868,961)	Computers and peripheral equipment (151,248)	Residential construction (530,861)
5	Oil and coal derivatives products elaboration (772,412)	Communication equipment (139,569)	Electric energy (216,101)

Parenthesis are the value of production, export and value-added, respectively

5 Results

In 2008, the Mexican economy was classified into 262 sectors. Among these sectors there were 19,800 input connections. These connections represented the 28.9 per cent of the potential connections that there would be if all sectors were connected to each other. Comparably, in 2012, the Mexican economy was classified into 259 sectors. There were 16,778 connections between these sectors, which represented 25.1 per cent. The decrease in the number of interactions between sectors is not entirely explained by the difference in the number of sectors from 1 year to another; this difference explains only 786 connections, but not the 3,022 missing connections we observe. These are a result of the changes in the structure of the production system.

We show the strongest connections between pair of sectors in Table 1. We highlight some similarities or changes from one period to another. The branch Oil and gas extraction gain strength and appeared in more of the strongest connections in 2012. In particular, in 2012 the branch Metallic minerals extraction; industries of non-ferrous metals except aluminum appears as the strongest connection but it did not appear in 2008. Oil and gas extraction; oil and coal derivatives and Oil and coal derivatives; regular air transport, appeared in both years, but one rank below in 2012. Oil seeds, legumes, cereals, grinding grains seeds; oil and grease obtaining and Felling of trees, lumber; conservation of wood, did not appear in 2012.

Table 3 Top ranked sectors according to macroeconomic variables (2012). Source: Results from authors calculations

Rank	Production	(Unit: million Mexican peso)	
		Exports	**Value-added**
1	Wholesale trade of food and groceries (3,103,125)	Oil and gas extraction (584,246.0)	Wholesale trade of food and groceries (2,410,203)
2	Renting without real-state intermediation (1,780,968)	Industry of non-ferrous metals industries except aluminum (135,552.0)	Renting without intermediation (1,667,123)
3	Oil and gas extraction (1,099,119)	Cars and trucksfabrication (511,357.0)	Oil and gas extraction (999,693)
4	Oil and coal derivatives products elaboration (1,052,998)	Wholesale trade of food and groceries (422,858.0)	Residential construction (576,999)
5	Residential construction (946,013)	Motor vehicles parts fabrication (400,254.0)	Electric energy (454,666)

Parenthesis are the value of production, export and value-added, respectively

The top ranked sectors according to production,[6] exports, and value-added generation for 2008 and 2012 are presented in Tables 2 and 3, respectively, where the first column is the rank of the sectors, the second column is production, the third exports, and the fourth value-added. In terms of production, the sector wholesale trade of food and groceries was the biggest one in both 2008 and 2012. Following, renting without real-state intermediation was the second, and then we find oil and gas extraction in third place. The remaining ranks differ from one period to another. In 2012, cars and truck fabrication went up four places one period to the other. On the other hand, oil and gas extraction appears in the first position in both years of analysis and oil and coal derivatives products elaborations went down the ranking and no longer appears as a top exporter in 2012. The rest of the sectors appear in 2012 on a different ranking as in 2008. Notably, in 2012 the sector wholesale trade of food and groceries climbed up the ranking from the 13th position to the fourth. In contrast, the sectors that showed the lowest exports were: poultry (13), bovines and goats (3), three fell (27), interior waters transport (1), collective foreign passenger transport of fixed route (3), bus rentals with a driver (1), other land passenger transport (1), touristic land transport (2), services related to highway transport (10), home and personal articles rental (4).

In 2008, most of sectors generated very low value-added. In contrast, only five sectors generate above 250 million pesos in value-added: wholesale trade of food and groceries, renting without intermediation, oil and gas extraction, residential construction, and electric energy (see Table 2). In 2012, the top four ranks were the same as in 2008. Nevertheless, we observe some differences in the following rankings.

If we compare 1 year to another, we observe that from the top exporters in 2008, only oil and gas extraction and oil and carbon derivatives products elaboration appear as sectors that generate high value-added.

From the sectors that generate high value-added, only the following are among the top according to production: food and groceries wholesale, renting without

[6] Production as in the Input–output Model, which is intermediate demands plus final demand: $X = Z1 + FD$.

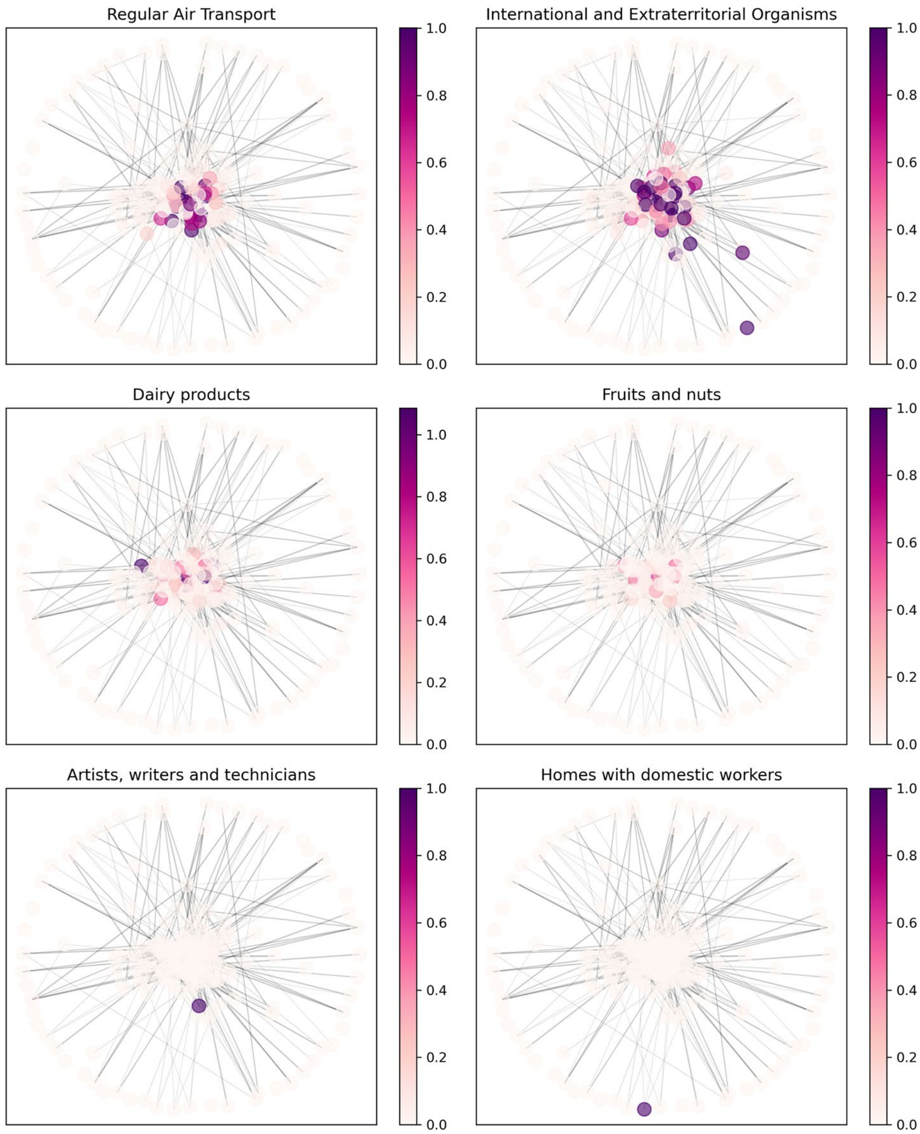

Fig. 1 Example of the diffusion of the effect of a shock in the Mexican economy. Color bar corresponds to magnitude of effect. Colors are normalized in each case to the maximum of the effect. The darkest color corresponds to 1 in the color bar and to the largest effect in each case. The network visualization corresponds to a spring layout with 200 iterations. This figure was generated by authors based on INEGI data using Python 3.8 and Python libraries scipy, numpy, networkX, and matplotlib. Source: Visualizations made by authors based on results

intermediation, oil and gas extraction, motor freight transport in general, and nonresidential construction.

The sectors that generate the lowest value-added were: other touristic transport, home for rehabilitation and terminal patients with nurse care, training services for employment for unemployed and disable persons, forestry, animal services, interior waters transport, and international and extra-territorial organisms.

From the top sectors according to exports, the following also appeared on the top according to production: oil and gas extraction, oil and coal derivatives, cars and trucks fabrication, motor vehicle parts fabrication, and freight transport in general.

Table 4 Top ranked sectors according to aggregate effect and diffusion (2008). Source: Results from authors calculations

Shocked sector	Shocked sector	Shocked sector
Air transport	Oil and gas extraction	0.24
	Fertilizers, pesticides and other agrochemicals production	0.45
	Sea transport	1.00
	Services related to highway transport	0.10
Tanning and finishing of leather	Cattle farming	0.06
	Swine farming	0.02
	Poultry farming	0.06
	Conservation of fruits, vegetables and prepared food	0.03
	Other food industries	0.33
	Sawing and conservation of wood	1.01
	Wholesale trade of food and groceries	0.17
	Protection, security and research services	0.08
International and extra-territorial organisms	Oil and gas extraction	0.67
	Generation, transmission and distribution of electric energy	0.12
	Treatment and supply of water	0.02
	Fertilizers, pesticides and other agrochemicals production	0.11
	Oil and coal derivatives production	0.03
	Pharmaceutical products	0.03
	Wholesale trade of food and groceries	0.08
	Services related to non-stock credit intermediation	0.15
	Car trucks and other land transport rentals	0.04
	International and extra-territorial organisms	1.00

Comparably, only two appeared as the top ten generators of value-added: oil and gas extraction and freight transport in general.

The association between these variables will be further explored together with the diffusion. First, we show results for diffusion and aggregate effect. We calculated the aggregate effect triggered by a sectoral shock on final demand, the disaggregation of this effect to observe how it was distributed across sectors, and its diffusion index according to Eqs. 2, 5, and 7, respectively. Figure 1 shows the visualizations of some examples of how the effect of the sectoral shock is diffused.

Visually, the sectors that have the best diffusion will distribute the effect of the shock to more sectors. Thus, these sectors will color more sectors in the network. The intensity of the effect that is absorbed by the shock will be observed as a darker color. The following plots in Fig. 1 show three pair of cases. The first row corresponds to sectors that have the best diffusion (regular air transport and international and extra-territorial organisms), thus colored more intensively more nodes in the network (subplots A and B). Then, the column in the middle are sectors that have a close to median diffusion(dairy product elaboration and fruits and nuts) and, therefore, color a few sectors (subplots C and D). Finally, the last row are examples of sectors with the worst diffusion (subplots E and F); this scenario corresponds to when sectors that experience a shock on final demand absorb all the effect of the shock themselves and do not diffuse it to others (artists, writers, and independent technicians and homes with domestic workers).

Results for 2008 data show that the top sectors with both high aggregate effect and good diffusion were: regular air transport; international and extraterritorial organisms; leather tanning and finishing, slaughter packing and processing of cattle, birds and other animals; other land passenger transport; metallic covering and finishing; orientation services and social work; and insurance and finance institutions. Table 4 shows the best performing sectors in 2008, where we highlight the top three cases: regular air transport, tanning and finishing of leather, and international and extraterritorial organisms. Third column shows the magnitude of the effect experienced by each sector in the chain of effects triggered by the shock. These are calculated using the disaggregation of the effect in Eq. 5.

Given the occurrence of the 2008–09 crisis and its consequences, we report results for the Insurance and finance institutions sector separately. This sector diffused most of the effect to: other telecommunication services: 0.23; electronic processing of information, lodging and related services: 0.15; other institution of credit intermediation and non-stock finance: 0.12; Real-state and real-state brokers: 1.01; services related to real-state services: 0.15; auto motor, trucks and other land transport rental: 0.03; specialized design: 0.04; employment services: 0.04; and research, protection and security services: 0.06.

Table 5 shows the sectors that generated the highest aggregate effect and that had the best diffusion in 2012. We observe some differences with respect to Table 4. In first place, the best performing sector is no longer Air transport but it is International and extraterritorial institutions; air transport drops to the fourth position. We find Tanning and finishing of leather in similar positions (second and third in 2008 and 2012, respectively). Finally, we have new appearances: Slaughter, packing, and processing of cattle meat, fowl and other edible animals, and metallic covering and finishing.

To summarize the association between aggregate effect and diffusion we compute the Spearman correlation coefficient. The Spearman correlation coefficient for 2008 was 0.975 with a $p = 0.000$, and for 2012 the Spearman correlation coefficient was 0.966 with a $p = 0.000$. The association has not changed and maintains a strong non-linear relation. To understand the non-lineal relationship that exists between diffusion and the aggregate effect of sectors we go beyond the Spearman correlation coefficient and fitted the data points to a polynomial of degree two and of degree three and chose the best fitting as the one with the least residuals (see Fig. 2), see the Appendix for the polynomial equations and residuals.

The following plots in Fig. 2 show the relation between aggregate effect and diffusion for all sectors in the Mexican economy for 2008 and 2012. The four scatterplots show the relations and the polynomial fit of degree 2 in the first row and of degree 3 in the second row (see equations A.1 to A.8 in the Appendix) for each year. The scatterplots give evidence that the best polynomial fit for both years was the polynomial of degree 3. Congruently, this fitting reported the least residuals. A polynomial of degree 3 shows that up to a certain value for diffusion, greater aggregate effect comes with higher diffusion. The amount by which it increases becomes smaller for higher values of aggregate effect. Then, at the upper right corner of the scatterplots, where we find the highest values of aggregate effect, the values of diffusion are higher again.

Table 5 Top ranked sectors according to aggregate effect and diffusion (2012). Source: Results from authors calculations

Shocked sector	Shocked sector	Shocked sector
International and extra-territorial institutions	International and extra-territorial institutions	1.00
	Financial institutions for economic development	0.14
	Generation, transmission and distribution of electric energy	0.11
	Oil and gas extraction	0.09
	Wholesale trade of food and groceries	0.08
	Accounting, audit, and related services	0.08
Slaughter, packing, and processing of cattle meat fowl and other edible animals	Slaughter, packing, and processing of cattle meat, fowl and other edible animals	1.07
	Poultry exploitation	0.08
	Cattle exploitation	0.05
	Wholesale trade of food and groceries	0.05
	Animal food elaboration	0.03
	Cultivation of oil seeds, legumes and cereals	0.03
Tanning and finishing of leather	Tanning and finishing of leather	1.01
	Slaughter, packing, and processing of cattle meat, fowl and other edible animals	0.25
	Wholesale trade of food and groceries	0.17
	Employment services	0.10
	Poultry exploitation	0.05
	Cattle exploitation	0.03
Regular air transport	Regular air transport	1.00
	Oil and coal derivatives product fabrication	0.07
	Oil and gas extraction	0.03
	Services related to air transport	0.03
	Employment services	0.03
	Accounting, audit and related services	0.02
Metallic covering and finishing	Metallic covering and finishing	1.02
	Iron and steel products fabrication	0.08
	Wholesale trade of food and groceries	0.04
	Non-ferrous metals industries except aluminum	0.03
	Metallic minerals mining	0.02
	Oil and coal derivatives products fabrication	0.02

This gives evidence that there are only a few sectors that share the characteristic of very high values of aggregate effect and diffusion.

From the most affected sectors in the cases described above, the sectors that appear the most area: oil and gas extraction, wholesale trade of food and groceries, oil and coal derivatives, sawing and conservation of food, and crops of oilseeds, legumes and cereals. Most of these sectors are sectors that are in the top exporters, producers and generators of value-added, although not in the same rank. In contrast, the sectors at the lower left corner of the figure above have shorter chains.

To study the association between the macroeconomic variables and the diffusion of shocks, we presented in Fig. 3. It shows two scatterplots that associate value-added generation, exports, production, and diffusion of the effect of a shock for 2008 (up)

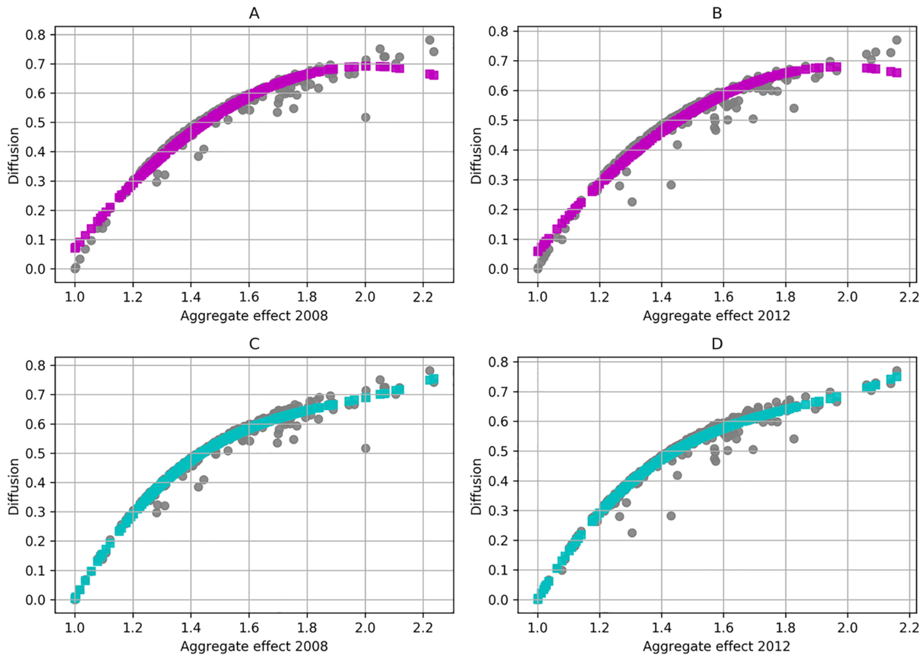

Fig. 2 Polynomial fitting of the relation between aggregate effect and diffusion. Horizontal axis is for aggregate effect and vertical axis is for diffusion. Polynomial fitting of degree 2 (first row) and of degree 3 (second row) of the relation between aggregate effect (*x*-axis) and diffusion (*y*-axis) for 2008 (first column) and 2012 (second column). Dots are data and squares are the fitted values. Source: Visualizations made by authors based on authors calculations using Python 3.8 and Python libraries scipy, numpy, and matplotlib

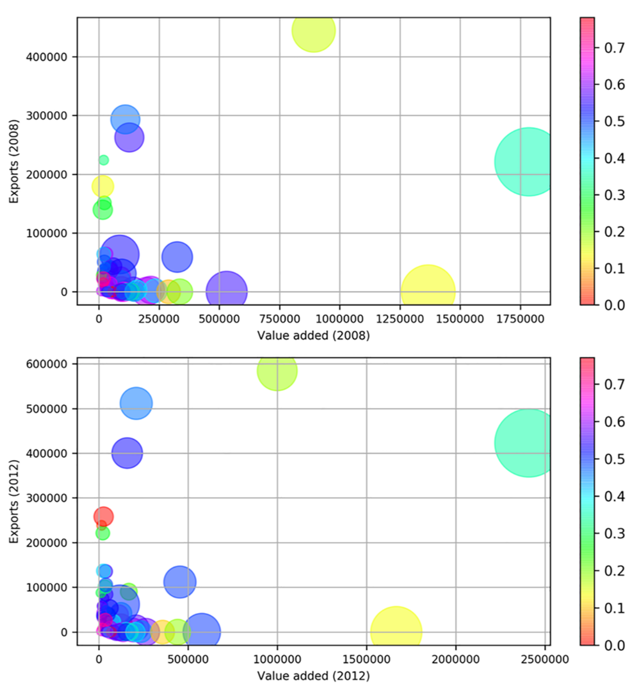

Fig. 3 Association between macroeconomic variables and diffusion. Value-added (*x*-axis), exports (*y*-axis), production (size) and diffusion (color bar) for 2008 (up) and 2012 (down). This figure was generated by authors based on INEGI data using Python 3.8 and Python libraries scipy, numpy, and matplotlib. Source: Visualizations made by authors based on authors calculations

and 2012 (down). It illustrates that sectors that export more, generally generate low value-added, and those sectors that generate more value-added are not great exporters. In addition, it shows that the sectors that have a higher diffusion (blues, pinks and reds) are at the bottom-left corner, where we find low values of both value-added and exports. Finally, the biggest sectors in terms of production have low diffusion and are more related to value-added generation than to exports. If we study the sectors connected, directly and indirectly, to the shocked sector we may be able to increase value-added by developing the production chain were this sector is embedded in. That is, increase production of intermediate goods used as inputs and goods that use the sector's product as input. The analysis of the diffusion of the effect along the specific chain of reaction told us this important information. Otherwise, we would be facing the problem of not knowing how to stimulate sectors that will also bring high value-added, exports, and production. The relation between value-added, exports and production remained the same in 2012. One difference is that we observe an increase in the diffusion measure for the exporters.

To study the characteristics of sectors in the input–output network, we compute a centrality measure. We want to answer the question: are the key sectors identified with the macroeconomic indicators and the diffusion measure also key according to their centrality in the network? To answer such a question we compute authority and hub scores and obtained the rank the sectors.

The top ten ranked authorities were in 2008: oil and coal derivatives products fabrication, wholesale trade of food and groceries, employment services, basic chemicals, electric energy generation and distribution, accounting, audit and related services, renting without real-state intermediation, iron and steel products fabrication, synthetic resins, rubber and chemical fibers, and iron and steel basic industry. The hubs were: other land passenger transport, regular air transport, staff and school transport, oil and coal derivatives products fabrication, collective foreign passenger transport of fixed route, internal waters transport, taxi and limousine services, collective urban and sub-urban passenger transport of fixed route, non-regular air transport, and touristic water transport.

In 2012, the top ten authority scores were: oil and coal derivatives products fabrication, other land passenger transport, regular air transport, staff and school transport, collective foreign passenger transport of fixed route, internal waters transport, Taxis and limousine services, collective urban and sub-urban passenger transport of fixed route, non-regular air transport, and water catchment, treatment, and supply. The hubs were: oil and coal derivatives products fabrication, wholesale trade of food and groceries, employment services, accounting, audit and related services, generation, transmission and distribution of electric energy, renting without real-state intermediation, iron and steel products fabrication, freight transport in general, basic chemical products fabrication, and water catchment, treatment, and supply.

The most central sectors are not necessarily the ones that are the best exporters, generators of value-added or the biggest in terms of production. We further investigate how these differences in ranking have an effect on the magnitude and diffusion of aggregate impacts on production. The sectors with the best diffusion properties are the most central sectors according to the outward global centrality given by the hub scores. This score organizes the sectors on a hierarchy, where the sectors at the top

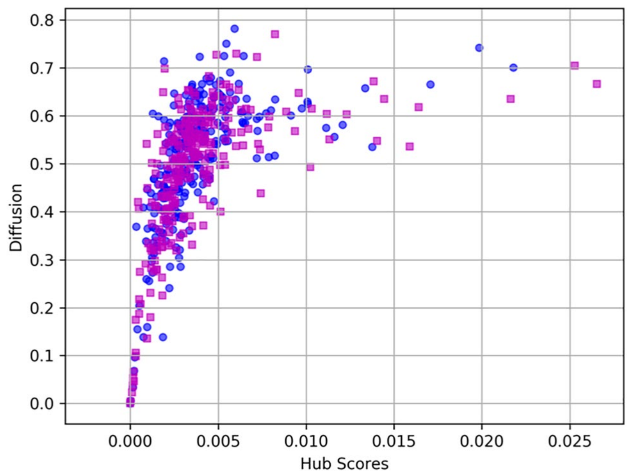

Fig. 4 Association between hub score centralities and diffusion. Blue circles are data for 2008, and magenta squares for 2012. Spearman correlation coefficient. r = 0.714, *p* value = 0.000 for 2008, and Spearman correlation coefficient r = 0.722, *p* value = 0.000 in 2012. This figure was generated by authors based on INEGI data using Python 3.8 and Python libraries scipy, numpy, and matplotlib. Source: Visualizations made by authors based on authors calculations

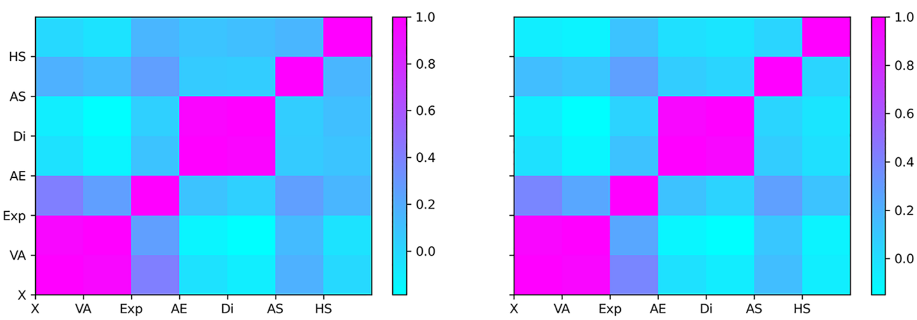

Fig. 5 Correlation matrix between macroeconomic variables and network properties. 2008 left and 2012 right. Each row (and column) is one variable. In axes one reads 'X' for production, 'VA' for value-added, 'Exp' for exports, 'AE' for aggregate effect, 'Di' for diffusion index, 'AS' for authority score, and 'HS' for hub score. Each cell is the Spearman correlation coefficient between pair of variables given by the color map. This figure was generated by authors based on INEGI data using Python 3.6 and Python libraries scipy, numpy, networkX, and matplotlib. Source: Visualizations made by authors based on authors calculations

are more important in the link structure of the network. In our context, the top sectors are the most important suppliers of inputs by being embedded in many production chains.

Figure 4 shows a strong and non-linear relation between hub scores and diffusion of sectors. The association is summarized in the Spearman correlation coefficient. It gives evidence of an association, where those sectors that are more central also have better diffusion of effects in the network. This relation is true for both periods of study.

Finally, to summarize the association between the macroeconomy and the sectoral properties, we computed the matrix of Spearman correlations between the variables in the following order: production, value-added, exports, aggregate effect, diffusion, authority scores and hub scores. Figure 5 shows these correlations for 2008 (left) and 2012 (right). We highlight the most relevant results (for the correlations and *p* values, see Tables 6 and 7 in the Appendix). There is no association between hub scores and production and value-added; their correlation becomes negative for 2012. There is also no association between aggregate effect and diffusion and production and value-added; relation that is maintained in 2012. On the contrary, there is a strong association between hub scores and aggregate effect, and hub scores and diffusion. This relation is also maintained in 2012. Finally, there is no association between exports and aggregate effect and exports and diffusion.

6 Discussion

We computed a diffusion index for sectors in an economy and related this index to the aggregate effect of a shock, centrality measures and macroeconomic variables, such as production, exports and value-added. Interestingly, when observing the relation between these variables for the whole economy we observe a low association. However, when comparing the rankings of each variable we identify strategic sectors with desirable characteristics.

Results for Mexico for the years 2008 and 2012 show that at the aggregate there is no change, but looking at individual examples, we find some changes that were reported in the results section. For example, we found that top exporters are sectors, such as computers and peripheral equipment, communication equipment, audio and video equipment, or electronic components. However, these sectors do not report high production or value-added. Furthermore, these sectors do not generate high aggregate effects on production or have a good diffusion.

Nevertheless, identified a few sectors that are among the top ranked sectors according to the three macroeconomic variables and that also have desirable characteristics: wholesale of food and groceries, oil and gas extraction, oil and coal derivatives products. These sectors diffused the effect of a shock to a wider set of sectors and generate high aggregate effects in production. Moreover, oil and gas extraction, oil and coal derivatives fabrication are also involved in the strongest connections in both years of analysis. The industrial policy recommendation based on these results is to focus on the diffusion properties of sectors, since these are associated with centralities and a good performance in macroeconomic variables, such as value-added.

There are additional interesting cases: slaughter, packing, and processing of cattle meat, fowl and other edible animals; tanning and leather finishing; and oilseeds legumes cereals, grinding grains seeds. These sectors generated a high aggregate effect, diffused the effect to a wide set of sectors, are among the most affected sectors when other sectors received a shock, and are part of the strongest connections. Therefore, targeting one of these sectors will bring cumulative effects that will stimulate many more sectors, and consequently generate positive effects on the macroeconomic variables studied in this investigation. Together with this strategy, another recommendation, more in the long run, is to develop the technology and knowledge to produce along the chains of effects of these sectors, from the inputs to the final high-technology goods, so that sectors such as computers and electronics will also generate high aggregate effects, value-added, and a wide diffusion of effects.

We found a strong positive association between the rank based on the hub centrality of a sector and its diffusion of an effect of a shock. This, together with the previous results, suggests that the structural properties measured as centralities of sectors in the network are relevant for understanding the relation between the macroeconomy and the properties of each sector. Moreover, the diffusion measure we propose builds a bridge between them. Production processes are important to diffuse the effects of shocks through the hubs of the input–output system. Consequently, when designing an industrial policy the government may target sectors that are ranked as hubs in the economic system, instead on focusing on an exports driven model. By doing so, the effects will reach, through subsequent indirect effects, sectors that are exporters and generators of value-added.

Studying the different chains of effects when a sector is affected by a shock allowed us to identify strategic sectors involved in key production processes. We complemented the impact analysis and the identification of key sectors with some measures of economic activity, such as exports, value-added, and diffusion and centralities. Identifying the key processes provides information useful to design industrial policies, where interventions can have more relevant effects and can be more effective.

7 Conclusions

In conclusion, our contribution is to associate a diffusion index, based on the Leontief inverse, to centrality of sectors in the input–output network, and to macroeconomic variables. Our results highlight the importance of the productive linkages and the direct and indirect effects that are diffused through the linkages of hub sectors. To amplify the effects of exports on growth and value-added, one needs to strengthen the productive linkages and the internal demand for inputs produced by the hub sectors. These results highlight the importance of analyzing the production processes strategic sectors are embedded, because these are the channels through which effects are diffused.

Identifying the sectors at the top of the ranking according to the diffusion index would be helpful for industrial policy design, since we have evidence these will be highly central in the input–output network and will be highly correlated with aggregate effect of a shock (output multiplier). Focusing on the top one, two, five or even top ten, depends on the context, budget, and term of the policy.

But, to be able to propose an effective industrial policy in different countries, policy makers have to consider correlations to exports, value-added, and production according to the objective of the policy. Building the scatterplots we present in this investigation is helpful for this purpose, because they summarize these important correlations that, together with the ranking of the diffusion measure, provide an informative guide.

The analysis of the diffusion properties of sectors showed that one of the reasons for the limited effects of exports on production in Mexico, and hence on growth, is the limited diffusion of effects and low association to other variables, such as value-added. Therefore, it is important to consider the linkage effects of export sectors on other sectors.

Appendix

Polynomial fits.

Polynomial fitting models the relation between a dependent variable (y) and an independent variable (x) as a nth degree polynomial.

$$y = c_n x^n + c_{n-1} x^{n-1} + \dots + cx + c_0$$

The process of curve fitting constructs a curve with a polynomial that best fits a set of data points. In our case we show polynomial of degree two and three to compare and show which one best fits the data. This best fit provides a mathematical function that best describes the relation between two variables and improves our understanding about the variables' behaviour. The process of curve fitting to a polynomial is related, but different, to regression analysis which focuses more on statistical inference. In polynomial curve fitting we choose the coefficients that best fits the curve to the data. These provide the curve that minimizes the residuals between the data y and the fit. The curve that provides the minimum residuals between the data and the fit is the best.

Table 6 shows the approximated curve fitting polynomials for the curves of aggregate effect and diffusion for both 2008 and 2012. These polynomials represent the best fit for the curves observed in the scatter plots in Fig. 2. In both years, the lowest residual is for the polynomial of degree 3; therefore, polynomial of degree 3 is the one that best

Table 6 Fitting polynomials for the curves of aggregate effect and diffusion. Source: made by authors based on authors calculations using Python 3.8 and Python libraries

		Degree 2	**Degree 3**
2008			
	Polynomial	$p(x) = -0.607x^2 + 2.442x - 1.765$	$p(x) = 0.589x^3 - 3.416x^2 + 6.809x - 3.978$
	Residuals	residuals = 0.200	residuals = 0.138
	R-squared	$r^2 = 0.957$	$r^2 = 0.971$
2012			
	Polynomial	$p(x) = -0.646x^2 + 2.560x - 1.856$	$p(x) = 0.698x^3 - 3.882x^2 + 7.454x - 4.269$
	Residuals	residuals = 0.268	residuals = 0.200
	R-squared	$r^2 = 0.948$	$r^2 = 0.961$

Numbers before the x are the coefficients of the polynomial and the variable x stands for the independent variable, in this case aggregate effect

Spearman correlation coefficients matrix

Table 7 Spearman correlation coefficients matrix (rho, *p* value) 2008. Source: made by authors based on authors calculations using Python 3.8 and Python libraries

	Production	**Value-added**	**Exports**	**Aggregate effect**	**Diffusion**	**Authority scores**	**Hub scores**
Production	(1.0, 0.00)	(0.96, 0.00)	(0.41, 0.00)	(−0.05, 0.41)	(−0.11, 0.09)	(0.54,0.00)	(−0.06,0.33)
Value-added	(0.96, 0.00)	(1.0, 0.0)	(0.26, 0.00)	(−0.14, 0.03)	(−0.19, 0.00)	(0.45, 0.00)	(−0.17, 0.01)
Exports	(0.41, 0.00)	(0.26, 0.00)	(1.0, 0.0)	(0.09, 0.13)	(0.03, 0.61)	(0.61, 0.00)	(0.26, 0.00)
Aggregate effect	(−0.05, 0.41)	(−0.14, 0.03)	(0.09, 0.13)	(1.0, 0.0)	(0.98, 0.00)	(0.02, 0.78)	(0.75, 0.00)
Diffusion	(−0.10, 0.09)	(-0.19, 0.00)	(0.03, 0.61)	(0.98, 0.00)	(1.0, 0.0)	(−0.06, 0.31)	(0.71, 0.00)
Authority scores	(0.54, 0.00)	(0.45, 0.00)	(0.61, 0.00)	(0.02, 0.78)	(-0.06, 0.31)	(1.0, 0.0)	(0.15, 0.01)
Hub scores	(−0.06, 0.33)	(−0.17, 0.01)	(0.26, 0.00)	(0.75, 0.00)	(0.71, 0.00)	(0.15, 0.01)	(1.0, 0.00)

Table 8 Spearman correlation coefficients matrix (rho, *p* value) 2012. Source: made by authors based on authors calculations using Python 3.8 and Python libraries

	Production	Value-added	Exports	Aggregate effect	Diffusion	Authority scores	Hub scores
Production	(1.0, 0.0)	(0.97, 0.00)	(0.40, 0.00)	(−0.01, 0.84)	(−0.07, 0.30)	(0.51, 0.00)	(−0.16, 0.01)
Value-added	(0.97, 0.00)	(1.0, 0.0)	(0.25, 0.00)	(−0.11, 0.09)	(−0.15, 0.02)	(0.49, 0.00)	(−0.21, 0.00)
Exports	(0.40, 0.00)	(0.25, 0.00)	(1.0, 0.0)	(0.13, 0.04)	(0.05, 0.41)	(0.39, 0.00)	(−0.00, 0.95)
Aggregate effect	(−0.01, 0.84)	(−0.11, 0.09)	(0.13, 0.04)	(1.0, 0.0)	(0.97, 0.00)	(0.12, 0.05)	(0.71, 0.00)
Diffusion	(−0.07, 0.29)	(−0.15, 0.02)	(0.05, 0.41)	(0.97, 0.00)	(1.0, 0.0)	(0.02, 0.74)	(0.72, 0.00)
Authority scores	(0.51, 0.00)	(0.49, 0.00)	(0.39, 0.00)	(0.12, 0.05)	(0.02, 0.74)	(1.0, 0.0)	(0.04, 0.50)
Hub scores	(−0.16, 0.01)	(−0.21, 0.00)	(−0.00, 0.95)	(0.71, 0.00)	(0.72, 0.00)	(0.04, 0.50)	(1.0, 0.0)

described the relation between aggregate effect and diffusion. This is confirmed by the high R-square reported. These results confirm what we observed in the scatter plots of Fig. 2 as the close relation between the magenta and cyan dots, and the high Spearman correlation coefficient and the *p* value reported (Tables 7 and 8).

Acknowledgements
Not applicable.

Author contributions
All authors contributed equally to the manuscript. Both authors read and approved the final manscript.

Funding
This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Availability of data and materials
All data supporting results is publicly available through the official INEGI web page (https://www.inegi.org.mx/programas/mip). Code used for the analysis is publicly available through the Open Science Framework projecthttps://www.osf.io/f7pys/?viewonly=ecc9e6aa71c74868a6fe5751306fb3a6.

Declarations

Competing interests
Both authors declares that they have no competing interests.

Received: 1 October 2020 Revised: 27 October 2022 Accepted: 28 October 2022
Published: 18 November 2022

References

Alatriste-Contreras MG (2015) The relationship between the key sectors in the European Union economy and the intra—European Union trade. J Econ Str 4(14):1–24
Alatriste-Contreras MG (2020) Detecting diffusion properties of sectors in the Mexican economy 2012. Investigación Económica 79(311):110–136
Alatriste-Contreras, M.G (2014) Essais sur les propriètés structurelles et la dynamique du système économique. PhD thesis, Aix-Marseille School of Economics, EHESS
Alatriste-Contreras MG, Fagiolo G (2014) Propagation of economic shocks in input—output networks: a cross country analysis. Phys Rev E 90(6):062812
Amaral J, Dias F, Lopes J (2007) Complexity as interdependence in input—output systems. Environ Plan A 39:1170–1182
Ascárraga-Sejas W (2012) Exports as an engine of economic growth and the position of emerging countries in the global value chains: a comparative analysis between china and México. 20th International Input-Output Conference that-took place IIOA 3:5–50
Blochl F, Theis F, Vega-Redondo F, Fisher E (2011) Vertex centralities in input iutput networks reveal the structure of modern economies. Phys Rev E 83(4):046127
Bonacich P (1987) Power and centrality: a family of measures. Am J Sociol 92(5):1170–1182
Collins SM, Bosworth BP, Rodrik D (1996) Economic growth in East Asia: accumulation versus assimilation. Brookings P Econ Act 2:135–203

de Estadística y Geografía (INEGI), IN (2013) Sistema de cuentas nacionales de México Fuentes y metodologías año base 2013. Instituto Nacional de Estadística y Geografía, Aguascalientes
Dietzenbacher E (1992) The measurement of interindustry linkages: key sectors in the Netherlands. Econ Model 9(4):419–437
Dietzenbacher E, van der Linden JA (1997) Sectoral and spatial linkages in the EC production structure. J Reg Sci 37(2):235–257
Dietzenbacher E, Romero I (2007) Production chains in an interregional framework: Identification by means of average propagation lengths. Int Reg Sci Rev 30(4):362–383
Fujii G, Cervantes-Martinez R (2013) México: valor agregado en las exportaciones manufactureras. Revista CEPAL 4:143–158
Fujii G, Cervantes-Martinez R (2017) The weak linkages between processing exports and the internal economy. Mexican Case Econ Syst Res 29(4):528–540
Fujii G, Gaona C (2004) El modelo maquilador como barrera al crecimiento del empleo y los salarios en México. Economía Informa 323:63
Fujii G, Candaudap E, Gaona C (2005) Exportaciones, industria maquiladora y crecimiento económico en México a partir de la década de los noventa. Investigación Económica 64(254):125–156
Hausmann R, Hidalgo CA (2009) The building blocks of economic complexity. PNAS 106(26):10570–10575
Hausmann R, Hidalgo CA (2011) The network structure of economic output. J Econ Growth 16:309–342
Herfindahl OC (1950) Concentration in the US Steel Industry. Columbia University, USA
Hirschman AO (1958) Strategy of economic development. Yale University Press, New Haven, CT, USA
Humavindu M, Stage J (2013) Key sectors of the Namibian economy. J Econ Str 2(1):1–15
Jones LP (1976) The measurement of Hirschmanian linkages. Q J Econ 90(2):323–333
Kleinberg JM (1999) Authoritative sources in a hyperlinked environment. J ACM 46(5):604–632
Leontief W (1936) Quantitative input and output relations in the economic systems of the United States. Rev Econ Stat 18(3):105–125
Marconi N, Rocha IL, Magacho RG (2016) Sectoral capabilities and productive structure: an input-output analysis of the key sectors of the Brazilian economy. Brazilian J Political Econ 36(3):470–492
McGilvray J (1977) Linkages, key sectors, and development strategy. In: Leontief W (ed) Structure, system, and economic policy. Cambridge University Press, NY, NY, USA, pp 49–56
McNerney J, Fath BD, Silverberg G (2012) Network structure of inter-industry flows. Phys A 392(24):6427–6441
Miller RE, Blair PD (2009) Input-output analysis foundations and extensions, 2nd edn. Cambridge University Press, NY, USA
Newman MEJ (2010) Networks: an introduction. Oxford University Press, Oxford
Rasmussen N (1956) Studies in intersectoral relations. North-Holland Publishing Co., Amsterdam
Rodrik D (1995) Getting interventions right: how south Korea and Taiwan grew rich. Economic Policy 10(20):53–107
Rodrik D (2008) Normalizing industrial policy. Commission on growth and development working paper no. 3. World Bank, Washington, DC
Slater P (1978) The network structure of the United States input-output table. Empirical Economics 3(1):49–70
Soyyig S, Cirpici YA (2017) An input-output network structure analysis of selected countries. Yildiz Soc Sci Rev 2(3):65–88
Temurshoev, U., Oosterhaven, J.: On input—output linkage measures (December, 2010). International Input-Output Association, Working papers in Input-Output Economics
Tsekeris T (2015) Network analysis of intersectoral relationships and key sectors in the Greek economy. J Econ Interact Coord 12:1–23

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.