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Difusión de diferentes tipos de perturbaciones sectoriales en la economía francesa

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Diffusion and effects of sectoral shocks in the French production network

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Abstract

Supply shocks are traditionally understood in economics as perturbations that have positive or negative effects in production. However, the mechanism through which these effects may diffuse across the economy is poorly understood. We investigate the diffusion mechanisms of two types of sectoral shocks that trigger avalanches. For that purpose, we represent the economy as a network and apply three diffusion models. The first model considers the spread of a shock on final demand based on the Input-output model. The second is a network diffusion model that evaluates the impact of changes in the technological relationships between sectors by decreasing the flow of inputs. The third model is an extension of the second, introducing an additional step where each sector updates its production level to the conditions after the shock. Results for the French economy show that the first model brought about very large and homogeneous avalanche sizes. Comparably, the second and third models show heterogeneous avalanche sizes displayed in skewed distributions. The sectors that triggered the largest avalanches have high global centrality in the French input-output network. Finally, we compared results to an asymmetric version of models two and three where shocks diffuse though the supply channel only and discover comparably large avalanches as before, although a weaker reinforcing mechanism in model three.

keywords: input-output network, sectoral shocks, diffusion, centrality

1 Introduction

Supply shocks are traditionally understood in economics as a perturbation that has positive or negative effects in production and prices. This perturbation may be caused by structural changes within industries, changes in technology, or changes in regulation. We are particularly interested in analyzing the effects of supply shocks caused by structural changes. The effects will be analyzed as the number of subsequent industries affected by the shock, which we call avalanche size. Large avalanches emerge in highly connected economic systems where the structure of intersectoral relationships shapes the diffusion mechanisms through which shocks may diffuse from one sector to others. Avalanches may reach a wide set of sectors or even the entire economy through direct and indirect channels. Nevertheless, the emergence and impact of avalanches has not been fully explored in the economic literature, thus remains poorly understood. In our paper, we investigate the emergence of avalanches triggered by two types of sectoral shocks across a national economy.

A recent paper [Alatriste-Contreras and Fagiolo (2014)] analyzes the spreading of two types of sectoral shocks in each of the countries of the European Union and relate the size of the avalanches experienced by these countries to their economic characteristics. The paper uses input-output data from Eurostat that classifies the economy into 60 sectors. In a complementary fashion, our paper studies the diffusion of shocks in the French economy at a higher level of disaggregation (118 sectors) to observe weather a finer granularity changes the results found for France in the cited paper. We also explore an asymmetric diffusion process where the supply of inputs is the only mechanism through which shocks can diffuse and asses which of the two mechanisms is the strongest to spread shocks.

The study of the interdependencies between sectors has been traditionally studied in economics by the input-output (I-O) literature. The I-O analysis is based on the identification of key sectors and other tools. In this analysis key sectors are found computing backward and forward linkages that measure the impact of a change in the final demand of a sector [Okuyama and Santos (2014), Miller and Blair (2009), Dietzenbacher (1992)]. Once identified, the key sectors can be object of selective promotion in a development strategy [Humavindu and Stage (2013), McGilvray (1977), Jones (1975), Chenery and Watanabe (1958), Hirschman (1958), Rasmussen (1956)]. Additionally, we find the mean of average propagation lengths [Dietzenbacher and Romero (2007)] that measures the average number of steps it takes for a shock on final demand of sector i to reach sector j. Even though efforts have been made to take into account the complex structure of the economy with I-O tables [Bino and Pellisery (2007)], I-O analysis has not incorporated some of the tools needed to characterize the different higher order properties of this structure and their impact in the diffusion of shocks. As a consequence, the mechanism of the diffusion of sectoral shocks and the emergence of avalanches have not been fully comprehended in I-O. Our investigation complements the analysis with the complex network approach, which allows going beyond the standard input-output impact analysis to identify the key sectors that trigger the largest avalanches.

The complex network approach provides a means to study the economy and its structural properties taking into account all higher order interactions between sectors using I-O data. The literature covers the identification of the most central sectors, clusters and communities in the economy [Slater (1978), Garcia-Muniz et al. (2008), Blöchl et al. (2011), Xu et al. (2011), Wen-Qi Duan (1997), McNerney et al. (2012), Tsekeris (2015)]. An example is [Duman and Özgüzer (2015)] relates the heterogeneity in the centrality of sectors, measured as in [Blöchl et al. (2011)], to the growth rate of OECD countries. [Acemoglu et al. (2012)] incorporates a centrality measure to capture intersectoral linkages in a multisectoral macroeconomic model and measure the impact of sectoral idiosyncratic shocks on aggregate volatility and [Acemoglu et al. (2013)] shows how those idiosyncratic shocks can propagate over the input-output linkages across sectors creating large economic downturns. However, they do not exploit the advantages of modeling the economy as a network and relating its structure to some phenomena like the diffusion of shocks. Our investigation complements the literature by evaluating the full impact of sectoral shocks applying network diffusion models. We relate the emergence of avalanches to the productive structure of a national economy and characterize the triggers of the largest avalanches.[1]

Diffusion models in networks are applied to study the spreading mechanisms of information, innovations, infectious diseases, and failures throughout a network [Morris (1993), Bakshay et al. (2013), Jackson and Yariv (2006), Zimmerman et al. (2005), Zimmerman et al. (2004), Zimmerman et al. (2001), Kinney et al. (2005)]. Recent applications of these models to study the economy have focused on the spread of crisis in the international trade network [Lee et al. (2011), Garas et al. (2010)], and the spread of shocks or crisis within the network embedded in the financial sector [Kücük et al. (2012), Toivanen (2013), Karimi et al. (2013)]. Using network diffusion models to analyze the diffusion of shocks among sectors has the advantage of capturing local and global effects. It also presents an opportunity to explore different settings beyond the linear and fixed relationships established in the Input-output model through the inclusion of technology shocks that change the flows of inputs.

For our investigation we use the 2007 French I-O table publish by the "Institute National de la Statistique et des Etudes Economiques" (INSEE) to represent the economy as an I-O network. We investigate the spread of two types of sectoral shocks using three diffusion models. The first model studies the impact of a shock on final demand, as in the I-O literature. The second model is a network diffusion model where a shock changes the flow of inputs and diffuses the shock depending on node connectivity and capacity of production. The third diffusion model adds a second step, where production level of each sector updates to the conditions after a shock. Main results for the French economy showed that the impact of shocks in final demand trigger homogeneous and very large avalanche sizes. On the other hand, the second and third models showed heterogeneous but predominantly medium and large avalanche sizes. The sectors that triggered the largest avalanches in the network diffusion models are similar but different from the ones observed with model one. Importantly, when the economy adjusts, the avalanches are larger. Network diffusion models highlighted the capacity of the most globally central sectors to trigger large avalanches.

The paper is organized as follows. Section two covers materials and meth-

[1] An avalanche is triggered by a sectoral shock and it is the number of subsequent sectors affected by the shock.

ods, where we detailed the database and the diffusion models applied for the evaluation of avalanches in the economy. Section tree presents the results for the French economy. Finally, on section four we make a discussion about the different results according to the models and conclude.

2 Data and Methods

Input-output tables are a natural source of data for representing the economy as a network. The representation of the economy depends on the classification of economic activities used in the analysis and there are as many representations as classifications. Using one that is more disaggregated is advantageous to identify key properties of the economy.

2.1 Data

We use the 2007 input-output table published by the INSEE for France. This table classifies the economy into 118 sectors according to the French classification and gives information on the intermediate demands for each sector. We take the 116 sectors with interactions with the rest of the economy, i.e. that are not isolated.[2] With the intermediate demand table we compute the direct input coefficients matrix following the I-O model [Leontief (1936)], and we represent the economy as an I-O network as described below.

2.2 Input-Output Network

The structure of input-output relationships gives rise to a weighted directed graph with self-loops. This graph is the network representation of the economy where a node represents a sector and a weighted directed edge represents an economic transaction between sectors to buy or sell inputs [Blind and Murphy (1974), Blöchl et al. (2011), Amaral et al. (2007)]. Self-loops capture the idea of a sector using its own product as input. The weighted adjacency matrix describing the network, $\mathbf{W}$, has entries $w_{ij} > 0$ if there exist a link between i and j and $w_{ij} = 0$ otherwise, where w_{ij} is the ij-th element of the direct input coefficients matrix defined in the I-O model (see next section). When sector i has a self-loop, then $w_{ii} > 0$. The network is directed, therefore $w_{ij} \neq w_{ji}$ so the flows of inputs are not symmetric between pairs of sectors.

2.3 Model 1. The Input-Output Model

According to the I-O model total output of a sector, x_i, is expressed as a function of the demand for the different commodities produced in the economy. Total output, or equivalently total production is defined in vector form as:

[2] The sectors uranium's mineral extraction and associative activities are disconnected from the rest of the economy and satisfy their demand of inputs by themselves.

$$\mathbf{x} = \mathbf{z1} + \mathbf{D} \tag{1}$$

where $\mathbf{x}$ is the $n \times 1$ column vector of total output, $\mathbf{z}$ is the intersectoral flow or intermediate demand matrix, $\mathbf{1}$ is a column vector of ones, and $\mathbf{D}$ is the $n \times 1$ column vector of final demand. [3] Equation 1 can be equivalently written as follows:

$$\mathbf{x} = \mathbf{xA} + \mathbf{D} \tag{2}$$

where $\mathbf{A} = [a_{ij}] = [z_{ij}/x_j]$ is the $n \times n$ matrix of direct input coefficients where each cell measures input per output.

Solving for x yields:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-\mathbf{1}}\mathbf{D} = \mathbf{LD} \tag{3}$$

where $\mathbf{L} = (I - A)^{-1} = [l_{ij}]$ is an $n \times n$ matrix known as the Leontief inverse or the total requirements matrix.

We can compute total output of all individual sectors as a function of final demand once we know the magnitudes of the direct input coefficients. The impact of sector i on aggregate production is defined as the change in production of sectors needed to compensate a change in final demand of sector i. The final demand is constituted by household consumption, government consumption, exports, and capital formation. Therefore, a shock on final demand can be thought of as a change on either of these components. The effect of a shock on final demand is computed in vector form as follows:

$$\mathbf{\Delta x} = \mathbf{x^1} - \mathbf{x^0} = \mathbf{L}(\mathbf{D^1} - \mathbf{D^0}) \tag{4}$$

Equivalently,

$$\mathbf{L\Delta D} = \mathbf{L} * \mathbf{f} \tag{5}$$

where $\mathbf{f}$ is a column vector with entries, assuming sector i receives a shock, $f_i = 1$ and $f_j = 0$ for $j \neq i$

The number of sectors with $\Delta x_i \neq 0$ defined as the elements of the vector in the left hand side of equation 4, gives the avalanche size triggered after introducing a shock on final demand. To compare the impact across sectors, we normalized the effect of the shock by the size of the shock, which implies that the aggregate impact is determined by the column sum of the Leontief matrix, $\mathbf{L}$, as if the shock was equal to 1 for all sectors (a unit decrease on final demand).[4]

[3] We use total output and total production interchangeably to denote the same quantity: intermediate demands plus final demand.

[4] This is know in the input-output literature as the output multiplier [Miller and Blair (2009)].

2.4 Model 2. Diffusion of a Shock on Technology

In this section we present the first network diffusion model to analyze the diffusion of technological shocks throughout the input-output network. We consider shocks that change symmetrically the flow of inputs from, and to, a sector to others. The diffusion mechanism of such a shock is modeled as a progressive process where a node is hit by a shock only once and diffuses the shock step by step following production chains. The shock is such that it affects a sector as a whole. A technology shock that changes the flow of inputs from, and to, a sector can be thought of as any situation where physical machinery or infrastructure is affected and the flow of inputs decreases because it does not have the capacity to process them; an external perturbation reduces the capacity of the sector's firms to supply and demand inputs even if the have the same infrastructure; substitution of inputs; or the collapse of a sector due to internal causes like the financial crisis that then diffuses to other sectors. In a similar fashion, [Alatriste-Contreras and Fagiolo (2014)] applied two models to study the spread of shocks in European countries using Eurostat data, [Kinney et al. (2005)] evaluate the avalanche mechanism of failures in power grids and [Lee et al. (2011)] measure the impact of the collapse of one country on the rest of the world's trade network using similar network diffusion models. In our investigation, the diffusion of shocks takes place in the input-output network of a national economy where nodes are sectors and weighted directed edges are the economic transactions between them. We assume that a shock arrives at one sector and modifies the supply and demand of inputs. This, in turn, changes the direct input coefficients. We will compare it the diffusion mechanisms to an asymmetric version of the model to study the rol of the supply channel in the diffusion of shocks. As opposed to the standard impact analysis in the input-output literature, in this case final demand remains fixed. Additionally, production levels are kept fixed during the diffusion process and only change at the end.

The model proceeds as follows. Initially, suppose that a shock hits sector i. This shock decreases the supply and demand of inputs of sector i by fraction $0 < f < 1$. New weights of the connections of i are defined as:

$$w^*_{ij} = (1 - f)w_{ij} \tag{6}$$

for the links between i and i's input buyers, and

$$w^*_{ji} = (1 - f)w_{ji} \tag{7}$$

for the links between i and i's input suppliers. If the total decrease of either the incoming or outgoing link weights of any sector j connected to the shocked sector i exceeds a threshold $0 < c < 1$ of its node capacity x_j, then the first shock diffuses. If i received the original shock, for j in the set of suppliers and buyers (neighborhood) of i, the shock will propagate to j if:

$$\left(\sum_{k\in N(j)} w_{jk} - \sum_{k\in N(j)} w^*_{jk}\right) + \left(\sum_{k\in N(j)} w_{kj} - \sum_{k\in N(j)} w^*_{kj}\right) > c * x_j \tag{8}$$

where $k \in N(j)$ is an input supplier or buyer of j or $j's$ neighborhood $(N(j))$.

If the previous condition holds, sector j is hit by the shock and its supply and demand of inputs decreases according to the following expressions:

$$w^*_{jk} = (1-f)w_{jk} \tag{9}$$

and

$$w^*_{kj} = (1-f)w_{kj} \tag{10}$$

for $k \in N(j)$. After the shock, supply and demand of inputs decrease, which has an impact over sector j's neighbors $N(j)$. Substituting w^*_{jk} and w^*_{kj} by their definitions given by equation 9 and equation 10, then equation 8 can be written, from sector j's perspective, as follows:

$$(\sum_{k \in N(j)} w_{jk} - \sum_{k \in N(j)} (1-f)w_{jk}) + (\sum_{k \in N(j)} w_{kj} - \sum_{k \in N(j)} (1-f)w_{kj}) > c * x_j \tag{11}$$

Equivalently,

$$\sum_{k \in N(j)} fw_{jk} + \sum_{k \in N(j)} fw_{kj} > c * x_j \tag{12}$$

Equation 12 yields the following condition for a shock to diffuse from one sector to other adjacent sectors:

$$\sum_{k \in N(j)} (w_{jk} + w_{kj}) > (c/f) * x_j \tag{13}$$

The first term on the left hand side of equation 13 is the outstrength of node j and the second term is the instrength of node j. Therefore, equation 13 can be further expressed in terms of node j's strengths as follows:

$$s^{out}_j + s^{in}_j > (c/f) * x_j \tag{14}$$

Equation 14 expresses that if the sector is strongly connected and node size is not large enough to absorb the shock, the shock diffuses and hits its neighbors.

The shock on sector j decreases the weight of the links by a fraction f and initiates an avalanche of shocks. The shock can diffuse further to their neighbors' neighbors creating an avalanche which proceeds until all sectors have evaluated equation 14. High connectivity and low capacity, together turn a node vulnerable to be hit by a shock.

We compare model 2 to an asymmetric version, where a shock on technology only decreases the supply of inputs of the sector that received the shock. The rest of the diffusion mechanism remains the same. In this asymmetric model we have that the supply of inputs from sector i to sector j decreases after a shock as follows:

$$w^*_{ij} = (1 - f)w_{ij} \tag{15}$$

for the links between i and i's input buyers.

The condition to spread the shock from sector i to a sector j in i's buyers (N^d) is an asymmetric version of equation 8 and is defined as follows:

$$(\sum_{k \in N^d} w_{jk} - \sum_{k \in N^d} w^*_{jk}) > c * x_j \tag{16}$$

where $k \in N^d(j)$ refers to some sector k in the set of input buyers of sector j.

After substituting the new magnitude of the supply of inputs in the condition to spread a shock, equation 16 now becomes:

$$s^{out}_j > (c/f) * x_j \tag{17}$$

where s^{out}_j is the outstrength of sector j.

2.5 Model 3. Diffusion of a Shock on Technology with Updating in Production

Model 3 incorporates the more realistic idea of being able to adjust to a shock. To do so, we introduce a second step in the diffusion process. First, a sector is hit by a shock and the flow of inputs from, and to, this sector decreases by fraction $0 < f < 1$. This translates into changes in the i-th row and i-th column of the input-output matrix, which in turn changes the direct input coefficients matrix. Second, sectoral production is updated due to the fact that a sector that is hit by a shock has fewer inputs to produce after the shock and supplies fewer inputs for the production of other sectors. As in model 2, final demand remains fixed. At stage t of the diffusion process, the weights of the links between sectors, as well as the other variables such as production, are indexed by t, for example: $z_{ij}(t)$. The flow of inputs decreases according to:

$$z_{ij}(t + 1) = z_{ij}(t) * (1 - f) \tag{18}$$

for sector i's input buyers, where $z_{ij}(t + 1)$ is the new magnitude of the supply and

$$z_{ji}(t + 1) = z_{ji}(t) * (1 - f) \tag{19}$$

for sector i's input suppliers, where $z_{ji}(t + 1)$ is the new magnitude of the demand for inputs of i. This decrease in the flows of inputs further changes the direct input coefficients, a_{ij}, as follows:

$$a_{ij}(t + 1) = z_{ij}(t + 1)/x_j(t) \tag{20}$$

and

$$a_{ji}(t+1) = z_{ji}(t+1)/x_i(t) \tag{21}$$

Then, the new production level is calculated as follows:

$$\mathbf{x(t+1)} = (\mathbf{1} - \mathbf{A(t+1)})^{\mathbf{-1}}\mathbf{d(t)} = \mathbf{L(t+1)d(t)} \tag{22}$$

where $\mathbf{x(t+1)}$ is the new production vector, $\mathbf{A}(t+1) = z_{ij}(t+1)/x_j(t)$ is the new direct input coefficients matrix, $\mathbf{L(t+1)}$ is the new Leontief inverse, and $\mathbf{d(t)}$ is the final demand vector, which remained fixed. This mechanism can be viewed as a process where positive feedbacks arise and effects are reinforced. Each update is incorporating previous updates.

After updating, sectors evaluate the same condition as before but with the new production value $\mathbf{x(t+1)}$. If i received the original shock, for j in the neighborhood of i, the shock will propagate to j if:

$$\sum_{k \in N(j)} (w_{jk}(t) - w_{jk}(t+1)) + \sum_{k \in N(j)} (w_{kj}(t) - w_{kj}(t+1)) > c * x_j(t+1) \tag{23}$$

After substituting the definitions of $w_{jk}(t+1)$ and $w_{jk}(t+1)$ in equation 23 and rearranging we obtain:

$$\sum_{k \in N(j)} (w_{jk}(t) + w_{kj}(t)) > (c/f) * x_j(t+1) \tag{24}$$

where the evaluation is made taking into account the new production value $x_j(t+1)$.

We also compare model 3 to an asymmetric version of the model where only the supply of inputs decrease when a sector is hit by a shock on technology. In this alternative version of model 3, the supply of inputs of sector i after being hit by a shock on technology decreases according to:

$$z_{ij}(t+1) = (1-f) * z_{ij}(t) \tag{25}$$

where $z_{ij}(t+1)$ is the new magnitude of the supply for inputs of i. The decrease in the flows of inputs further changes the direct input coefficients, as follows:

$$a_{ij}(t+1) = z_{ij}(t+1)/x_j(t) \tag{26}$$

Then, the new production level under this asymmetric model is calculated as before (see equation 22), but now only the ith row of the matrix $\mathbf{A}$ changes.

Finally, the shock propagates from sector i to sector j, for j in the set of i's input buyers, if:

$$\sum_{k \in N^s(j)} (w_{jk}(t) - w_{jk}(t+1)) > c * x_j(t+1) \tag{27}$$

where w_{jk} is the supply of inputs from j to k, for k in the set of input buyers of j.

In the specifications of diffusion models 2 and 3, the f and c parameters are the same for all the sectors in the economy and are values between zero and one. The determinants of the diffusion mechanism are not each parameter alone but the ratio of the two: c/f. This ratio gives information on the total vulnerability of the system, both of connections and nodes. The key quantities in the resulting dynamics of the models are: 1) the number of subsequently sectors that are hit by a shock starting from a triggering sector (avalanche size); and 2) the avalanche size distribution of all sectors in the economy.

3 Results

In this section we present the results of the diffusion models for the case of the French economy. We present the results according to each model in the form of avalanche size distributions.

3.1 Model 1

The avalanche size triggered by the diffusion of a shock on final demand according to the Input-output model is 107 of 116 sectors and is the same for all sectors. This results in a homogeneous avalanche size distribution (black squares line in figure 1). To introduce heterogeneity we can establish a threshold above which we count an effect as part of an avalanche. If the effect on sector j of a diffusing shock originally triggered by sector i is larger than some threshold, then sector j is part of an avalanche triggered by sector i. In figure 1 we show the distribution of avalanches sizes according to different thresholds as percentage of the aggregate effect.

Figure 1) shows that as the threshold becomes larger, the distributions become more positively skewed, to the point of having mainly small avalanche sizes. Since most of the magnitudes of the effects are very small, we only require a small threshold to observe heterogeneity. As soon as we disregard effects smaller than 0.25 percent of the aggregate effect, the concentration of avalanche sizes falls in a wider range, mainly from 25 to 40 sectors. However, the maximum number of sectors that can be part of an avalanche is reduced by half, from 116 to 58.

In most cases, the sectors that triggered the smallest avalanche sizes were: domestic services and road, rail, and waterways network sanitation. On the other hand, the sectors that triggered the largest avalanche sizes are not the same for every threshold. When the threshold is large artificial fibbers and mechanic equipment and fabrication of machinery triggered the largest avalanches. But when the threshold became smaller, the sectors home appliances, weapons and ammunition, and automobile equipment triggered the largest avalanches.

Nevertheless, imposing a threshold to count an effect as part of an avalanche reduces the information we observe and under-reports the impact of sectoral

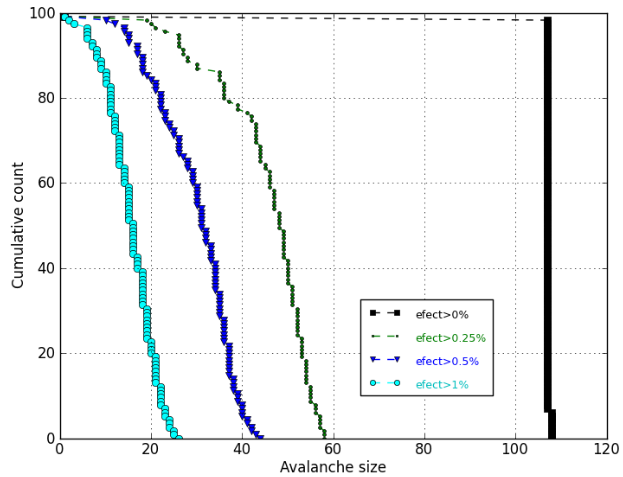

Figure 1: Avalanche size distributions for different effect thresholds as percentage of aggregate effect.

shocks. As the threshold increases, the number of sectors observed decreases. Even so, avalanches cover half of the economy. The homogeneity in avalanche sizes without a threshold is a direct result from using the input-output model, were the linear and fixed intersectoral relationships bring about the same diffusion of a shock.[5] To overcome this limitation, we explore the diffusion of a shock using network diffusion models. This type of models allow introducing threshold effects causing non linearities in the diffusion process without losing information and breaking the fixed technological relationships between sectors.

3.2 Model 2

In this section we report the results for the diffusion of a shock according to model two. For a shock, f, much smaller than the capacity threshold, c, the French economy experienced no avalanches ($A = 0$). Therefore we focus on results for $f/c > 1$. Results of this diffusion model for the French economy showed that the diffusion of a shock on technology triggers heterogeneous avalanche sizes thereby creating skewed distributions that differ according to the specification of the parameters, f and c.

The avalanche size distributions show diversity in sizes (figure 2), although in all cases the largest size is above 100 sectors. When the ratio was the largest (f/c=7), the largest avalanche size was 108 triggered by financial intermediaries, real-estate, computer and related activities, security and cleaning services, and hotels and restaurants. When the ratio was the smallest ($f/c = 1.5$), the largest

[5]This result confirms the results found in [Alatriste-Contreras and Fagiolo (2014)] for a more aggregate representation of an economy.

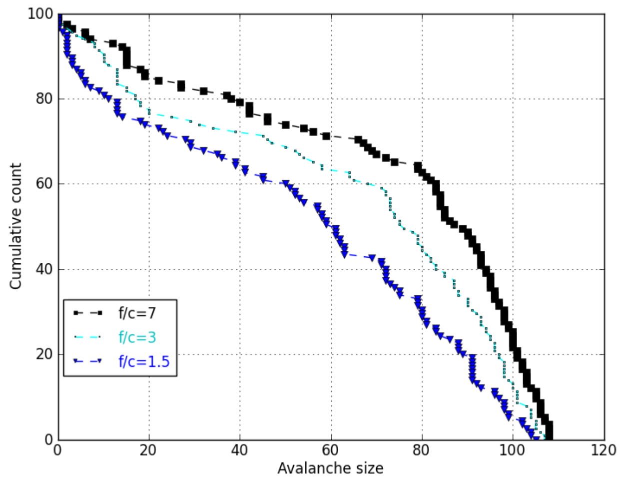

Figure 2: Avalanche size distributions for different c/f.

avalanche size was 105 triggered by security and cleaning services, telecommunications, computer and related services, hotels and restaurants, and the food industry. The frequency of avalanches above 105 sectors is the highest for the largest ratios. As the ratio decreases, the frequency of avalanches of size zero, one, or two sectors increases. The largest difference in avalanche size between a small and a large parameters' ratio is at around 85 sectors, where the probability to observe an avalanche this size doubles for the pessimistic scenario.

As the parameters ratio becomes smaller (lower f and higher c), the financial intermediaries and real-estate sectors lost their place as triggers of the largest avalanches and security, cleaning and other services, computer and related activities, hotels and restaurants, and telecommunications took their place. This result emphasizes the impact of a large shock on the financial sector on the rest of the economy when the system is weak and vulnerable. On the contrary, when the shock is smaller and the economy is more resilient, the financial sector has a smaller impact, although it still triggers large avalanches.

The sectors that triggered the smallest avalanche size in most of the cases were: tobacco and domestic services. As the parameters' ratio became smaller, the group of sectors that triggered the smallest avalanche size grew to include other sectors like photographic and optic materials and weapons and ammunition. The higher frequency of very small avalanche sizes gives evidence that as the f parameter gets smaller and the c parameter gets larger it is more difficult to trigger large avalanches, which increases the number of sectors that spread small avalanches.

Results for France of the asymmetric version of model 2 show smaller and more heterogeneous avalanche sizes (see figure 3). Nevertheless, the triggers of the largest and smallest avalanches are the same as with the symmetric model. The largest avalanche size when the f/c was the highest was 108 sectors, as with the symmetric model and was triggered by the sectors computer and related activities and professional services. In third and fourth place we found the sectors oil refining which triggered an avalanche of size 107 sectors, and the sector security cleaning and other services that triggered and avalanche of 104. For the lower parameters' ratios the avalanches are smaller in general and the triggers of the largest avalanches remain the same, although in different rankings.

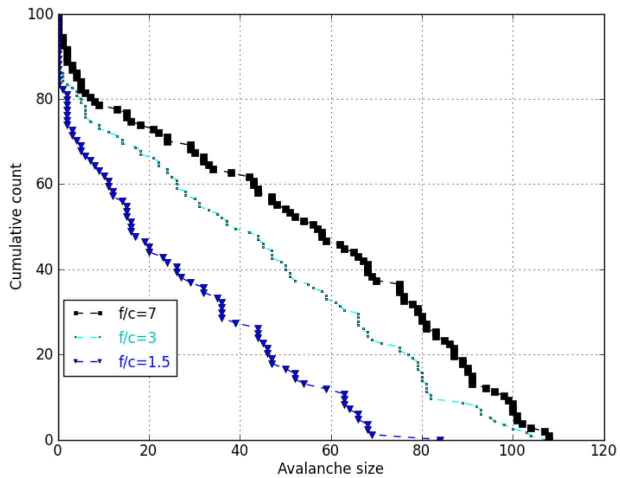

Figure 3: Avalanche Size Distributions for Asymmetric Model 2 and Different f/c in France.

3.3 Model 3

Results of the third diffusion model showed that when the economy can adjust to the effect of the shock, it experiences larger avalanche sizes. As a result, the frequency of medium and large avalanches increases, as the smallest avalanche sizes, compared to the results of model 2. The size of the largest avalanche was larger than with model two by one sector. The higher frequency of larger avalanches are a result of a self-reinforcing mechanism and positive feedback effects, where the economy becomes more fragile and reduces the flow of inputs throughout, turning sectors more vulnerable each time step. Therefore, the shock spreads easier creating larger avalanches.

In figure 4 we show the distributions for the simulation results using different parameters' ratios. We use the same ratios as with model two to be able to compare results. The avalanches are larger, but there still is a degree of heterogeneity in sizes displaying a skewed distribution. In particular, the probability to find an avalanche larger than half of the economy increased. We observe the larger change for the avalanche sizes of more than 80 sectors ($> 90\%$). Larger parameters' ratio bring about larger avalanches and more frequent very large avalanches.

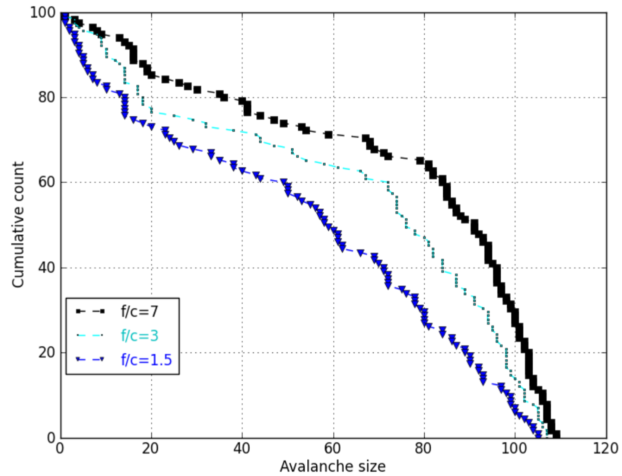

Figure 4: Avalanche size distribution with model 3 for different c/f.

The sectors that triggered the largest and smallest avalanches are similar to those found applying model 2. Examples include security, cleaning and other services, construction, and telecommunications for the triggers of the largest avalanches, and domestic services for the trigger of the smallest avalanches.

Results of the asymmetric version of model 3 show smaller avalanche sizes compared to the symmetric model 3 (see figure 5), therefore the reinforcing mechanism found with symmetric model 3 is weaker. The avalanche sizes are larger than with the asymmetric version of model 2. The largest avalanche sizes for the highest f/c was of 107 sectors triggered by oil refining, and 100 triggered by electricity production and distribution. For the lower f/c the largest avalanches decreased to 104 and 90 and were triggered by financial intermediaries and the sector advertising and market studies respectively. In every f/c case the smallest avalanche was of one sector.

Results suggest that updating in production reinforced the behavior found previously with model 2. It also gives evidence that the strongest mechanism to diffuse shocks on technology is the supply of inputs. When the shock changed only the supply of inputs, the avalanches that emerged were comparably large and only a few sectors smaller than those triggered with the symmetric models.

3.4 Characteristics of the Triggers of the Largest Avalanches

To explore the characteristics of the triggers of the largest avalanches applying the network diffusion models we compute different measures of centralities: the standard input-output total backward and forward linkages, indegree and outdegree centralities, and the authority and hub scores of sectors. Total backward and forward linkages are computed as the column sum of the Leontief inverse ($L = (I - A)^{-1}$) where $A = [z_{ij}/x_j]$, and the row sum of the output inverse

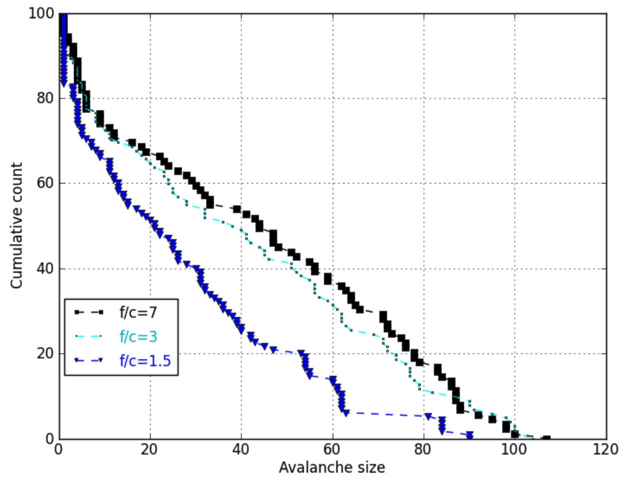

Figure 5: Avalanche Size Distribution with Asymmetric Model 3 for Different f/c.

($O = (I - G)^{-1}$ where $G = [z_{ij}/x_i]$) respectively [Miller and Blair (2009)]. Indegree and outdegree are the total number of direct incoming and outgoing connections that a sector has. Degrees are computed as the column and row sum of the boolean adjacency matrix which has entries equal to one if there exist a connection between two sectors and zero otherwise [Newman (2010)]. Finally, we compute the authority and hub scores of sectors. These measures give a ranking of sectors according to their global centralities taking into account positive feedbacks in the diffusion process of a shock. The scores are based on a mutually reinforcing relationship, where a good authority is pointed by a good hub and a good hub points to a good authority [Kleinberg (1999), Newman (2010)]. [6] In the input-output context, a good authority is a sector that buys inputs from equally important hubs or input suppliers thus, is highly connected, directly or indirectly, to other sectors through different production chains. Connections between sectors are appropriately weighted to take into account that the supply of inputs from a highly ranked sector is more important than that of a low ranked one.[7]

Table 1 shows the ranking of sectors according to the largest avalanche size, centralities, and size of production. The triggers of the largest avalanches in the French economy have high local and global centralities. Some of these sectors are also among the biggest ones in the French economy, pointing to the fact that

[6]These scores were originally applied to analyze web pages through the HITS (Hypertext Induced Topic Selection) algorithm. This algorithm assigns a hub score y_i and an authority score x_i to each node or web page, where the authorities are the most prominent sources of primary content, and hubs assemble high-quality guides and resource lists directing the users of web pages to recommended authorities [Kleinberg (1999)].

[7]For a more complete description of the interpretation of these measure in the input-output network see [Alatriste-Contreras (2015)].

Table 1: Ranking of the Triggers of the Largest Avalanches According to Structural Properties

Triggers	Authority Scores	Hub Scores	Out-degree	In-degree	Backward linkages	Forward linkages	Size
1. **Telecommunications**	7	10	3	17	85	20	12
2. **Professional services**	9	16	1	8	102	7	16
3. **Financial intermediaries**	2	3	1	21	87	63	7
4. **Real-estate**	4	9	4	13	112	100	1
5. **Security, cleaning and other services**	1	4	2	4	93	28	6
6. **Food industry**	33	26	5	2	43	34	109
7. **Computer and related activities**	11	15	1	9	100	16	11
8. **R&D**	108	84	7	1	86	109	72
9. **Electricity production and distribution**	24	25	1	11	73	67	21
10. **Hotel and restaurants**	16	14	116	33	76	43	9

they are "too big to fail". However, these sectors do not necessarily have high input-output total backward and forward linkages. This result gives evidence of the additional information that we can obtain from network measures of centrality.

4 Discussion

In this paper we evaluated different diffusion mechanisms through which a shock diffuses throughout the economy creating avalanches. The complex architecture of the French input-output network makes the economy vulnerable to a wide diffusion of shocks. The complexity implies high connectivity between sectors, and therefore a highly developed economy that uses a wide range of inputs to produce. However, this increased interconnectivity, at the same time, turns the economy more vulnerable to the emergence of large avalanches.

To investigate the emergence of avalanches in the economy we applied three diffusion models: the I-O model to evaluate the impact of a shock on final demand, and two types of network diffusion models where a shock on technology changes the flows of inputs and a second type of diffusion model has a second step in the diffusion process where production is updated after a shock.

Results of model one showed that the diffusion of the shock is homogeneous and very large but not very informative. To capture the heterogeneity in the avalanche sizes we must impose a threshold above which we count an effect of a shock as part of an avalanche. However, by imposing a threshold to count an effect as part of an avalanche we lose information because the maximum number of sectors that are part of an avalanche decreases considerably since most of the effects are small.

Comparably, avalanche sizes that emerged applying network diffusion models were heterogeneous and concentrated on medium an large sizes affecting more than half of the sectors in the economy. With these models we identified that the sectors that triggered the largest avalanches are predominantly services activities like financial intermediaries, real-estate, security cleaning and other services, and hotels and restaurants. On the other hand, the sector that triggered the smallest avalanches is domestic services, a sector that is practically isolated.

The third diffusion model brought about heterogeneous and larger avalanches. As a result, the frequency of large avalanches increased. When the system adjusts, as it happens in the real economy, the effects of a shock are reinforced through positive feedback effects that turn other sectors more vulnerable, facilitating the diffusion of shocks across the economy. The triggers of the largest avalanche sizes were similar to the ones found previously with model two.

Compared to the results found in [Alatriste-Contreras and Fagiolo (2014)], the network diffusion models applied to a finer granularity of the French input-output network implied that the largest avalanches covered a slightly smaller fraction of the economy. In the cited paper the largest avalanches in France covered 95 and 98 percent of the sectors whereas in our investigation the largest avalanches covered from 88 to 94 percent. This result is in part due to a lower connectivity. Nevertheless, a lower connectivity still triggers avalanches covering 90 percent of the economy.

Results for the asymmetric models showed that the supply of inputs is a strong mechanism to diffuse shocks throughout the economy. The avalanches that emerged with the asymmetric model are as large as the symmetric mechanism evaluated. This gives evidence that the supply of inputs is the most affected channel when a sector receives a shock.

Finally, results showed that the Input-output model does not allow disentangling the different diffusion mechanisms and the wide range of impacts of sectoral shocks. According to their role and importance in the economy, different sectors impact the economy in different magnitudes and through different channels. An example is the financial sector, which triggered the largest avalanche size applying the network diffusion models when the shock is large and the economy is fragile. This result points out the limitations of using linear and fixed relationships between sectors to model the diffusion of shocks and highlight the advantages of applying network diffusion models to evaluate the impact of sectoral shocks, incorporating non linear effects. Results have important insights for the policy-makers who can design policies taking into account the full spectrum of impacts of different types of sectoral shocks according to all channels of diffusion.

Future research avenues related to our investigation include analyzing other diffusion mechanisms such as the spreading of infectious diseases and analyzing the different impacts of a shock on the different components of final demand such as government expenditure or exports separately.

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