Diffusion in the French Input-output Network

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Outline

1. Research question
2. Related literature
3. Data and Methods
4. Structural Properties
5. Spreading Mechanisms in the input-output network
6. Discussion

Motivation

- Structure determines functionality and performance
- Structure of the economy can be represented by the input-output network: how sectors use output of other sectors as input to produce.
- Change in structure $\rightarrow$ Technological change due to:
  1. Changes in final demand of HH, Gov't, X, K,
  2. Changes in technology

Research question

- How to better capture linkages among sectors and how changes in structure impact the macroeconomy through these linkages?
- Are complex network measures useful tools to identify key sectors in the economy and make policy recommendations?

Related literature

Input-output Analysis:

- Interdependencies between sectors in an economy or region (Leontief, 1936,1967; Isard, 1951; Hewings et al., 1986).
- Backward and forward linkages, key sectors, and structural decomposition (Dietzenbacher and Los, 1998; Dietzenbacher, 1992; McGilvray,1977; Rasmussen,1956).

Input-output and network analysis:

- Network properties of the economy (Slater, 1978; Blochlet al., 2011; Xu, 2011; Wen-Qi Duan, 2012)
- Intersectoral linkages in a multisectoral macroeconomic model (Carvalho, 2010; Acemoglu et al., 2012).

Networks and diffusion:

- spread of ideas, innovations, diseases, failures (Kinney et al., 2005; Garal et al., 2010; Lee et al., 2011).

Data and Methods

Data

- Input-output table for France for 2007 provided by the INSEE: 116 sectors at current prices in euros

The Input-output Model

- The flow of products from one sector to another is captured in the interindustry transactions table z_{ij}:

Input-output Table of Interindustry Flows of Goods				
	Buying sector			
Selling sector		1	2	3
	1	z_{11}	z_{12}	z_{13}
	2	z_{21}	z_{22}	z_{23}
	3	z_{31}	z_{32}	z_{33}

- Output of a sector, x_i, is expressed as a function of the demand for inputs, $[a_{ij}] = [z_{ij}/x_j]$. In matrix form:

$$x = Ax + DF \Rightarrow x = (I - A)^{-1}DF = LDF \qquad (1)$$

where x is the production vector, $A = [a_{ij}]$ is the technical coefficients matrix, DF is the final demand of the exogenous sector (HH, Gov't, exports), and $L = [l_{ij}]$ is the Leontief inverse

Input-output Analysis: Linkages and Key Sectors

An increase in production has two effects:

$$\Delta x = x^1 - x^0 = LDF^1 - LDF^0 = L = I + A + A^2 + ... = (I - A)^{-1} \quad (2)$$

- **Total Backward linkages**: direct and indirect effects on demand. Measures the output needed to satisfy additional demand $\Delta x \rightarrow \Delta D$

$$BL(total)_{.j} = \sum_{i=1}^{n} l_{ij} = (I - A)^{-1} 1 \quad (3)$$

- **Total Forward linkages**: direct and indirect effects on supply. Measures additional output available to be used as inputs $\Delta x \rightarrow \Delta S$

$$FL(total)_{i.} = \sum_{j=1}^{n} l_{ij} = (I - A)^{-1} 1 \quad (4)$$

- **Key Sectors**: those with both linkages above average

The Input-Output Network

The matrix of technological coefficients gives rise to a weighted directed graph with self loops: A=[a_{ij}]=W=[w_{ij}]

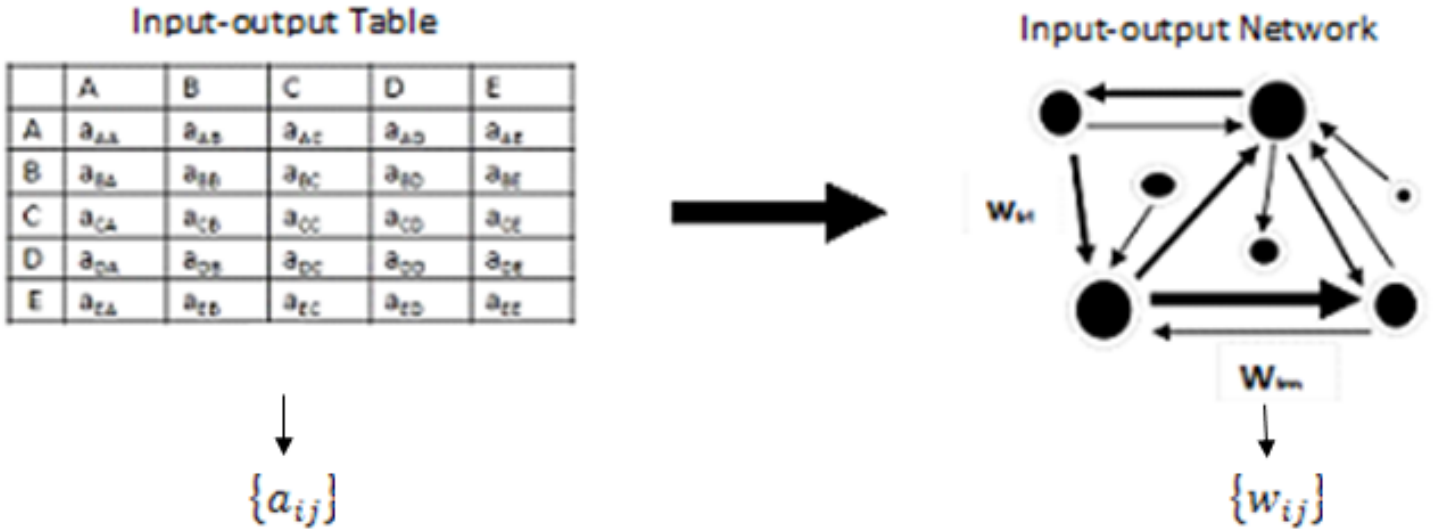

Figure : Construction of the input-output network. Nodes are sectors and weighted, directed edges represent economic relationships between sectors.

Complex Network Analysis

Network measures

- Measures of local centrality:
  - **In strength**: magnitude of economic relationship between a sector and its direct input suppliers

$$s^{in} = \sum_{j \neq i} a_{ji} = A^T 1 \tag{5}$$

  - **Out strength**: magnitude of economic relationship between a sector and its direct input buyers

$$s^{out} = \sum_{j \neq i} a_{ij} = A1 \tag{6}$$

- This measures are equivalent to the **direct linkage** measures proposed in Input-output analysis using the A matrix.

Authority and Hub Scores

Production of sector j increases. **Two chains of effects**:

1. 1. Demand of j for inputs increases; 2. Supply of inputs increase, but to do so sectors increase production; 3. To produce more they demand more inputs: D $\rightarrow$ S $\rightarrow$ D.
2. 1. Sector j increases supply of inputs; 2. Demand for inputs increase and production increases; 3. Supply of inputs increases: S $\rightarrow$ D $\rightarrow$ S.

$$s(j) \leftarrow \sum_{j \rightarrow i} d(i) \tag{7}$$

$$d(i) \leftarrow \sum_{i \rightarrow j} s(j) \tag{8}$$

$$\vec{s} \leftarrow A\vec{d} \Rightarrow \vec{s} \leftarrow AA^T\vec{s} \tag{9}$$

$$\vec{d} \leftarrow A^T\vec{s} \Rightarrow \vec{d} \leftarrow A^TA\vec{d} \tag{10}$$

This was a 1st round of effects. For higher order effects we iterate this process $k \rightarrow \infty$, this converges to the principal eigenvectors of AA^T and A^TA.

Complex Network Analysis

Measures of global centrality:

- **Authority scores**: a buyer that is pointed to by highly ranked (important) suppliers $\Rightarrow$ higher order effects on supply

$$X = (I - \lambda A^T A)^{-1} 1 \tag{11}$$

- **Hub scores**: a supplier that points to highly ranked (important) buyers $\Rightarrow$ higher order effects on demand

$$Y = (I - \lambda A A^T)^{-1} 1 \tag{12}$$

- Authority (hub) scores are the principal eigenvectors of $A^T A$ ($A A^T$).
- Mutually reinforcing relationship
- **Key sectors:** those with the highest authority score, hub score, or both.

Structural properties of the French input-output network

Input-Output Network, France 2007

Characteristic of the I-O network, France 2007	
Number of sectors	116
Interactions (number of edge weights>0)	7,983
Density	0.59
Percentage of sectors with self loops	90

Figure : Topology

Input-Output Network, France 2007

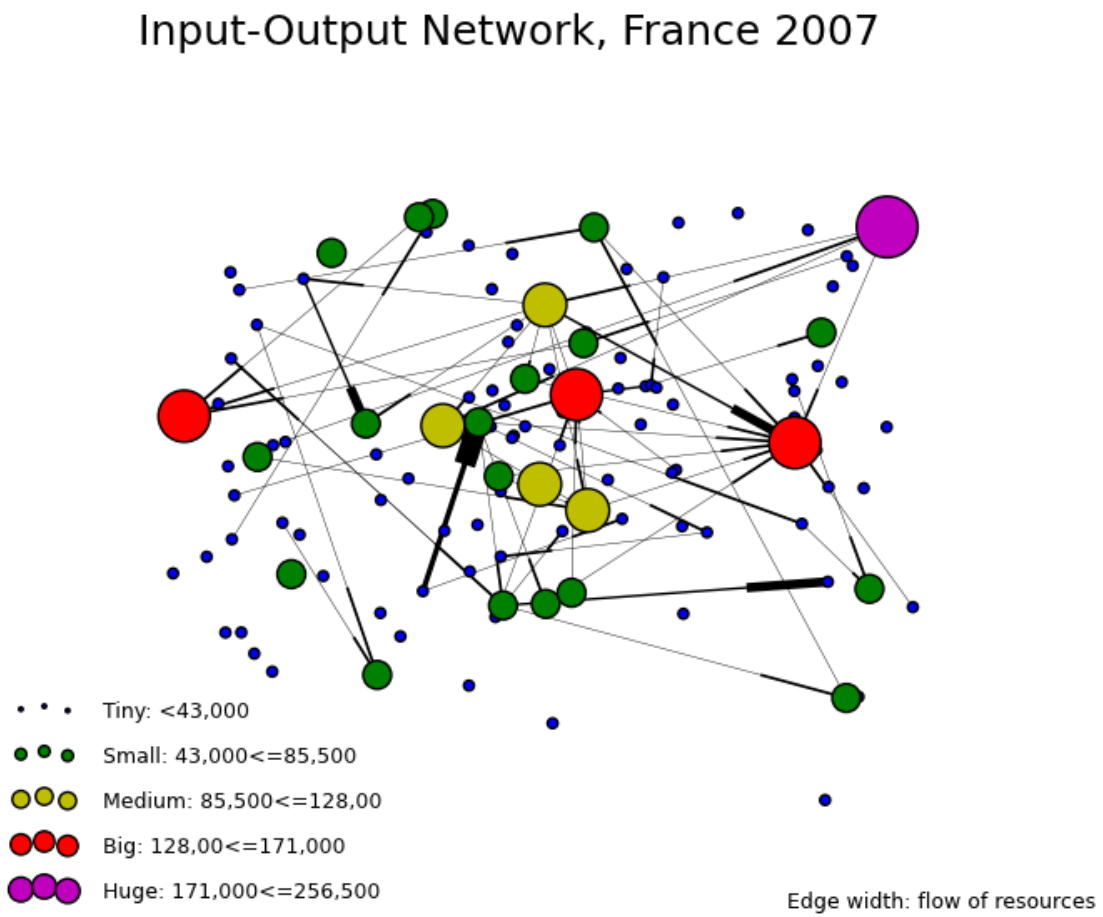

Figure : French input-output network. 25 percent largest transactions. Sectors' size and color is production level in million Euro.

Properties of the Input-Output Network, France 2007

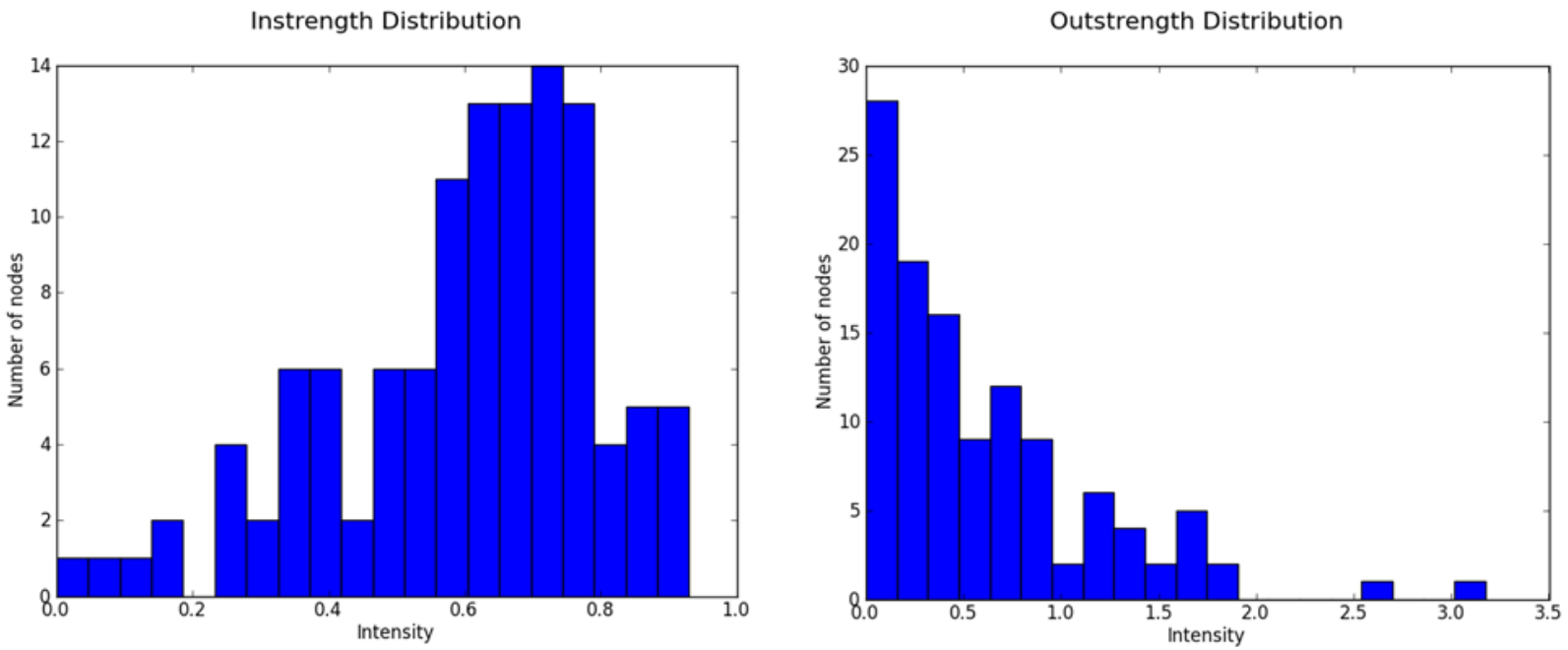

Figure : Strength Distributions

Properties of the Input-Output Network, France 2007

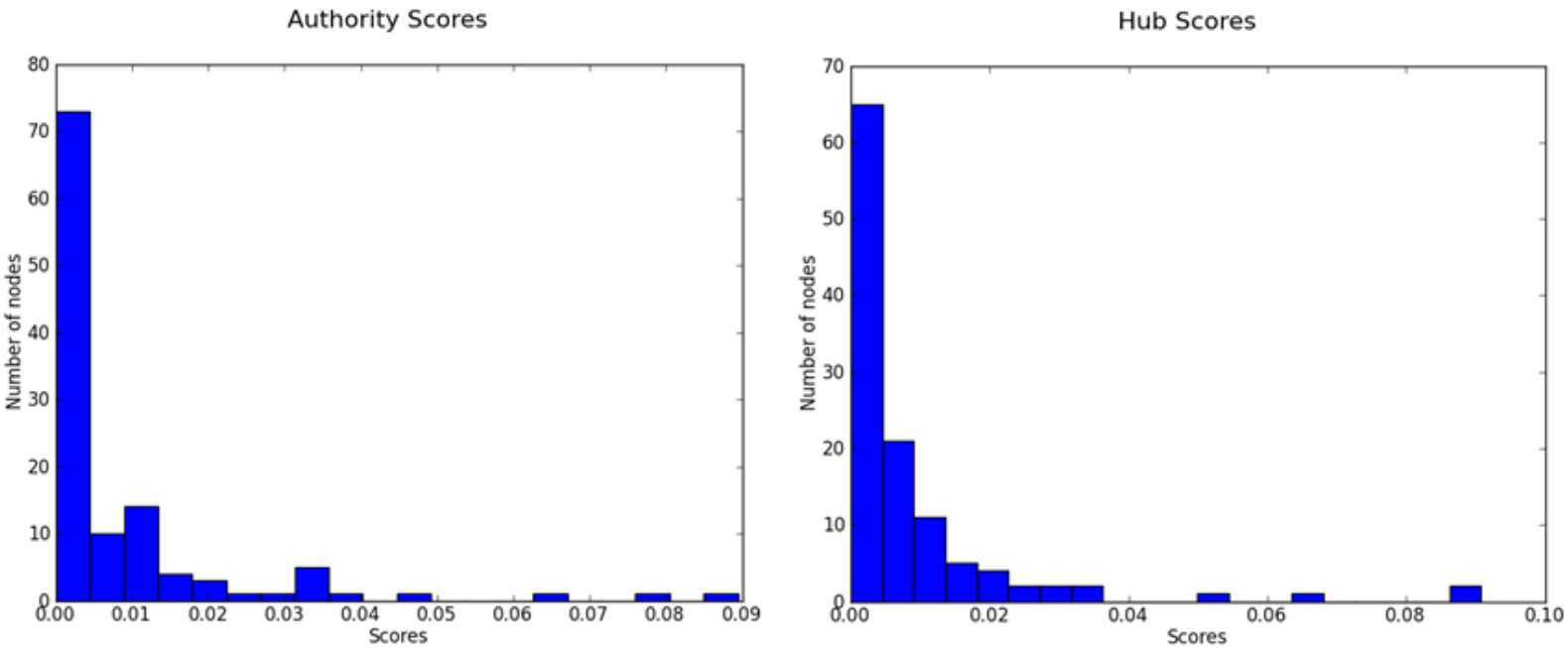

Figure : Authority and hub scores

Key Sectors, France

Key Sectors According to Standard IO Analysis					
Ranking (most to less important)	**Backward linkage**	**Forward linkage**	**Linkage Key sectors**	**Authority Score**	**Hub Score**
1	Aeronautics and space building	Security, cleaning and other services	Aeronautics and space building	Oil refining	**Metallic minerals extraction**
2	Automobile	Oil refining	Non-ferrous metals production	Security cleaning and other services	Oil refining
3	Non-ferrous metals production	Hydrocarbon extraction	Organic chemistry industry	Hydrocarbon extraction	Organic chemistry industry
4	Metallic minerals extraction	Financial intermediaries	Mineral chemistry industry	**Agriculture**	**Meat industry**
5	Artificial fibers	Steel industry and steel first transformation	Paper pulp and paper	Steel industry and steel first transformation	Milk industry
6	Mineral chemistry industry	Organic chemistry industry	Steel industry and steel first transformation	Organic chemistry industry	**Fuel production and distribution**
7	Reception devices fabrication	Professional services	Plastic materials transformation	Non-ferrous metals production	**Food industry**
8	Paper pulp and paper	Non-ferrous metals production	Para-chemistry	Metallic products fabrication	Steel industry and steel transformation
9	Milk industry	Business administration	Electrical material fabrication	Financial intermediaries	Reception devices fabrication
10	Steel industry and steel first transformation	Advertising and market studies	Oil refining	Advertising and market studies	**Motorcycle materials**

Diffusion

- **Distribution of effect of a shock**: An increase in output has effects on supply an demand which diffuse among sectors. If sector k received the shock:

$$D_k^D = 1 - (\sum_{j=1}^{n} (l_{jk} / \sum_{j=1}^{n} l_{jk})^2) \tag{13}$$

- 0<D<1
- Low D $\rightarrow$ more concentrated effect on one or few sectors

Diffusion of Effect and Aggregate Impact of Shock

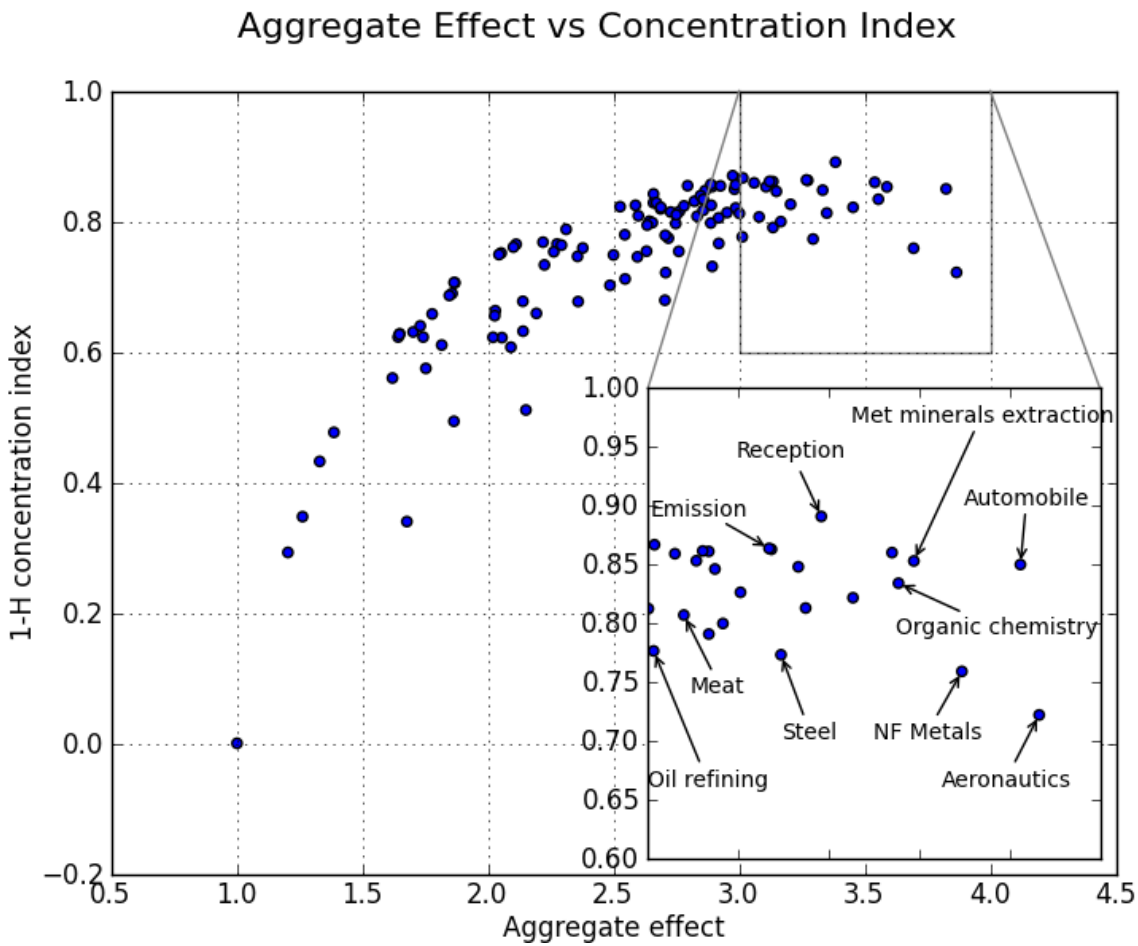

Figure : Aggregate effect on production and concentration of the effect

Diffusion of Effect of a Targeted shock, France

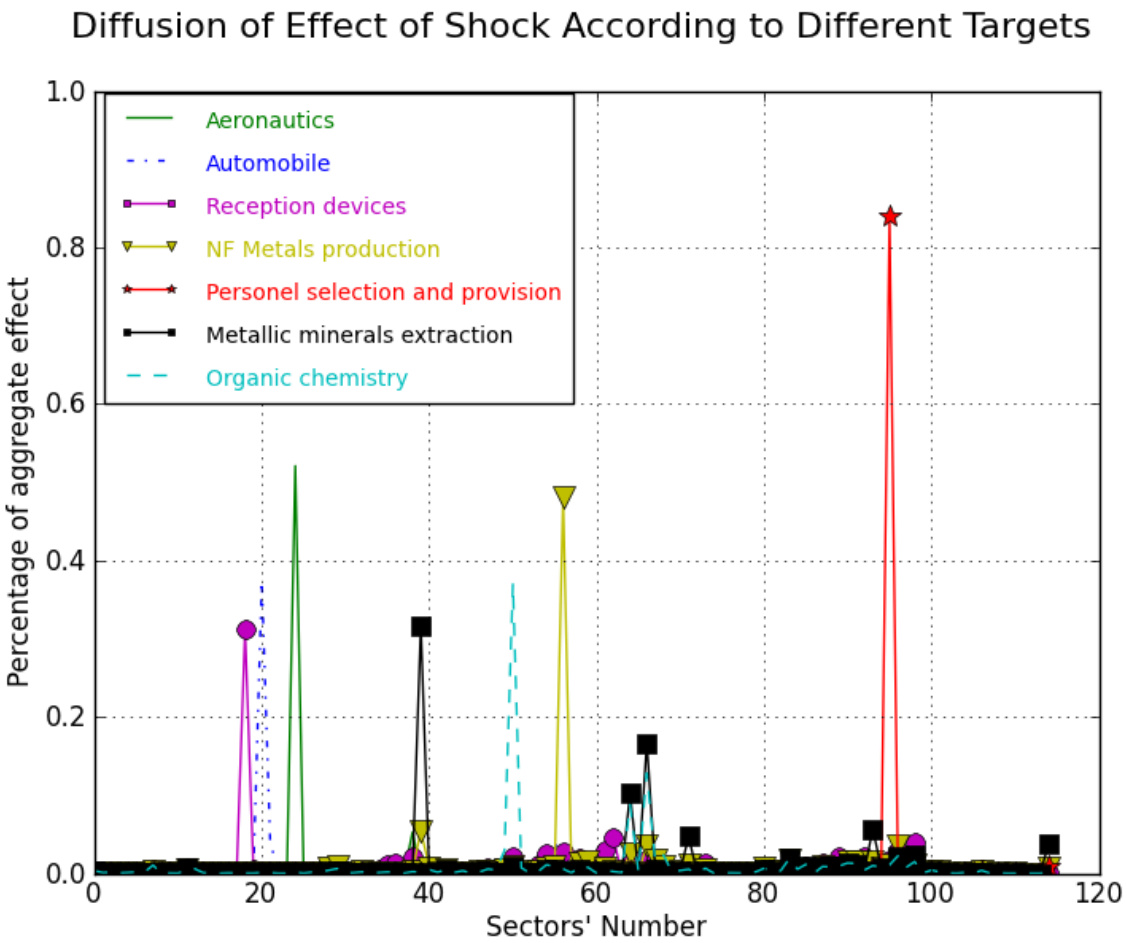

Figure : Diffusion of aggregate effect among sectors. Peacks show a high concentration of the effect.

Spreading Mechanisms

Avalanches: number of sectors affected by a propagating shock

- Shock on final demand
- Shock on technology

Spreading Mechanisms in IO model

IO Model: how is a shock on final demand spread throughout the economy? Sector j is part of an avalanche triggered by sector i if:

$$effect_j = (x_j^i - x_j) / \sum_{j=1}^{n} x_j^i = l_{ji} / \sum_{j=1}^{n} l_{ji} > threshold \qquad (14)$$

where x_j^i is production of j after a shock on final demand of i, x_j is original production of j, and l_{ji} is the element of the jth row and ith column of the L matrix (IO Model).

- normalized shock = 1 (a unit increase in final demand) and A matrix remains fixed

Avalanche Size with IO Model, France

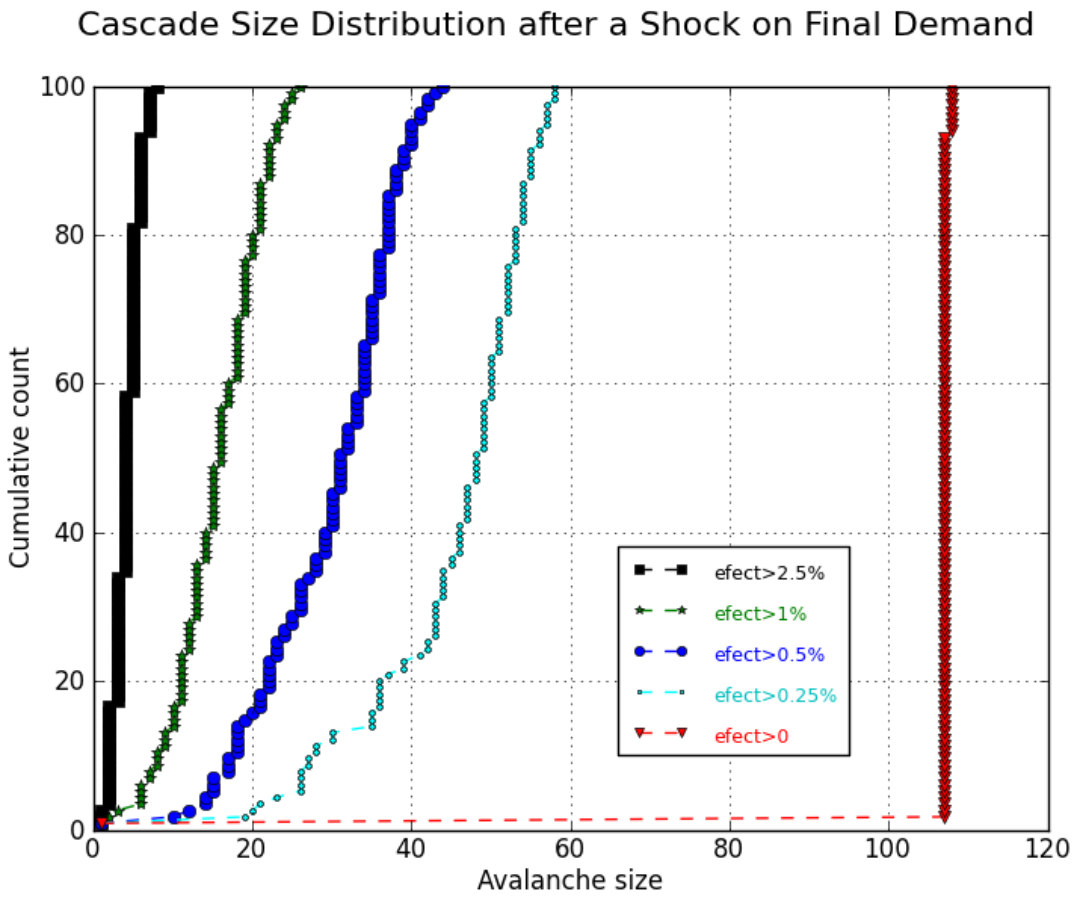

Figure : Avalanche size distribution according to different thresholds. Largest avalanches triggered by home appliances, weapons and ammunitions, and automobile equipment

A shock on technology

Model 1. How is a shock on technology spread from one sector to another? (Kinney et al., 2005; Lee et al., 2011)

- Node attribute: capacity x_i = each sector's production
- Edge attribute: weight $w_{ij} = z_{ij}$ economic transaction
- FD fixed and shock = $f * w_{ij}$ and is the same for all sectors
- A shock hits sector i. As a result, the supply and demand of inputs of sector i decrease by a fraction f.

$$w_{ij}^{*} = (1 - f)w_{ij}, 0 < f < 1 \tag{15}$$

- The shock spreads to j if:

$$\sum_{k \in N(j)} (w_{jk} + w_{kj}) > (t/f) * x_j \tag{16}$$

where t: capacity threshold, 0<t<1

Avalanche Size with Model 1, France

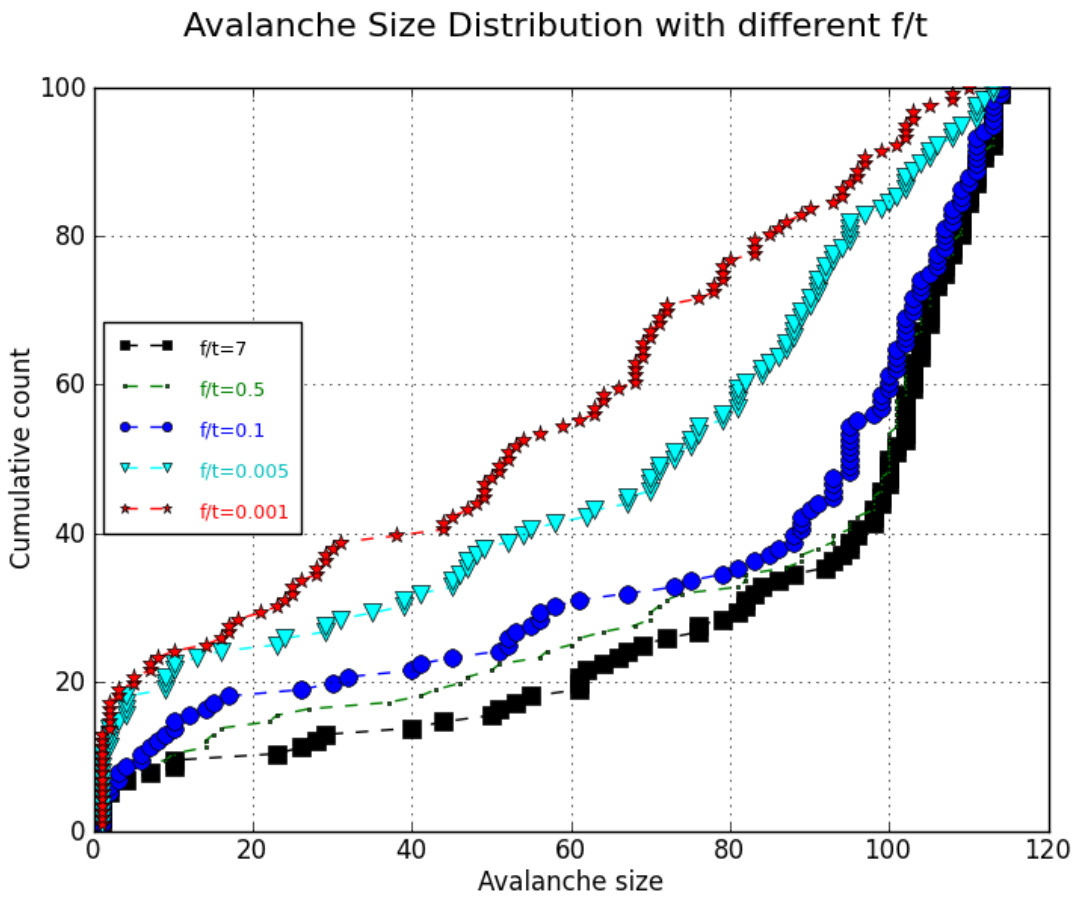

Figure : Avalanche size distribution according to different f/t.
Largest avalanches triggered by financial, oil refining and construction

A shock on technology

Model 2. A sector gets hit by a shock, then, its input supply and demand decrease by a fraction f. Following, production level gets updated according to the input-output model $(w_{ij}^* = (1-f)w_{ij} \rightarrow a_{ij}^* = z_{ij}^*/x_j)$.

$$x^* = (1 - A^*)^{-1} DF \tag{17}$$

Finally, the shock spreads to other sectors according to the same rule: if sector i received the original shock, for j in the neighbourhood of i, if:

$$\sum_{k \in N(j)} (w_{jk} + w_{kj}) > (t/f) * x_j \tag{18}$$

the shock spreads to j.

Avalanche Size with Model 2, France

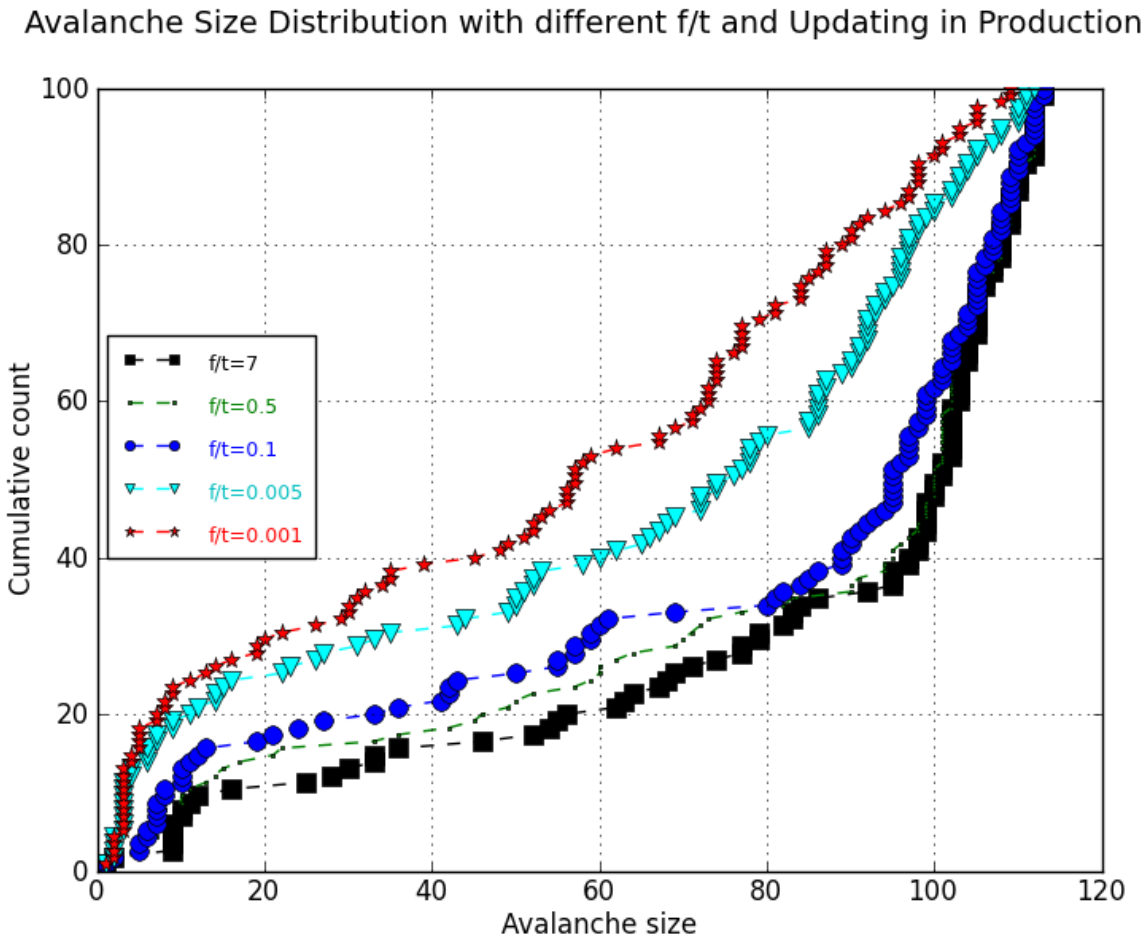

Figure : Avalanche size distribution according to different f/t and updating in production. Largest avalanches triggered by financial, oil refining, and electricity

Summary of Results

Structural properties

- Asymmetrical structure where sectors have different roles and are organized in a hierarchy which allows the identification of key sectors.
- Sectors with the widest diffusion of effect and a high aggregate effect on production have the highest authority and/or hub scores but not necessarily the highest (IO) linkages.
- Authority scores: higher order effects on supply of inputs.
- Hub scores: higher order effects on intermediate demand of inputs.

Results on Spreading Mechanisms

- **IO model**: every sector triggers large avalanches of same size (107 sectors)
- **Model 1**: heterogeneous but predominantly large avalanches
- **Model 2**: P(A>85%) decreased, but P(A<50%) increased $\rightarrow$ more small-med avalanches; P(50%<A<85%) mixed results
- Capacity threshold and weights distribution are stronger determinants of spreading mechanisms.
- Sectors that triggered the largest avalanches using model 1 are the same as using model 2 but different from IO model: financial, oil refining, and construction.

Discussion

- Authority and hub scores provide additional information taking into account higher order effects on supply and demand $\rightarrow$ ranking of sectors.
- Identification of key sectors in the economy leads to policy recommendations:
  - Good hubs that have high aggregate effect and good diffusion of a shock on FD
  - Triggers of large avalanches or good spreaders of a shock on technology
- Advantages of applying network analysis: spreading of a shock on technology different from spreading of a shock on final demand $\rightarrow$ beyond Input-Output model
- Analysing the structure of the economy and how it reacts to shocks as a first step to model its evolution.

Thank you for your attention!