Granular fluctuations: Theory and evidence

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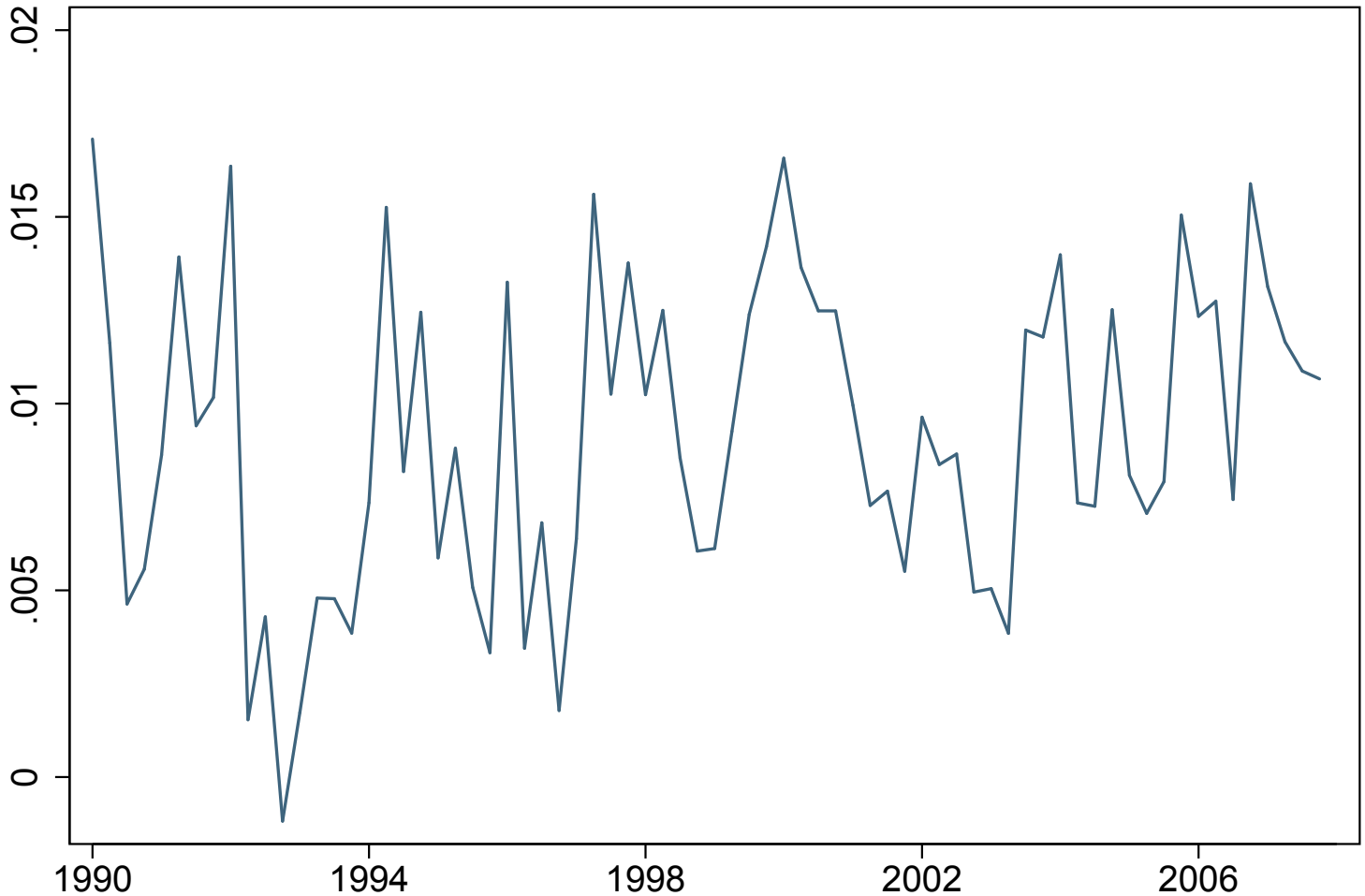
Motivating literature

- Most of the macroeconomic literature uses dynamic GE models in which **aggregate fluctuations** are driven by **aggregate shocks**
  - See the RBC/DSGE literatures in a closed economy, Backus, Kehoe and Kydland (1995) in an open-economy context
  - Microeconomic shocks neglected on the ground of a "law of large numbers" argument
  - Need to feed models with quite volatile aggregate processes to match the evidence on macroeconomic volatility
  - Unable to replicate other BC stylized facts such as the trade-comovement correlation (Johnson, 2014)
- Recent works challenge this view : **Idiosyncratic shocks** to individual firms or sectors might generate significant volatility

Motivating literature

FIGURE – French Business Cycle Fluctuations



Note : Standard deviation of quarterly growth rates .004 (mean growth rate over the period .009). Source INSEE

Motivating literature (ii)

- The **microeconomic origin** of aggregate fluctuations
  - Gabaix (2011) : **"Granular fluctuations"**
    When the distribution of firms' size is fat-tailed, shocks to the largest firms in the economy do not compensate with shocks to small firms
  - Acemoglu et al (2012) : **"Transmission of shocks in networks"**
    When there are sufficiently strong interconnections between firms/sectors, shocks to upstream units propagate throughout the value chain (see also Long and Plosser, 1983)

$\Rightarrow$ The concentration of firms' size distribution and/or of IO networks prevents microeconomic shocks to cancel out in the aggregate with an end-effect on macroeconomic fluctuations

This talk : Empirical evidence

- The role of large firms as a driver of macroeconomic volatility
- Amplifying mechanisms :
  - Large firms in IO networks
  - Large firms in international markets
  - Large firms and large business groups

A sketch of the theoretical argument

Intuition : Granular fluctuations

- When the distribution of firms' size is fat-tailed, the variance of the distribution is not finite and the central limit theorem does not apply
- Micro shocks need not average out in the aggregate : Shocks to the largest firms in the economy do not cancel out with shocks to small firms
- "Aggregate" fluctuations can be generated by a relatively low level of idiosyncratic risk (Gabaix, 2011)

Intuition : Propagation in Networks

- Initially idiosyncratic shocks might propagate in network economies with an amplified end-effect on (equilibrium) aggregate fluctuations
- Acemoglu et al (2012) : IO relationships create real transmission channels for such shocks $\Rightarrow$ Shocks to the productivity of upwards firms affect their (equilibrium) prices, thus the costs of inputs at the level of downward firms
- For the aggregate end-effect to be substantial, it must be that these shocks do not cancel out, which happens if IO networks are sufficiently asymmetric

Anecdotal evidence

- In 2000, Nokia contributed 1.6 percentage points of Findland's GDP growth (OECD, 2004)
- " The sales of Apples new device [iPhone5] could add as much as half a percentage point to U.S. fourth quarter GDP, according to JPMorgan" (CNBC, Sept. 17, 2012)
- Domino effect across production chains in the French economy due to poor performances at Renault and Peugeot ; e.g., a job lost in Renault leads to 2 or 3 disappearing in parts makers (Le Point, July 23, 2012)

A simple model : Assumptions

- Consider an economy made of N entrepreneurs, indexed by f, each one being characterized by its size at time t, S_{ft}
- The only source of volatility are idiosyncratic shocks to firms :

$$g_{S_{ft}} \equiv \frac{\Delta S_{ft}}{S_{ft-1}} = \sigma_f \varepsilon_{ft}$$

where σ_f is firm f's volatility and ε_{ft} an idiosyncratic shock of mean 0 and variance 1

- Total GDP is defined as $Y_t = \sum_f S_{ft}$ thus GDP growth :

$$g_{Y_t} \equiv \frac{\Delta Y_t}{Y_{t-1}} = \sum_f \sigma_f w_{ft-1} \varepsilon_{ft}$$

with $w_{ft-1} \equiv \frac{S_{ft-1}}{Y_{t-1}}$ the share of f in the aggregate

A simple model : Macroeconomic Volatility

- When shocks are uncorrelated and the relative size of firms is constant, the standard deviation of GDP growth (the "macroeconomic volatility") is :

$$\sigma_Y = \left[\sum_f \sigma_f^2 \left(w_f\right)^2\right]^{1/2}$$

- If the volatility of individual firms is homogenous ($\sigma_f = \sigma \quad \forall f$) :

$$\sigma_Y = \sigma \left[\sum_f \left(w_f\right)^2\right]^{1/2} = \sigma\sqrt{Herf}$$

- Numerical exemple (di Giovanni et al, 2014) : Take $\sigma = .2$ and $N = 1,024,770$,
  - If $Herf = 1/N$, $\sigma_Y = .0002$
  - If $Herf = .0011$, $\sigma_Y = .0067$

A simple model : General results

- If the size distribution is uniform

$$\sigma_Y = \frac{\sigma}{\sqrt{N}}$$

- If the size distribution has finite variance

$$\sigma_Y = \frac{E[S^2]^{1/2}}{E[S]} \frac{\sigma}{\sqrt{N}}$$

(Converges to 0 at rate $1/\sqrt{N}$)

A simple model : General results

- If the size distribution is a power law $P(S > x) = ax^{-\xi}$ with $\xi \geq 1$:

$$\begin{array}{lcll} \sigma_Y & \sim & \frac{\nu_\xi}{\ln N}\sigma & \text{for} \quad \xi = 1 \\ \sigma_Y & \sim & \frac{\nu_\xi}{N^{1-1/\xi}}\sigma & \text{for} \quad 1 < \xi < 2 \\ \sigma_Y & \sim & \frac{\nu_\xi}{N^{1/2}}\sigma & \text{for} \quad \xi \geq 2 \end{array}$$

  where ν_ξ is a random variable that is independent of N and σ

$\Rightarrow$ Implications :

- If the size distribution has thin tails ($\xi > 2$), σ_Y decays at rate $1/\sqrt{N}$
- With a fat tail distribution, σ_Y decays much more slowly
- Zipf law ($\xi = 1$) : Top K firms account for a finite (as opposed to infinitesimal) fraction of aggregate output $\rightarrow$ "Granularity"

A simple model : Remarks

- In the data, microeconomic shocks will generate a substantial amount of aggregate volatility whenever the Herfindahl of sales is "large" enough (i.e. Zipf is not necessary, a lognormal distribution with high variance would work as well)
- When the volatility of individual firms is decreasing in their size (i.e. $\sigma_f(S_{ft}) = kS_{ft}^{-\alpha}$, $\alpha > 0$), as observed in the data, the contribution of large firms to aggregate volatility is reduced, but still substantial under reasonable parametric value for α

Extension to IO networks

- When firms/sectors are inter-related through IO linkages, the "size" of a firm is larger than its contribution to aggregate GDP
- Gabaix' results generalize to an economy with intermediate goods but the proper definition of the Herfindahl index is based on Domar weights :

$$Herf = \sum_f (w_f)^2, \quad w_f = \frac{Sales_f}{GDP}, \quad \sum_f w_f > 1$$

- Acemoglu et al (2012) : In IO networks, large/central firms not only contribute more to aggregate GDP. Their links with other firms/sectors can also be a *propagation channel* for idiosyncratic shocks $\Rightarrow$ Amplification mechanism

Extension to IO networks

- With IO linkages, productivity shocks to upwards firms transmit to downward firms through input prices
- Role of networks as an amplification mechanism depends on their shape :
  - Symmetric networks induce perfect diversification :

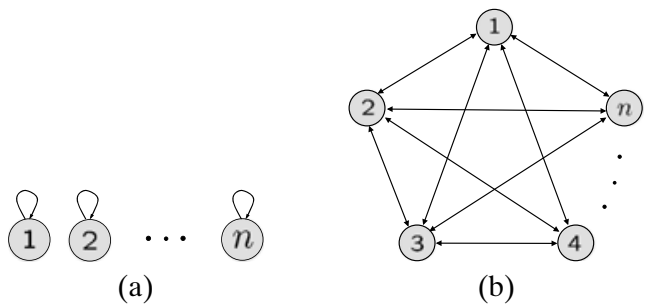


FIGURE 1.—The network representations of two symmetric economies. (a) An economy in which no sector relies on other sectors for production. (b) An economy in which each sector relies equally on all other sectors.

$\Rightarrow$ Idiosyncratic shocks average out rapidly (at the rate $\sqrt{N}$)

Extension to IO networks

- With IO linkages, productivity shocks to upwards firms transmit to downward firms through input prices
- Role of networks as an amplification mechanism depends on their shape :
  - Symmetric networks induce perfect diversification
  - "Star networks" display extreme amplification

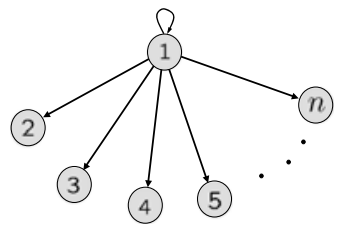


FIGURE 2.—An economy where one sector is the only supplier of all other sectors.

$\Rightarrow$ Idiosyncratic shocks do not average out, even when N tends to infinity

Extension to IO networks

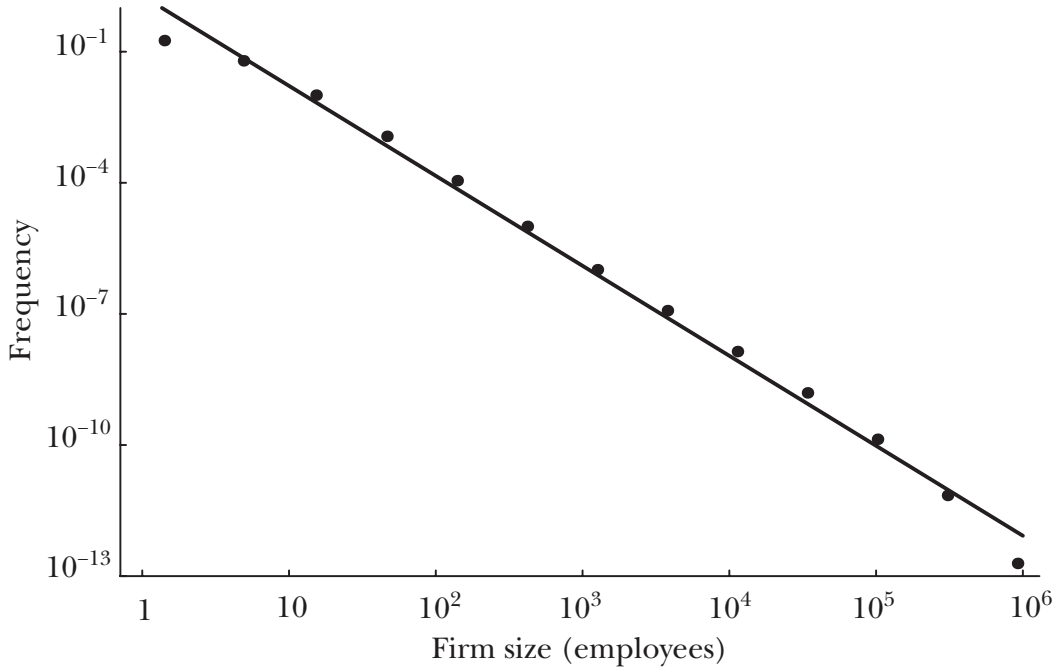
- With IO linkages, productivity shocks to upwards firms transmit to downward firms through input prices
- Role of networks as an amplification mechanism depends on their shape :
  - Symmetric networks induce perfect diversification
  - "Star networks" display extreme amplification
  - More generally, the rate at which the aggregate impact of idiosyncratic shocks vanishes is small when :
    i) first-order interconnections are highly concentrated (a single firm/sector is a supplier to a disproportionally large number of firms/sectors), or
    ii) high-order interconnections are important (a single firm/sector is at the top of a long chain of interconnections)

Empirical evidence : Granular fluctuations

Concentration of firms' size distributions

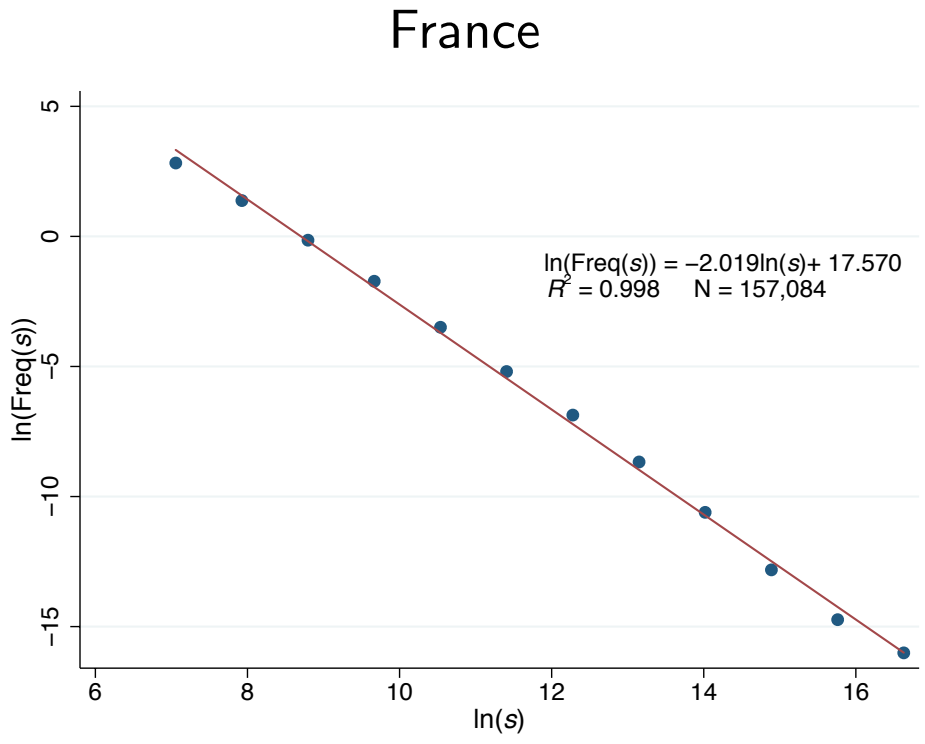
United States

Log *Frequency* versus log *Size* of US firms (by Number of Employees) for 1997



Source: Axtell (2001).
Notes: Ordinary least squares (OLS) fit gives a slope of 2.06 (s.e. = 0.054; $R^2 = 0.99$). This corresponds to a frequency $f(S) \sim S^{-2.059}$, which is a power law distribution with exponent 1.059. This is very close to an ideal Zipf's law, which would have an exponent $\zeta = 1$.

Concentration of firms' size distributions



(b)

Notes: This figure reports the estimated power laws in firm size based on total sales and all firms. The power laws are estimated with two different methods, the cdf (panel a) and the pdf (panel b).

Source : di Giovanni et al (2011)

The share of big firms in aggregate activity

- In Korea, the 10 biggest business groups account for 54% of GDP (among which 23% is attributable to the largest one, Samsung) (di Giovanni and Levchenko, 2012)
- In the US, the top 50 firms account for 25% of output (Gabaix, 2011)
- In France, the top 100 (non-financial) firms represent 22% of aggregate value added (di Giovanni et al, 2016)

Evidence on granular fluctuations

- Gabaix (2011) : One third of US GDP fluctuations accounted for by the top 100 firms
- di Giovanni et al (2014)
  - Variance decomposition allowing to separate in disaggregated data "macro" (sector×country) and "individual" (firm× destination) components :

$$gs_{fnt} = g_{njt} + \varepsilon_{fnt}$$

  - Contribution of "individual" components to aggregate fluctuations :

$$\frac{StDev\left(\sum_{f,n} w_{fnt-1}\varepsilon_{fnt}\right)}{StdDev(g_{Y_t})}$$

  - Contribution substantial if the distribution of sales is sufficiently fat-tailed and/or if there is sufficient comovements in sales across firms :

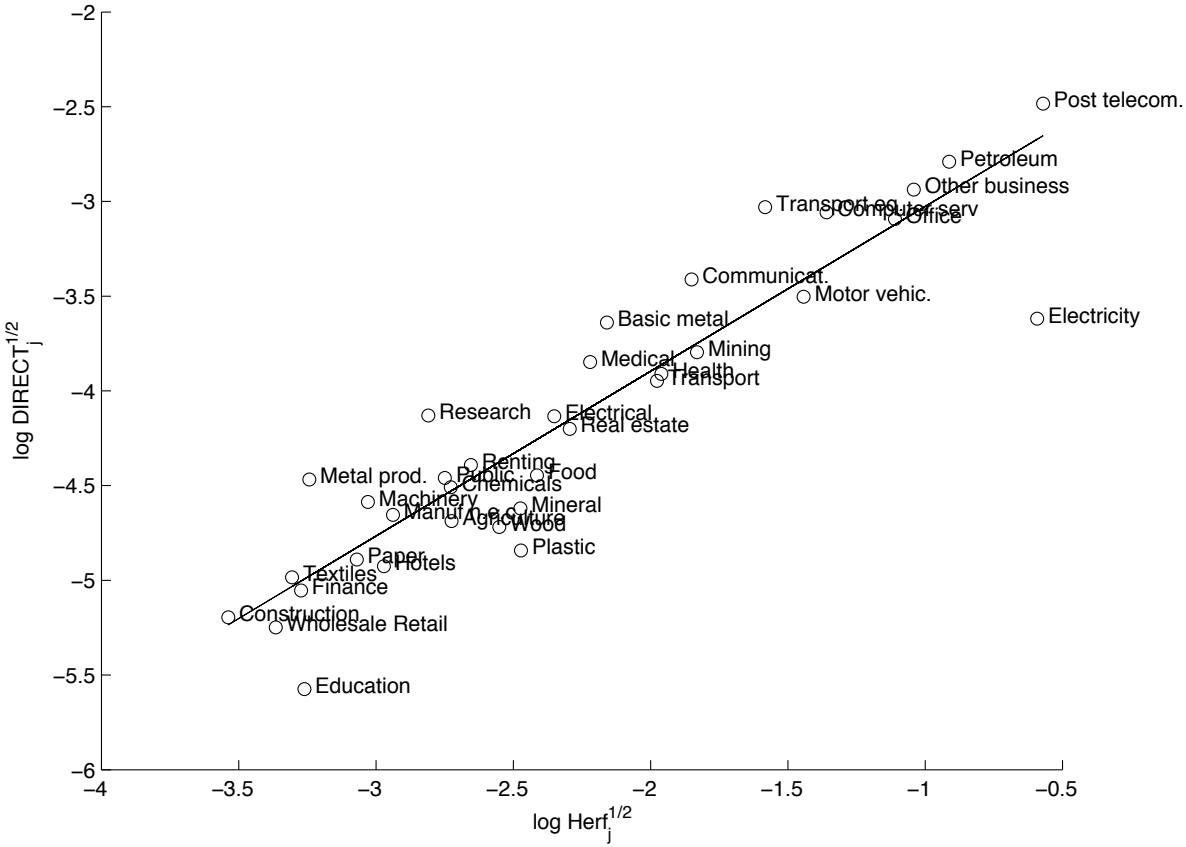
$$Var\left(\sum_{f,n} w_{fn}\varepsilon_{fnt}\right) = \underbrace{\sum_{f,n} w_{fn}^2 Var(\varepsilon_{fnt})}_{DIRECT} + \underbrace{\sum_{g\neq f, m\neq n}\sum_{f,n} w_{fn}w_{gm}Cov(\varepsilon_{fnt},\varepsilon_{gmt})}_{LINK}$$

Evidence on granular fluctuations

	Whole Economy		*Manufacturing Sector*	
	(1)	(2)	(3)	(4)
	St. Dev.	Relative SD	St. Dev.	Relative SD
I. Total Sales				
Actual	0.0206	1.0000	0.0244	1.0000
Firm-Specific	0.0165	0.8010	0.0168	0.6885
Sector-Destination	0.0109	0.5291	0.0157	0.6434
II. Domestic Sales				
Actual	0.0196	1.0000	0.0231	1.0000
Firm-Specific	0.0154	0.7857	0.0151	0.6537
Sector-Destination	0.0112	0.5714	0.0167	0.7229
III. Export Sales				
Actual	0.0361	1.0000	0.0374	1.0000
Firm-Specific	0.0304	0.8421	0.0287	0.7674
Sector-Destination	0.0129	0.3573	0.0153	0.4091
IV. Value Added				
Actual	0.0210	1.0000	0.0215	1.0000
Firm-Specific	0.0190	0.9048	0.0184	0.8558
Sector-Destination	0.0107	0.5095	0.0123	0.5721

Notes : The variance components do not add up to the actual variance due to unreported covariance terms. Source : di Giovanni et al. (2014)

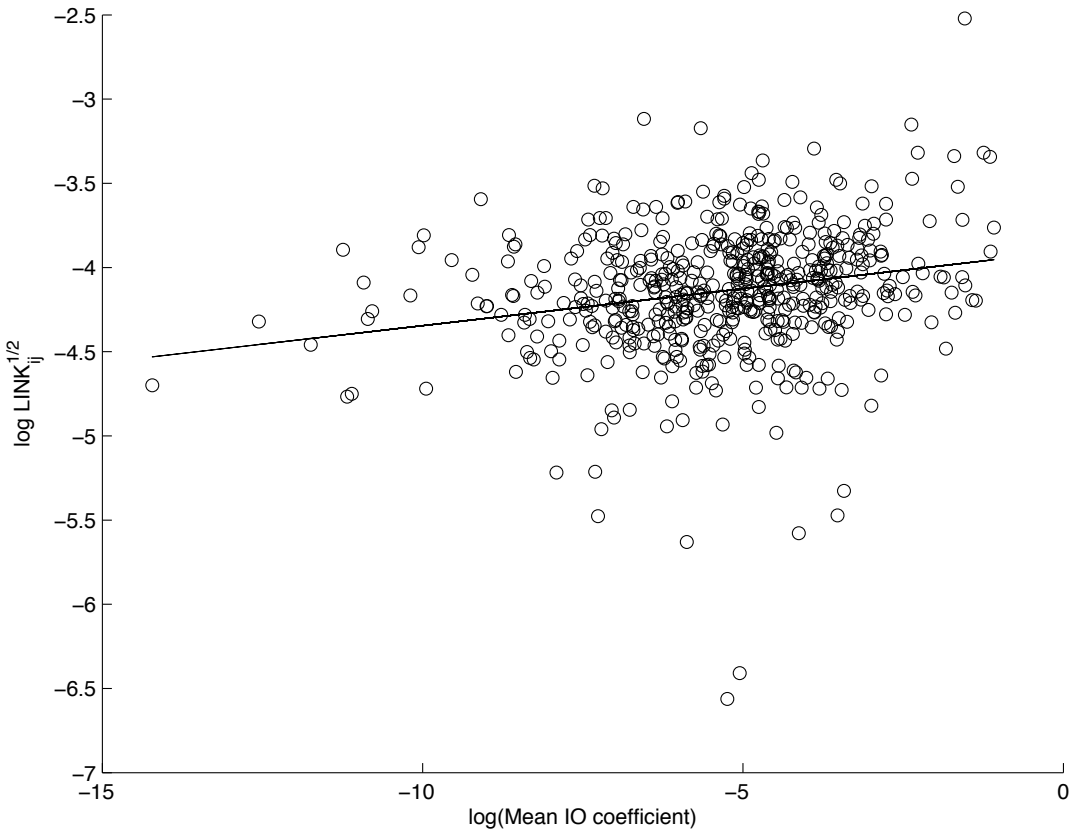
Evidence on granular fluctuations



Source : di Giovanni et al (2011)

"DIRECT" term accounts for 25-40% of "granular" fluctuations

Evidence on granular fluctuations



Source : di Giovanni et al (2011)

"LINK" term accounts for 60-75% of "granular" fluctuations

Amplification mechanisms

Large firms in IO networks

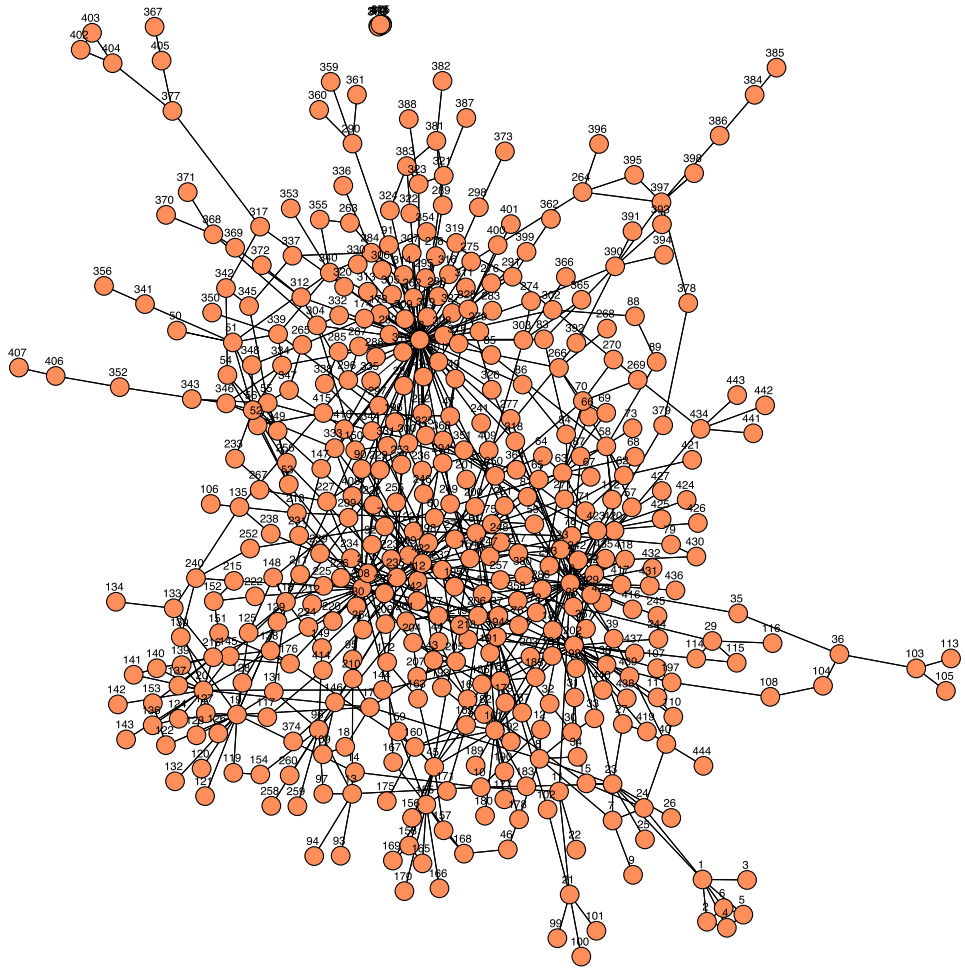


FIGURE 3.—Intersectoral network corresponding to the U.S. input–output matrix in 1997. (Source: Bureau of Economic Analysis. See Section 4 for more details on the data.) Each vertex corresponds to a sector in the 1997 benchmark detailed commodity-by-commodity direct requirements table. For every input transaction above 5% of the total input purchases of a sector, a link is drawn between that sector and the input supplier.

Source : Acemoglu et al (2012)

Large firms in IO Networks

- De Bruyne et al (2017) : Use Belgian firm-to-firm data
- Stylized facts on firm-to-firm IO networks :
  - 3.5 millions F2F relationships in a sample of 80,000 firms
  - 67,000 firms have at least one business customers (Median=11 business customers)
  - Almost all firms have at least one supplier (Median=28 suppliers)
  - Highly skewed distribution of firms' size / of firms' influence factor
- Consequences for granular fluctuations :
  - Once indirect influences are taken into account, top 100 firms account for about 90% of the volatility
  - The most central firms are found in a number of business services (Distribution of fuels, Renting of light vehicles, Temporary employment agencies), and a couple of manufacturing sectors (Basic chemicals and motor vehicles)
  - Distribution of the firm-level influence vectors is closed to a log-normal

Large firms in international markets

- These phenomena are further reinforced in an **open-economy context** because
  - Firms engaged in international markets are large, on average (Bernard and Jensen, 1995, Mayer and Ottaviano, 2007) ▸ Graph
  - Trade liberalization makes large firms even larger (Pavcnik, 2002, Bernard et al., 2003)
  - Large firms are also more likely to engage in multinational activities (Helpman et al., 2004)
  - Globalization has induced an increasing international vertical fragmentation of production processes (Hummels et al, 2001)

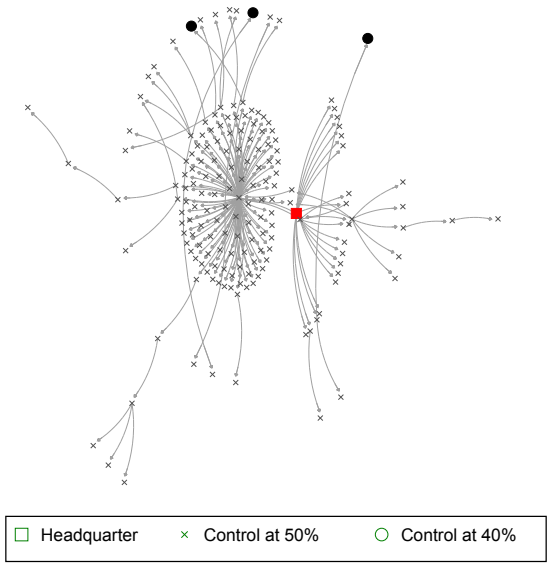
$\Rightarrow$ International markets characterize by their granularity and the magnitude of interdependence between firms

Large firms in international markets

- Consequences for aggregate fluctuations (di Giovanni and Levchenko, 2012)
  - Opening to trade increases the importance of large firms, thus the amount of granular fluctuations
  - Trade increases volatility by up to 15-20% for small open economies like Denmark or Romania
- Consequences for the transmission of shocks across countries (di Giovanni et al, 2017)
  - Firms at the top of the distribution are more likely to export, import, be part of multinational companies
  - Being "internationally connected" is associated with significantly more correlation between the firm's value added and the foreign country's GDP
  - Transmission of shocks through firm-to-country linkages explain around one third of the aggregate comovement

Large firms and large business groups

- The boundary (thus the size) of a firm is an endogenous variable
- For instance, financial linkages across firms create a network of firm-to-firm interactions that decomposes into "business groups" (Lelarge, 2017)



Sources: LIFI files, 2012. Domestic units only.

Source : Lelarge (2017)

Large firms and large business groups

- The boundary (thus the size) of a firm is an endogenous variable
- For instance, financial linkages across firms create a network of firm-to-firm interactions that decomposes into "business groups" (Lelarge, 2017)
- The structure of these business groups has consequences for how volatile they are and thus, given their size, how much they add to macroeconomic fluctuations
    1. Are idiosyncratic shocks diversified within a group ?

$$\sigma_{BG} = \left[\sum_{f \in BG} \sigma_f^2 \left(w_f \right)^2 \right]^{1/2}$$

    2. Do financial linkages create transmission mechanisms for idiosyncratic shocks within the group ?

$$\sigma_{BG} = \left[\sum_{f \in BG} \sigma_f^2 \left(w_f \right)^2 + \sum_{f} \sum_{f' \neq f} \sigma_{ff'} \left(w_f w_{f'} \right) \right]^{1/2}$$

Large firms and large business groups

- Lelarge (2017)
  - Around 250,000 ($\approx$ 25%) of French firms belong to a "Business group", they constitute around 85,000 such business groups and represent 60% of aggregate value added
  - Firms affiliated to a business group are 5-10% more volatile than firms that do not (everything else equal)
  - Firms at the top of the hierarchy are significantly more volatile
  - (Some) evidence that firms comove positively, within a business group

$\Rightarrow$ The constitution of large business groups between volatile and positively correlated firms might expose the economy to even more granularity

Conclusion

- Under some conditions regarding the micro-structure of the economy, shocks to individual firms can generate a substantial amount of "macroeconomic" volatility
- These conditions are empirically relevant, especially in modern, internationally integrated and vertically fragmented production processes
- Remaining questions :
  - How can we explain that such conditions arise, in equilibrium ?
  - Welfare implications

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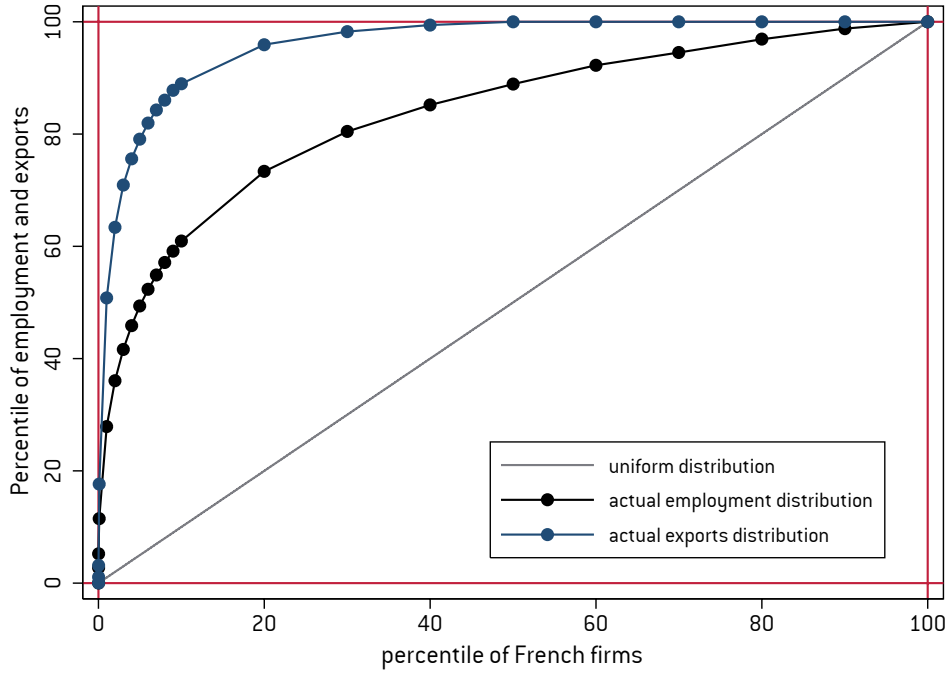
The "Happy few"



Source : Mayer and Ottaviano (2007).

- The top one percent of French firms is responsible for 68% of aggregate exports (44% in the sample of EAE firms)
- In the manufacturing sector only 17.4% of firms exports and 34% of exporters serve a single market
- The distribution of exports is even more skewed than the distribution of employment

Back