Financial Shocks Propagating in a Large Economy: Theory and Application

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Motivation

- **Financial networks**: monetary shocks that
  - originate in *credit* or *liquidity* unanticipated disturbances
  - propagate through *lending/borrowing* or *ownership/securitization* relationships among banks and financial institutions.

  (Acemoglu *et al.*, 2014; Elliott et al., 2014; Cabrales et al. 2017, RFS)
- **Production networks**: real shocks that
  - originate in changes in *productivity* or *demand*, or natural *disasters*
  - propagate through *transactions* (sales/purchases) across prod. firms

  (Magerman et al., 2018; Acemoglu et al., 2015; Carvalho et al., 2018)
- **This paper**:
  studies the interplay btw financial and production networks, focusing on the propagation of financial shocks through the production network

  Important phenomenon, often highlighted, but mostly unexplored!

... more concretely ...

we proceed on the theoretical and empirical fronts as follows:

1. build a simple model of production networks with financial distortions/shocks (Bigio-La'O 2016, WP; Baqaee-Farhi 2018, WP)
2. use universal data (Credit Registry) on bank-to-firm and bank-to-bank connections to identify bank-supply shocks in 2008-09 financial crisis
3. rely on universal data (VAT) of firm-to-firm transactions in Spain to construct empirical counterpart of firm-level production network
4. matching the two data-sets in ② and ③ and applying the theory in ① compute *direct* bank-to-firm and *indirect* firm-to-firm contagion effects
5. test the theory by using the effects computed in ④ to predict the extent of direct and indirect shock propagation

Related Work

- Financial shocks + sector level network
  (Bigio & La'O 2016, WP; Alfaro et al. 2018, WP)
- Financial shocks + firm-level network
  (Costello 2018, WP; Cortes et al. 2019, WP)
- In contrast, our contribution:
  - comprehensive & matched administrative (VAT+Credit Registry) data
  - build on GE theory to identify/construct the relevant variables
  - study both upstream & downstream propagation effects
  - find empirical support for sizable and comparable network effects in shock propagation, up- and downstream, at first and higher orders

Plan for the Rest of the Talk

- Theoretical framework
- A brief description of the data
- Empirical implementation and some results
- Summary and conclusions

Theoretical framework: firms

- Set of firms N, grouped in m sectors.
- Cost minimizing firm i uses intermediate inputs ($\boldsymbol{z}$) and labor (ℓ) in production.

$$y_i = \zeta_i \ell_i^{\beta_i} \left(\prod_{j \in N_i^+} z_{ji}^{g_{ji}} \right)^{\alpha_i}, \tag{1}$$

  with $\alpha_i + \beta_i = 1$, $\sum_{j \in N} g_{jk} = 1$.

- $\mathbf{G} = (g_{jk})_{j,k=1}^n$ column-stochastic adjacency matrix: formalizes the technology/production network.
- Firms set $p_i = \mu_i \lambda_i$, where λ_i is the per-unit cost, and μ_i is the markup (Baqaee, 2018, Ecta).

Theoretical framework: financial shocks

- Firm i is required to pay in advance a share χ_i of variable costs: standard "cash-in-advance constraint" (CIAC)
- Firm i borrows at interest rate r_i to meet CIAC, hence the cost of inputs for firm i is:

$$
\begin{aligned}
c_i =& (1-\chi_i)\left(\sum_{j\in N_i^+} p_j z_{ji} + w\ell_i\right) + \chi_i(1+r_i)\left(\sum_{j\in N_i^+} p_j z_{ji} + w\ell_i\right) \\
=& (1+\tau_i)\left(\sum_{j\in N_k^+} p_j z_{ji} + w\ell_i\right).
\end{aligned}
$$

- Denoting $\tau_i \equiv \chi_i r_i$, the *financial shock* interpreted as a credit shock: a *change* $\Delta\tau_i$ in τ_i.

Theoretical framework: consumer

- The consumer owns the firms, including those in the financial sector,
- supplies innelastically one unit of labor,
- maximizes $U(\boldsymbol{c}) = \prod_{i=1}^{m} c_i^{\gamma_i}$ subject to
- the budget constraint:

$$\sum_i p_i c_i \leq w + \sum_{i \in N} \pi_i + \sum_{i \in N} \sum_{j \in N_i^+} \tau_i \left(p_j z_{ji} + w \ell_i\right).$$

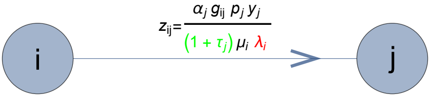
Theoretical framework: equilibrium

Definition

Given a vector of financial distortions $\boldsymbol{\tau}$ a *Market Equilibrium* is an array $\{[(\boldsymbol{p}^* \, w^*)], [\boldsymbol{c}^*, \boldsymbol{y}^*, \boldsymbol{Z}^*, \boldsymbol{\ell}^*]\}$ that satisfies the following conditions:

- each firm i minimizes production costs and sets its price by applying its mark-up μ_i;
- the consumption plan maximizes the consumer's utility, subject to the corresponding budget constraint;
- markets for each output (intermediate input) and labor clear.

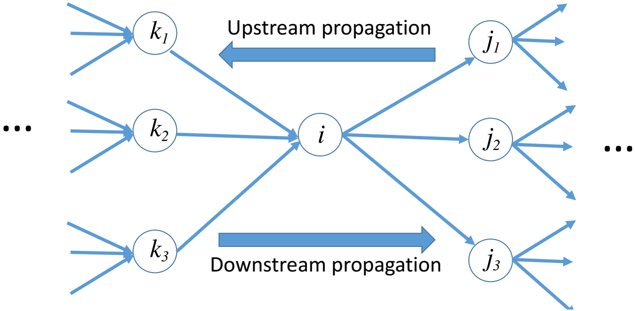
Shock propagation: link level



1. **Upstream**:
   - Suppose j is affected by $\Delta\tau_j$, borrowing becomes more expensive
   - Firm j buys less inputs
   - Firm i is affected (and sells less)
2. **Downstream**:
   - Suppose i is affected by shock $\Delta\tau_i$
   - Per unit cost λ_i of firm i increases
   - Firm j is affected (and buys less)

Shock propagation: node level

- Aggregate across customers of i: total (direct) upstream effect
- Aggregate across suppliers of i: total (direct) downstream effect



Indirect effects: customers of customers? suppliers of suppliers?

Node-level propagation: theoretical predictions

- Denote by E the wage-normalized income of the consumer (GDP).
- Let $\mathbf{A} \equiv diag(\alpha_i)$, $\mathbf{H}(\boldsymbol{\tau}) = \left[\frac{p_i z_{ij}}{p_i y_i}\right]_{i,j=1}^{n}$, and $\hat{x} = \ln x$.

Proposition

$$\frac{\partial \hat{y}_i}{\partial \tau_k} = -\frac{1}{1+\tau_k} \overbrace{\boldsymbol{e}_i'(\mathbf{I}-\mathbf{AG}')^{-1}\boldsymbol{e}_k}^{\textit{Downstream: supply effect}} + \overbrace{\boldsymbol{e}_i'(\mathbf{I}-\mathbf{AG}')^{-1}\boldsymbol{\beta}\frac{\partial \hat{E}}{\partial \tau_k}}^{\textit{Downstream: income effect}} - \frac{1}{1+\tau_k} \overbrace{\boldsymbol{e}_i'(\mathbf{I}-\mathbf{H}(\boldsymbol{\tau}))^{-1}\mathbf{H}(\boldsymbol{\tau})\boldsymbol{e}_k}^{\textit{Upstream: demand effect}},$$

Then, denoting $\hat{\tau_k} \equiv \ln(1+\tau_k)$ and making initial $\tau_0 = 0$, we approximate:

$$\hat{y}_i(\boldsymbol{\tau}) - \hat{y}_i(0) \simeq - \overbrace{\boldsymbol{e}_i'(\mathbf{I}-\mathbf{AG}')^{-1}\hat{\boldsymbol{\tau}}}^{\text{own \& downstream effect}} + \overbrace{\boldsymbol{e}_i'(\mathbf{I}-\mathbf{AG}')^{-1}\boldsymbol{\beta}\sum_{k=1}^{n}\left[\frac{\partial \hat{E}}{\partial \tau_k}(0)\,\tau_k\right]}^{\text{income effect}} - \overbrace{\boldsymbol{e}_i'(\mathbf{I}-\mathbf{H}(0))^{-1}\mathbf{H}(0)\hat{\boldsymbol{\tau}}}^{\text{upstream effect}}$$

Shock propagation: theory-induced predictions

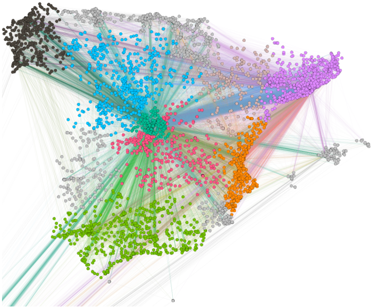
1. **Link level**: Once firm effects are controlled for, FONC of firms' optimization problem readily lead to:
   - **P1, P2**: Downstream and upstream, link-based direct effects are negative
   - **P3, $\widetilde{\text{P4}}$**: Downstream and upstream, link-based indirect effects negative
2. **Node level**: From the former proposition, we have:
   - **P5**: Own-shock effects are negative
   - **P6, P7***: Downstream and upstream, node-based direct effects negative
   - **P8, $\widetilde{\text{P9}}$**: Downstream and upstream, node-based indirect effects negative
   - **P10**: Downstream, income-based effect is negative

Given our identification of shocks (explained later), all predictions can be quantified (and hence tested precisely) except upstream ones: $\widetilde{\text{P4}}$, P7*, and $\widetilde{\text{P9}}$.

- $\widetilde{\text{P4}}$ & $\widetilde{\text{P9}}$: linear approx. of complex non-linear functions of $\boldsymbol{\tau}$ (all-order effects)
- P7*: suitable to approximate linearly first-order upstream effects? – to check!

Production Network Data

- Source: Spanish Tax Agency (AEAT). (Agencia Estatal Admon. Tributaria)
- Data on the universe of firm-to-firm annual transactions between Spanish firms (with annual total $\geq$ 3000 euros)
- Years: 2008 and 2009.



- We consider links for which both the seller and the customer are firms, public or limited liability companies, excluding financial sector
- 13,822,286 transactions between 867,013 firms in 2008 and 11,973,733 transactions between 861,231 firms in 2009.
- We calculate $g_{ij} = \frac{p_j z_{ij}}{\sum_{k \in N_j^+} p_k z_{kj}}$ and $h_{ij} = \frac{p_i z_{ij}}{p_i y_i}$.

Identification

1. **Financial shocks** identified through within-firm cross-bank variation (used by Khwaja-Mian, 2008, AER; Amiti-Weinstein, 2018, JPE):
   Comparison of how a bank treats its customers (firms) relative to how other banks treat the same customers

2. **Firm-to-firm (link-based) direct propagation** identified by within-firm variation for multi-customer (multi-supplier) firms:
   Comparison of sales to customers (purchases from suppliers), differentially hit by shocks w/ individual observable & fixed effects

3. **Firm- (node-)based direct and indirect propagation** identified by firm-specific weights aggregating alternative shock-exposure channels:
   Combination of theory & full inter-firm transaction data to compute, aggregating at all orders, effects from (in)direct suppliers (customers)

Link level: econometric specification

- **Link-level propagation (in)direct effects**, downstream & upstream

$$\Delta \ln y_{is} = \beta_D \text{Shock}_s^{2008} + \boldsymbol{\theta}'_D \boldsymbol{X}_S + \boldsymbol{\delta_D} \boldsymbol{W}_{is} + FE_i + \nu_{is}$$
$$\Delta \ln y_{ic} = \beta_U \text{Shock}_c^{2008} + \boldsymbol{\theta}'_U \boldsymbol{X}_C + \boldsymbol{\delta_U} \boldsymbol{W}_{ic} + FE_i + \nu_{ic}.$$

where: $\Delta \ln y_{ic}$ is the growth rate of sales from i to c and

Shock$_c^{2008}$, Shock$_c^{2008}$ $\in \{0,1\}$ if above/below population median

- **Node-level propagation (in)direct effects**, downstream & upstream

$$\Delta \ln y_i = \beta_O \text{ OwnShock}_i^{2008} + \beta_D \text{ AggSupShock}_i^{2008} + \beta_U \text{ AggCustShock}_i^{2008} + \boldsymbol{\theta}' \boldsymbol{Z}_i + \nu_i$$

where AggSupShock$_i$ AggCustShock$_i$ $\in \{0,1\}$ if above/below population median

Link-level propagation: downstream direct effects

Downstream propagation, dep. variable: growth of purchases from suppliers

	Dependent variable: Δlog(purchases to suppliers)			
	(1)	(2)	(3)	(4)
Own Shock	-5.620**	-5.162**	-5.441**	
	(2.811)	(2.339)	(2.452)	
Supplier Shock		-1.672*	-1.463**	-2.950*
		(0.895)	(0.691)	(1.525)
Supplier:				
Controls	-	Yes	Yes	Yes
Province*Industry Fixed Effects	-	Yes	No	No
Fixed Effects	Yes	No	No	No
Firm:				
Controls	Yes	Yes	Yes	-
Province*Industry Fixed Effects	Yes	Yes	No	-
Fixed Effects	No	No	No	Yes
Firm*Supplier Province & Industry Fixed Effects	No	No	Yes	Yes
R-squared	0.337	0.090	0.124	0.380
Observations	1.114.421	1.114.421	1.114.421	1.114.421

Robust standard errors corrected for clustering at the firm, main bank and supplier or customer level in parenthesis.
*** Significant at 1%, ** significant at 5%, * significant at 10%.

Link-level propagation: upstream direct effects

Upstream propagation, dep. variable: growth of sales to customers

	Dependent variable: Δlog(sales to customers)			
	(1)	(2)	(3)	(4)
Own Shock	-2.506**	-1.949	-1.551*	
	(1.267)	(1.354)	(0.903)	
Customer Shock		-5.675**	-5.686**	-4.637**
		(2.346)	(2.374)	(2.255)
Customer:				
Controls	-	Yes	Yes	Yes
Province*Industry Fixed Effects	-	Yes	No	No
Fixed Effects	Yes	No	No	No
Firm:				
Controls	Yes	Yes	Yes	-
Province*Industry Fixed Effects	Yes	Yes	No	-
Fixed Effects	No	No	No	Yes
Firm*Customer Province & Industry Fixed Effects	No	No	Yes	Yes
R-squared	0.378	0.101	0.140	0.361
Observations	1.119.169	1.119.169	1.119.169	1.119.169

Robust standard errors corrected for clustering at the firm, main bank and supplier or customer level in parenthesis.
*** Significant at 1%, ** significant at 5%, * significant at 10%.

Node level: econometric specification

- To estimate aggregate node level effects we estimate the following equation:

$$\Delta \ln y_i = \beta_O \text{ OwnShock}_i^{2008} + \beta_U \text{ AggCustShock}_i^{2008} + \beta_D \text{ AggSupShock}_i^{2008} + \boldsymbol{\theta}' \boldsymbol{Z}_i + \nu_i,$$

where:

$$\text{AggCustShock}_i = \begin{cases} 1 \text{ if } \sum_{j \in N_i^-} h_{ij}^{2008} \tilde{\tau}_j > med \left\{ \sum_{j \in N_k^-} h_{kj}^{2008} \tilde{\tau}_j \right\}_{k \in N}, \\ 0, \text{otherwise} \end{cases}$$

$$\text{AggSupShock}_i = \begin{cases} 1 \text{ if } \sum_{j \in N_i^+} g_{ji}^{2008} \tilde{\tau}_j > med \left\{ \sum_{j \in N_k^+} g_{jk}^{2008} \tilde{\tau}_j \right\}_{k \in N}, \\ 0, \text{otherwise} \end{cases}$$

Node-level propagation: direct (first-order) effects

Aggregate Node Level Outcomes

Dependent Variable:	Δlog(purchases)		Δlog(sales)		Δlog(purchases+sales)
	(1)	(2)	(3)	(4)	(5)
Own Shock	2.233*	2.220*	0.994**	1.000**	1.028**
	(1.144)	(1.141)	(0.482)	(0.475)	(0.507)
Supplier Shock	2.399***	2.325***		-0.111	
	(0.745)	(0.745)		(0.383)	
Customer Shock		1.175	1.888***	1.896***	
		(1.094)	(0.571)	(0.562)	
Average Sup&Cust Shock					1.007**
					(0.464)
CentralityAsCustomer	-2.544***	-2.534***	-0.888***	-0.890***	-1.895***
	(0.498)	(0.495)	(0.210)	(0.208)	(0.307)
R-squared	0.417	0.417	0.282	0.282	0.401
Observations	170,942	170,942	155,065	155,065	178,006

Robust standard errors corrected for clustering at the main bank level in parenthesis. All the regressions include two-digit NACE and zip-code fixed effects. *** Significant at 1%, ** significant at 5%, * significant at 10%.

Node-level propagation: indirect (higher-order) effects

Aggregate Node Level Outcomes

Dependent Variable:	Δlog(purchases)		Δlog(sales)		Δlog(purchases+sales)
	(1)	(2)	(3)	(4)	(5)
Own Shock	2.156*	2.210*	0.999**	0.929*	0.955*
	(1.128)	(1.124)	(0.482)	(0.477)	(0.503)
Supplier Shock	2.066**	1.985**		-0.397	
	(0.808)	(0.803)		(0.419)	
Supplier Higher Order Shock	2.031**	2.056**		1.738***	
	(0.833)	(0.858)		(0.411)	
Customer Shock		1.319	1.950***	1.932***	
		(1.020)	(0.532)	(0.524)	
Customer Higher Order Shock		-1.105	-0.327	-0.410	
		(1.025)	(0.427)	(0.435)	
Average Sup&Cust Shock					0.883*
					(0.456)
Average Sup&Cust Higher Order Shock					1.152*
					(0.665)
R-squared	0.417	0.418	0.282	0.283	0.403
Observations	170,942	170,942	155,065	155,065	178,006

Robust standard errors corrected for clustering at the main bank level in parenthesis. All the regressions include two-digit NACE and zip-code fixed effects. *** Significant at 1%, ** significant at 5%, * significant at 10%.

Summary

- This paper studies the important problem of whether and how financial shocks affect, and propagate in, the real economy.
- To this end we perform two preliminary steps:
  1. Provide a theory-based decomposition/quantification of propagation effects: up/downstream, link/node/income-based, direct/indirect
  2. Exploit universal data on f2f transactions and b2f loans for Spain to identify financial shocks and test the predicted propagation effects
- **Main conclusion**: shock propagation in the production network leads to direct and indirect effects that are of significant and similar size, themselves comparable to the effects of the original financial shocks