Production and Financial Networks in Interplay: Crisis Evidence from Supplier-Customer and Credit Registers

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Motivation

- In the aftermath of the 2008 financial crisis, academics and policy-makers alike have largely come to accept that the role financial and production networks was not suitably recognized, leading to the failure in foreseeing its deep impact and wide span (Bernanke (2013, JEP); Acemoglu et al. (2015, AER); Freixas et al. (2015, MIT Press)).
- Financial networks: propagation of shocks in networks of mutual ownership, Cabrales et al. (2017, RFS); lending and borrowing relationships, Acemoglu et al. (2014, AER) ...
- Production networks: propagation of productivity shocks, Magerman et al. (2018, WP); demand shocks Acemoglu et al. (2015, NBER Macro); natural disaster, Carvalho et al. (2021, QJE) ...
- Direct effect of financial shocks on a firm performance Jiménez et al. (2017, JPE).
- **Propagation of financial shocks through firm-level production networks and interplay between financial and production networks remains mostly unexplored.**

This Paper

We study propagation of financial shocks through firm-level production network.

- We build a model of production networks with financial shocks/distortions,
- We apply it to biennium 2008-09, exploiting variability of shock exposure in financial crisis.
  - We use comprehensive firm-bank connections (Spanish Credit registry) to estimate bank-credit supply shocks (financial shocks).
  - We use data on the universe of firm-to-firm transactions in Spain (VAT) to construct an empirical counterpart of the firm-level production network.
  - We match these two data-sets, estimate the direct and indirect (i.e. propagation) effects, as well as important structural parameters of the model.
- Overall, our aim is to provide an integrated theoretical and empirical understanding of how financial and real production networks interplay in times of crisis.

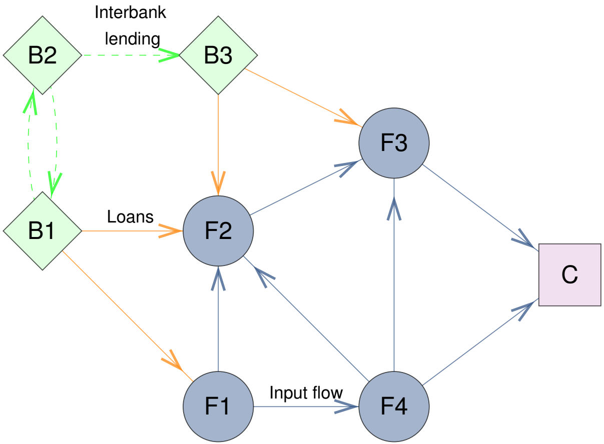
Related Work

- Financial shocks + sector level network Bigio & La'O (2020, QJE), Alfaro et al. (2021, JFE).
- Financial shocks + firm-level network Costello (2020, JPE), Cortes et al. (2019, WP), Dewachter et al. (2018, WP)
- Our contribution:
  - Comprehensive matched VAT and the Credit Registry data.
  - We study and find evidence of higher order effect (i.e. suppliers of suppliers).
  - We use information on financial network structure to strengthen the identification of financial shocks.
  - We propose a model to identify and construct relevant variables, and to rationalize results.
  - We structurally estimate equilibrium equations.
  - We quantify the aggregate effects of financial shocks.

Plan for the rest of the talk

- A very simple illustration of the networks we focus on.
- Outcomes of interest: link-level and node-level outcomes, first and higher order effects.
- Data and identification of financial shocks impinging on bank credit supply
- Reduced form analysis of link-level and (time permitting) node-level outcomes.
- Theoretical model and structural estimation of link-level and node-level outcomes.
- Aggregation (time permitting).
- Summary and conclusion.

A simple example of the economy



B – Banks, F – Firms, C – Final Consumer

Link-level: Downstream

- Purchases of i from its suppliers: s_{ji}, $j \in N_i^+$.
  - **Downstream propagation effect**: How do purchases of a customer change across suppliers when some of the suppliers are affected by financial shocks.

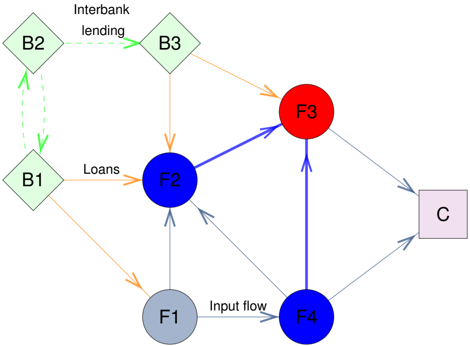


Figure: Downstream propagation link-level effects

Link-level: Upstream

- Sales of j to its customers: $s_{ji},\ i \in N_j^-$.
  - **Upstream propagation effect**: How do sales of a supplier change across customers when some of the customers are affected by financial shock

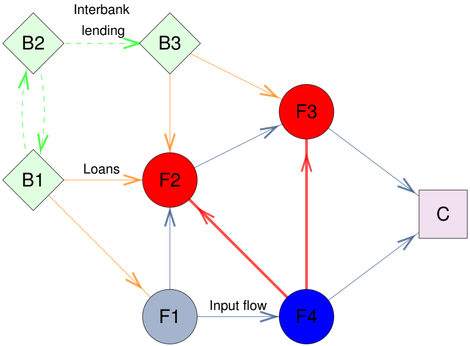


Figure: Upstream propagation link-level effects

Node-level Outcomes

- Sales of *i* (to its customers and the final consumer).
  - How do sales of a firm change as a response to shocks hitting its suppliers and customers.

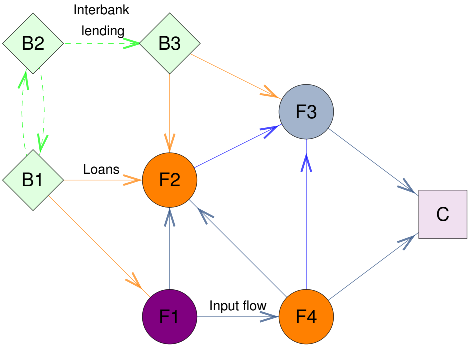


Figure: Node-level effects

Estimation of link-level effects: data requirement

- Data/estimates of *exogenous* financial shocks.
  - (i) Using Amiti & Weinstein (2018, JPE) which is based on Abowd et al. (1999, Ecta) [AKM] and exploiting bank-to-firm connections.
  - (ii) Using exposure of banks to interbank lending network (before the crisis).
- Data on bilateral sales for years of interest (2008 and 2009).

Financial shocks (i): Data

- Confidential, administrative loan-level data for Spanish non-financial companies from the Spanish Credit Register (CIR).
- Annual loan level data since 1984 on all loan commitments (commercial and industrial) above 6,000 euro granted by any bank (also credit cooperatives) operating in Spain.
- 1,682,654 loans from 206 active banks.
- Spain being bank-dominated country, other financial intermediaries are practically irrelevant: Jiménez et al. (2017, JPE).

Financial shocks (i): Estimation

- Exploit firm-to-bank connections in a connected bipartite graph.
- Idea: use the variation in credit growth across banks for a given firm, and across firms for a given bank.
- Estimate the following double fixed effect specification (Amiti & Weinstein (JPE, 2018)):

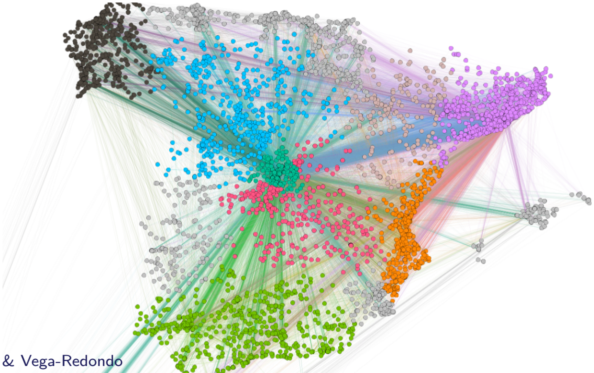
$$\Delta c_{bft} = \delta_{ft} + \lambda_{bt} + \epsilon_{bft}. \tag{1}$$

c_{bft}: yearly average of outstanding credit of firm f with bank b in year t.

- Firm specific credit supply shock: weighted average of $\hat{\lambda}_{bt}$ across banks b connected to it.
- Balance test checks out.

Transaction level data

- VAT (M.347 form) data on all annual transactions between Spanish firms in the amount above 3005 Euro.
- Observed in 2008 and 2009.
- Each transaction reported by both the buyer and the seller.
- 5,023,101 repeated transactions (links).



Estimation of the link-level regression: non-structural

- We estimate the following specifications:

$$\Delta \log s_{ji} = \alpha^{u} \tau_i^{AW} + \alpha^{d} \tau_j^{AW} + \boldsymbol{\beta}' \mathbf{x}_i + \boldsymbol{\gamma}' \mathbf{z}_j + \boldsymbol{\delta}' \mathbf{w}_{ji} + FE + \epsilon_{ji} \tag{2}$$

where s_{ji} is the sales from $j \rightarrow i$ (purchase of i from j).

- The estimation relies on full granularity at the customer-supplier level.
- Most stringent specification: firm-level fixed effects to control for unobserved heterogeneity.
  - Identification based on within-firm variation from multi-supplier and multi-customer firms.

Results link-level: Upstream

Upstream propagation (indirect shocks via bank credit supply shocks to first-order customers)

Dependent Variable: Δlog(sales to customers)			IV. Instrument: Bank Net Interbank Borrowing		IV. Instrument: Bank Shock	
			1st Stage	2º Stage	1st Stage	2º Stage
	(1)	(2)	(3)	(4)	(5)	(6)
Direct (Bank Credit Supply) Shock	-0.919*					
	(0.506)					
1st Order Customer (Bank) Effect		-2.544**		-6.000**	3.685***	
		(1.217)		(2.676)	(0.997)	
Customer (Bank) Net Interbank Borrowing			9.760***			
			(0.707)			
Customer Reduction of Bank Debt						-0.547*
						(0.285)
Customer:						
Controls	-	Yes	Yes	Yes	Yes	Yes
Spatial*Industry Fixed Effects	-	Yes	Yes	Yes	Yes	Yes
Fixed Effects	Yes	No	No	No	No	No
Firm:						
Controls	Yes	-	-	-	-	-
Spatial*Industry Fixed Effects	Yes	-	-	-	-	-
Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Firm*Supplier Spatial & Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
First Stage F-test	-	-	190.72	-	13.69	-
R-squared	0.404	0.474	-	-	-	-
Observations	1,119,169	1,119,169	1,119,169	1,119,169	1,119,169	1,119,169

Robust standard errors corrected for clustering at the firm's main bank in parenthesis. *** Significant at 1%, ** significant at 5%, * significant at 10%.

Median of the dependent variable: -13.9%

Results link-level: Downstream

Downstream propagation (indirect shocks via bank credit supply shocks to first-order suppliers)

Dependent Variable: Δlog(purchases from suppliers)			IV. Instrument: Bank Net Interbank Borrowing		IV. Instrument: Bank Shock	
			1st Stage	2º Stage	1st Stage	2º Stage
	(1)	(2)	(3)	(4)	(5)	(6)
Direct (Bank Credit Supply) Shock	-3.064**					
	(1.393)					
1st Order Supplier (Bank) Effect		-1.161**		-5.370**	7.608***	
		(0.561)		(2.370)	(2.276)	
Supplier (Bank) Net Interbank Borrowing			10.576***			
			(0.337)			
Supplier Reduction of Bank Debt						-0.153*
						(0.089)
Supplier:						
Controls	-	Yes	Yes	Yes	Yes	Yes
Spatial*Industry Fixed Effects	-	Yes	Yes	Yes	Yes	Yes
Fixed Effects	Yes	No	No	No	No	No
Firm:						
Controls	Yes	-	-	-	-	-
Spatial*Industry Fixed Effects	Yes	-	-	-	-	-
Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Firm*Supplier Spatial & Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
First Stage F-test	-	-	943.72	-	11.16	-
R-squared	0.358	0.483	-	-	-	-
Observations	1,114,421	1,114,421	1,114,421	1,114,421	1,114,421	1,114,421

Robust standard errors corrected for clustering at the firm's main bank in parenthesis. *** Significant at 1%, ** significant at 5%, * significant at 10%.

Median of the dependent variable: -12.7%

Results node-level

Dependent Variable:	Δlog(sales)		Δlog(employment)	
	(1)	(2)	(3)	(4)
Direct (Bank Credit Supply) Shock	-0.630**	-0.625**	-0.176**	-0.160**
	(0.260)	(0.258)	(0.082)	(0.081)
1st Order Customer (Bank) Effect		-0.554***		-0.130*
		(0.184)		(0.054)
1st Order Supplier (Bank) Effect		0.251		-0.200*
		(0.215)		(0.113)
Firm Controls	Yes	Yes	Yes	Yes
Spatial & Industry Fixed Effects	Yes	Yes	Yes	Yes
R-squared	0.361	0.361	0.081	0.081
Observations	196.561	196.561	196.561	196.561

Robust standard errors corrected for clustering at the firm's main bank in parenthesis. *** Significant at 1%, ** significant at 5%, * significant at 10%.

Median of the dependent variable: Sales: -12.7% Employment:

Why do we need a model?

- To identify higher-order shocks – e.g those hitting suppliers of suppliers, which requires suitable (theory-based) aggregation.
- To explain/rationalize findings – for instance, answering questions such as:
  - Why upstream & downstream effects of shocks are of different **magnitude** in link-level regressions?
  - Why (as will see) upstream & downstream effects of **indirect** shocks are of different **sign**?
- To account for the GE effects – prices and quantities adjust as a response to shocks.
- To aggregate the effects and study interesting counterfactuals, e.g. what if shocks did not propagate?

Theoretical Framework: Firms

- Set of firms N
- Cost minimizing firm i uses intermediate input bundle (M), labor (ℓ), and physical capital (k) to produce output according to:

$$y_i = f_i\left(\ell_i, k_i, M_i\right) = \zeta_i k_i^{\rho} \ell_i^{\beta} M_i^{\alpha} \tag{3}$$

where:

$$M_i = \left(\sum_{j \in N} g_{ji}^{\frac{1}{\sigma}} z_{ji}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \tag{4}$$

and z_{ji} denotes the amount of output of firm j that i uses as an input.

- $\alpha, \beta, \rho, \sigma, g_{ji}$ have standard interpretation.
- Assume $\alpha + \beta + \rho = 1$, $\sum_{j \in N} g_{jk} = 1$.
- $\mathbf{G} = (g_{jk})_{j,k=1}^{n}$ column-stochastic adjacency matrix of the technological production network.

Theoretical Framework: Financial Shocks

- Firm i is required to pay in advance a share χ_i of variable costs.
- Firm i can borrow with interest rate R_i.
- The profit of firm i:

$$\pi_i = p_i y_i - (1-\chi_i)\left(\sum_{j\in N_i^+} p_j z_{jk} + w\ell_i + r_i k_i\right) - \chi_i(1+R_i)\left(\sum_{j\in N_i^+} p_j z_{ji} + w\ell_i + rk_i\right)$$
$$= p_i y_i - (1+\theta_i)\left(\sum_{j\in N_i^+} p_j z_{ji} + w\ell_i + rk_i\right),$$

- $\theta_i \equiv \chi_i R_i$.
- Bank credit supply shock (financial shock): Change in θ_i.
- We decompose $\theta_i \equiv \nu + \tau_i$.

Theoretical Framework: The Consumer

- Owns firms, including the financial sector.
- Supplies L units of labor (elastically) and K units of physical capital inelastically.
- Maximizes:

$$U(\boldsymbol{c}) = \frac{c^{1-\delta}}{1-\delta} - \frac{L^{1+\eta}}{1+\eta}, \tag{5}$$

  subject to a budget constraint

$$\sum_i p_i c_i \leq E, \tag{6}$$

  where $c = \prod_{i=1}^{n} c_i^{\gamma_i}$, $\delta \geq 0$ captures the income elasticity of labor supply, and $\eta > 0$ corresponds to the inverse Frisch elasticity of labor supply.

- $E = wL + rK + \sum_{i \in N} \pi_i + T$, with $T \equiv \sum_{i \in N} \theta_i \left(\sum_{j \in N_i^+} p_j z_{ji} + w\ell_i + rk_i \right)$.

Theoretical Framework: Equilibrium

Definition 1

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

- Each firm i minimizes production costs and applies its mark-up μ_i to set its price.
- The consumption plan maximizes the consumer's utility subject to her budget constraint.
- Markets for each intermediate input, labor and capital clear.

The uniqueness follow from the gross-substitutes property.

Link-level equation

- Taking total derivative at the equilibrium we get:

Proposition 1

$$\overbrace{d\log s_{ji}}^{\substack{\textit{Change in log sales}\\ \textit{from } j \textit{ to } i}} - \overbrace{\mathrm{d}\log s_i}^{\substack{\textit{Change in log sales}\\ \textit{of customer } i}} = -\overbrace{\nu}^{\textit{common shock}} - \left(\overbrace{\sigma}^{\substack{\textit{Elasticity of}\\ \textit{substitution}}} -1\right)\overbrace{\tau_j}^{\substack{\textit{Supplier}\\ \textit{shock}}} - \overbrace{\tau_i}^{\substack{\textit{Customer}\\ \textit{shock}}}$$

$$-(\sigma-1)\left[\overbrace{\alpha}^{\approx 0.48}\overbrace{\mathbf{e}_j'\mathbf{G}'(\mathbf{I}-\alpha\mathbf{G}')^{-1}\boldsymbol{\tau}}^{\substack{\textit{Higher order supplier}\\ \textit{shock (Net}_j\textit{)}}} - \overbrace{\mathbf{e}_i'\mathbf{G}'(\mathbf{I}-\alpha\mathbf{G}')^{-1}\boldsymbol{\tau}}^{\substack{\textit{Higher order customer}\\ \textit{shock (Net}_i\textit{)}}}\right] \quad (7)$$

- Higher order shocks: capture the shocks of all orders on intermediate inputs, weighted by relative technological importance & modulated by GE price adjustment.
- There are several testable predictions of the model.

Parameters of the model

- We show that g_{ji} can be calibrated as $\frac{s_{ji}}{\sum_{k \in N_i^+} s_{ki}}$ as observed in 2008.
- $\alpha = 0.483$, $\beta = 0.317$ and $\rho = 0.225$ are obtained from a production function estimation, Ackeberg et al. (2015, Ecta).
- Within the model:
  - We estimate σ.
  - We recover the mapping between AW shocks τ_i^{AW} and theoretical shocks τ_i in the form $\tau_i = \xi \tau_i^{AW}$.

Estimation

- We directly bring (7) to data as:

$$\Delta \log\left(\frac{s_{ji}}{s_i}\right) = -\nu - (\sigma-1)\xi\tau_j^{AW} - \xi\tau_i^{AW} - (\sigma-1)\alpha\xi Net_j^{AW} + (\sigma-1)\xi Net_i^{AW} + \boldsymbol{b}^u\boldsymbol{x}_i + \boldsymbol{b}^d\boldsymbol{x}_j + \boldsymbol{b}^{du}\boldsymbol{w}_{ij} + FE + \epsilon_{ji}$$

- There are different ways to recover structural parameters ξ and σ.
- We obtain estimate $\sigma \in [1.44, 2.2]$ which is consistent with other estimates, Carvalho et al. (2020, QJE), Peter & Ruane (2020, WP).

Results link-level: structural

Estimation of equation (7)

	Upstream propagation		Downstream propagation	
	(1)	(2)	(3)	(4)
1st Order Customer (Bank) Effect	-2.550**	-2.521**		
	(1.102)	(1.080)		
Higher Order Customer (Bank) Effect		1.224**		
		(0.551)		
1st Order Supplier (Bank) Effect			-1.161**	-1.120**
			(0.561)	(0.516)
Higher Order Supplier (Bank) Effect				-0.755*
				(0.439)
Supplier/Customer:				
Controls	Yes	Yes	Yes	Yes
Spatial*Industry Fixed Effects	Yes	Yes	Yes	Yes
Firm:				
Fixed Effects	Yes	Yes	Yes	Yes
Firm*Supplier/Customer Spatial & Industry Fixed Effects	Yes	Yes	Yes	Yes
R-squared	0.477	0.478	0.493	0.493
Observations	1,119,169	1,119,169	1,114,421	1,114,421

Robust standard errors corrected for clustering at the firm's main bank in parenthesis. *** Significant at 1%, ** significant at 5%, * significant at 10%.

$$\Delta \log \left(\frac{s_{ji}}{s_i} \right) = -\nu - (\sigma - 1)\xi \tau_j^{AW} - \xi \tau_i^{AW} - (\sigma - 1)\alpha \xi Net_j^{AW} + (\sigma - 1)\xi Net_i^{AW} + \boldsymbol{b}^u x_i + \boldsymbol{b}^d x_j + \boldsymbol{b}^{du} \boldsymbol{w}_{ij} + FE + \epsilon_{ji}$$

Propagation equation

Again, taking total derivative at the equilibrium we get:

Proposition 2

The following holds:

$$d \log s_i = d \log E - \mathbf{e}_i' \overbrace{[\mathbf{I} - \mathbf{H}]^{-1} \mathbf{H}}^{Upstream} \boldsymbol{\theta} + (1-\sigma)\mathbf{e}_i' \overbrace{\boldsymbol{\Lambda}}^{Bidirectional} \boldsymbol{\tau}, \quad (8)$$

where

$$\boldsymbol{\theta} = \boldsymbol{\tau} + \nu \mathbf{1}$$

$$\boldsymbol{\Lambda} = \overbrace{(\mathbf{I} - \mathbf{H})^{-1}}^{Upstream} \overbrace{\left(diag(\mathbf{H1}) - \mathbf{HG}'\right)}^{Substitution} \overbrace{\left(\mathbf{I} - \alpha \mathbf{G}'\right)^{-1}}^{Downstream}.$$

$$\mathbf{H} = (h_{ij})_{i,j=1}^{n} \quad \text{with} \quad h_{ij} = \frac{s_{ij}}{s_i} \quad \text{for all} \quad i, j$$

Results node-level: structural

Dependent Variable: Δlog(sales)	(1)	(1)	(3)	(4)	(5)
Idiosyncratic Upstream (1st & Higher Order Effects)	-0.490**	-0.648***		-0.483**	-0.435**
	(0.241)	(0.226)		(0.239)	(0.206)
Bidirectional (Up & Down 1st & Higher Order Effects)	-1.013*	-0.900*	-1.129*	-1.256*	
	(0.612)	(0.533)	(0.636)	(0.758)	
Common Upstream (1st & Higher Order Effects)	-2.643***			-2.660***	-1.610***
	(0.487)			(0.474)	(0.410)
Total Upstream (1st & Higher Order Effects)			-2.700***		
			(0.472)		
Direct (Bank Credit Supply) Shock				0.606	-0.424*
				(0.440)	(0.251)
Firm Controls	Yes	Yes	Yes	Yes	Yes
Spatial & Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes
R-squared	0.381	0.378	0.381	0.381	0.381
Observations	196.561	196.561	196.561	196.561	196.561

Robust standard errors corrected for clustering at the firm's main bank in parenthesis. *** Significant at 1%, ** significant at 5%, * significant at 10%.

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Aggregation

Proposition 3

The first order approximation of the effects of financial shocks on GDP is given with:

$$\mathrm{d}\log c = -\boldsymbol{\gamma}' \left[\mathbf{I} - \alpha \mathbf{G}'\right]^{-1} \boldsymbol{\tau} - \frac{1}{1-\alpha}\nu - \frac{\beta}{1-\alpha}\mathrm{d}\log w - \frac{\rho}{1-\alpha}\mathrm{d}\log r, \tag{9}$$

where

$$\mathrm{d}\log w = \frac{\eta}{1+\eta}\frac{1}{wL}\boldsymbol{s}'\mathbf{M}\mathrm{d}\log \boldsymbol{s} - \frac{1-\delta}{1+\eta}\mathrm{d}\log c, \tag{10}$$

$$\mathrm{d}\log r = \frac{1}{rK}\boldsymbol{s}'\mathbf{M}\mathrm{d}\log \boldsymbol{s}. \tag{11}$$

and

$$\mathrm{d}log\boldsymbol{s} = -\left[\mathbf{I} - \mathbf{H}\right]^{-1}\mathbf{H}\left(\boldsymbol{\tau} + \nu\mathbf{1}\right) + (1-\sigma)\boldsymbol{\Lambda}\boldsymbol{\tau}$$

Preliminary results: Network propagation more than doubles the effect of shocks.

Summary

- We study propagation of financial shocks through a firm-level production network.
- We find evidence if significant direct and network-mediated indirect effects of financial shocks for both firm-level and transaction-level outcomes.
- We develop a model to rationalize our empirical findings and bring it directly to data.
- We quantify the aggregate effects of financial shocks.

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