Supply Chain Resilience: Evidence from Indian Firms

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The views expressed are those of the authors and do not necessarily reflect those of the Federal Reserve Bank of Richmond or the Board of Governors.

Motivation

- Rise of complex supply chains:
  - Key feature of recent globalization: Efficiency gains from specialization in production.
  - But, can propagate and amplify economic shocks.
- Supply chain disruptions (e.g. Covid lockdowns, port bottlenecks) can create supply shortages and inflationary pressures.

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- Renewed attention to supply chain resilience: the ability to respond to disruptions, minimize their impact, and recover.
- Question: *What makes supply chains more resilient to shocks?*

This paper

1. Universe of firm-to-firm transactions for a large Indian state.
2. Quantify supply-chain disruptions after big shock:
   - Spatial variation on COVID-19 lockdowns across India.
   - Event study approach: Compare firms with suppliers in strict vs mild lockdown districts.
   - Measure resilience through: 1) separations from suppliers, 2) ease of finding new suppliers and, 3) input/output changes.

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   - Event study approach: Compare firms with suppliers in strict vs mild lockdown districts.
   - Measure resilience through: 1) separations from suppliers, 2) ease of finding new suppliers and, 3) input/output changes.
3. Evaluate features increasing supply chains' resilience:
   - Supply chain complexity, supplier availability, concentration.
4. How does supplier composition change after the shock?

Related Literature

Production networks and shock transmission

- Barrot and Sauvagnat (2016), Boehm et al (2019), Carvalho et al. (2021), Huneeus (2021), Dhyne et. al. (2021).
- Contribution: focus on extensive margin, new data+novel identification+large shock.

Supply chain resilience

- Elliot et al (2022), Grossman et al (2022), Arkolakis et al (2023), Dhyne et. al. (2023).
- Contribution: new empirics to show which features make supply chains more resilient

Covid-19 pandemic and supply chains

- Baqaee and Farhi (2020), Barrot et al. (2020), Bonadio et al (2021), del Rio-Chanona et al. (2020), Cevallos Fujiy et. al (2022), DiGiovanni et. al. (2022).
- Contribution: focus on extensive margin and detailed firm-to-firm networks data.

Data

- Universe of firm-to firm transactions for a large Indian state
  - 3x Belgium, 7x Costa Rica, and 2x Chile.
- Unique origin/destination establishment identifier
- Value of transaction, 8-digit product code, quantity.
- Daily data from January 2018 to December 2020.
- Network details

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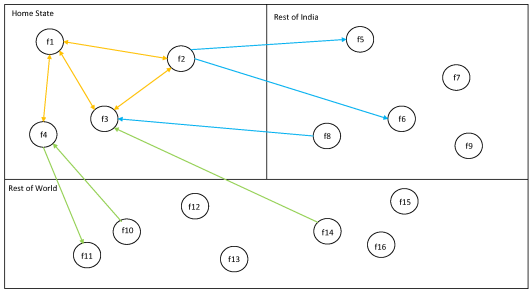
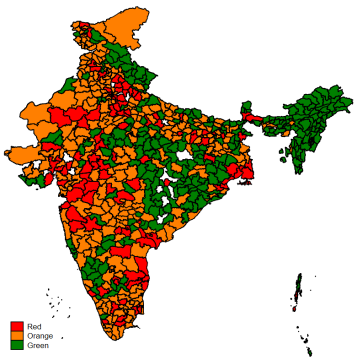
Figure: Stylized Example: Establishment-Level Network



COVID-19 lockdowns in India

India's Covid Lockdowns



March 25th 2020 - nationwide lockdowns

- District lockdown stringency: strict, moderate, mild
- Policy based on March Covid cases, red areas slightly larger.

Stats

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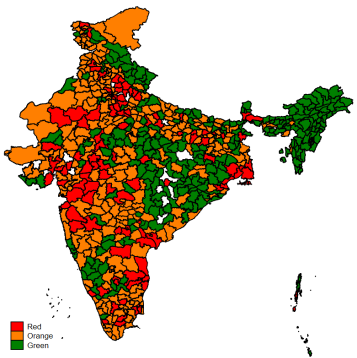

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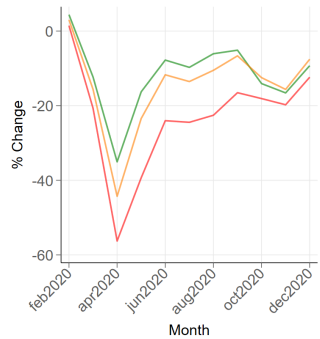
Google Mobility Trends: Workplaces



- Lockdown zones correlated with economic activity and mobility.
- Google Mobility Nightlights Separations

Event-study design

- Firms buying from red face $\neq$ shocks than firms buying from green.
- Covid is a national shock, own-lockdown can drive separations.

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1. Index to measure "supplier risk" before the shock:

$$(\text{Supplier Risk})_j = \sum_i^N \underbrace{s_{i,j,t_0-1}}_{\text{Share purch. from } i} \times (\text{Supplier } i\text{'s lockdown stringency in } t_0)$$

2. Set up event study approach using standardized supplier risk

$$\text{Outcome}_{j,t} = \sum_{x=1}^{T} \gamma_x \underbrace{1(t=x)}_{\text{Time-dummies}} \times \underbrace{(\text{Supplier Risk})_j}_{\text{Treatment exposure}} + \underbrace{\delta_j}_{\text{Firm FE}} + \underbrace{\delta_{k,t}}_{\text{Ind-time FE}} + \underbrace{\delta_{r,t}}_{\text{Own-region-time FE}} + \underbrace{\epsilon_{j,t}}_{\text{error}}$$

Measuring supply chain resilience

Three measures of resilience:

1. Maintain buyer-supplier links: Separation rate from suppliers

$$\text{Separation Rate}_{j,t} = \frac{\text{N of suppliers to } j \text{ in } t-1, \text{ not in } t}{\frac{1}{2}\left(\text{N of supp to } j \text{ in } t\right) + \frac{1}{2}\left(\text{N of supp to } j \text{ in } t-1\right)}$$

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2. Ease of finding new suppliers: Net separation rate

$$\text{Net Sep. Rate}_{j,t} = \text{Sep. Rate}_{j,t} - \underbrace{\frac{\text{N of suppliers to } j \text{ in } t, \text{ not in } t-1}{\frac{1}{2}\left(\text{N of supp to } j \text{ in } t\right) + \frac{1}{2}\left(\text{N of supp to } j \text{ in } t-1\right)}}_{\text{Entry rate}}$$

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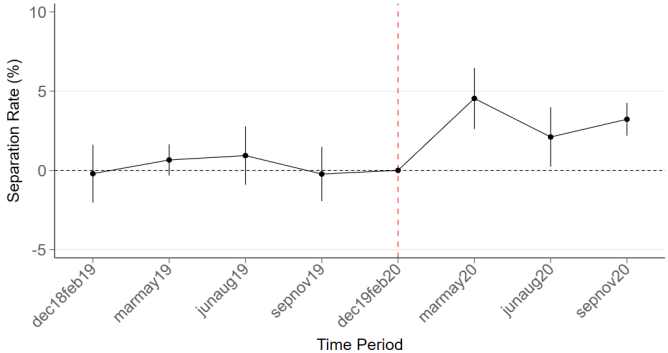
3. Real value of inputs purchased and output sold.

Separations increase for highly exposed firms

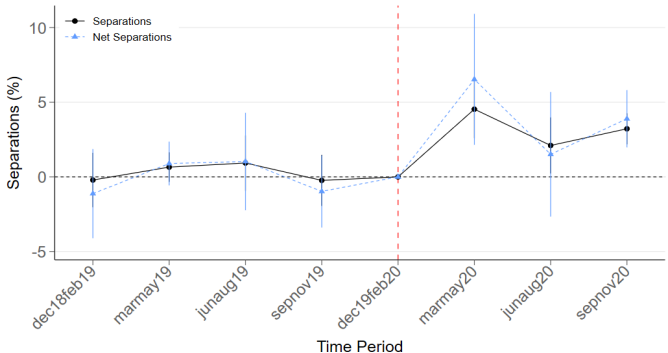
$$\text{Separation rate}_{j,t} = \sum_{x=1}^{T} \gamma_x 1\left(t = x\right) \times \left(\text{Supplier Risk}\right)_j + \delta_j + \delta_{r,t} + \delta_{k,t} + \epsilon_{j,t}$$



- Firm with all red suppliers had a sep. rate 8.8pp higher (28%) than firm with all green suppliers.
- Average separation rate in the omitted period: 30.9%. 4 months | 6 months | Demand control

Net separation rates also increase

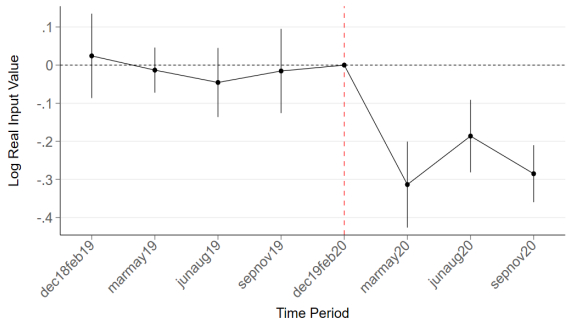
$$\text{Net Separation rate}_{j,t} = \sum_{x=1}^{T} \gamma_x 1\left(t = x\right) \times \left(\text{Supplier Risk}\right)_j + \delta_j + \delta_{r,t} + \delta_{k,t} + \epsilon_{j,t}$$



- Net separations responds more than separations. Harder to find new suppliers for high-exposed firms.

Real input value goes down

$$\text{Log(Input value)}_{j,t} = \sum_{x=1}^{T} \gamma_x 1\left(t = x\right) \times \left(\text{Supplier Risk}\right)_j + \delta_j + \delta_{r,t} + \delta_{k,t} + \epsilon_{j,t}$$



- Firms with supplier risk 1 SD above mean had 30% larger input drop compared to mean risk.
- Output also decreases Results
- Extensive margin drives 87% of the input drop. Decomposition

What features of supply chains drive resilience?

- Triple difference approach.

$$\text{Outcome}_{j,t} = \underbrace{\gamma \times 1\,(t > \text{Feb2020}) \times (\text{Supplier Risk})_j}_{\text{post-period} \times \text{risk exposure}} + \underbrace{\alpha \times 1\,(t > \text{Feb2020}) \times Z_j}_{\text{post-period} \times \text{characteristic}}$$
$$+ \underbrace{\beta \times 1\,(t > \text{Feb2020}) \times (\text{Supplier Risk})_j \times Z_j}_{\text{post-period} \times \text{characteristic} \times \text{risk exposure}} + \delta_j + \delta_{r,t} + \delta_{k,t} + \epsilon_{j,t}$$

- Z_j characteristic of supply chain
- β : differential impact of lockdowns between high and low supplier-risk firms with 1 SD above mean Z_j, relative to mean Z_j

Firms that buy more products are more resilient

- Input differentiation metrics
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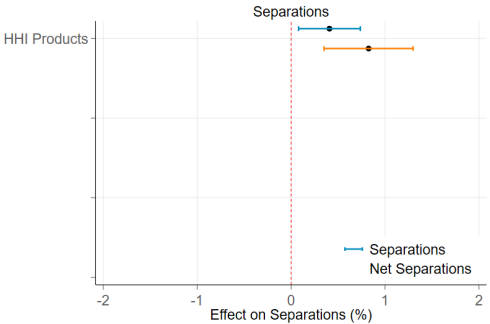

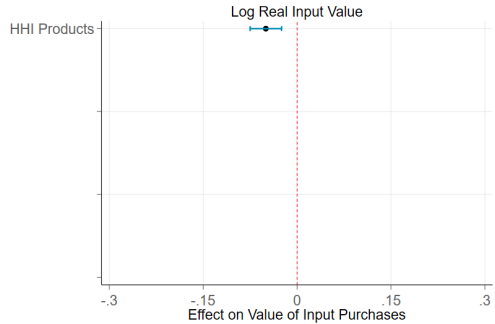

- More variety of products → fewer net separations
- Firm in 90th vs 10th HHI percentile has 2pp higher net separation rate (baseline: 3.7pp). Stats

More complex supply chains are more resilient

- Measure of complexity: How many products are needed to produce a given product?
  - Complexity of products firm buys (Degree 1) and products suppliers buy (Degree 2)

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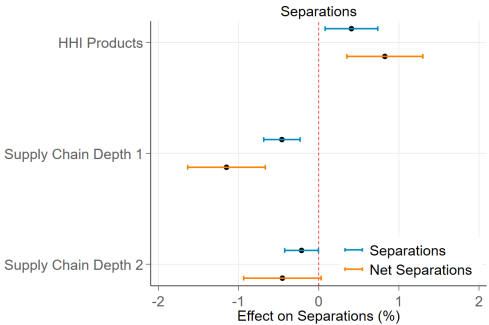

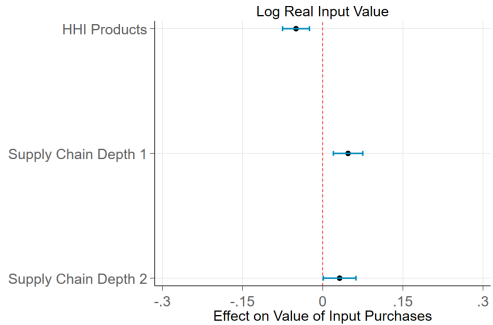

- More complex products → lower input drop, fewer net separations. If supply chain complex, more likely to have invested in resilience
- 90th vs 10th: 2.5pp and 0.98pp lower net separations, respectively.

Buying from a connected supplier makes link more resilient

- How important are your suppliers?
  - Outdegree: measure on how nodal firm j's suppliers (i) are.

$$\frac{\sum_i \sum_\ell \text{Share of } i \text{ sales in } \ell \text{ purchases.}}{\text{N suppliers of } j}$$

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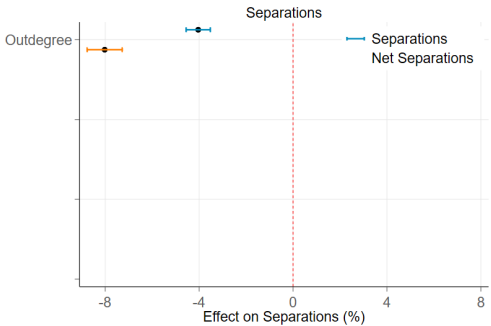

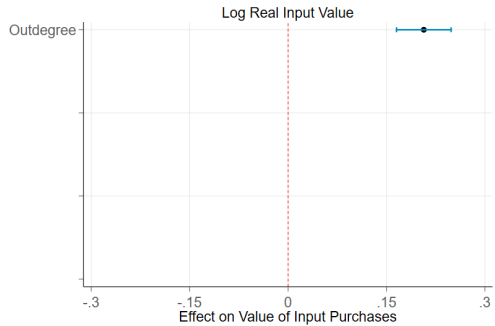

- If more concentrated in more nodal suppliers → more resilient. (90th vs 10th: 6.3pp lower net separations).

More dependence on a supplier makes link more resilient

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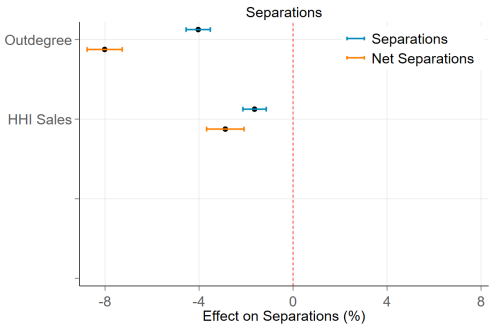

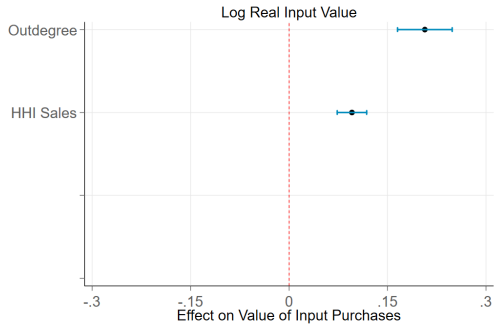

- If more concentrated in fewer suppliers → more resilient. (90th vs 10th: 6.6pp lower net separations).

More alternatives in the market, more likely to break links

1. How many suppliers are there in the market for the products you buy?

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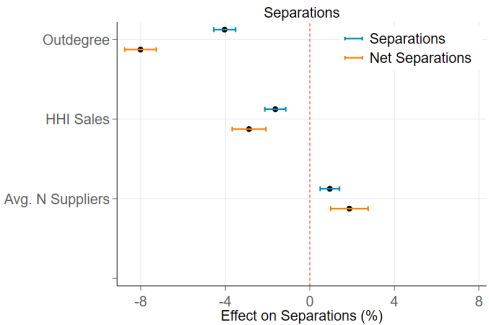

- More suppliers available → less costly to break links. (90th vs 10th: 4.7pp higher net separations).
- Investing in resilience only relevant if good is not easily available. (Elliott et al (2022))

Summary

- What features distinguish more resilient supply chains?
  - More complex supply chains less likely to break links.
  - If purchases more concentrated in a single supplier $\rightarrow$ less likely to break those links.
  - Product easily available $\rightarrow$ more likely to break links.

Summary

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  - If purchases more concentrated in a single supplier → less likely to break those links.
  - Product easily available → more likely to break links.
- Robustness checks:
  - Controls for firm size Separations Net Separations Input Value
  - Supplier shock exposure concentration Concentration
  - Demand exposure to lockdowns Buyer exposure
  - Weighting separations by supplier size Weighted Indegree by firm-size Indegree/Size

How do firms change the composition of their suppliers?

$$\overline{\text{Supplier Outcome}}_{j,t} = \gamma \times 1\,(t > \text{Feb2020}) \times (\text{Supp. Risk})_j + \delta_j + \delta_{r,t} + \delta_{k,t} + \delta_{s,t} + \epsilon_{j,t}$$

- $\overline{\text{Supplier Outcome}}_{j,t}$ is the avg. of firm j suppliers' characteristic.
- Restricted to those that buy and sell every period.

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	Avg Supp Outdegree	Avg Supp Size	Avg dist to supp	Share non-home state	Number of Suppliers
$1\,(t > \text{Feb2020}) \times (\text{Supplier Risk})_j$	1.25***	6.03***	-1.53	-2.56**	-0.12*
	(0.26)	(1.06)	(1.96)	(0.11)	(0.06)
Pre-period mean	43	106	486	38.54	12.35
Observations	264,648	264,648	264,648	264,648	264,648

Note. *** p<0.01, ** p<0.05, * p<0.1, SE clustered at buyer level.

- Event studies: Results

Conclusion

- New dataset on the universe of firm-to-firm transactions in a large Indian state.
- Spatial variation in lockdown stringency across India.
- Firms with suppliers in high lockdown areas experience more separations, fewer entries, and lower input value.
- Which features distinguish more resilient supply chains?
  - More complex supply chains → less likely to break links.
  - If products easily available → more likely to break links.
- Firms shift to larger suppliers.
- Ongoing work: responses of supply chains to climate disruptions

Thank you!

Describing the Network

Table: Network Characteristics

	Mean	p50	p10	p90
N suppliers per buyer	5.19	2.00	1.00	11.00
N products purchased	6.62	3.00	1.00	16.00
N buyers per supplier	5.71	2.00	1.00	11.00
Value of inputs purchased (millions of Rupees)	5.90	0.48	0.05	7.28
HHI products	0.65	0.62	0.23	1.00
Avg. HHI Sales	0.83	1.00	0.47	1.00
Indegree	0.93	0.11	0.00	2.05
Outdegree	1.10	0.13	0.00	1.88

- We focus on the responses of firms in the network, not the network overall Back

Table: Summary statistics for main variables

Outcome	Mean	p25	p50	p75
Separation Rate (%)	30.9	0	16.67	52.78
Entry Rate (%)	74.06	0	50	106.67
Net Separations (%)	-43.12	-70	0	0
Real Input Value (log)	14.91	12.48	14.55	16.96
Real Sales (log)	16.33	13.57	16.05	18.66
Avg. Supplier Size (millions of rupees)	106.42	9.65	34.04	127.49
Avg. Supplier Outdegree	43.04	3.3	10.97	31.99
Share Purch. Lgst. Supplier (%)	52.39	31.06	47.84	71.82
Number Products	12.05	3	7	14
Share Purch. Diff. Prod. (%)	60.19	21.25	72.78	97.81
Supply Chain Depth	32.32	28.15	31.46	36.35
Number Suppliers	12.35	3	7	14
Avg. Distance (km)	486.71	97.13	251.65	712.75
Share Purch. Non-Home State (%)	38.54	0	24.42	78.48

Table: Summary statistics by district lockdown degree Back

Zone	Avg. Cases/Million	Avg. Deaths/Million	Avg. Population	Total Cases	Total Deaths	Total Population
Green	26.316	0.1865	1,135,294	7,533	50	287,229,399
Orange	69.841	0.9236	1,990,250	24,713	364	469,698,944
Red	369.80	10.901	3,196,090	143,828	4,796	354,766,033

Lockdowns decreased economic activity

- We validate our lockdown measures using Google Mobility data (left-panel) and the VIIRS Satellite Nighttime lights data (right-panel). Back

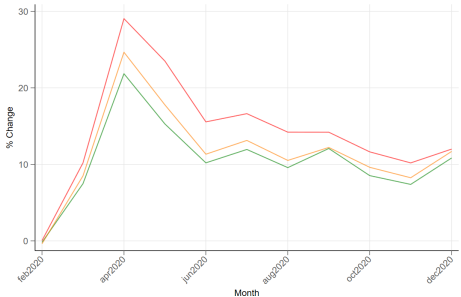


Figure: Google Mobility Place of Residence

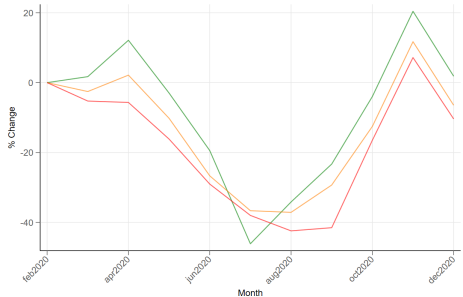
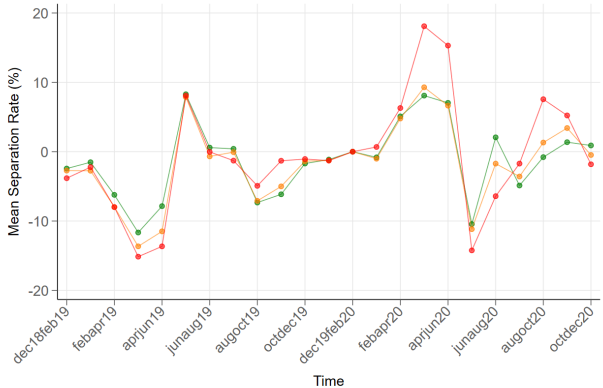


Figure: VIIRS Nighttime Lights

Firms break supplier links after the lockdowns imposed

Figure: Mean separation rate for firms in orange zones by supplier location.



But, measuring the true impact of lockdowns on separations not trivial:

- Firms buying from red face $\neq$ shocks than firms buying from green.
- Covid is a national shock, own-lockdown can drive separations. Back

Alternative time periods

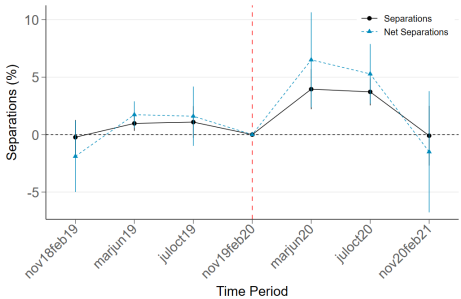


Figure: Separations - 4 month

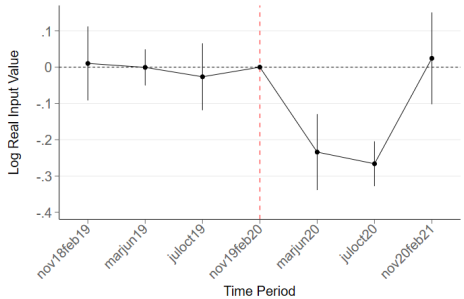


Figure: Input Value - 4 month

- *Note.* Number of observations is 843,910; mean net-separation rate in the omitted period is -38.7%; mean separation rate in the omitted period is 33.0%; mean log real input value in omitted period is 15.38. Back

Alternative time periods

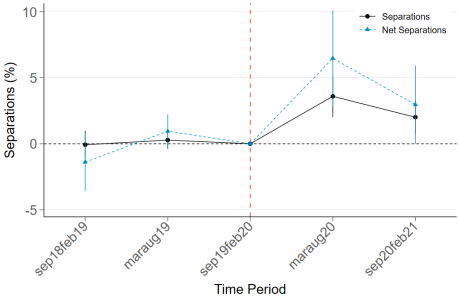


Figure: Separations - 6 month

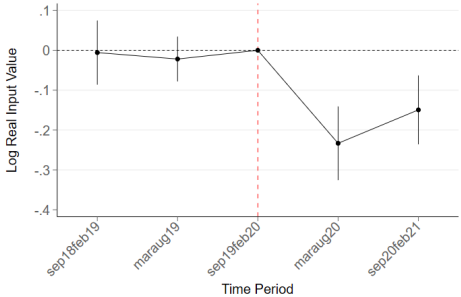
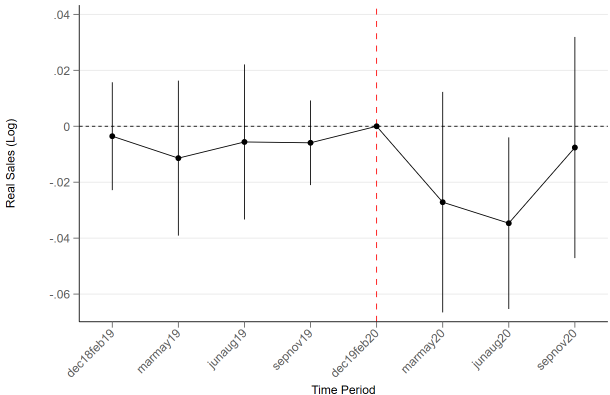


Figure: Input Value - 6 month

- *Note.* Number of observations is 625,686; mean net-separation rate in the omitted period is -30.6%; mean separation rate in the omitted period is 37.5%; mean log real input value in omitted period is 15.97. Back

Real sales go down

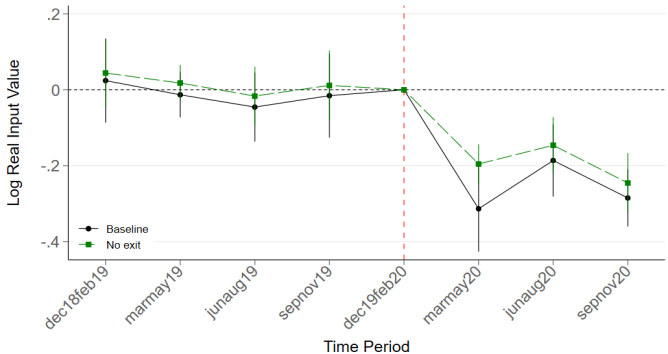
- Real sales: nominal sales deflated by price index.



- The sample is restricted to include firms with positive real sales. Number of observations: 214,412. Standard errors clustered at buyer level Back

Firm exit plays a large role

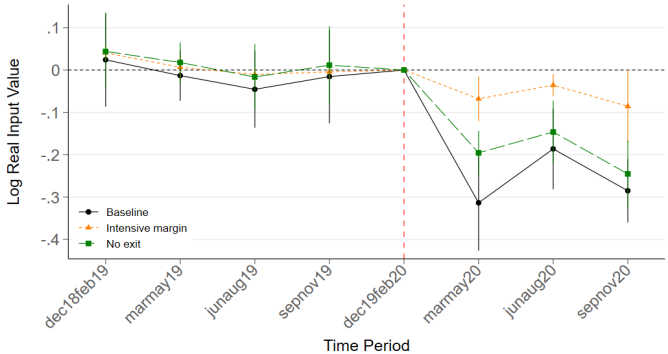
- Focus only on firms that don't exit after March 2020.



- If we remove firms that exit after March 2020 input drop goes from -30% to -18%
- Total number of observations: 946,665. Continuers: 864,076 Back

Extensive margin drives a majority of the input drop.

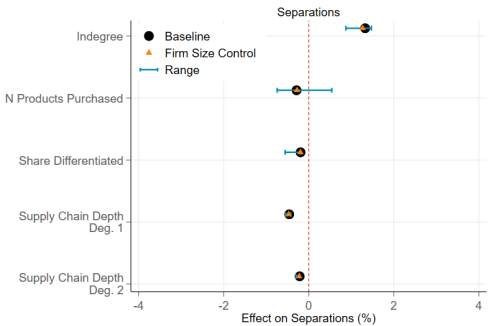
- Focus only on inputs purchased from continuing buyer-supplier relationships.

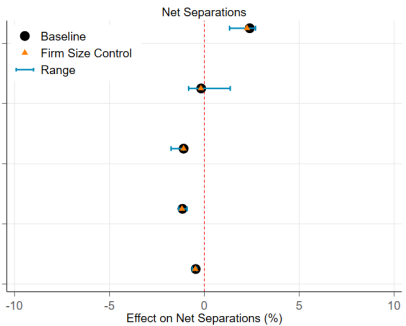


- If we only look at continuing relationships → input drop goes from -18% to -4%
- Total number of observations: 946,665. Continuers: 864,076. Continuing pairs: 675,261 Back

Robustness: Controlling for Firm Size

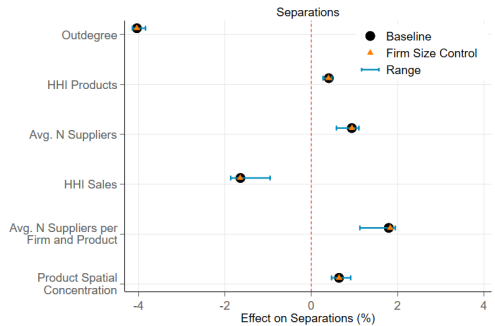
Back

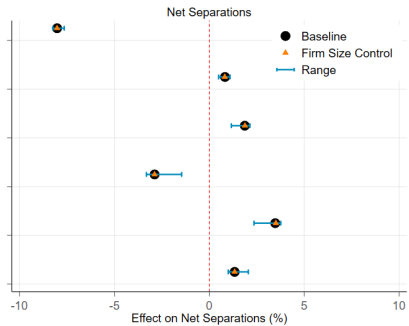




Robustness: Controlling for Firm Size

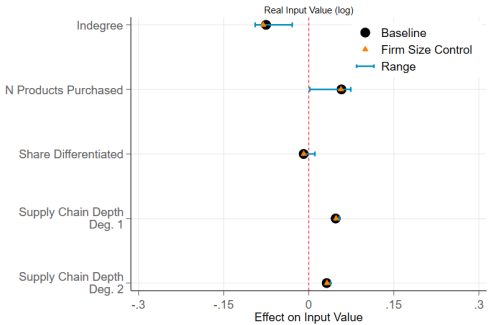
Back

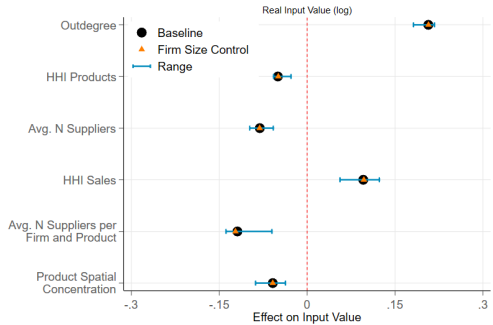




Robustness: Controlling for Firm Size

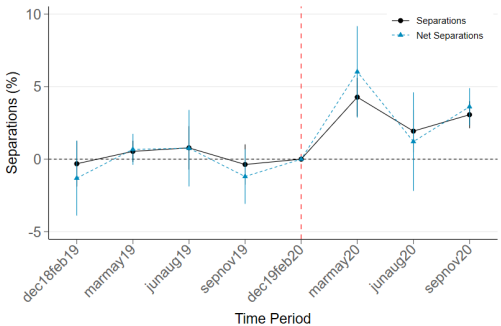
Back

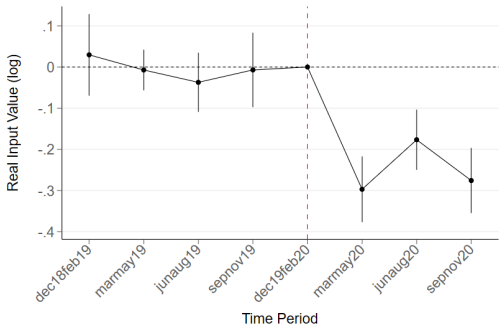




Robustness: Demand Control

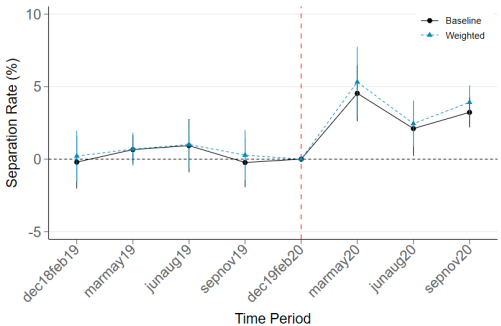
Back

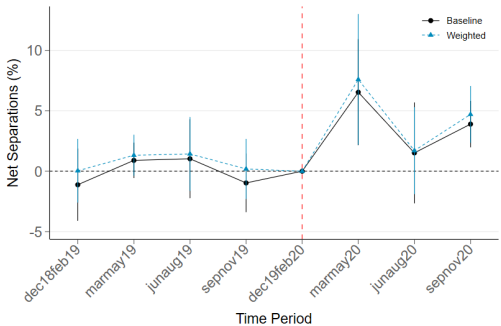




Robustness: Weighting by Supplier Size

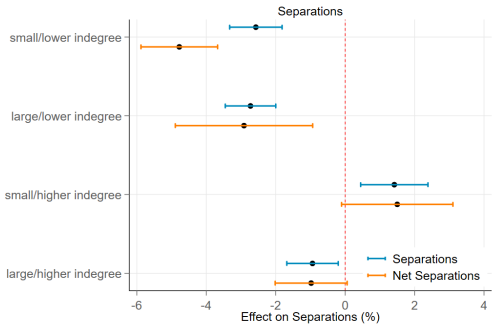
Back

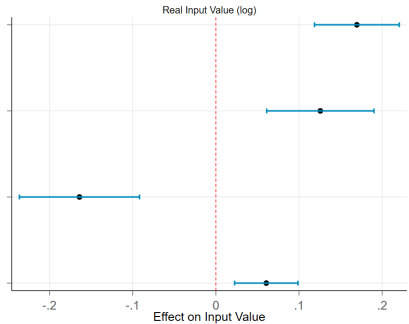




Robustness: Indegree by Firm Size

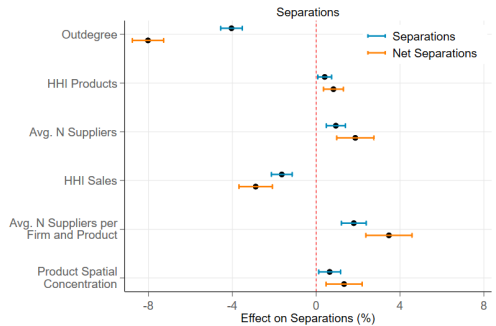
Back





Robustness: Supplier Shock Concentration

Back



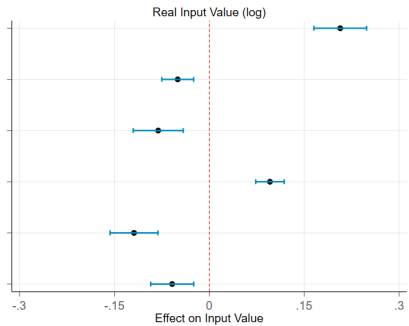


Table: Characteristic Statistics

Characteristic	HHI Prod	Share Differentiated	Supply Chain Depth 1	Supply Chain Depth 2
p10	0.235648	0	20.98185	737.8309
p90	1	1	40.59343	1772.42
sd	0.302429	0.404453	8.962374	475.2833
Characteristic	Avg. Supplier Outdegree	HHI Sales	Avg. N Suppliers	Avg. N Suppliers per Firm/Prod.
p10	1.11585	0.471417	303.3891	1
p90	104.9078	1	2775.365	6.179948
sd	130.3216	0.228987	974.0743	5.489354

Back

Changes in supplier composition

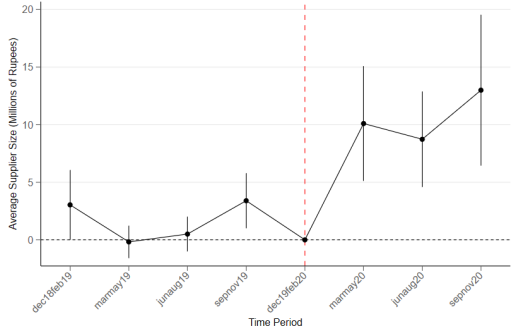
- How do firms change the composition of their suppliers?

$$\overline{\text{Outcome}}_{j,t} = \sum_{x=1}^{T} \gamma_x \times 1\left(t = x\right) \times \left(\text{Supplier Risk}\right)_j + \delta_j + \delta_{r,t} + \delta_{k,t} + \delta_{s,t} + \epsilon_{j,t}$$

- $\overline{\text{Outcome}}_{j,t}$ is the avg. of firm j suppliers' characteristic.
- Additional restrictions:
  - Restricted to those that buy and sell every period.
  - Additional FEs $\delta_{s,t}$: time interacted with whether the firm buys from each state s in pre-period. Back

Firms concentrate in larger suppliers

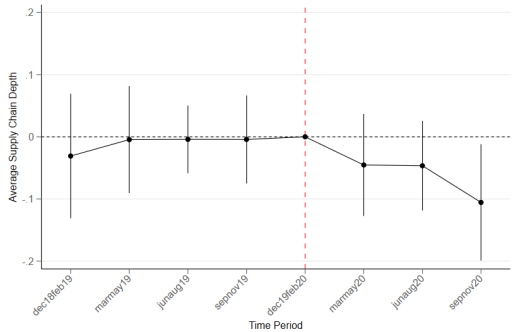
$$\overline{\text{Supp. Size}}_{j,t} = \sum_{x=1}^{T} \gamma_x \times 1\,(t = x) \times (\text{Supp. Risk})_j + \delta_j + \delta_{r,t} + \delta_{k,t} + \delta_{s,t} + \epsilon_{j,t}$$



- Firms with 1 SD above mean in supplier risk concentrate in suppliers that are 10% bigger.
- Number of observations: 249,346. Pre-period mean 106 mn rupees. Back

Supply chains get slightly less complex

$$\overline{\text{S Chain Depth}}_{j,t} = \sum_{x=1}^{T} \gamma_x \times 1\,(t = x) \times (\text{Supp. Risk})_j + \delta_j + \delta_{r,t} + \delta_{k,t} + \delta_{s,t} + \epsilon_{j,t}$$



- Pre-period average supply chain depth: 32 products Back