Endogenous Production Networks and Supply Chain Disruptions

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Motivation

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Research Question

How do supply chains affect prices and productivity?

This Paper

How do supply chains affect prices and productivity?

1. Empirics

- Provides a causal estimate on prices and productivity
- With **exogenous** variation in their suppliers
- Tracks network linkages across firms

Disruptions in Supply Chains

- Price $\rightarrow$ %11 Increase
- Labor Productivity $\rightarrow$ %24 Decrease
- Complements in production across inputs

This Paper

How do supply chains affect prices and productivity?

2. Theory

- Build a model of endogenous production networks
- Supply Chains $\rightarrow$ An important layer for firm heterogeneity
- With firm-to-firm linkages react endogenously to **supply chain shocks** on both intensive and extensive margins

This Paper

How do supply chains affect prices and productivity?

3. Quantitative

- Test the predicted effects
- Build a **counterfactual supply chain**

Counterfactual Supply Chain

- Shock the model
- How firms respond to the shocks in supply chains?

Contribution to the Literature

1. Networks
   - Long and Plossner (1983), Acemoglu et al.(2012), Acemoglu et al.(2016), Grassi (2017), Baqaee & Farhi (2020), Bigio & La'O (2020)
2. Endogenous Formation of Production Networks
   - Carvalho & Voigtländer (2014), Lim (2017), Oberfield (2018), Acemoglu & Azar (2020), Taschereau-Dumouchel (2020)
3. Supply chain distruptions
   - Barrot & Sauvagnat (2016), Carvalho et al. (2021), Lafrogne-Joussier et al.(2022)

Contribution,

$*$ **Supply Chains** $\rightarrow$ **affect prices** & **productivity**

$*$ **Interdependent Choices** $\rightarrow$ **Endogenous Production Networks**

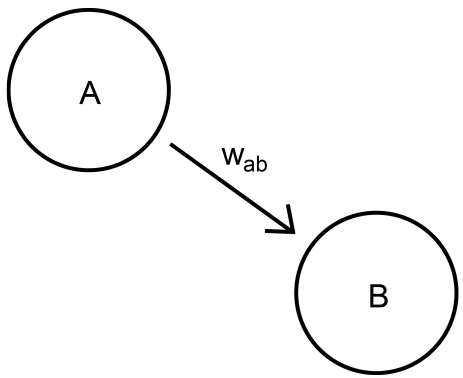
Contribution to the Literature

4. Trade with Heterogeneous Firms
   - Eaton and Kortum (2002), Melitz (2003), Melitz and Ottaviano (2008), Halpern et al.(2015), Antras et al.(2017), Antras et al.(2022)
5. Production Networks and Trade
   - Tintelnot et al.(2017), Demir et al.(2021), , Rachapalli (2021), Zi and Bernard (2021), Alfaro-Ureña et al. (2022), Bernard et al.(2022)

Contribution,

* **Networks** $\rightarrow$ **Firm Heterogeneity**
* **Importance of Network Interactions**

What is a Supply Chain?



1. Directed $\rightarrow$ Firm A to Firm B
2. Weighted $\rightarrow$ w_{ab}

Production Network

Nodes: Firms

Edges: Intermediate Inputs

Data

- Firm-level Data, Turkey
  - 2006-2020, NACE Rev.2.
  - Ministry of Industry and Technology
- Weighted and Directed **Networks**
  - VAT $\rightarrow$ Weights
  - Business-to-business
- Networks
  - Directed $\rightarrow$ Identify Supplier and Customer

# of Transactions	# of Suppliers	# of Customers	# of Years
405.8 mil.	1.94 mil.	2.14 mil.	15

- Threshold: $\sim$ 270 USD

Data

- Match datasets $\rightarrow$ VAT number
- Imports

# of Transactions	# of Firms	# of Products (HS6)	# of Years
123.5 mil.	235586	5837	15

- Exports

# of Transactions	# of Firms	# of Products (HS6)	# of Years
146.4 mil.	228827	5798	15

- Balance Sheet
- Social Security

Facts: Productive firms have productive supply chains

Fact 1. Productive firms rely on productive suppliers.

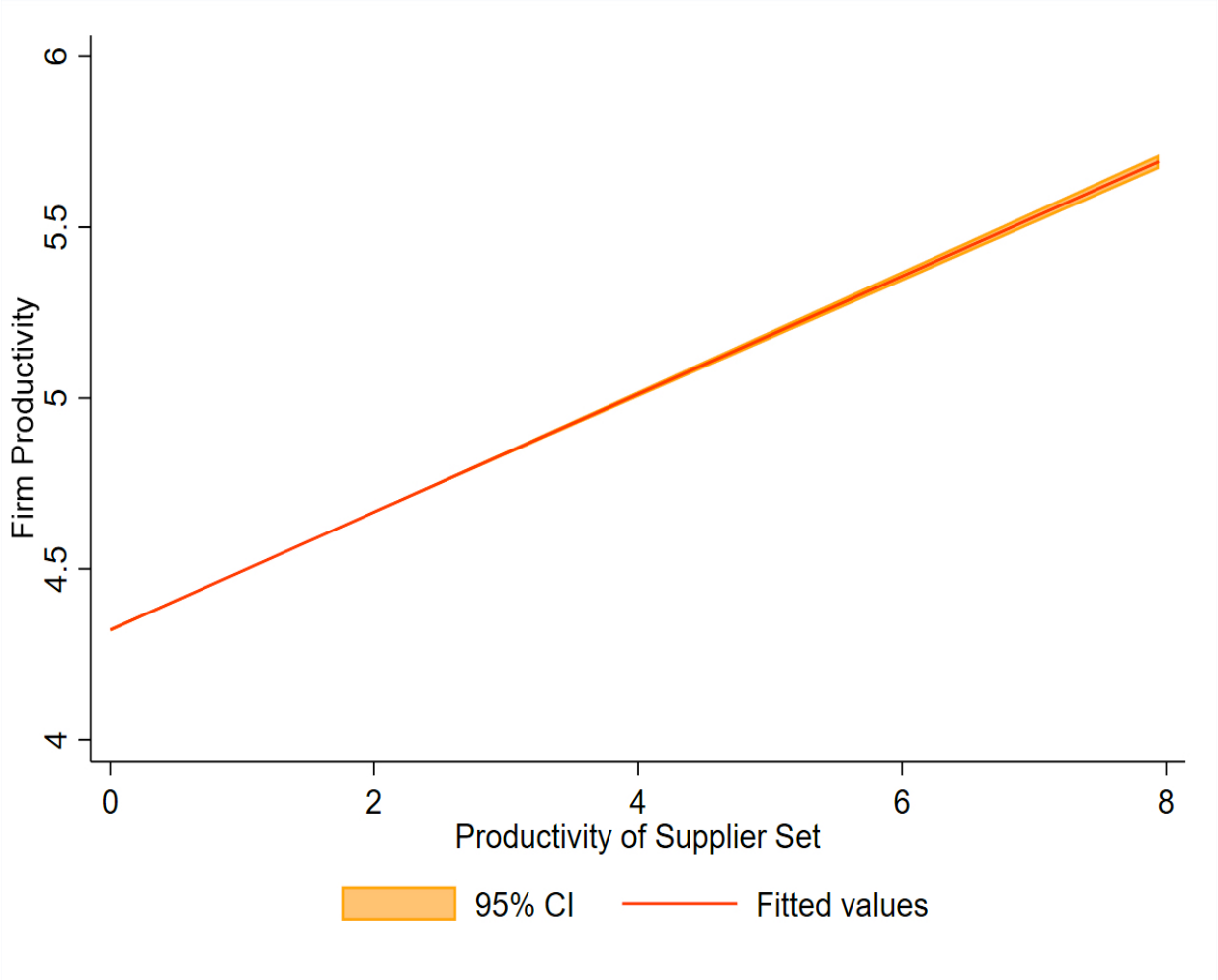


Figure: Supplier Set Productivity *Notes:* The estimation is weighted by the number of employees.

Facts: Costs to Network?

Fact 2. Only a small percentage of firms rely on different suppliers.

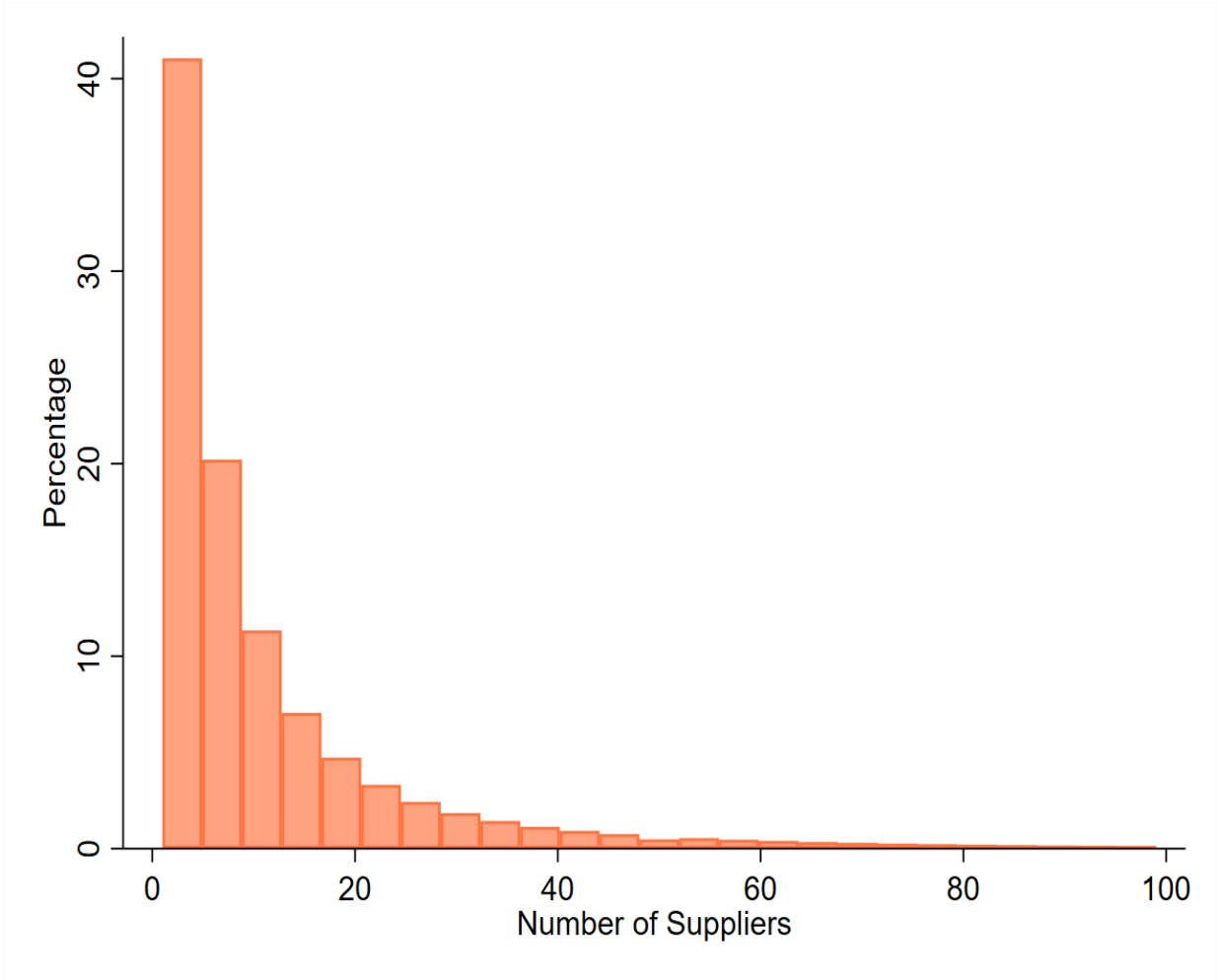


Figure: Number of Different Suppliers per Firm *Notes:* This figure presents the firms that has less than 100 suppliers .

Empirical Evidence

Empirical Evidence on Productive Clusters

Question How firm productivity and supply chain productivity is linked?

Productivity of the Firm

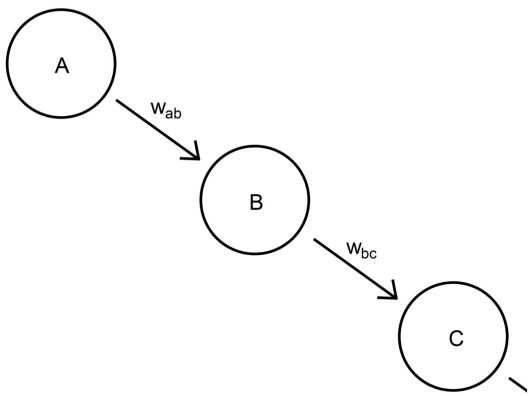
- Total Factor Productivity
- Levinsohn and Petrin

Productivity of the Network

- Total Factor Productivity
- Weighted by sales

Empirical Evidence on Productive Clusters

$$FirmProductivity_{i,t} = \alpha + \beta_k NetworkProd_{i,t} + \mu_i + \lambda_{ht} + \gamma_{rt} + \epsilon_{i,t}$$



Network Productivity defined as :

1. Productivity of the Supplier Set, *weighted by the inputs*
2. Productivity of the Customer Set, *weighted by the sales*

- μ_i: Firm FE
- λ_{ht}: Industry x year FE
- γ_{rt}: Region x year FE

Empirical Evidence on Productive Clusters

	Firm Productivity		
Productivity of the Supplier Set	1.269***		1.168***
	(0.000)		(0.000)
Productivity of the Customer Set		0.649***	0.216***
		(0.000)	(0.000)
Obs.	5393026	5018888	4817901
R^2	0.034	0.039	0.062
Firm FE	Yes	Yes	Yes
Industry-year FE	Yes	Yes	Yes
Region-year FE	Yes	Yes	Yes

Empirical Evidence on Productive Clusters

In OLS $\rightarrow$ there is a significant and positive correlation between firm productivity and their suppliers

- But it does not answer how supply chains affect prices, productivity
- The challenge is to find an identification strategy as firms choose their supplier network

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First paper to provide a causal estimate $\rightarrow$ impact of firm's supply chain on prices and productivity exploiting the disruption from Chinese suppliers due to covid lockdowns

Identification Strategy

The main identifying assumptions are:

(1) Supply chain disruption can be employed to identify the effects on importers as an exogenous event.

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(2) Firms importing from China and firms importing from other countries have no differential trends absent the Chinese lockdowns.

(3) All importing firms are subject to identical demand shocks.

Treated $\rightarrow$ Importers from China

Control: $\rightarrow$ Importers from all other countries

Empirical Strategy: Supply Chain Disruptions

Event $\rightarrow$ Early lockdown in China

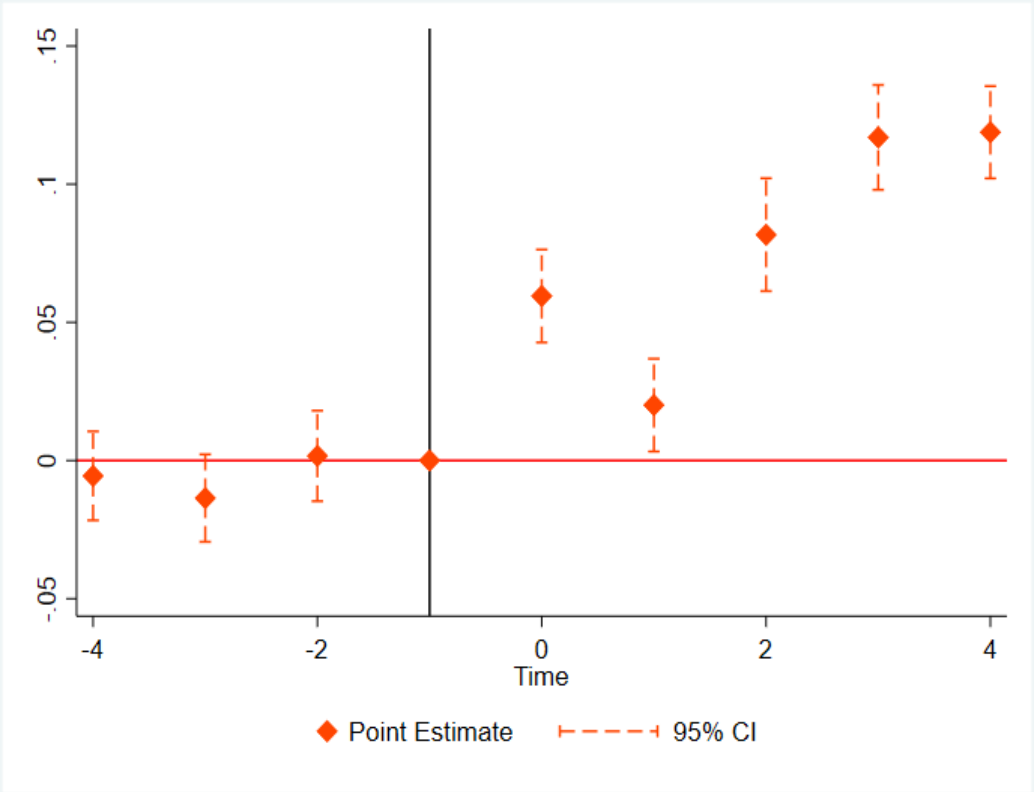
$$y_{i,t} = \alpha + \sum_{(j=-4),(j\neq -1)}^{4} \beta_k Disruption_{i,t-j} + \mu_i + \lambda_{ht} + \epsilon_{i,t}$$

- Aim
  - Explore the timing and evolution of variables
- Specification
  - 4 Leads & 4 Lags
- Identification
  - Insignificant Leads
- Timeline
  - Months arranged according to disruption
- Baseline
  - $t = -1$
- Event
  - $t = 0 \rightarrow$ Lockdown

Supply Chain Disruptions

Price Effects

- Leads to % 11 increase
- Robust to
  - *Industry*
  - *Broad Economic Category*
- Includes controls for Firm and Industry-Month



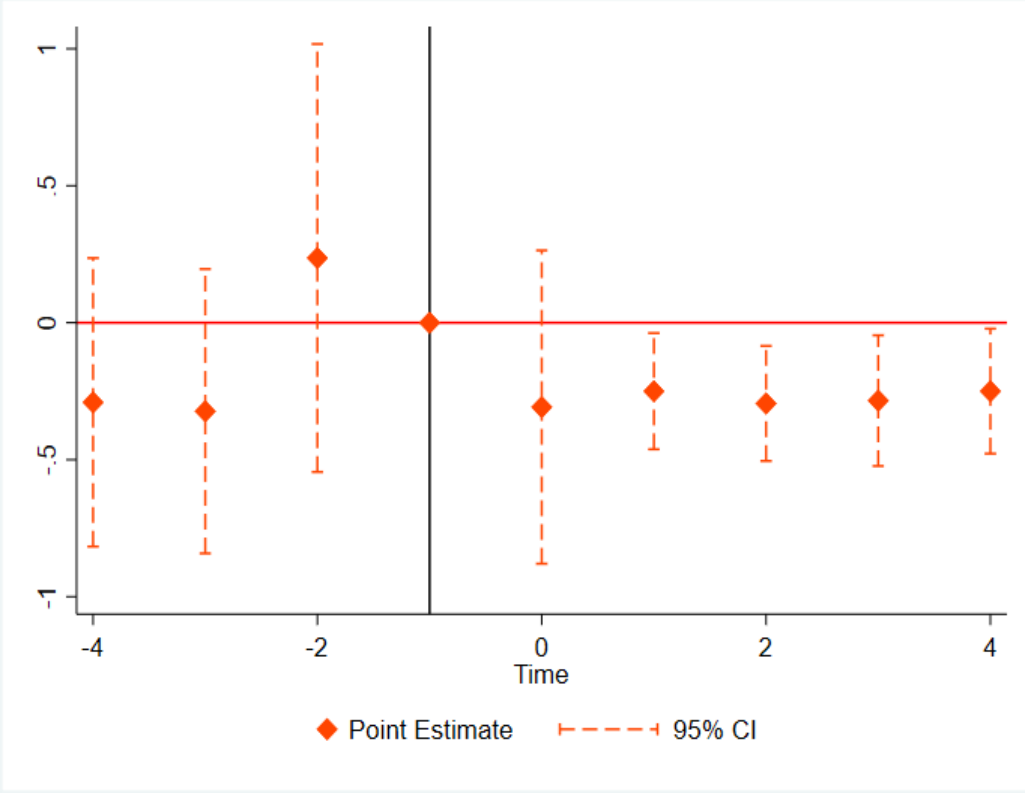
Supply Chain Disruptions: Price Effects

	Industry		BEC Classification		
	All	Manu	Inter	Capital	Final
4 months before the Disruption	-0.00554 (0.500)	0.0127 (0.295)	-0.00300 (0.731)	-0.00745 (0.472)	-0.0102 (0.305)
3 months before the Disruption	-0.0136 (0.092)	-0.00750 (0.533)	-0.00107 (0.212)	-0.0117 (0.250)	-0.0103 (0.291)
2 months before the Disruption	0.00167 (0.842)	0.0202 (0.098)	0.00514 (0.562)	0.00792 (0.452)	-0.000261 (0.979)
Distruption	0.0595*** (0.000)	0.0542*** (0.000)	0.0534*** (0.000)	0.0615*** (0.000)	0.0418*** (0.000)
1 month after disruption	0.0200* (0.019)	0.0173 (0.164)	0.0134 (0.140)	0.0169 (0.113)	0.00709 (0.491)
2 months after disruption	0.0817*** (0.000)	0.0972*** (0.000)	0.0803*** (0.000)	0.0749*** (0.000)	0.0956*** (0.000)
3 months after disruption	0.117*** (0.000)	0.121*** (0.000)	0.106*** (0.000)	0.117*** (0.000)	0.133*** (0.000)
4 months after disruption	0.119*** (0.000)	0.134*** (0.000)	0.113*** (0.000)	0.110*** (0.000)	0.121*** (0.000)
Obs.	1131637	510291	1005993	730519	767366
R^2	0.005	0.004	0.005	0.005	0.004
Firm FE	Yes	Yes	Yes	Yes	Yes
Industry-month FE	Yes	Yes	Yes	Yes	Yes

Supply Chain Disruptions

Productivity

- To explore the mechanism: How are efficiency and supplier choice related?
- Leads to % 24 decrease
- Product-Supplier Level
  - Intermediate
  - Capital
  - Final



Supply Chain Disruptions: Productivity

	Industry		BEC Classification		
	All	Manu	Inter	Capital	Final
4 months before the Disruption	-0.291	-0.0264	-0.306	-0.598	-0.598
	(0.279)	(0.816)	(0.327)	(0.229)	(0.309)
3 months before the Disruption	-0.323	-0.0486	-0.366	-0.590	-0.546
	(0.222)	(0.654)	(0.238)	(0.231)	(0.355)
2 months before the Disruption	0.236	0.126	0.308	-0.418	-0.302
	(0.553)	(0.138)	(0.509)	(0.399)	(0.609)
Distruption	-0.308	-0.113**	-0.288	-0.520	-0.705
	(0.291)	(0.004)	(0.397)	(0.335)	(0.234)
1 month after disruption	-0.250*	-0.0950*	-0.247*	-0.395*	-0.339
	(0.021)	(0.018)	(0.049)	(0.045)	(0.149)
2 months after disruption	-0.295**	-0.0990*	-0.297*	-0.424*	-0.326
	(0.006)	(0.026)	(0.016)	(0.030)	(0.161)
3 months after disruption	-0.284*	-0.157	-0.264*	-0.472*	-0.302
	(0.019)	(0.134)	(0.050)	(0.032)	(0.197)
4 months after disruption	-0.250*	-0.126	-0.240	-0.443*	-0.317
	(0.032)	(0.218)	(0.075)	(0.037)	(0.175)
Obs.	1266463	550356	1077805	680756	557294
R^2	0.000	0.000	0.000	0.000	0.000
Firm FE	Yes	Yes	Yes	Yes	Yes
Industry-year FE	Yes	Yes	Yes	Yes	Yes

Model

Model

According to empirical findings,

1. Productive Clusters in Network

2. Supply Chain Disruptions

- Prices $\uparrow$
- Labor Productivity $\downarrow$

3. Labor productivity is primarily driven by intermediate or capital imports from China

Model

According to empirical findings,

1. Productive Clusters in Network

2. Supply Chain Disruptions

- Prices $\uparrow$
- Labor Productivity $\downarrow$

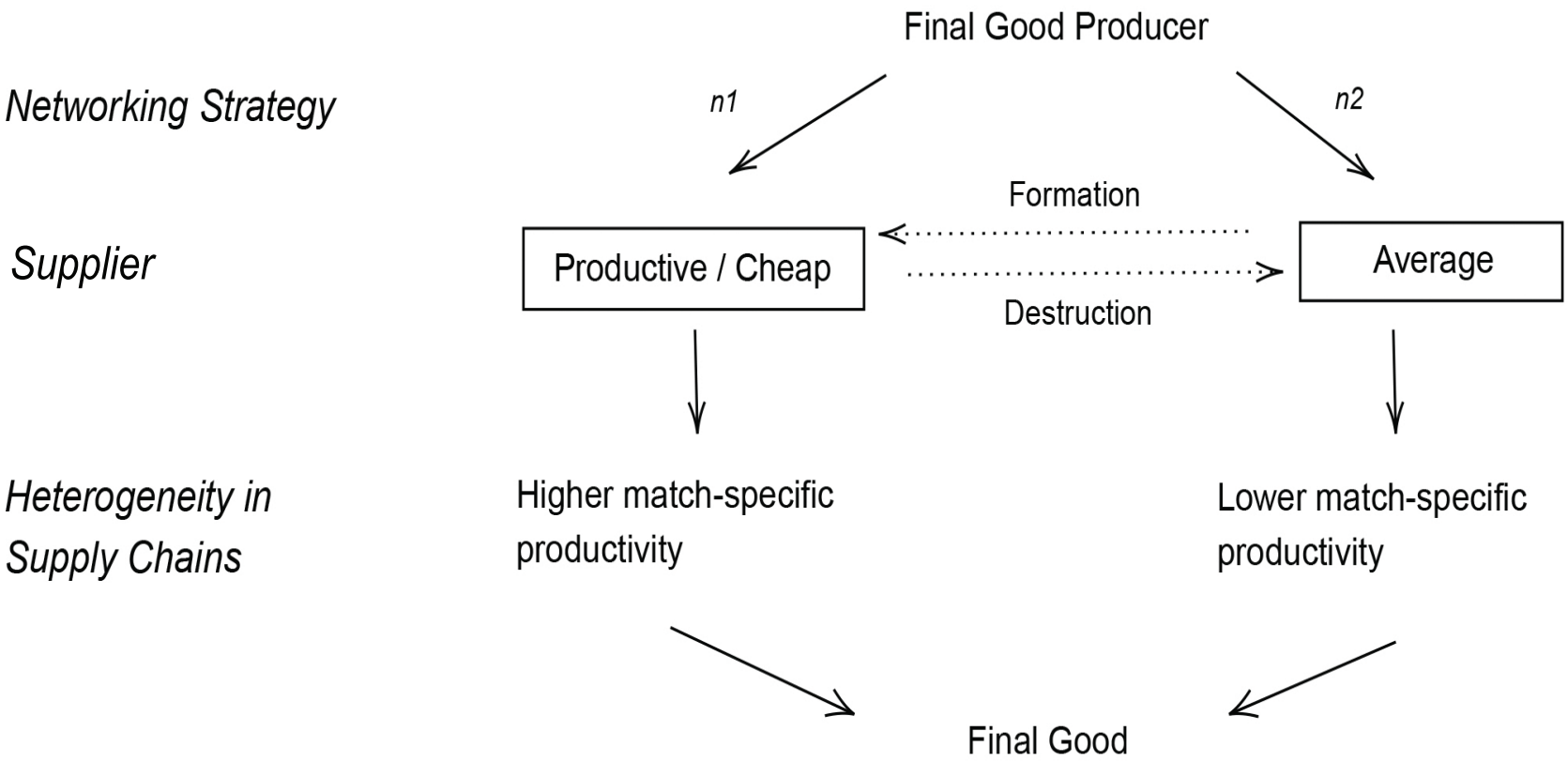
3. Labor productivity is primarily driven by intermediate or capital imports from China

Model serves for three main purposes

1. Selection into supply chains and these linkages are not random
2. Framework to understand supply chain disruptions
3. Test the predicted effects

Model

Model Sketch



Model

Environment

Preferences,

- Dixit-Stiglitz preferences over final good

$$U_i = \left(\int_{w \in W} q_i(w)^{\frac{(\sigma-1)}{\sigma}} dw \right)^{\frac{\sigma}{(\sigma-1)}} \tag{1}$$

- Consume at the final good sector

Economy consists of two sectors:

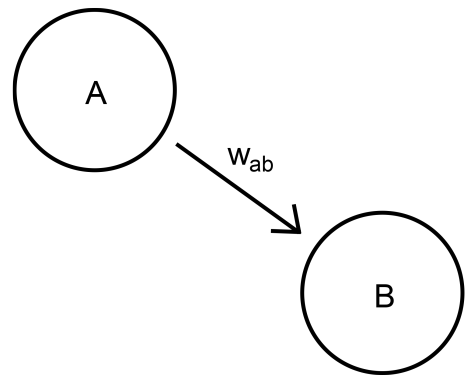
1. Manufacturing
2. Services

Model

Production

Value Chain $\rightarrow$ Two types of Firms

1. Upstream Suppliers : "A"
   - Producing intermediate goods
2. Downstream Firms : "B"
   - Producing final goods



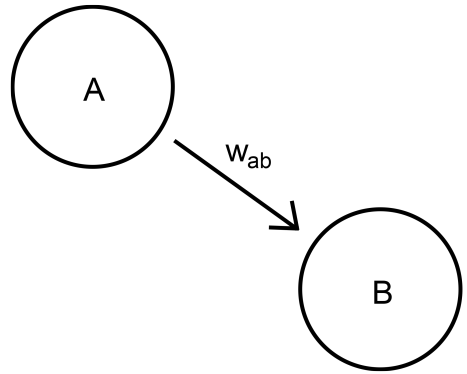
Model

Production

Value Chain $\rightarrow$ Two types of Firms

1. Upstream Suppliers : "A"
   - Producing intermediate goods
     - **Input Market**
       - Perfectly competitive
       - Modeled as EK (2002)

2. Downstream Firms : "B"
   - Producing final goods
   - **Final Goods Market**
     - Monopolistically competitive
       - Modeled as Melitz (2003)



Model

Production

Value Chain $\rightarrow$ Two types of Firms

1. Upstream Suppliers

Draw their efficency in production

Fréchet Distribution

- Same shape parameter
- Different location parameter
- State of Technology is different

2. Downstream Firms

Draw their efficiency in production

Pareto Distribution

- Same shape parameter
- Same location parameter

Model

How to build the best supply-chain?

To source from a supplier $\rightarrow$ **Sourcing Cost**

- Fixed Cost
- Set up input-output linkages
- Different for each supplier

Model

How to build the best supply-chain?

To source from a supplier $\rightarrow$ **Sourcing Cost**

- Fixed Cost
- Set up input-output linkages
- Different for each supplier

Better suppliers are those

- Quoting lower prices
- Associated with higher sourcing cost

Self-selection of better/efficient firms into cheaper suppliers and worse/inefficient firms source from worse suppliers

Model

Downstream Firms

Problem:

1. Downstream firms draw potential supplier
2. Downstream firms decide on which firms to use their product as input
3. Firms make production decision

Production Decision:

- Marginal cost
- Supply chain determined by maximizing the profits by firms
- Equilibrium exists

Model

Supplier-Match-Specific Productivity

$z_j(m, \varphi) \rightarrow$ **Realization of random variable** Z_i

Upstream Productivity: Fréchet

$$F_j(z) = e^{-T_j z^{\theta}}$$

T_j : Tech of supplier

θ : Productivity Dispersion Parameter

How to get better draws?

- Productive Suppliers
- More suppliers, higher θ reduces dispersion of pair productivity

Model

Downstream Price

The price of the downstream firm

$$p_i = \frac{1}{\varphi}\left(\gamma \sum_{j=1}^{N} T_j c_j^{-\theta}\right)^{-\frac{1}{\theta}}$$

where γ is $\left[\Gamma\left(\frac{\theta+1-\rho}{\theta}\right)\right]^{\frac{\theta}{(1-\rho)}}$

Price depends on

a. Core productivity

b. Supplier input costs

c. Supplier productivity

Model

Downstream Profit

The profit of the downstream firm

$$max_{I_{ij} \in \{0,1\}_{j=1}^{N}} \pi_i(\varphi, I_{i1}, .., I_{ij}) = \varphi^{\sigma-1}(\gamma \sum_{j=1}^{N} I_{ij} T_j(c_j)^{-\theta})^{\frac{\sigma-1}{\theta}} B_i - \sum_{j=1}^{N} I_{ij} S_{ij}$$

I_{ij} : Indicator Func

S_{ij} : Supplier Fixed Cost

B_i : Residual Demand

Endogenous Production Network

- Interdependency of supply chain strategy
- Nonlinear & Not separable profit function
- Each decision is linked to the other

General Equilibrium

- Fixed point for B_i and free entry condition

Industry Equilibrium

There exists a unique B_i in equilibrium

Model Implications

Supply Chain Disruptions

Probability of Best Suppliers $\rightarrow$ Chinese

- Lower Factor Costs
- Better State of Art
- Higher Sourcing Costs

Model Implications

Supply Chain Disruptions

Probability of Best Suppliers $\rightarrow$ Chinese

- Lower Factor Costs
- Better State of Art
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Supply Chain Disruptions:

- All firms affected
- Reconfiguration of Manufacturing Industry

Model Implications

Supply Chain Disruptions

Disruption $\rightarrow$ Increase in Fixed Costs

- Increase in sourcing costs of best suppliers, i.e. Chinese

Disruption has several effects,

1. Better firms reduce their share of inputs they source from China

1. Least efficient firms among the Chinese suppliers stop sourcing from China

2. Supplier networks of better firms become similar to worse firms

3. Competitiveness of productive firms fall

4. Decrease in the intensity of import competition of Turkish firms

$\rightarrow$ competition in Turkish market

- Leading fewer entrants and less selection

Model Implications

Supply Chain Disruptions

Manufacturing prices increase and Labor productivity decrease

First, Inputs are more expensive

Second, Firms are less efficient due to weaker selection

Structural Analysis

Structural Analysis

Structural Analysis is required to understand

- Model is empirically relevant ?
- Predicted effects are quantitatively relevant ?
- Counterfactual Scenarios
  - 1. Counterfactual Supply Chains
  - 2. Simulated Disruptions, exogenous increase in fixed costs

Structural Analysis

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Plan

1. Calibrate the model with the firm-level data
2. Counterfactual tests
3. Simulation

Calibration

- Calibrate the model relying on the firm-level data
- Internal Calibarations & SMM

Calibration follows four consecutive steps

1. Calculating supplier advantage of each country
   - *Relative to domestic suppliers and other countries*
2. Estimation of productivity dispersion across domestic suppliers
3. Calculation of demand elasticity
4. Computation of fixed costs of firm-supplier-origin pairs
   - *Jia (2008)*

Calibration

Parameter	**Variable**	**Source**
ε	Sourcing Potential	Microdata
θ	Productivity Dispersion	Microdata
σ	Demand Elasticity	Microdata
φ	Core Productivity	Melitz and Redding (2015)
S_{ij}	Supplier-Country Fixed Cost	SMM

Calibration

Step 1. Supplier Advantage

- Each supplier country advantage is defined as

$$\varepsilon_j = \frac{T_j}{c_j^{\theta}}$$

- Normalizing a firms' domestic and imported input purchases

$$\frac{X_{ij}}{X_{ii}} = \frac{T_j c_i^{\theta}}{T_i c_j^{\theta}}$$

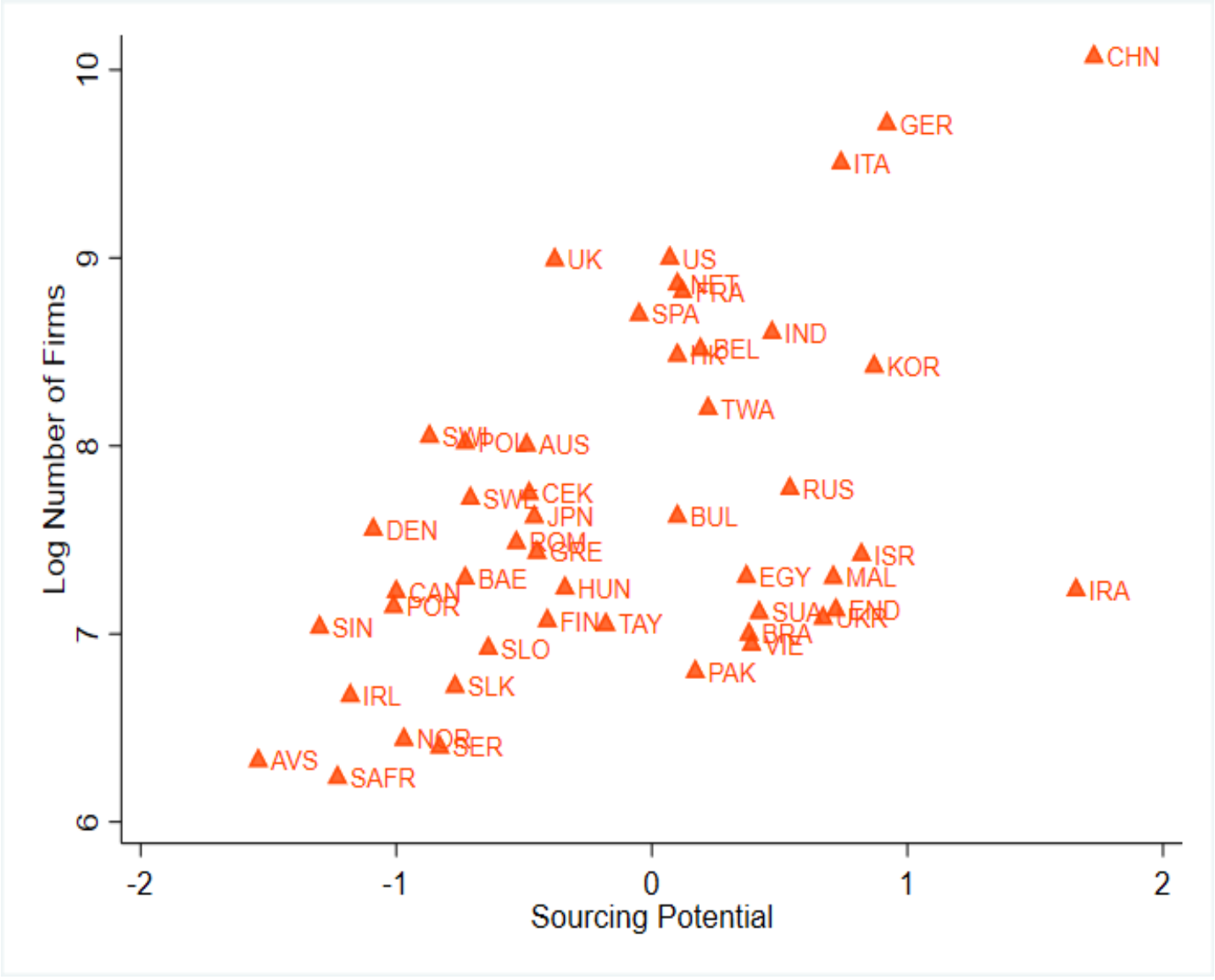
- Log-linearize

$$logX_{ij} - logX_{ii} = log\varepsilon_j + log\epsilon_j^n$$

Estimate via OLS $\rightarrow$ Sourcing Potential for each firm

Calibration

Step 1. Supplier Advantage



Calibration

Step 2 and 3. Productivity Dispersion and Demand Elasticity

2. Productivity Dispersion, θ

- How shares toward to productive suppliers
- Control for distance and the transaction
- 1.97 theta

3. Demand Elasticity, σ

- Observed markups, 1.38
- Elasticity of demand, sigma $\rightarrow$ 3.63

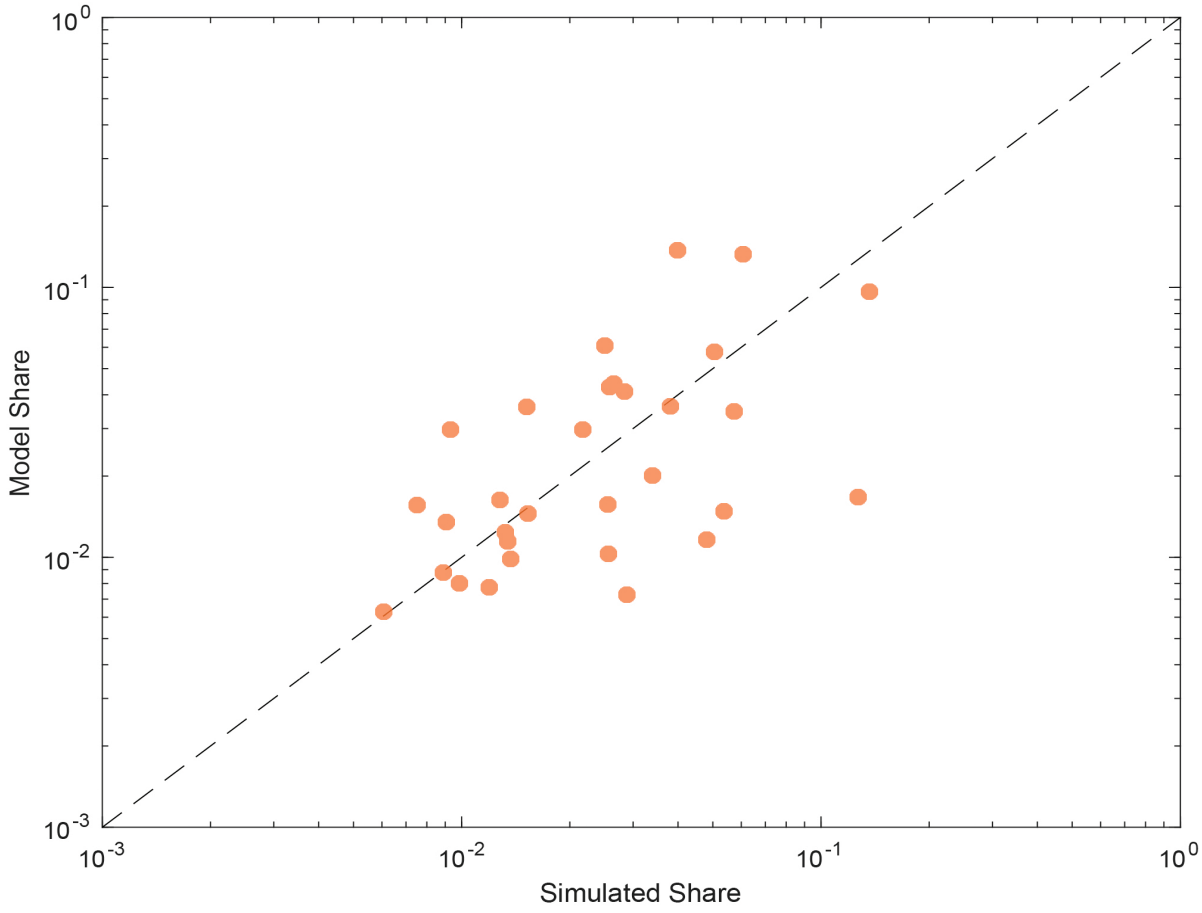
Calibration

Step 3. SMM

- Simulate firms
- Pareto Dist $\rightarrow$ Core Productivity
- How firms source based on the model
- Estimation of Sales

$2^{supplierset}$, $\rightarrow$Jia (2008)

Model Fit



Counterfactual Scenarios

Counterfactual 1: Counterfactual Supply Chains

- Exogenously impose the same fixed cost
- Prices and Share of Importers?

Counterfactual Supply Chains

Impose fixed costs of Turkey → New Supply Chain → no tariffs

	Turkey	China	Greece
Price	↓		
% *of Importers*	↑		
% *of Importers from China*	↑		
% *of Importers from Greece*	↑		
% *of Importers from Taiwan*	↑		
% *of Importers from U.S.*	↑		

Table: Counterfactual Supply Chain *Notes: The table reports price and import shares in the counterfactual scenarios compared to the baseline.*

Counterfactual Supply Chains

Impose fixed costs of China $\rightarrow$ New Supply Chain

	Turkey	China	Greece
Price	$\downarrow$	$\uparrow$	
% *of Importers*	$\uparrow$	$\downarrow$	
% *of Importers from China*	$\uparrow$	$\downarrow$	
% *of Importers from Greece*	$\uparrow$	$\downarrow$	
% *of Importers from Taiwan*	$\uparrow$	$\uparrow$	
% *of Importers from U.S.*	$\uparrow$	$\uparrow$	

Table: Counterfactual Supply Chain *Notes: The table reports price and import shares in the counterfactual scenarios compared to the baseline.*

Counterfactual Supply Chains

Impose fixed costs of Greece $\rightarrow$ New Supply Chain

	Turkey	China	Greece
Price	$\downarrow$	$\uparrow$	$\downarrow$
% *of Importers*	$\uparrow$	$\downarrow$	$\uparrow$
% *of Importers from China*	$\uparrow$	$\downarrow$	$\uparrow$
% *of Importers from Greece*	$\uparrow$	$\downarrow$	$\downarrow$
% *of Importers from Taiwan*	$\uparrow$	$\uparrow$	$\uparrow$
% *of Importers from U.S.*	$\uparrow$	$\uparrow$	$\uparrow$

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Counterfactual Scenarios

Counterfactual 1: Counterfactual Supply Chains

- Exogenously impose the same fixed cost
- Prices and Share of Importers?

Counterfactual 2: Simulated Disruptions

- Imitate the supply chain disruptions
- Exogenous negative shock to sourcing costs from China
- Increasing from 100% to 1000%

Simulated Disruptions: Share of Importers from China, Hong Kong, South Korea, Taiwan

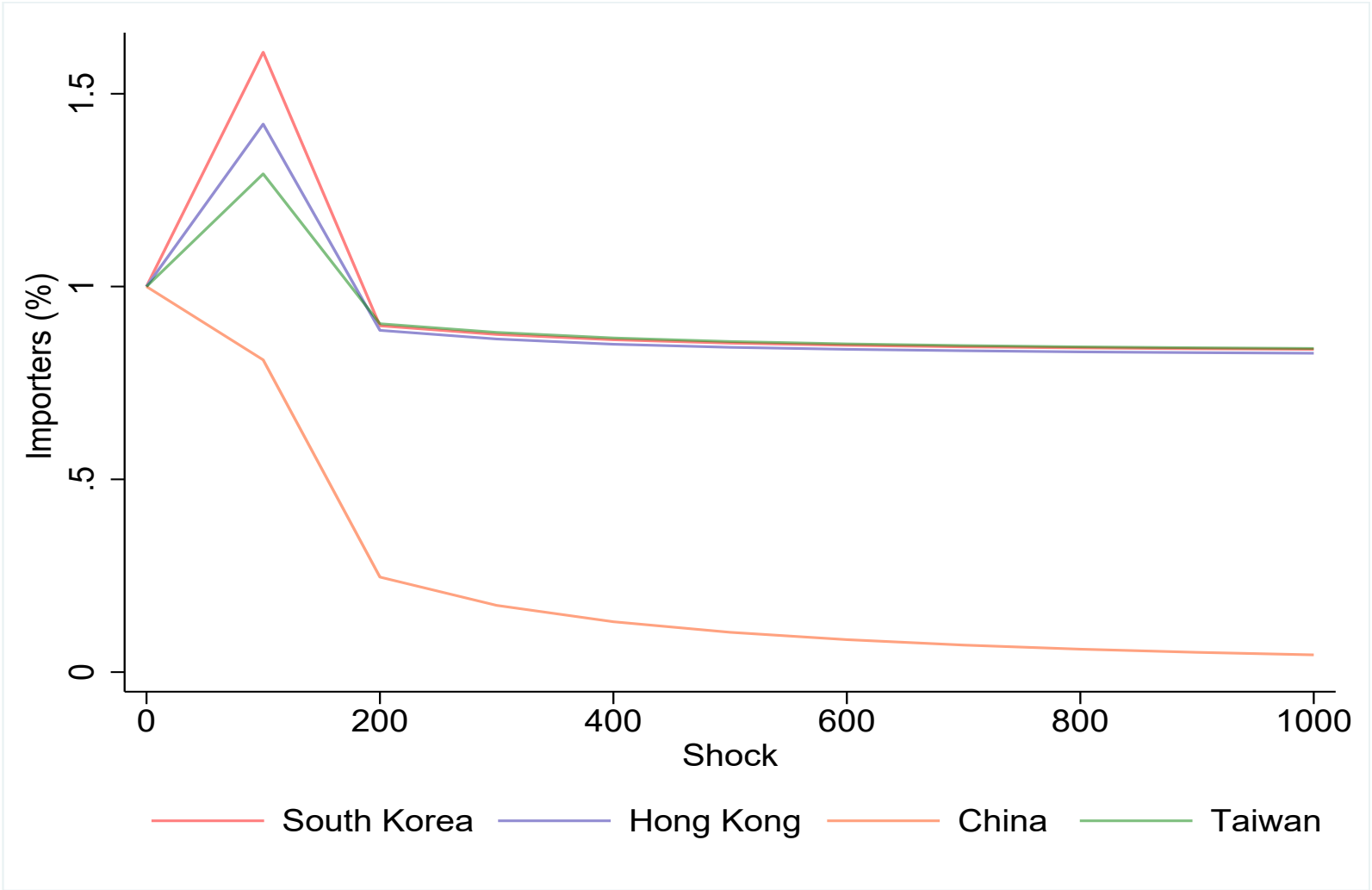

Figure: Share of Importers

Simulated Disruptions: Share of Importers

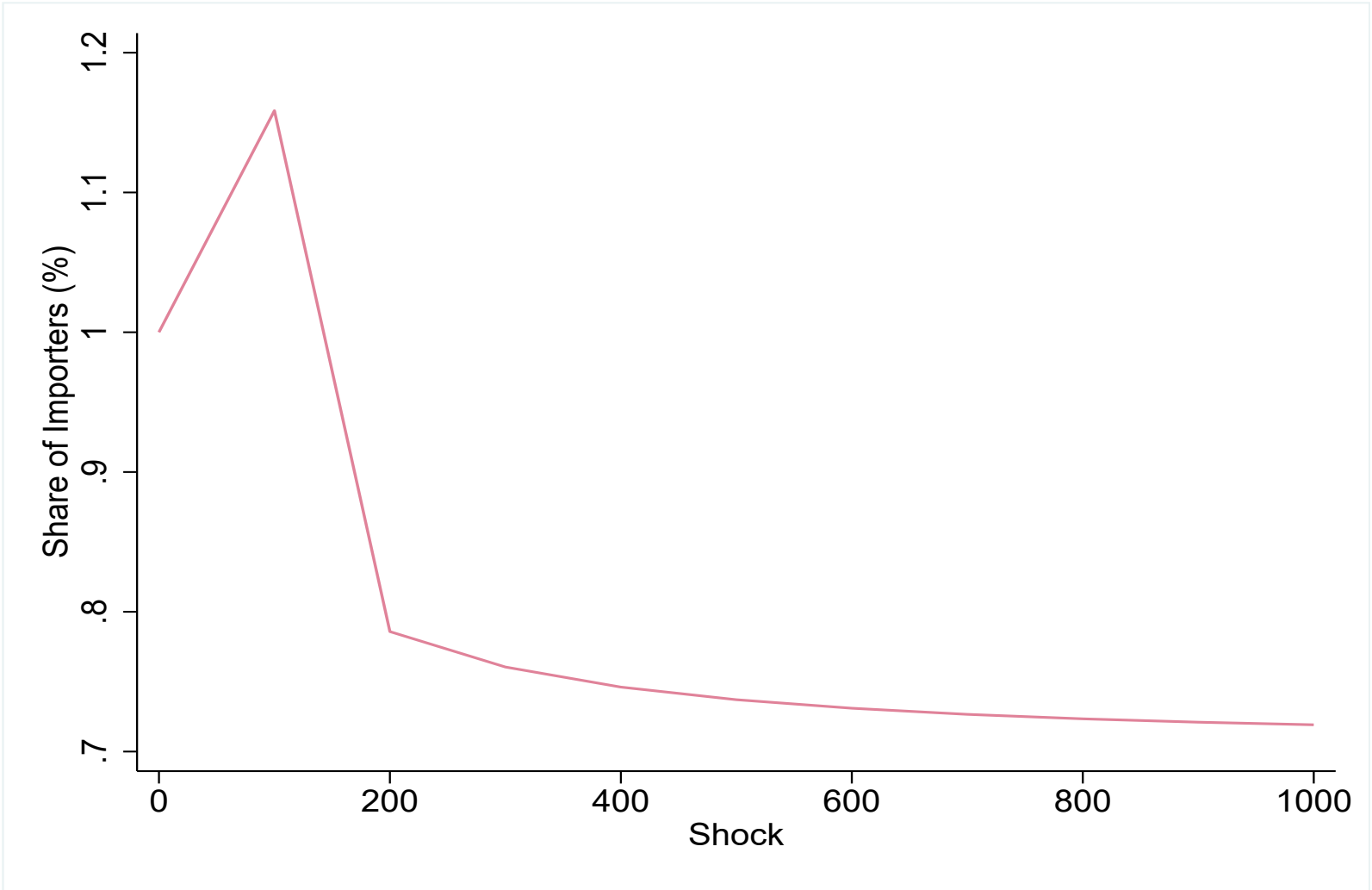

Figure: Share of Importers from China, Hong Kong, South Korea and Taiwan

Policy Implications

These findings have important policy implications.

First, even though the price effect is a micro finding, it has critical policy implications. From micro to macro,these price shocks can have a domino effect in a granular and linked production network.

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Second, labor productivity estimates are driven mainly by imports of low cost capital and intermediate goods inputs. This has critical implications for shaping industrial policies.

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Second, labor productivity estimates are driven mainly by imports of low cost capital and intermediate goods inputs. This has critical implications for shaping industrial policies.

Third, in future research, the proposed framework in this paper can be used to understand,

- Role of supply chains on the productivity puzzle
- Diffusion of inflation through supply chains
- Fragility of supply chains
- Intuition for the deglobalization trend

Conclusion

- First paper to provide causal estimates of networks on prices and productivity
- Supply-chain disruptions
  - higher prices
  - decrease in productivity
- New layer of firm heterogeneity as supply-chains
- Better firms select into better/cheaper suppliers
- A disruption in supply-chains, i.e. exogenous increase in fixed costs $\rightarrow$ higher aggregate prices and firms shrink their production networks