Concentrated Global Production of Semiconductors and Chip Wars

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Concentration and Slowbalization

Why does the trajectory toward globalization seem to have slowed down?

- This paper suggests a new explanation: a concentration of global production

What happens to oligopolistic producers across production stages during trade conflicts?

- Simultaneous adjustments in sourcing and selling prices due to the two-side market power

  $\Rightarrow$ A conflict between a small number of countries can have a far-reaching impact

  $\Rightarrow$ Incentives for in-house production arise

  e.g. US: CHIPS and Science Act, China: semiconductor state fund, Korea: materials, parts, and equipment support packages

Concentration in High-tech Goods Production

Manufacturing has become fragmented across countries

- Productivity gain from specialization

Advanced, complicated products often require a prohibitive initial investment

$\Rightarrow$ Each production stage concentrated to **few** producers and countries $\Rightarrow$ Bilateral oligopoly

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What are the implications of these trends on globalization?
$\Rightarrow$ Explore the adjustment in two-sided market power, in response to trade shocks

- Challenge: unclear market segmentation, large seller $\neq$ large buyer

Trade conflicts and two-sided market power

I exploit the global production of memory chips to overcome this challenge

- Few upstream firms produce each type of input, non-substitutable in chip production
- Few chip makers source the inputs and globally supply the outputs essential to the final good (PC, smartphone, server, etc.)

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I build and estimate a model of oligopolistic production stages to quantify trade conflicts Model

- mechanism: the firms exposed to trade conflicts experience a 'double dip' in profit
  1. The exposed chip makers lose market shares $\Rightarrow$ lower markups
  2. Decreased contribution to its upstream suppliers' profits $\Rightarrow$ higher sourcing costs

  $\Rightarrow$ magnified impact via adjustments in market power

Memory Chip Production is Concentrated at Firm and Country Level

Chip maker	Samsung (S. Korea)	SK Hynix (S. Korea)	Micron (USA)
Plant site (City, Country)	Hwaseong, S. Korea Pyeongtaek, S. Korea	Incheon, S. Korea Wuxi, China	Manassas, USA Linko, Taiwan Higashi Hiroshima, Japan Taichung, Taiwan

Table: Plants are ordered in production capacity.

- Chip-producing plants are concentrated among a few countries and firms World map
- Top three firms take $> 95\%$ of the global market
- Extensive margins have been muted Mkt Shr

Input Production is Concentrated at Firm and Country Level

Input Type	PR	HF	Wafer
Producer (HQ location, market share %)	Tokyo Ohka Kogyo (Japan, 28) Shin-Etsu Chemical (Japan, 20) JSR Corporation (Japan, 17) Fuji Film (Japan, 14) Sumitomo Chemical (Japan, 8)	Morita Chemical (Japan) Stella Chemifa (Japan)	Shin-Etsu Chemical (Japan, 32) SUMCO Corporation (Japan, 25) Global Wafers (Taiwan, 17) Siltronic AG (Germany, 13) SK Siltron (Korea, 13)

Table: PR: photoresists, HF: hydrogen fluoride.

- Different input types (across columns) are non-substitutable
- Input production is concentrated on a few firms and countries World map

Preview of the Results

Model-based regressions: two-sided market power shapes output/input pricing

- 5% expansion of a chip maker $\Rightarrow$ 4 to 10% increase in chip price reg:down
- 5% expansion of of a chip maker $\Rightarrow$ 8% increase in sourcing price of its competitors reg:up

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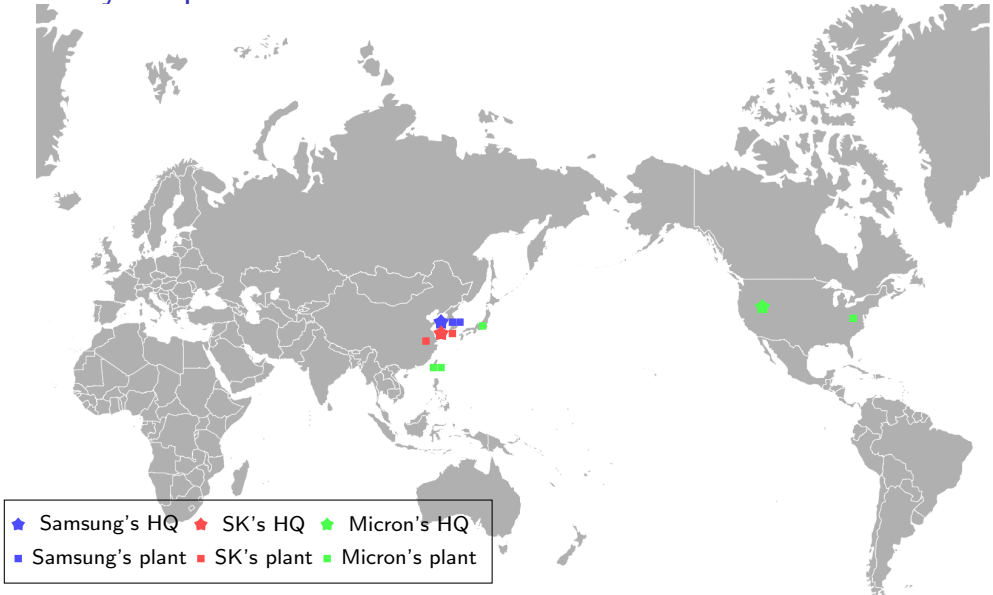
Two-sided market power in effect counterfactuals

- US-China Chip War: US's restriction on memory **chip export** to China
  - US chip maker incurs 4.1% higher input sourcing costs and 1.7% lower markup
  - US chip maker loses 6.7% of profit, while its competitors gain 1.4%
- Japan-Korea Trade Conflict: Japan's restriction on memory chip **input export** to Korea
  - Korean chip makers incur 2.0% higher input sourcing costs and 0.6% lower markup
  - Korean chip makers lose -2.1% of profit, while their competitor gains 0.9%

The Memory Chip Production Is Concentrated

go back



The Memory Chip Input Production Is Concentrated

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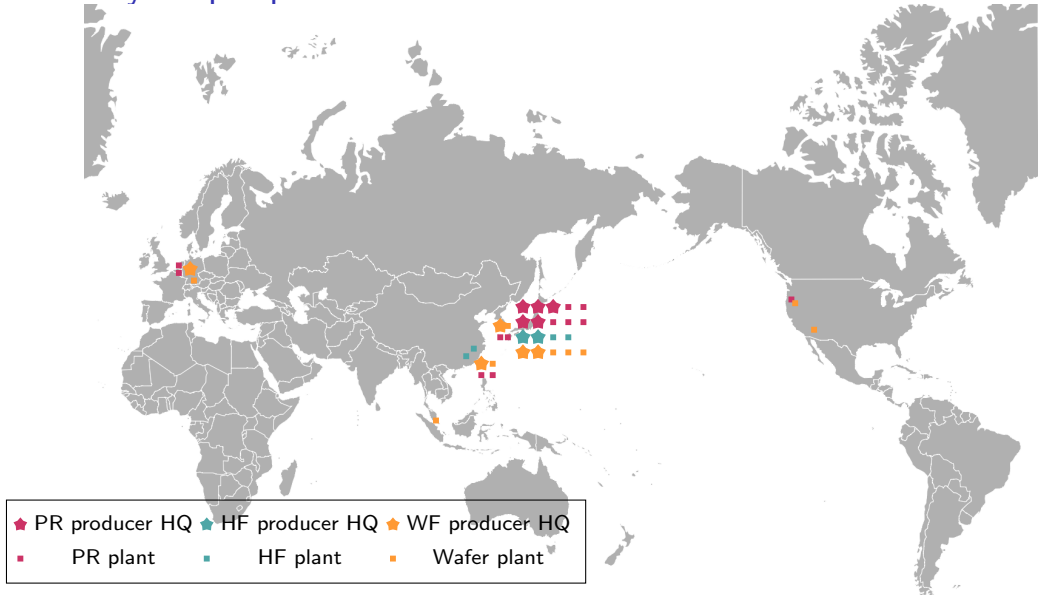

The Input Trade Is Concentrated

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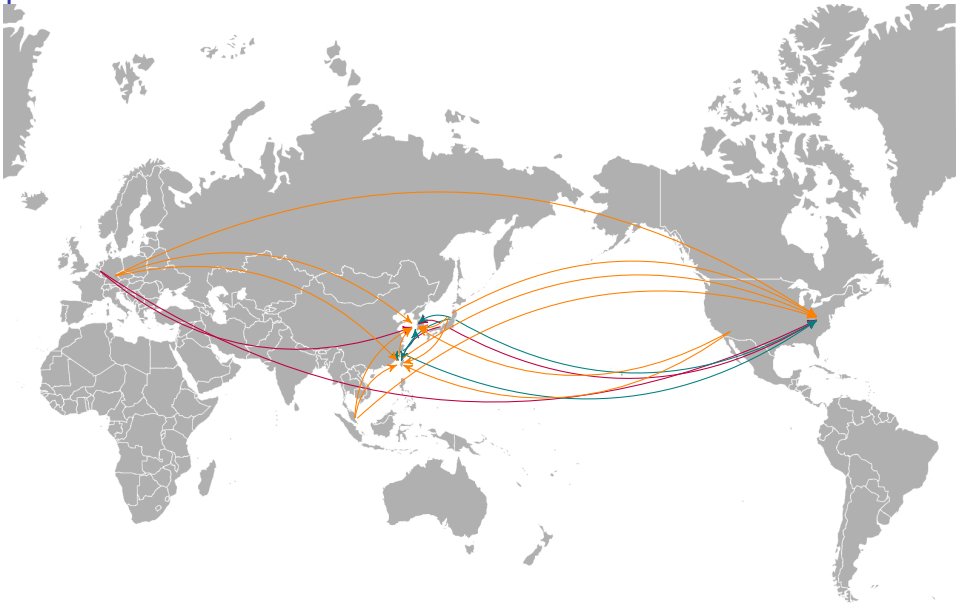


Model

Indexing Plants

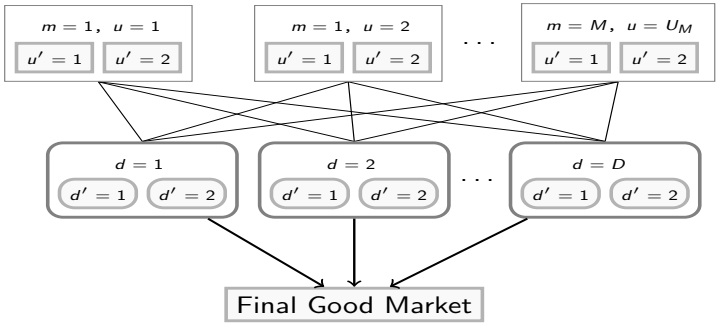
Upstream plants are indexed by $\bar{u} = (m, u, u')$

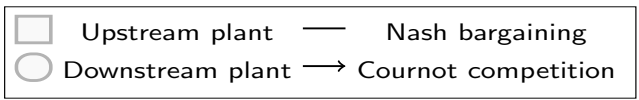
- $m = 1, \ldots, M$: type of upstream intermediate input
- $u = 1, \ldots, U_m$: upstream firm that produces m
- $u' = 1, \ldots, U_{m,u}$: upstream plant owned by u that produces m

Downstream plants are indexed by $\bar{d} = (d, d')$

- $d = 1, \ldots, D$: downstream firm
- $d' = 1, \ldots, D_d$: downstream plant owned by d

Vertical Production Stages

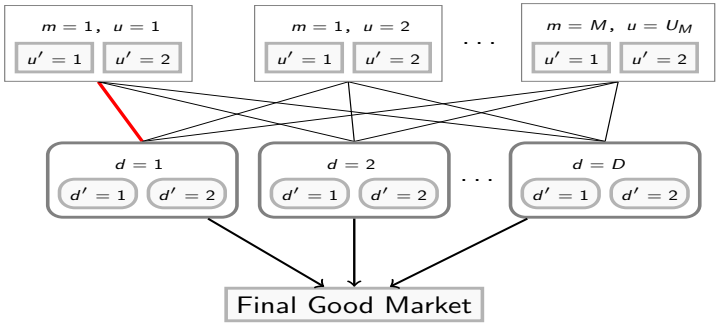




Consider an example

- $m = 1$ PR
- $u = 1$ JSR Corp owns two plants
- $d = 1$ SK Hynix owns two plants

Bargaining: Firms Bargain over Plant-to-Plant Input Prices



Consider an example

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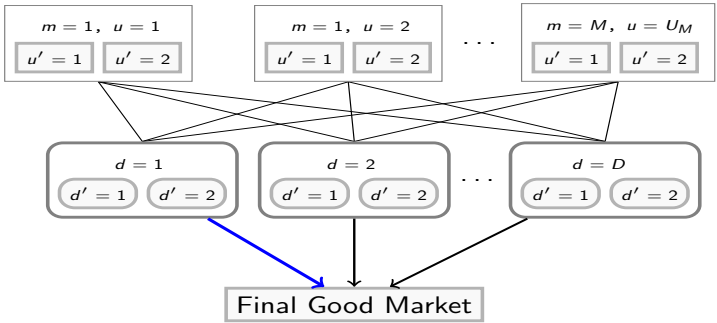
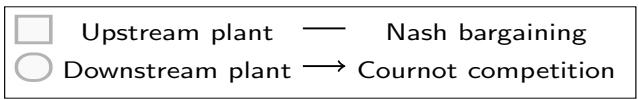
JSR and SK bargain for upstream product prices

- Four prices are bargained over ($u' = 1, 2$ and $d' = 1, 2$)

Competition: Downstream Firms Compete Under Cournot





Consider an example

- $m = 1$ PR
- $u = 1$ JSR Corp owns two plants
- $d = 1$ SK Hynix owns two plants

SK competes under Cournot

- choosing two quantities $(d' = 1, 2)$

Go back

Market Share and Markup

Market shares and markups are endogenous [Atkeson and Burstein, 2008]

$$p_{n,\bar{d}} = \frac{\epsilon_{n,d}}{\epsilon_{n,d} - 1} C_{n,\bar{d}}$$

$$\text{where } \epsilon_d = \Big(\frac{1}{\rho} s_d + \frac{1}{\sigma}(1 - s_d)\Big)^{-1}, \text{ and } s_d = \frac{\sum_{\bar{d}(d)} q_{\bar{d}}^{\frac{\sigma-1}{\sigma}}}{\sum_{\bar{d}} q_{\bar{d}}^{\frac{\sigma-1}{\sigma}}}$$

- $s_d = s_{d(\bar{d})}$: market share of firm d that owns $\bar{d}$

Implications

- Markup ($\frac{\epsilon_{n,d}}{\epsilon_{n,d}-1}$) increasing in market share
- Upstream input prices ($p_{\bar{d},\bar{u}}$) influence downstream competition

Bargaining and Equilibrium

The upstream prices are determined as a solution to Nash-in-Nash bargaining

- Seller u and buyer d contribute to the profit of each other
- The equilibrium maximizes the geometric average of this contribution, given other prices

Equilibrium

- $\mathbf{p_{d,u}} = [p_{\bar{u}(u),\bar{d}(d)}]$
- $\pi_{d,(-u)}$ and $\pi_{u,(-d)}$: profits of d and u without the contribution of u and d, respectively

$$\mathbf{p}^* = \arg\max NP_{d,u}(\mathbf{p_{d,u}}; \mathbf{p}^*)$$
$$\text{where } NP_{d,u}(\mathbf{p_{d,u}}, \mathbf{p}^*) = [\pi_d - \pi_{d,(-u)}]^{\gamma} \times [\pi_u - \pi_{u,(-d)}]^{1-\gamma}.$$

- Smaller downstream firms source the upstream products at higher prices

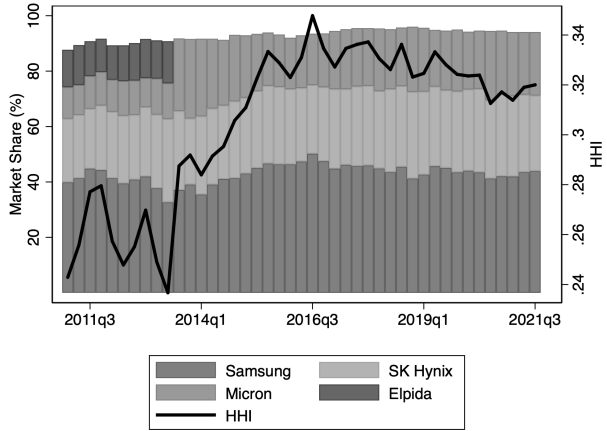
Partial Equilibrium Regression

Goal: Use the model-motivated regression equations as auxiliary models for indirect inference

- observe the downstream market power's influence on upstream and downstream prices
  regression: downstream regression: upstream
- Even after partial out the impact of unobserved productivity shocks using exchange rates, the auxiliary model is still misspecified, taking the prices on the other side given
- I use the regression coefficients as the moments to infer plant-level substitution parameters indirect inference

Counterfactual Exercises

Concentrated Global Production of Memory Chip



- Top firms take $> 95\%$ of the global market
- Extensive margins are muted go back

HHI-Price Regression

	(1) output price	(2) input price
HHI	3.929**	-5.022***
	(1.876)	(1.760)
FE: item		Yes
FE: country	Yes	Yes
Observations	3,031	2,601
R-squared	0.898	0.722

Table: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

go back

Model Parameterization: Plant-level Productivity Processes

I parameterize plant-level productivity $z_{d'}$ and $z_{u'_m}$ as an AR(1) process

$$\log z_{d',t} = \mu_{d'} + \nu \log z_{d',t-1} + \lambda_d \epsilon_{d',t}, \quad \epsilon_{d',t} \sim_{i.i.d.} \mathcal{N}(0,1)$$
$$\log z_{d',u'_m,t} = \mu_{u'_m} + \nu_m \log z_{d',u'_m,t-1} + \lambda_{u'_m} \epsilon_{d',u'_m,t}, \quad \epsilon_{d',u'_m,t} \sim_{i.i.d.} \mathcal{N}(0,1)$$

- μ: plant-level long-run productivity fundamental
- λ: the fluctuations in international trade and the global market shares
- ν: persistency of productivity shocks

Model Parametrization: Matching to the Data

I match the productivity processes to the trade and firm-level data $\{\tilde{X}^m, \tilde{X}^d, p_d q_d, p_{u'_m}, q_{u'_m}\}$

- assume $z_{d',u'_m,t}$ is the same across d'
- use the plant locations to generate country-level aggregates

Scale Volatility, and Persistency					
μ_k, Φ_k	China	Japan	Korea	Taiwan	USA
Samsung			0.370, 0.097		
SK Hynix	0.183, 0.140		0.223, 0.110		
Micron		0.152, 0.305		0.152, 0.136	0.152, 0.083
ν_{DRAM}			0.7110		

go back

Model Fit: Targeted Moments

Moment	Targeted	Simulated
α_{SK}	2.064	0.904
α_{Micron}	0.887	0.852
β_{Micron}	1.627	1.893

- The model matches Micron's impact on input sourcing costs of Korean firms well
- It also matches Micron's market power on output prices
- It misses the impact of SK Hynix's market share on output prices

Data

Global market shares of major memory chip producers

- Semiconductor International Association

Monthly trade value, quantity, and price

- Memory chips: UN Comtrade, Korea Trade Statistics System
- Inputs: Korea Trade Statistics System
  : Upstream product classification is reserved for inputs for semiconductor production

HQ/plant locations, revenue, and input share

- Annual reports

go back

Related Literature

Market power in the global production network

- Markup [Gaubert and Itskhoki, 2021], [Gaubert et al., 2021]
- Markdown [Alviarez et al., 2021], [Juarez, 2022], [Morlacco, 2019], [Zavala, 2020]

  This paper: market power in selling leads to market power in sourcing, and vice versa

Propagation and magnification of the impact of trade policies

- Extensive margin: country-level adjustment [Antras et al., 2017], [Tintelnot, 2017] firm-level adjustment [Bernard and Zi, 2021], [Dhyne et al., 2021], [Eaton et al., 2022]
- Intensive margin: via production networks [Antràs and De Gortari, 2020], [Caliendo and Parro, 2015], [Johnson and Moxnes, 2019]

  This paper: amplified effect of trade conflicts via adjustments in two-sided market power

go back

Market Power and Downstream Pricing

Using the endogenous markup equation, approximate the equation with log

$$\log \tilde{p}_{nn',t} = \sum_{d \in SK,MI} \alpha_d \log \tilde{s}_{d,t} I_{\{\exists \bar{d} \in \bar{d}(d): n(\bar{d}) = n'\}} + \sum_k \alpha_k \log p^k_{n',t} + \delta_n + \delta_{n',q(t)} + \varepsilon_{nn',t}$$

- $\tilde{s}_d = \frac{s_{d,t}}{s_{Samsung,t}}$: SK Hynix and Micron's market share relative to Samsung
- $I_{\{\exists \bar{d} \in \bar{d}(d): n(\bar{d}) = n'\}}$: firm d has a plant in origin n'
- p^k: input price
- $\delta_{n',q(t)}, \delta_n$: origin and destination FE
- $\varepsilon_{nn',t}$: include the variations in TFP $z_{\bar{d},t}$

Challenge: identifying the markup channel from the TFP channel ($z \uparrow \Rightarrow \tilde{p} \downarrow \Rightarrow s \uparrow$)

- Leverage the key exchange rates ($e_{KR,CN}$, $e_{KR,US}$) as plausibly exogenous variations

Downstream Price Regression

	(1)	(2)	(3)	(4)
Dependant variable:				
$\log p_{DRAM}$	OLS	OLS	IV	IV
$\tilde{s}_{Micron} I_{\{\exists i: i \in d^{-1}(Micron), n(i)=n'\}}$	-0.392***	0.167	1.002***	0.809*
	(0.143)	(0.432)	(0.416)	(0.469)
$\tilde{s}_{SK} I_{\{\exists i: i \in d^{-1}(SK), n(i)=n'\}}$	1.120***	1.587***	1.467***	2.064***
	(0.211)	(0.238)	(0.248)	(0.463)
$\log p_{PR}$		-0.0396		-0.0309
		(0.0364)		(0.0393)
$\log p_{HF}$		0.0329		0.0970**
		(0.0441)		(0.0481)
$\log p_{wafer}$		0.177***		0.0901
		(0.0631)		(0.0776)
Observations	5,587	414	2,211	354
Destination FE	YES	YES	YES	YES
Origin-Time FE	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

- Unobserved shocks place downward biases on the coefficient of downstream firms' market power in pricing
- 5% increase in the relative market share of SK Hynix enables a 10% increase in price

go back

Market Power and Upstream Price

The model opens a channel between downstream firms' competition and upstream pricing

- Suppose an enlargement of a downstream firm
- It becomes closer to a monopsony and able to push down the upstream input price

Idea: An enlargement of Micron would increase Korea's input importing price

$$\ln p^k_{Korea,n',t} = \sum_{d \in SK,MI} \beta_d \tilde{s}_{d,t} + \beta_{DRAM} \ln p_{Korea,t} + \delta^k + \delta_{n',q(t)} + \epsilon^k_{n',t}$$

Challenge: productivity shock might affect both competition and input price bargaining ($z \uparrow \Rightarrow \pi_u \uparrow \Rightarrow p_{d,u_m} \downarrow$, and $z \uparrow \Rightarrow s \uparrow$)

- Leverage the key exchange rates ($e_{KR,CN}$, $e_{KR,US}$) as plausibly exogenous variations

go back

Upstream Price Regression

	(1)	(2)	(3)	(4)
Dependant variable:				
$\log p_{Input}$	OLS	OLS	IV	IV
$\tilde{s}_{Micron}$	1.306***	1.387***	2.285***	1.627***
	(0.374)	(0.376)	(0.851)	(0.415)
$\tilde{s}_{SK}$	1.741**	1.727**	-1.766	0.426
	(0.682)	(0.679)	(2.349)	(0.792)
$\log p_{n,t}$		-0.0642*		-0.0850*
		(0.0345)		(0.0323)
Observations	860	860	860	860
Input FE	YES	YES	YES	YES
Exporter-Time FE	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

- Unobserved shocks place downward biases on Micron's impact on the upstream pricing
- Micron's 5% expansion disadvantages Korean firms in sourcing price by 8%

go back

Indirect Inference on Substitution Parameters

Quantifying trade policy requires estimates of substitution parameter

- Structural regressions are often used to infer the parameters [Atkin and Donaldson, 2015], [Bergquist and Dinerstein, 2020], [Felix, 2021]
- Challenge: Strategic interactions of prices across production stages
- Solution: Indirect inference [Zavala, 2020], [Berger et al., 2022]

I relate each period's market equilibrium to the realization of plant-level productivity

- Each plant has time-varying productivity processes parametrization
- Given productivities, compute the market equilibrium at each period
- This generates simulated data of price and market share

go back

Moments and Identification

I compare the regression coefficients obtained from the actual data $\hat{\Theta} = [\hat{\alpha}_{SK}, \hat{\alpha}_{MI}, \hat{\beta}_{MI}]'$ and those from the simulated data $\Theta(\eta', \sigma)$

- Search for (η', σ) that minimize

$$\Theta^* = \arg\min_{\eta', \sigma} (\Theta(\eta', \sigma) - \hat{\Theta})' \mathcal{W} (\Theta(\eta', \sigma) - \hat{\Theta})$$

  where $\mathcal{W}$ is a weighting matrix

The identification hinges on how sensitive the market power-pricing associations are to plant-level substitutabilities go back

Estimation Results

Panel A: Estimated	σ	η'	
Estimates (s.e.)	3.052 (0.0408)	1.549 (0.636)	
Panel B: Calibrated	γ	η	ρ
	0.765	0	1.0

- σ, η': downstream and upstream plant-level substitutability
- γ: downstream bargaining power [Alviarez et al., 2021]
- η: upstream item-level substitutability [Rubens, 2021]
- ρ: final good producers' demand elasticity

Upstream plants are more difficult to substitute go back

Quantifying Trade Policy: US-China Chip War

Background: Washington's efforts to restrict Beijing's access to key semiconductor technology

- US restricts the exports of certain types of memory chips
- China bans the use of U.S.-based Micron's chips as retaliation (May 2023)

  $\Rightarrow$ Trade of **downstream product** is restricted

Approach: Increase the trade cost of the US downstream products by 20%

- For the Japan-Korea trade dispute, raise the trade cost of upstream input between Japan and Korea, matching the decreased Japanese share in Korea

Quantification Results on the US-China Chip War

%Δ Downstream firms	Unit Cost	Mkt Share	Markup	Price	Quantity	Profit
Samsung (unexposed)	0.00	1.54	1.02	1.02	−0.81	0.93
SK Hynix (unexposed)	0.00	1.93	0.84	0.84	−0.25	1.38
Micron (exposed)	4.08	−3.95	−1.68	2.33	−7.38	−6.73

go back

Quantifying Trade Policy: 2019 Japan-Korea Trade Dispute

Background: trade barrier between upstream and downstream plants

- The government of Japan restricted the export of upstream products to Korea

  "the Japan-ROK relationship of trust is . . . significantly undermined" because *"Supreme court of South Korea made a decision (on a historic issue)"*

  $\Rightarrow$ Trade of **upstream product** is restricted

Approach: Increase the trade costs between Japanese-Korean plants

- matching the decreased Japanese share in Korea counterfactual results

Quantification Results on the Japan-Korea Trade Conflict

%Δ	Unit Cost	Mkt Share	Markup	Price	Quantity	Profit
Panel A: Downstream firms						
Samsung (exposed)	2.04	−0.90	−0.58	1.44	−3.10	−2.11
SK Hynix (exposed)	1.14	−0.00	0.00	1.14	−1.94	−0.82
Micron (unexposed)	0.00	1.18	0.51	0.51	−0.15	0.85
Panel B: Upstream products						
HF (exposed)	–	–	–	−15.04	−13.13	−27.47
PR (exposed)	–	–	–	−7.08	−3.17	−11.92
WF (unexposed)	–	–	–	0.59	−2.57	−2.00

go back

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