

Production Network Formation, Trade, and Welfare¹

Costas Arkolakis

Yale University

Federico Huneus

Duke University & Central Bank of Chile

Yuhei Miyauchi

Boston University

2025/11/14

Michigan

¹The views and opinions expressed are those of the authors alone and do not necessarily reflect those of the Central Bank of Chile.

Production Network Formation and Trade

- ▶ How do trade shocks affect aggregate economic activity and welfare?

Production Network Formation and Trade

- ▶ How do trade shocks affect aggregate economic activity and welfare?
- ▶ Key mechanism: Propagation through production networks
 - ▶ But trade models typically take the relationships between buyers and suppliers as **fixed**

Production Network Formation and Trade

- ▶ How do trade shocks affect aggregate economic activity and welfare?
- ▶ Key mechanism: Propagation through production networks
 - ▶ But trade models typically take the relationships between buyers and suppliers as **fixed**
- ▶ Firms **endogenously form** networks of suppliers and buyers, under various trade frictions
 - ▶ Shipment and transaction cost
 - ▶ Matching frictions (Rauch-Trindade '02, Allen '14, Bernard-Moxnes-Saito '19, Miyauchi '24, Startz '24, Cai-Lin-Szeidl '24, Demir-Javorcik-Panigrahi '24...)

Production Network Formation and Trade

- ▶ How do trade shocks affect aggregate economic activity and welfare?
- ▶ Key mechanism: Propagation through production networks
 - ▶ But trade models typically take the relationships between buyers and suppliers as **fixed**
- ▶ Firms **endogenously form** networks of suppliers and buyers, under various trade frictions
 - ▶ Shipment and transaction cost
 - ▶ Matching frictions (Rauch-Trindade '02, Allen '14, Bernard-Moxnes-Saito '19, Miyauchi '24, Startz '24, Cai-Lin-Szeidl '24, Demir-Javorcik-Panigrahi '24...)
- ▶ Current debate about how supply chain response might influence the impact of trade shocks

Production Network Formation and Trade

- ▶ How do trade shocks affect aggregate economic activity and welfare?
- ▶ Key mechanism: Propagation through production networks
 - ▶ But trade models typically take the relationships between buyers and suppliers as **fixed**
- ▶ Firms **endogenously form** networks of suppliers and buyers, under various trade frictions
 - ▶ Shipment and transaction cost
 - ▶ Matching frictions (Rauch-Trindade '02, Allen '14, Bernard-Moxnes-Saito '19, Miyauchi '24, Startz '24, Cai-Lin-Szeidl '24, Demir-Javorcik-Panigrahi '24...)
- ▶ Current debate about how supply chain response might influence the impact of trade shocks
- ▶ **How does firms' endogenous network formation affect aggregate impact of trade shocks?**

This Paper

- ▶ Multi-location quantitative general equilibrium model of production network formation
 - ▶ Supplier and buyer spend resources in forming links and match across locations $\Rightarrow$ Gravity

This Paper

- ▶ Multi-location quantitative general equilibrium model of production network formation
 - ▶ Supplier and buyer spend resources in forming links and match across locations $\Rightarrow$ Gravity
- ▶ Derive sufficient statistics for aggregate effects of trade shocks
 - ▶ Ex-ante global welfare: Deviates from **Hulten** due to inefficient network formation
 - ▶ Ex-post regional welfare: Deviate from **ACR** due to network formation cost amplification
 - ▶ Extensions to other network microfoundation, e.g., fixed cost, discrete supplier choice

This Paper

- ▶ Multi-location quantitative general equilibrium model of production network formation
 - ▶ Supplier and buyer spend resources in forming links and match across locations $\Rightarrow$ Gravity
- ▶ Derive sufficient statistics for aggregate effects of trade shocks
 - ▶ Ex-ante global welfare: Deviates from **Hulten** due to inefficient network formation
 - ▶ Ex-post regional welfare: Deviate from **ACR** due to network formation cost amplification
 - ▶ Extensions to other network microfoundation, e.g., fixed cost, discrete supplier choice
- ▶ Multi-sector quantification using Chilean domestic and international firm-to-firm trade data
 - ▶ Estimate model and rationalize $\uparrow$ foreign and domestic links during trade liberalization
 - ▶ Endogenous network **increases** welfare effects of...
 - ▶ import cost increase from trade liberalization by 60% (fixing trade elasticity)
 - ▶ gains from trade relative to municipality autarky by 100% (fixing trade elasticity)

Literature

- ▶ Production network formation and trade Antràs-Fort-Tintelnot '17; Oberfield '18; Lim '18; Huneus '19; Antràs-de-Gortari '20; Bernard-Moxnes-Saito '20; Dhyne et al '23; Demir et al '24; Eaton-Kortum-Kramarz '24
⇒ Aggregate implications of production network formation in multi-location GE environment
- ▶ Welfare sufficient statistics in trade Atkeson-Burstein '10; Arkolakis-Costinot-Rodriguez-Clare '12; Melitz-Redding '15; Caliendo-Parro '15; Blaum-Lelarge-Peters '18; Baqaee-Fahri '24; Burstein et al '24
⇒ Incorporate endogenous production network formation
- ▶ Inefficiency in production network formation Boehm-Oberfield '20; Grossman-Helpman-Lhuillier '23; Grossman-Helpman-Sabal '24; Acemoglu-Tahbaz-Salehi '24
⇒ Matching externality; relate to sufficient statistics in multi-location GE environment
- ▶ Matching frictions in trade Rauch '01; Chaney '14; Allen '14; Brancaccio et al '20; Bernard-Moxnes-Saito '20; Lenoir-Martin-Mejean '20; Krolkowski-McCallum '21; Startz '24; Miyauchi '24; Eaton et al '22; Huang et al '24, Cai et al '24
⇒ Characterize equilibrium inefficiency, optimal policy and aggregate welfare

Outline

Model

Planning Problem and Equilibrium Inefficiency

Aggregate Effects of Trade Cost Shocks

Data and Reduced-Form Evidence

Quantitative Analysis

Conclusion

Outline

Model

Planning Problem and Equilibrium Inefficiency

Aggregate Effects of Trade Cost Shocks

Data and Reduced-Form Evidence

Quantitative Analysis

Conclusion

Environment

- ▶ Locations $i, u, d \in \mathcal{N}$, measure L_i households
- ▶ Goods
 - ▶ Intermediate goods: iceberg trade cost $\tau_{ud} \geq 1$
 - ▶ Retail goods: nontraded, used for final consumption and firm's relationship-formation costs
- ▶ Firms (intermediate goods producers)
 - ▶ Measure N_i , productivity $z \sim g_i(z)$
 - ▶ Buy (supply) intermediate goods from (to) other connected firms
 - ▶ Connections are formed under firms' expenditure in forming linkages and matching
- ▶ Retailers
 - ▶ Produce retail goods with CRS aggregator from local intermediates under perfect competition

Production given Networks

- ▶ Unit cost of production by firm ω in location d

$$c_d(\omega) = \frac{1}{z(\omega)} w_d^\beta \left(\sum_{u \in \mathcal{N}} \int_{v \in \mathcal{S}_{ud}(\omega)} p_{ud}(v, \omega)^{1-\sigma} dv \right)^{\frac{1-\beta}{1-\sigma}}$$

- ▶ w_d : wage
 - ▶ $\mathcal{S}_{ud}(\omega)$: set of suppliers in location u that ω has access to: endogenize later
 - ▶ $p_{ud}(v, \omega)$: price charged by supplier v in location u to buyer ω in location d
- ▶ Each supplier is monopolistic to each buyer $\Rightarrow$ constant markup

$$p_{ud}(v, \omega) = \tilde{\sigma} \tau_{ud} c_u(v), \quad \tilde{\sigma} = \frac{\sigma}{\sigma - 1}$$

- ▶ Retail goods prices (no markups charged by firms): $P_i = \tilde{g}_i \left(\{c_i(\omega)\}_{\omega \in \Omega_i} \right)$

Firms' Relationship Formation Decisions with Suppliers and Buyers

- ▶ Firms decide resources to spend on forming relationships with each location $\{n_{ui}^S\}_u, \{n_{id}^B\}_d$
- ▶ Random matching with endogenous rate $\{m_{ui}^S\}_u, \{m_{id}^B\}_d$
 - ▶ $\Rightarrow$ realized connections $\{n_{ui}^S m_{ui}^S\}_u, \{n_{id}^B m_{id}^B\}_d$
 - ▶ Firms take matching rates as given; determined endogenously through matching technology
- ▶ Relationship-formation costs

$$e_i \left\{ \sum_{d \in \mathcal{N}} f_{id}^B \frac{(n_{id}^B)^{\gamma^B}}{\gamma^B} + \sum_{u \in \mathcal{N}} f_{ui}^S \frac{(n_{ui}^S)^{\gamma^S}}{\gamma^S} \right\}, \quad e_i = (w_i)^\mu (P_i)^{1-\mu}$$

- ▶ Use labor and retail goods for forming relationships with labor share μ
- ▶ E.g., advertisement cost, product customization, quality assurance

Firm's Relationship-Formation Problem

$$\begin{aligned}
 & \max_{\{n_{id}^B\}_d, \{n_{ui}^S\}_u} \sum_{d \in \mathcal{N}} \underbrace{n_{id}^B m_{id}^B}_{\text{buyer links to } d} \underbrace{\frac{1}{\sigma} r_{id}(z, \{n_{ui}^S\}_u)}_{\text{average profit per link}} - e_i \underbrace{\left\{ \sum_{d \in \mathcal{N}} f_{id}^B \frac{(n_{id}^B)^{\gamma^B}}{\gamma^B} + \sum_{u \in \mathcal{N}} f_{ui}^S \frac{(n_{ui}^S)^{\gamma^S}}{\gamma^S} \right\}}_{\text{relationship formation cost}} \\
 & \text{subject to } \underbrace{c_i(z, \{n_{ui}^S\}_u)}_{\text{unit production cost}} = \frac{1}{z} w_i^\beta \left(\sum_{u \in \mathcal{N}} \underbrace{n_{ui}^S m_{ui}^S}_{\text{supplier links from } u} (C_{ui})^{1-\sigma} \right)^{\frac{1-\beta}{1-\sigma}}
 \end{aligned}$$

► Solution: $n_{id}^B(z) = a_{id}^B z^{\frac{\delta}{\gamma^B}}$, $n_{ui}^S(z) = a_{ui}^S z^{\frac{\delta}{\gamma^S}}$, with $\delta \equiv (\sigma - 1)/(1 - \frac{1}{\gamma^B} - \frac{1-\beta}{\gamma^S})$

Matching Technology

- Equilibrium measure of supplier-to-buyer relationships

$$M_{ud} = \kappa_{ud} \left(\underbrace{N_u \int n_{ud}^B(z) dG_u(z)}_{\text{effort on buyers } \bar{M}_{ud}^B} \right)^{\lambda^B} \left(\underbrace{N_d \int n_{ud}^S(z) dG_d(z)}_{\text{effort on suppliers } \bar{M}_{ud}^S} \right)^{\lambda^S}$$

- Note! Elasticity wrt effort to form relationship with buyer (by suppliers): λ^B ; wrt effort on suppliers (by buyers): λ^S
- Allow for $\lambda^B + \lambda^S \neq 1$ (Miyauchi '24; Eaton-Kortum-Kramarz '24)
- Matching probability (intensity)

$$m_{ud}^S = \frac{M_{ud}}{\bar{M}_{ud}^S} \quad m_{ud}^B = \frac{M_{ud}}{\bar{M}_{ud}^B}$$

Gravity Equations of Trade Flows

- **Intensive Margin**: Transaction volume per relationship

$$\bar{r}_{ud} = \frac{X_{ud}}{M_{ud}} = \varrho^I \chi_{ud}^I \zeta_u^I \xi_d^I, \quad \chi_{ud}^I \equiv (\tau_{ud})^{1-\sigma}$$

- **Extensive Margin**: Total number of successful relationships

$$M_{ud} = \varrho^E \chi_{ud}^E \zeta_u^E \xi_d^E, \quad \chi_{ud}^E \equiv \left[\kappa_{ud} \left(f_{ud}^B \right)^{-\tilde{\lambda}^B} \left(f_{ud}^S \right)^{-\tilde{\lambda}^S} \left(\tau_{ud}^{1-\sigma} \right)^{\tilde{\lambda}^S + \tilde{\lambda}^B} \right]^{\frac{1}{1 - (\tilde{\lambda}^S + \tilde{\lambda}^B)}}$$

$$\tilde{\lambda}^S \equiv \frac{\lambda^S}{\gamma^S}, \quad \tilde{\lambda}^B \equiv \frac{\lambda^B}{\gamma^B}$$

- Intensive + extensive margin $\Rightarrow$ Aggregate trade elasticity

$$\varepsilon \equiv \frac{\partial \ln X_{ud}}{\partial \ln \tau_{ud}} = \frac{\sigma - 1}{1 - (\tilde{\lambda}^S + \tilde{\lambda}^B)}$$

General Equilibrium

- ▶ Intermediate goods, retail goods, and labor markets clear
- ▶ Gravity equations $\Rightarrow$
 - ▶ constant aggregate trade elasticity
 - ▶ conditions for equilibrium uniqueness
 - ▶ exact-hat algebra for counterfactuals
- ▶ $\lambda^B = \lambda^S = 0$ and $\gamma^B, \gamma^S \rightarrow \infty$ ($\tilde{\lambda}^B = \tilde{\lambda}^S = 0$): “fixed networks”

Outline

Model

Planning Problem and Equilibrium Inefficiency

Aggregate Effects of Trade Cost Shocks

Data and Reduced-Form Evidence

Quantitative Analysis

Conclusion

Equilibrium Inefficiency

- ▶ Equilibrium is inefficient due to
 1. Double marginalization (present with both fixed and endogenous networks)
 2. Relationship-formation inefficiency (present only with endogenous networks)
- ▶ Impacts aggregate effects of shocks; deviation from Hulten

Equilibrium Inefficiency

- ▶ Equilibrium is inefficient due to
 1. Double marginalization (present with both fixed and endogenous networks)
 2. Relationship-formation inefficiency (present only with endogenous networks)
- ▶ Impacts aggregate effects of shocks; deviation from Hulten
- ▶ Consider (constrained) planning problem with 3 types of instruments [detail](#)
 - ▶ sales subsidy $s_{id}^I \Rightarrow$ offset markups and double marginalization $\Rightarrow s_{id}^I = \frac{1}{\sigma}$
 - ▶ relationship formation taxes t_{id}^S and $t_{id}^B \Rightarrow$ equate social vs private returns for forming links
 - ▶ balances two classic inefficiencies: non-appropriability and business stealing
 - ▶ lump-sum transfers $T_i^F \Rightarrow$ redistribution

Constrained Efficiency: Hosios-Type Result

- ▶ Suppose $s_{id}^I = \frac{1}{\sigma}$. Then, $t_{id}^B = t_{id}^S = 0$ if and only if

$$\lambda^B = 1, \quad \lambda^S = 1 - \beta$$

- ▶ $\lambda^B = 1$: buyer relationship formation does not crowd-out each other
 - ▶ Similar to efficient entry with monopolistic competition & CES demand (Dixit-Stiglitz '77)
 - ▶ $\lambda^B < 1 \Rightarrow$ Congestion $\Rightarrow$ Too much equilibrium buyer relationship formation
- ▶ $\lambda^S = 1 - \beta \Rightarrow$ Lower private incentive for forming relationships with suppliers than buyers
- ▶ Efficiency requires IRS matching technology, unlike Hosios '90
 - ▶ Due to additional business stealing effects among connected supplier

Outline

Model

Planning Problem and Equilibrium Inefficiency

Aggregate Effects of Trade Cost Shocks

Data and Reduced-Form Evidence

Quantitative Analysis

Conclusion

Ex-Ante Sufficient Statistics: $\{d \ln \tau_{ud}\}$ on Global Welfare

$$d \ln \mathcal{W} \equiv \sum_i P_i^F Q_i^F d \ln Q_i^F = - \frac{\varsigma}{\frac{\beta}{1-\beta} - \frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)} \underbrace{\sum_{u,d} X_{ud} d \ln \tau_{ud}}_{\text{Hulten}}$$

- ς : GDP to intermediate goods revenue ratio (inverse of Domar weights)

$$\varsigma = \underbrace{\frac{\beta}{1-\beta}}_{\text{IO multiplier}} + \underbrace{\frac{1}{\sigma}}_{\text{double marginalization}} \underbrace{- \frac{1-\mu}{\sigma} \left(\frac{1}{\gamma^B} + \frac{1-\beta}{\gamma^S} \right)}_{\text{retail goods expenditure on forming links}}$$

- Double marginalization + relationship-formation inefficiency $\Rightarrow$ Deviation from Hulten

Special Case: Fixed Networks

$$d \ln \mathcal{W}^{\text{Fixed}} = - \underbrace{\frac{\varsigma^{\text{Fixed}}}{\beta}}_{\text{IO multiplier}} \underbrace{\sum_{u,d} X_{ud} d \ln \tau_{ud}}_{\text{Hulten}}$$

$$\varsigma^{\text{Fixed}} = \underbrace{\frac{\beta}{1-\beta}}_{\text{IO multiplier}} + \underbrace{\frac{1}{\sigma}}_{\text{double marginalization}}$$

- ▶ Double marginalization $\Rightarrow$ Hulten underpredicts welfare changes (e.g., Baqaee-Farhi '23)
- ▶ Optimal sales subsidy $s_{id}^I = \frac{1}{\sigma} \Rightarrow$ Hulten

Fixed vs Endogenous Networks

$$d \ln \mathcal{W} = -\frac{\varsigma}{\frac{\beta}{1-\beta}} \sum_{u,d} X_{ud} \left(d \ln \tau_{ud} - \frac{1}{\sigma-1} d \ln M_{ud} \right)$$

- Endogenous networks $\Rightarrow$ (1) $d \ln M_{ud} \neq 0$ and (2) $\varsigma < \varsigma^{\text{Fixed}}$

Fixed vs Endogenous Networks

$$d \ln \mathcal{W} = -\frac{\varsigma}{\frac{\beta}{1-\beta}} \sum_{u,d} X_{ud} \left(d \ln \tau_{ud} - \frac{1}{\sigma-1} d \ln M_{ud} \right)$$

- Endogenous networks $\Rightarrow$ (1) $d \ln M_{ud} \neq 0$ and (2) $\varsigma < \varsigma^{\text{Fixed}}$

$$\sum_{u,d} X_{ud} \frac{1}{\sigma-1} d \ln M_{ud} = -\frac{\frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)}{\frac{\beta}{1-\beta} - \frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)} \sum_{u,d} X_{ud} d \ln \tau_{ud}$$

Fixed vs Endogenous Networks

$$d \ln \mathcal{W} = -\frac{\varsigma}{\frac{\beta}{1-\beta}} \sum_{u,d} X_{ud} \left(d \ln \tau_{ud} - \frac{1}{\sigma-1} d \ln M_{ud} \right)$$

- Endogenous networks $\Rightarrow$ (1) $d \ln M_{ud} \neq 0$ and (2) $\varsigma < \varsigma^{\text{Fixed}}$

$$\sum_{u,d} X_{ud} \frac{1}{\sigma-1} d \ln M_{ud} = -\frac{\frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)}{\frac{\beta}{1-\beta} - \frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)} \sum_{u,d} X_{ud} d \ln \tau_{ud}$$

- $\Rightarrow$ Larger first-order aggregate effect in endogenous vs fixed network (conditional on X_{ud}) iff

$$\underbrace{\frac{\varsigma^{\text{Fixed}}}{\varsigma}}_{\text{Private cost of intermediate input use}} < \underbrace{\frac{\frac{\beta}{1-\beta}}{\frac{\beta}{1-\beta} - \frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)}}_{\text{Social value of intermediate input use}}$$

Ex-Post Sufficient Statistics for Each Region's Welfare

$$d \ln Q_i^F = - \underbrace{\frac{1}{\varepsilon}}_{\text{trade elasticity}} \underbrace{\frac{\beta}{1-\beta}}_{\text{IO multiplier}} - \underbrace{\frac{1}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)}_{\text{multiplier effect through relation-formation cost}} \underbrace{d \ln \Lambda_{ij}}_{\text{intra-region exp share}}$$

Ex-Post Sufficient Statistics for Each Region's Welfare

$$d \ln Q_i^F = - \underbrace{\frac{1}{\varepsilon}}_{\text{trade elasticity}} \underbrace{\frac{\beta}{1-\beta}}_{\text{IO multiplier}} - \underbrace{\frac{1}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)}_{\text{multiplier effect through relation-formation cost}} \underbrace{d \ln \Lambda_{ij}}_{\text{intra-region exp share}}$$

► Deviation from fixed networks:

1. Larger trade elasticity: $\varepsilon > \varepsilon^{\text{Fixed}}$ (ACR '12) $\Rightarrow$ smaller effects
2. Multiplier effect through relationship-formation cost $\Rightarrow$ larger effects

- Trade elasticity matters for distributional effects or large shocks, i.e., Le Chatelier's principle
- Efficiency does not play a role: Aggregate trade shocks $\Rightarrow$ no labor reallocation between production and relationship formation

Extension to Alternative Production Network Formation Models

- Assume ACR's three macro restrictions, and

$$d \ln M_{ud} = (\delta_{L,U} + \delta_{Q,U} + \delta_{L,D} + \delta_{Q,D}) d \ln X_{ud} \\ - \delta_{L,U} d \ln w_u - \delta_{Q,U} d \ln P_u - \delta_{L,D} d \ln w_d - \delta_{Q,D} d \ln P_d$$

$$d \ln P_i = \beta d \ln w_i + (1 - \beta) \sum_u \Lambda_{ui} (\nu d \ln M_{ui} - d \ln P_u - d \ln \tau_{ui})$$

- Two propositions generalize

$$d\mathcal{W} = \frac{\varsigma}{\frac{\beta}{1-\beta} - \nu (\delta_{Q,U} + \delta_{Q,D})} \sum_{u,d} X_{ud} d \ln \tau_{ud}, \quad d \ln Q_i^F = -\frac{1}{\varepsilon} \frac{1}{\frac{\beta}{1-\beta} - \nu (\delta_{Q,U} + \delta_{Q,D})} d \ln \Lambda_{ii}$$

- Cover models with relationship-fixed costs and discrete supplier choice with Pareto

Outline

Model

Planning Problem and Equilibrium Inefficiency

Aggregate Effects of Trade Cost Shocks

Data and Reduced-Form Evidence

Quantitative Analysis

Conclusion

Data

- ▶ Domestic firm-to-firm transaction data from Chile
 - ▶ Collected for value-added tax collection purpose
 - ▶ Seller and buyer tax ID, dates, total amounts
 - ▶ Origin and destination municipalities of establishments since 2018 (345 municipalities in Chile)
- ▶ Customs firm-to-firm data $\Rightarrow$ Imports and exports
- ▶ Firm balance sheet characteristics $\Rightarrow$ Total sales, labor expenditure, sector
- ▶ Country-sector international trade data: Input-output database from OECD (ICIO)

Reduced-Form Evidence for Endogenous Network Formation

- Firm-level impacts of **tariff reduction** (US '04 and China '06 FTA) using **shift-share** design

$$\Delta \log y_{it} = \alpha \sum_{c,k} \underbrace{w_{ickt_0=2003}^D}_{\text{import by firm } i} \times \underbrace{\Delta_{2007-2003} \log(1 + \tau_{ckt})}_{\text{Chile's import tariffs with country } c \text{ of product } k} + \gamma X_{it} + \varepsilon_{it}$$

	Total Imports (1)	Number Int. Suppliers (2)	Number Dom. Buyers (3)	Number Dom. Suppliers (4)
Import Tariff Shock	-3.20 (1.26)	-1.88 (0.61)	-1.30 (1.10)	-1.52 (0.71)
Number Observations			33260	
Sector FE (6 digit)			Yes	
Prior Import Share			Yes	
Export Shock Residualized			Yes	
Period			2003-2007	

- Domestic links **decrease** in response to tariff **increase** $\Rightarrow$ import complementarity

Outline

Model

Planning Problem and Equilibrium Inefficiency

Aggregate Effects of Trade Cost Shocks

Data and Reduced-Form Evidence

Quantitative Analysis

Conclusion

Calibration

- ▶ Multi-sector (2) extension as in Caliendo-Parro '15: Cobb-Douglas in tech/pref [detail](#)
- ▶ Calibrate the model with 345 municipalities in Chile + US, China, ROW
 - ▶ Match observed $\{X_{ud,kl}\}$
 - ▶ Calibrate $\{\alpha_k, \beta_{km}, \gamma_k^S, \gamma_k^B\}$ from data and $\{\varepsilon_k\}$ literature
 - ▶ Calibrate $\mu = 0.35$ from firms' expenditure in relationship-formation-related services
 - ▶ $\lambda^S = \lambda^B = 0.56$ by targeting reduced-form effects of import tariff reduction

	Untargeted			Targeted
	Total Imports (1)	Number Int. Suppliers (2)	Number Dom. Buyers (3)	Number Dom. Suppliers (4)
Data	-3.20 (1.26)	-1.88 (0.61)	-1.30 (1.10)	-1.52 (0.71)
Model	-4.10	-1.68	-2.10	-1.49

- ▶ $\mu < 1$ rationalize the domestic supplier link **decrease** in response to tariff increase

↑ Iceberg import cost by the amount of the US & CN tariff reduction

	1) $\widehat{\text{Welfare}}$ (%)	2) Rel. to Baseline	3) $\hat{X}_{ui, u \in \text{US, CN}}$	4) $\hat{M}_{ui, u \in \text{US, CN}}$	5) $\hat{M}_{ui, u \in \text{CL}}$
a) Baseline	-0.89	100	-21.4	-8.4	-0.1
b) Fixed Network, fix ε_k	-0.55	62	-21.3	0	0

► Endogenous networks increases welfare loss by $\approx 60\%$

↑ Iceberg import cost by the amount of the US & CN tariff reduction

	1) $\widehat{\text{Welfare}} (\%)$	2) Rel. to Baseline	3) $\hat{X}_{ui, u \in \text{US, CN}}$	4) $\hat{M}_{ui, u \in \text{US, CN}}$	5) $\hat{M}_{ui, u \in \text{CL}}$
a) Baseline	-0.89	100	-21.4	-8.4	-0.1
b) Fixed Network, fix ε_k	-0.55	62	-21.3	0	0

- ▶ Endogenous networks increases welfare loss by $\approx 60\%$
 - ▶ Consistent with inefficiently low relationship-formation effort and thus low X_{ud}

↑ Iceberg import cost by the amount of the US & CN tariff reduction

	1) $\widehat{\text{Welfare}} \text{ (%)}$	2) Rel. to Baseline	3) $\hat{X}_{ui, u \in \text{US, CN}}$	4) $\hat{M}_{ui, u \in \text{US, CN}}$	5) $\hat{M}_{ui, u \in \text{CL}}$
a) Baseline	-0.89	100	-21.4	-8.4	-0.1
b) Fixed Network, fix ε_k	-0.55	62	-21.3	0	0

- ▶ Endogenous networks increases welfare loss by $\approx 60\%$
 - ▶ Consistent with inefficiently low relationship-formation effort and thus low X_{ud}
- ▶ Even though response of trade flows is similar (Column 3), because trade elasticity is the same, welfare effects are not

↑ Iceberg import cost by the amount of the US & CN tariff reduction

	1) $\widehat{\text{Welfare}} \text{ (%)}$	2) Rel. to Baseline	3) $\hat{X}_{ui, u \in \text{US, CN}}$	4) $\hat{M}_{ui, u \in \text{US, CN}}$	5) $\hat{M}_{ui, u \in \text{CL}}$
a) Baseline	-0.89	100	-21.4	-8.4	-0.1
b) Fixed Network, fix ε_k	-0.55	62	-21.3	0	0

- ▶ Endogenous networks increases welfare loss by $\approx 60\%$
 - ▶ Consistent with inefficiently low relationship-formation effort and thus low X_{ud}
- ▶ Even though response of trade flows is similar (Column 3), because trade elasticity is the same, welfare effects are not
- ▶ Confirms complementarity of domestic link formation, consistent with DiD (Column 5)

Gains From Trade

(a) Relative to Municipality Autarky

	$\widehat{\text{Welfare}} \text{ (%)}$	% of Baseline
1) Baseline	406	100
2) Fixed Networks, fix ε_k	190	47

Gains From Trade

(a) Relative to Municipality Autarky

	$\widehat{\text{Welfare}} (\%)$	% of Baseline
1) Baseline	406	100
2) Fixed Networks, fix ε_k	190	47

(b) Relative to International Autarky (Allow for Trade within Chile)

	$\widehat{\text{Welfare}} (\%)$	% of Baseline
1) Baseline	15.1	100
2) Fixed Networks, fix ε_k	10.9	72

- More “attenuation” effects from endogenous networks when we allow for domestic trade

Conclusion

- ▶ Build a multi-location GE model of production network formation under matching frictions
 - ▶ Tractably incorporate production network formation into the workhorse quantitative trade toolkit
- ▶ Provide ex-ante and ex-post sufficient statistics for aggregate effects of trade cost shocks
 - ▶ Network formation matters due to inefficiency, amplification and reallocation
- ▶ Estimated model with Chilean data shows that endogenous network tend to increase welfare effects of various trade shocks
 - ▶ Depends on the nature of experiment (sign, magnitudes, scope of shocks)

Appendix

(Constrained) Planning Problem

- ▶ Ad-valorem sales subsidy s_{id}^I
- ▶ Ad-valorem supplier and buyer search taxes t_{id}^S and t_{id}^B
- ▶ Lump-sum transfers to household T_i^F
- ▶ Planning problem with welfare weight ψ_i :

$$\max_{\{\{s_{id}^I, t_{id}^B, t_{id}^S\}, T_i^F\}} \sum_i \psi_i L_i Q_i^F$$

subject to equilibrium constraints and global planner balanced budget

- ▶ Focus on welfare weight $\psi_i = P_i$; see paper for general case

Optimal Policy Formula

- ▶ Optimal taxes/subsidies must satisfy

$$s_{id}^I = \frac{1}{\sigma}, \quad t_{id}^B = \frac{1}{\lambda^B} - 1, \quad t_{id}^S = \frac{1}{\lambda^S} (1 - \beta) \frac{E_d}{R_d} - 1$$

- ▶ s_{id}^I offset double marginalization
- ▶ t_{id}^B and t_{id}^S offset search and matching externalities, balancing two inefficiencies
 - ▶ non-appropriability: capture only a fraction of social surplus as revenue
 - ▶ business stealing: through congestion in matching and substitution among connected suppliers

Constrained Efficiency: Hosios-Type Result

Suppose $s_{id}^I = \frac{1}{\sigma}$. Then, $t_{id}^B = t_{id}^S = 0$ if and only if

$$\lambda^B = 1, \quad \lambda^S = 1 - \beta$$

- Intuition of buyer search:

$$\underbrace{\frac{1}{\sigma - 1} \frac{\lambda^B}{\gamma^B}}_{\text{social return of buyer search}} = \underbrace{\frac{1}{1 - s_{id}^I} \frac{1}{\sigma} \frac{1}{\gamma^B}}_{\text{firms' expenditure share for buyer search}}$$

- $\lambda^B = 1 \Rightarrow$ No congestion externality $\Rightarrow$ Two inefficiencies cancel out
 - Similar to entry models with monopolistic competition & CES demand (Dixit-Stiglitz '77)
 - Efficiency requires IRS matching technology, unlike Hosios '90
 - Due to business stealing among connected suppliers

Ex-Ante Sufficient Statistics: $\{d \ln \tau_{ud}\}$ on Global Welfare

For welfare weights $\psi_i = P_i$,

$$d \ln \mathcal{W} = - \frac{\varsigma}{\frac{\beta}{1-\beta} - \frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)} \underbrace{\sum_{u,d} X_{ud} d \ln \tau_{ud}}_{\text{Hulten}}$$

- ς : GDP to intermediate goods revenue ratio

$$\varsigma = \frac{\beta}{1-\beta} + \frac{1}{\sigma} - \frac{1-\mu}{\sigma} \left(\frac{1}{\gamma^B} + \frac{1-\beta}{\gamma^S} \right)$$

- Will proceed with special cases to build intuition

Special Case 1: Fixed Networks

$$d \ln \mathcal{W}^{\text{Fixed}} = - \underbrace{\frac{\zeta^{\text{Fixed}}}{\beta}}_{\text{IO multiplier}} \underbrace{\sum_{u,d} X_{ud} d \ln \tau_{ud}}_{\text{Hulten}}$$

$$\zeta^{\text{Fixed}} = \frac{\beta}{1 - \beta} + \frac{1}{\sigma}$$

- ▶ Double marginalization $\Rightarrow$ Hulten underpredicts welfare changes (e.g., Baqaee-Farhi '23)
- ▶ Optimal sales subsidy $s_{id}^I = \frac{1}{\sigma} \Rightarrow$ Hulten

Special Case 2: Endogenous Networks with Sales Subsidy $s_{id}^I = \frac{1}{\sigma}$

$$d \ln \mathcal{W}^{\text{SalesSubsidy}} = - \frac{\varsigma}{\frac{\beta}{1-\beta} - \underbrace{\frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)}_{\text{multiplier effect through search cost}}} \underbrace{\sum_{u,d} X_{ud} d \ln \tau_{ud}}_{\text{Hulten}}$$

$$\varsigma = \frac{\beta}{1-\beta} - \underbrace{\frac{1-\mu}{\sigma-1} \left(\frac{1}{\gamma^B} + \frac{1-\beta}{\gamma^S} \right)}_{\text{spending of retail goods for search activity}}$$

► $\lambda^B = 1, \lambda^S = 1 - \beta \Rightarrow$ Search is constrained efficient $\Rightarrow$ Hulten

Special Case 2: Endogenous Networks with Sales Subsidy $s_{id}^I = \frac{1}{\sigma}$

$$d \ln \mathcal{W}^{\text{SalesSubsidy}} = - \frac{\varsigma}{\frac{\beta}{1-\beta} - \underbrace{\frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)}_{\text{multiplier effect through search cost}}} \underbrace{\sum_{u,d} X_{ud} d \ln \tau_{ud}}_{\text{Hulten}}$$

$$\varsigma = \frac{\beta}{1-\beta} - \underbrace{\frac{1-\mu}{\sigma-1} \left(\frac{1}{\gamma^B} + \frac{1-\beta}{\gamma^S} \right)}_{\text{spending of retail goods for search activity}}$$

- ▶ $\lambda^B = 1, \lambda^S = 1 - \beta \Rightarrow$ Search is constrained efficient $\Rightarrow$ Hulten
- ▶ ... but not vice versa if $\mu = 1$ (no intermediates in search costs) or $\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} = \frac{1}{\gamma^B} + \frac{1-\beta}{\gamma^S}$
 - ▶ While labor may be misallocated, trade flows are not distorted
 - ▶ Misallocation between buyer and supplier search also does not matter if total search is not

Endogenous Networks with Laissez-Faire Equilibrium $s_{id}^I = 0$

$$d \ln \mathcal{W} = - \frac{\varsigma}{\frac{\beta}{1-\beta} - \underbrace{\frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)}_{\text{multiplier effect through search cost}}} \underbrace{\sum_{u,d} X_{ud} d \ln \tau_{ud}}_{\text{Hulten}}$$

$$\varsigma = \frac{\beta}{1-\beta} + \frac{1}{\sigma} - \underbrace{\frac{1-\mu}{\sigma} \left(\frac{1}{\gamma^B} + \frac{1-\beta}{\gamma^S} \right)}_{\text{spending of retail goods for search activity}}$$

- Fixed networks: double marginalization
- Endogenous networks: double marginalization + search inefficiency

Endogenous Networks with Laissez-Faire Equilibrium $s_{id}^l = 0$

$$d \ln \mathcal{W} = - \frac{\varsigma}{\frac{\beta}{1-\beta} - \underbrace{\frac{1-\mu}{\sigma-1} \left(\frac{\lambda^B}{\gamma^B} + \frac{\lambda^S}{\gamma^S} \right)}_{\text{multiplier effect through search cost}}} \underbrace{\sum_{u,d} X_{ud} d \ln \tau_{ud}}_{\text{Hulten}}$$

$$\varsigma = \frac{\beta}{1-\beta} + \frac{1}{\sigma} - \underbrace{\frac{1-\mu}{\sigma} \left(\frac{1}{\gamma^B} + \frac{1-\beta}{\gamma^S} \right)}_{\text{spending of retail goods for search activity}}$$

- ▶ Fixed networks: double marginalization
- ▶ Endogenous networks: double marginalization + search inefficiency
- ▶ Two inefficiencies interact
 - ▶ Double marginalization lowers firm revenue, decreasing private incentive for search
 - ▶ Even if $\lambda^B = 1$, $\lambda^S = 1 - \beta$, endogenous networks implies a larger coefficient

Calibration

- ▶ Multi-sector (2) extension as in Caliendo-Parro '15: Cobb-Douglas in tech/pref [detail](#)
- ▶ Calibrate the model with 345 municipalities in Chile + US, China, ROW
- ▶ Match bilateral sectoral domestic & international trade flows ($X_{ud,kl}$)
- ▶ Calibrated parameters [detail](#)
 - ▶ Input coefficients and final consumption $\{\alpha_k, \beta_{km}\}$ from aggregate IO table
 - ▶ $\{\gamma_k^S, \gamma_k^B\}$ from firm-level relationship between sales and number of linkages
 - ▶ Trade elasticities $\{\varepsilon_k\}$ from literature ([Fontagné et al., 2022](#); [Gervais and Jensen, 2019](#))
 - ▶ $\{\lambda^S = \lambda^B, \mu\}$ by targeting reduced-form effects of import tariff reduction $\Rightarrow$ Indirect inference

Impacts of Import Tariff Changes: Data vs Model

- ▶ Simulate the import tariff reduction from US and China
- ▶ Choose $\{\lambda^S = \lambda^B, \mu\}$ that minimize squared distance to targeted regression coefficients

Parameters	Value
$\lambda^S = \lambda^B$	0.64
μ	0.05

	Untargeted		Targeted	
	Total Imports (1)	Number Foreign Suppliers (2)	Number Domestic Suppliers (3)	Number Domestic Buyers (4)
Data	-3.20 (1.11)	-1.86 (0.61)	-1.48 (0.72)	-1.23 (1.10)
Model	-3.93	-1.44	-1.40	-1.54

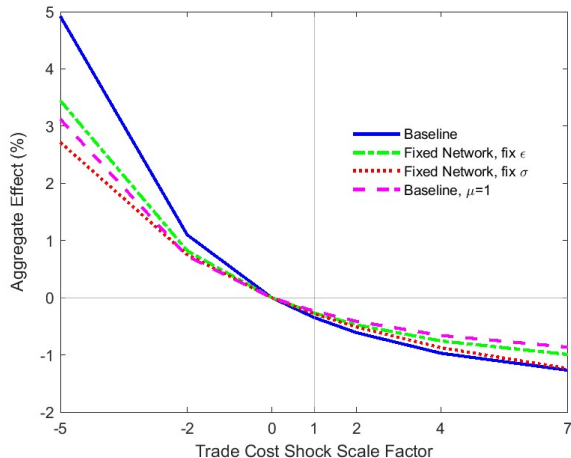
- ▶ $\mu \ll 1$ rationalize the domestic supplier link **decrease** in response to tariff increase

intuition

Calibration Results

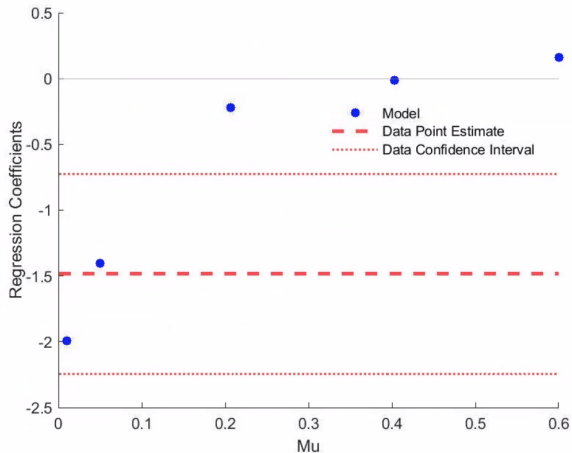
Parameters	Goods	Services	Description
α_k	0.25	0.75	Final consumption share
$\{\beta_{k,L}\}$	0.14	0.33	Labor coefficient in production
$\{\beta_{lk}\}$			Intermediate input coefficient in production
l : Goods Sector	0.45	0.10	
l : Services Sector	0.41	0.57	
γ_k^S	2.6	2.7	Search cost curvature w.r.t. suppliers
γ_k^B	4.5	2.8	Search cost curvature w.r.t. buyers
ε_k	5.0	4.6	Trade elasticity
μ_k	0.05	0.05	Labor coefficient in search
$\lambda_{kl}^S = \lambda_{kl}^B (\forall k, l)$	0.64	0.64	Matching function elasticity
σ_k	4.1	3.5	Elasticity of substitution

Nonlinear Effects



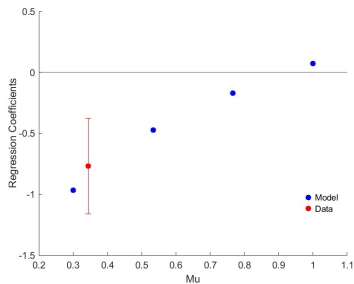
- ▶ Fixing trade elasticity ϵ , shutting down endogenous networks always $\downarrow$ effects
 - ▶ From search cost amplification ($\mu < 1$)
- ▶ Fixing elasticity of substitution σ , shutting down endogenous networks can $\uparrow$ welfare effects for large increase in trade costs
 - ▶ Larger $\epsilon \Rightarrow$ reallocation of trade flows

Intuition Behind Identification of μ

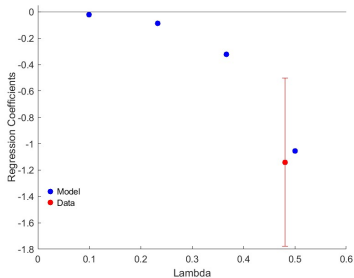


(a) μ : Number of Domestic Suppliers

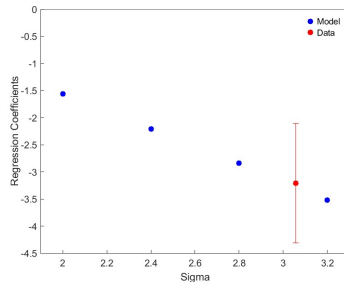
Identification of $\lambda^S = \lambda^B$, σ , μ from Indirect Inference



(b) μ : Number of Domestic Suppliers



(c) λ : Number of Domestic Buyers



(d) σ : Total Imports