Trade and Technology Compatibility in General Equilibrium

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- Recent world events lead countries reduce economic dependence on geopolitical rivals

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    U.S.—near-shoring/friend-shoring; China—'Made in China 2025'

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- A concern: the risk of losing access to foreign input push firms towards alternative technologies/ecosystems that are incompatible with each other
- Anecdotes:
  - Concerned over China's control over cobalt, U.S. battery producers started to develop cobalt-free battery $\Rightarrow$ new protocols for charging stations and EVs
  - Discontinued license for x86 instruction sets pushed Chinese CPU maker to alternative designs $\Rightarrow$ software shifting away from the Windows ecosystem

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  - trade shock $\rightarrow$ change in trading partner $\rightarrow$ change in the choice of technology

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  - country-sector (*not today*): causal effects of tariff changes on proximity; isolating exogenous bilateral variations due to MFN tariffs
- **Quantification**:
  - accounting for country-pair technology proximity
    - model explains 69%. Compatibility incentive explains 31%
  - technology decoupling more than doubles the losses from semi-conductor embargo to China

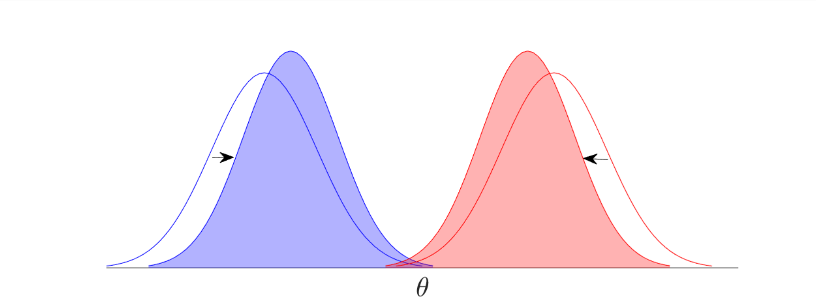
Outline

- A model of endogenous production networks with technology compatibility
- Empirics: bilateral relationship between technology proximity and trade intensity
- Quantification
  - Accounting for country-pair proximity of technology
  - The effects of trade shock amplified by technology decoupling

Model - Overview

- N regions, denoted (d, o). S sectors (i, j). Mass one firm in each region-sector, each with a differentiated variety
- Firms differ in productivity and technology, $\theta \in \mathbb{R}$
  - technology: a combination of knowledge from different scientific/engineering disciplines (EV - hybrid -hydrogen- ICE); alternatively, specific protocol/networks/ecosystem
  - firms in region-sector (o, j) draw *endowment technology* $\bar{\theta}$ from distribution $\overline{\Theta}_o^j$
  - firms choose θ; cost of adaption increases in dist$(\theta, \bar{\theta})$
- Firms choose the suppliers for each input sector
  - sourcing efficiency decays in distance of θ, b/w firm and its supplier
- Production takes place, firms sell to consumers and downstream firms

Distribution of Endowment and Chosen Direction: An Example



Adaptation Input Sourcing Production Sales

- Marginal cost pricing when selling to downstream firms
- Monopolistic competitive markups when selling to consumers, which have preference

$$U_d \equiv \prod_{j=1}^{S}[U_d^j]^{\rho_d^j}, \quad U_d^j = \left[\sum_o \int_0^1 [q_{do}^j(\omega_o^j)]^{\frac{\eta-1}{\eta}} d\omega_o^j\right]^{\frac{\eta}{\eta-1}}, \eta > 1$$

- Expected profits for firms from region-sector (o, j) with technology θ:

$$\mathbb{E}\Pi_o^j(c_o^j(\theta)) \propto \mathbb{E}\frac{1}{\eta}\sum_d \rho_d^j I_d \frac{[c_o^j(\theta)\tau_{do}^{Uj}]^{1-\eta}}{[P_d^j]^{1-\eta}},$$

where $c_o^j(\theta)$ is a r.v. that denotes the production cost of a firm with θ in (o, j)

- Adaptation costs $\phi(\bar{\theta}, \theta)$ rises in $|\theta - \bar{\theta}|$. Firms choosing technology solving

$$\max_\theta \left[1 - \phi(\bar{\theta}, \theta)\right]\mathbb{E}\Pi_o^j(c_o^j(\theta))$$

- Ex-ante dist. of technology, $\overline{\Theta}_o^j$ + Adaptation $\Rightarrow$ ex-post dist Θ_o^j

Adaptation   Input Sourcing   Production   Sales

- A firm ν from region-sector (d, i) chooses $\theta(\nu)$ and then draws a random set of production *techniques* and minimizes its unit production cost
- A technique **r** is characterized by (1) TFP $A(\nu, r)$ and (2) a set of potential suppliers from each country-sector, denoted by $\Omega_o^j(\nu, r)$
- For firm ν from region-sector (d, i) with technique **r**, output given by

$$y(\nu, r) = A(\nu, r)\, [\ell(\nu, r)]^{\gamma^{iL}} \prod_{j=1}^{S} \left[m^j(\nu, \omega(r)) \right]^{\gamma^{ij}},$$

with $\gamma^{iL} + \sum_j \gamma^{ij} = 1; \omega(r)$ is the supplier choice under technique r.

- Given technique **r** and input costs $\{c^j(\nu, r)\}_{j=1}^S$, i.e., the price of $\{m^j(v, \omega(r))\}_{j=1}^S$, the unit production cost $\propto$

$$c_o^j(\theta(\nu)) \propto \min_r \frac{1}{A(\nu, r)} \cdot [w_d]^{\gamma^{iL}} \cdot \prod_{j=1}^{S} \left[c^j(\nu, r) \right]^{\gamma^{ij}}$$

Input cost of j, $c^j(\nu, r)$, given by choosing most efficient supplier from $\Omega_o^j(\nu, r)$:

$$c^j(\nu, r) = \min_o \min_{\omega \in \Omega_o^j(\nu, r)} \tilde{c}^j(\nu, \omega)$$

- Each supplier $\omega \in \Omega_o^j$ drawn with a match-specific sourcing efficiency $z(\omega)$
- Input cost affected by (1) trade costs; (2) technology distance $||\theta(\nu) - \theta(\omega)||$
- Effective unit input cost for firm ν sourcing from supplier ω:

$$\tilde{c}^j(\nu, \omega) = \underbrace{p(\omega)}_{\text{supplier prod. cost}} \cdot \underbrace{\frac{1}{z(\omega)}}_{\text{sourcing efficiency}} \cdot \underbrace{\tau_{do}^j}_{\text{iceberg trade costs}} \cdot \underbrace{t(\theta(\nu), \theta(\omega))}_{\text{compatibility costs}}$$

Adaptation Input Sourcing Production Sales

[Assumption 1] (How the set of techniques is drawn):

- $\forall a > 0$, # of techniques with $A(\nu, r) \geq a$ follows Poisson with mean $[a/A_d^i]^{-\lambda}$
- Draw of $\theta(\omega)$ is from distribution Θ_o^j and independent of $z(\omega)$
- $\forall \tilde{z} > 0$, # of suppliers in $\Omega_o^j(\nu, r)$ with $z(\omega) \geq \tilde{z}$ follows Poisson with mean $\tilde{z}^{-\zeta}$

Proposition (Aggregation)

Under Assumption 1, the unit production cost for a firm with θ from (d, i), $c_d^i(\theta)$, follows a Weibull (inverse Frechet) distribution with the following CDF—$F_d^i(x;\theta) = 1 - e^{-(x/C_d^i(\theta))^\lambda}$, with $\boldsymbol{C_d^i(\theta)}$ determined as the fixed point of

$$\boldsymbol{C_d^i(\theta)} = \frac{\Xi^i}{A_d^i}[w_d]^{\gamma^{iL}} \prod_j \left(\sum_o \int [\boldsymbol{C_o^j(\tilde{\theta})}\tau_{do}^j]^{-\zeta} [t(\theta, \tilde{\theta})]^{-\zeta} \, d\Theta_o^j(\tilde{\theta}) \right)^{-\frac{\gamma^{ij}}{\zeta}}$$

Moreover, firm-to-firm sourcing decision can be expressed with $\{C_d^i(\theta), \Theta_o^j\}$ analytically.

- exogenous and degenerate $\Theta_o^j \implies$ Caliendo and Parro (2015)

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Definition of Equilibrium

Given geography $\{\tau^j_{do}, L_d\}$, production technology $\{\gamma^{ij}, \gamma^{iL}, A^i_d, \lambda, \zeta, t(\cdot,\cdot), \phi(\cdot,\cdot)\}$, preference $\{\rho^j, \eta\}$, and ex-ante distribution of technology $\{\overline{\Theta}^j_o\}$,

A competitive equilibrium is (1) wages, prices and income $\{w_d, P_d, I_d\}$, (2) sales to firms and final goods $\{X^j_o(\theta), M^j_o(\theta)\}$, (3) production costs characterized by $\{C^j_o(\theta)\}$, (4) ex-post technology distribution $\{\Theta^j_o\}$, s.t.

- $\{C^j_o(\theta)\}$ are consistent with the input sourcing - production decisions
- $\{\Theta^j_o\}$ are consistent with policy functions for adaptation, $\{C^j_o(\theta)\}$ and $\{\overline{\Theta}^j_o\}$
- Labor markets clear; goods markets clear by θ; consumer income equals wage income plus profits.

▸ Existence and Uniqueness

Discussions on Model's Implications

Positive:

Normative:

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- Across firms within a (d, i) (due to differences in $\bar{\theta}$): higher technology proximity to region $o \Rightarrow$ higher efficiency sourcing from $o \Rightarrow$ more imports from o ▸ proposition *Firm-level* corr. b/w technology and trade identifies incompat. cost $t(\cdot, \cdot)$

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  Countries' technology responding to trade shocks identifies adaptation cost $\phi(\cdot, \cdot)$

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  Unique prediction: neighboring country defined based on technology in addition to geography

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Normative:

- Technology choice impose externalities on down-stream firms
- Firms from different countries/sectors tend to locate too distant from each other compared to social optimum ▸ proposition

Trade and Technology Proximity: Country and Firm-level Evidence

Data and Measurements

- Patent and citations: universe of world patents (PATSTAT)
- Trade: China's customs data (firm-level)
- Sample
  - Countries (d, o): grouped into 28 geo-political regions
  - Industries j: CIC-3 (firm-level)
  - Time t: 2000-2014 and aggregated to five 3-year periods

Firm-level Evidence: correlation between citation and trade

$$\mathbb{I}(\text{Import}_{\omega ot} > 0) = \beta \mathbb{I}[\text{Citation}_{\omega ot} > 0] + FE^{(1)}_{\omega t} + FE^{(2)}_{\omega o} + FE^{(3)}_{ot} + \gamma X_{i(\omega)ot} + \varepsilon_{\omega ot}$$

ω: a Chinese firm. o: origin region. t: period. $i(\omega)$: CSC-3 industry of firm ω

$X_{i(\omega)ot}$: (i, o, t)-level fixed effects

	$\mathbb{I}(\text{Import}_{\omega ot} > 0)$		
	(1)	(2)	(3)
$\mathbb{I}[\text{Citation}_{\omega ot} > 0]$	0.024***	0.023***	0.022***
	(0.001)	(0.001)	(0.001)
FE ω-t	Yes	Yes	Yes
FE ω-o	Yes	Yes	Yes
FE o-t	Yes	Yes	
X_{iot}		Yes	
FE i-o-t-province			Yes
Observations	9108423	8771074	9080046

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are clustered by firm.

Results hold for intensive margin: citing o increases imports from o by 5%; robust to the exclusion of MNCs and JVs

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Interpretation: different endowment draws or idiosyncratic trade costs lead firms to pursue different combination of sourcing and technology strategies

Example of idiosyncratic trade cost: my cousin knows a guy in o, so I import from that guy. To use his product effectively, I pivot my technology.

Firm-level Evidence: correlation between citation and trade

- **Alternative story**: my cousin knows a guy in o, so I buy from that guy. Moreover, my cousin helps me understand that guy's tech, so I design my product accordingly
- **Idea to address this story**: see if importing from a country o' with similar technology to o correlated with importing from o:

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  Closeness based on residuals from regressions citation on o and o' FE.

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  Closeness based on residuals from regressions citation on o and o' FE.
- Of course, if o' is close to o, my cousin may also know a guy from o', but such information network is likely correlated with geography and language more than technology $\Longrightarrow$ control for whether ω cites the geo and linguistic neighbors of o

	$\mathbb{I}[\text{Import}_{\omega ot} > 0]$		
	(4)	(5)	(6)
$\mathbb{I}[\text{Citation}_{\omega ot} > 0]$	0.022***	0.021***	0.021***
	(0.001)	(0.001)	(0.001)
$\mathbb{I}[\text{Citation}_{\omega,\mathcal{R}_t^{tech}(o),t} > 0]$		0.008***	0.007***
		(0.001)	(0.001)
$\mathbb{I}[\text{Citation}_{\omega,\mathcal{R}^{distw}(o),t} > 0]$			0.004***
			(0.001)
$\mathbb{I}[\text{Citation}_{\omega,\mathcal{R}^{comlang}(o),t} > 0]$			0.004***
			(0.000)
$\mathbb{I}[\text{Citation}_{\omega,\mathcal{R}_t^{trade}(o),t} > 0]$			-0.002
			(0.001)
Firm-Year FE	Yes	Yes	Yes
Firm-Region FE	Yes	Yes	Yes
Province-Industry-Region-Year FE	Yes	Yes	Yes
$\mathbb{I}[\text{Import}_{\omega,\mathcal{R}_t^{citation}(o),t} > 0]$ FE		Yes	Yes
Observations	11582228	11582228	11582228
R^2	0.671	0.688	0.688

Quantification

[Assumption 2]:

- Costs of technology incompatibility: $t(\theta, \tilde{\theta}) = \exp(\bar{t}(\theta - \tilde{\theta})^2)$
- Adaptation costs: $\phi(\bar{\theta}, \theta) = 1 - \exp(-\bar{\phi}(\bar{\theta} - \theta)^2)$
- Ex-ante technology distribution $\{\overline{\Theta}^j_o\}$ each follows a normal distribution

Proposition (Ex-post Distribution is Normal)

Under Assumption 1+2. The solutions to $\{C^j_o(\theta), \Theta^j_o\}$ are characterized by

- $\ln C^j_o(\theta) = k^j_{A,o} + m^j_A(\theta - n^j_{A,o})^2$
- $\Theta^j_o \sim Normal(\mu^j_o, [\sigma^j_o]^2)$

up to a second order approximation for $\ln C^j_o(\theta)$ *with respect to* θ.

$\{k^j_{A,o}, m^j_A, n^j_{A,o}, \mu^j_o, \sigma^j_o\}$ *are coefficients that depend on parameters and* $\{w_d\}$ *only*

Measuring Technology Proximity with Citation Shares

- Used Data citation shares to measure tech. proximity between (d, i) and (o, j):

$$\Psi_{di}^{oj} = \frac{\#\text{ citations made to } (o, j) \text{ by } (d, i)}{\text{total } \#\text{ citations made by } (d, i)}$$

- In Model, for firm from (d, i) that chooses θ, the proximity between θ and Θ_o^j:

$$\psi_{di}^{oj}(\theta) \equiv \frac{\delta^{ij} H_o^j \cdot \mathrm{d}\Theta_o^j(\theta)}{\sum_{o',j'} \delta^{ij'} H_{o'}^{j'} \cdot \mathrm{d}\Theta_{o'}^{j'}(\theta)},$$

H_o^j: total number of citations made to (o, j) in data
δ^{ij}: share of citations made to industry j by industry i in data

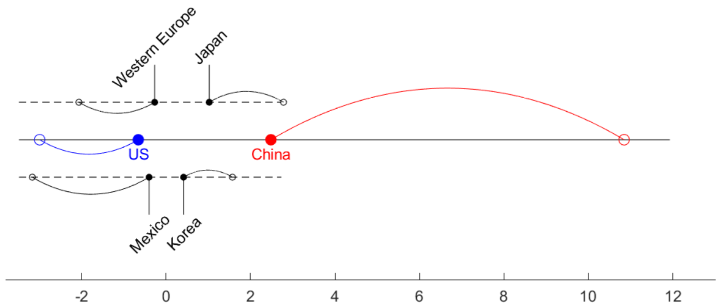
- Aggregating $\psi_{di}^{oj}(\theta)$ across $\theta \Rightarrow$ model counterpart of citation shares Ψ_{di}^{oj}

Calibration

Parameters	Descriptions	Value	Target/Source
A. Externally calibrated			
$\gamma^{ij}, \gamma^{iL}, \rho^{j}$	IO structure and consumption share	-	WIOT; $N = 15, S = 19$
L_d	Labor endowment	-	PWT
$\eta, \zeta - 1$	Trade elasticity	4	Literature
B. Exactly identified			
$\bar{t}$	Params in compatibility cost	0.05	Firm-level Import-citation corr: 0.022
$\bar{\phi}$	Params in adaptation cost	0.005	Country-level citation-tariff elas.: -0.296
$\tau^{j}_{do}, \tau^{Uj}_{do}$	Iceberg trade costs		Bilateral trade shares
C. Nonlinear Least Square			
$\bar{\mu}^{j}_{o}, \bar{\sigma}^{j}$	Dist. of endowment technology	-	Bilateral citation shares

Inferred Distribution of Technology Choice

Figure 1: Mean Technology Positions Ex-ante (circle) v.s Ex-post (dot)



Accounting for Cross-Country Technology Proximity

Table 1: Bilateral Citation Shares: Model v.s Data

	Citation Share in Data		
Citation Share in Model	(1)	(2)	(3)
at Ex-post Tech. Dist.	0.855		
	(0.002)		
with Identical Tech.		0.657	
		(0.003)	
at Ex-ante Tech. Dist.			0.709
			(0.001)
Observations	81,225	81,225	81,225
Adjusted R^2	0.688	0.303	0.377

Note: Each column reports the regression of the citation share in data on model-implied citations. Column (1) uses the calibrated ex-post technology distribution $\{\mu_o^j, \sigma^j\}$. Column (2) restricts to the case where $\mu_o^j = 0$ and $\sigma^j = 0$ for all (o, j). Column (3) restricts the technology distribution to the ex-ante distribution $\{\bar{\mu}_o^j, \bar{\sigma}^j\}$.

Cost due to technology incompatibility

Table 2: Technology Incompatibility Costs as Shares of GDP

Country/Region	Tech Compat. Costs (T)	Tech Compat. Costs (T) for Foreign Inputs
BRA	2.64	0.66
CAN	2.31	0.96
CEU	2.58	1.03
CHN	6.60	2.19
IND	2.75	0.72
IDN	3.17	1.06
JPN	3.04	1.25
KOR	3.23	1.52
MEX	2.96	1.26
OCE	2.11	0.87
ROW	3.08	1.54
RUS	2.20	0.57
TUR	2.60	0.83
USA	2.27	0.67
WEU	2.20	0.55
World	**3.41**	**1.16**

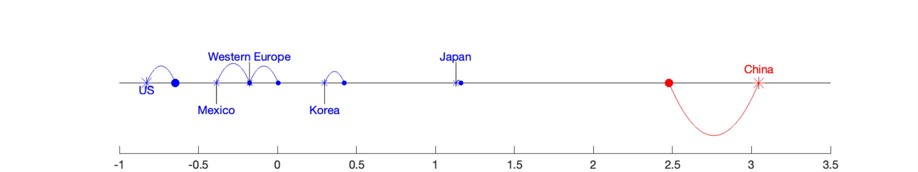
The Technology Decoupling Effect of a Trade Embargo

Embargo: increase cost of exporting to Chinese firms to infinity for industry *Computer, electronic and optical products*

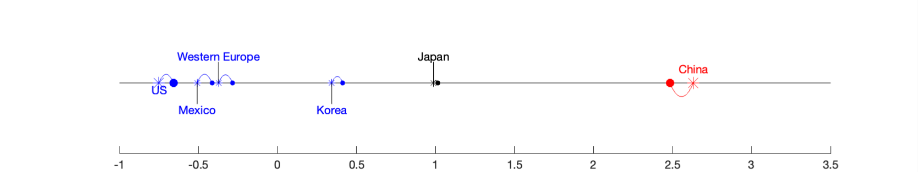
Embargo Origin	Share of imports (%)	Δ Cites from CHN to USA (%)	Endo. Tech. ($\Delta \ln U$ %)		Fixed Tech. ($\Delta \ln U$ %)	
			CHN	USA	CHN	USA
USA Only	2.1	-1.321	-0.016	-0.004	-0.010	-0.002
All but Russia	99.9	-50.516	-0.795	-0.081	-0.419	-0.016

- Technology decoupling amplifies the losses from the embargo
- The U.S. also lose from technology decoupling

Decoupling and Re-alignment



(a) The Average Technology in the Targeted Sector



(b) The Average Technology of Other Sectors

Note: Dots are the ex-post mean in the baseline equilibrium, and stars are the equilibrium with the embargo. Blue indicates countries with distance to the USA relative to China decreased by more than 5%.

Decomposing the Technology Decoupling Effect

Table 3: Technology Decoupling - Mechanism Decomposition

	$\Delta \ln U_{CHN}$ (%)	$\Delta \ln U_{USA}$ (%)
No Response of **Technology**	-0.419	-0.016
+ Response from the targeted Chinese Sector	-0.576	-0.030
+ Response from All Chinese Sectors	-0.692	-0.069
+ Response from All Countries	-0.795	-0.081

Conclusion

- A GE model of trade with technology compatibility between firms and suppliers
- Empirical evidence
  - cross-country: bilateral tariff negatively affects intensity of bilateral citations
  - firm-level: positive correlation between citations and imports from same country
- Countries' trade linkages and choice of technology mutually shape each other
- Endogenous technology response amplifies the welfare loss of a trade conflict

Existence and Uniqueness of Technology Equilibrium

Definition

Given $\{w_d\}$, a technology equilibrium is $\{C_d^i(\theta), \Theta_d^i\}$ that is consistent with firms' technology choice and sourcing decisions. That is, $\{C_d^i(\theta), \Theta_d^i\}$ solve

$$C_d^i(\theta) = \frac{\Xi^i}{A_d^i}[w_d]^{\gamma^{iL}} \prod_j \left(\sum_o \int [C_o^j(\tilde{\theta})\tau_{do}^j]^{-\zeta} [t(\theta, \tilde{\theta})]^{-\zeta} \, \mathrm{d}\Theta_o^j(\tilde{\theta}) \right)^{-\frac{\gamma^{ij}}{\zeta}},$$

$$\Theta_d^i(\theta) = \int_{\bar{\theta} \in T} \mathbb{I}[g_d^i(\bar{\theta}) = \theta] d\bar{\Theta}_d^i(\bar{\theta}),$$

where $g_d^i(\bar{\theta})$ is the policy function for the technology choice

$$g_d^i(\bar{\theta}) \equiv \text{argmax}_\theta \left[1 - \phi(\bar{\theta}, \theta)\right] \mathbb{E}\Pi_o^j(\theta).$$

Existence and Uniqueness of Technology Equilibrium, cont'd

Assumption

- *Costs of technology incompatibility:* $t(\theta, \tilde{\theta}) = \exp(\bar{t}(\theta - \tilde{\theta})^2)$
- *Adaptation costs:* $\phi(\bar{\theta}, \theta) = 1 - \exp(-\bar{\phi}(\bar{\theta} - \theta)^2)$

Proposition

- *Assume* $\{\overline{\Theta}_d^i\}$ *have bounded support that is contained in* $[-M, M]$ *for some* $M > 0$ *and have associated density functions* $\{\overline{\varsigma}_d^i\}$*. If* $\zeta \bar{t} < 1/M^2$*, then there exists an equilibrium with firms' technology choice* $\{g_d^i\}$ *being continuously differentiable functions. This first-order condition has a unique solution.*
- *If, in addition,* $\bar{t} < \frac{1}{2M}$ *and* $\bar{\phi} > \underline{\phi}$*, where* $\underline{\phi} > 0$ *is a constant determined by parameters* $(\zeta, \bar{t}, \lambda, M, \gamma^{iL})$ *as detailed in the proof, then such an equilibrium is unique.*

◂ Back

Firm-level Correlation b/w Tech. Proximity and Trade

Proposition

Suppose firms in (d, i) have an endowment technology of $\bar{\theta}_d^i$ with probability 1 but a zero-measure of set of firms in (d, i), denoted by ν, have an endowment of $\bar{\theta}(\nu)$. Then in response to a change in $\bar{\theta}(\nu)$ that reduces $\|\bar{\theta}(\nu) - \theta_o^j\|$,

- *Firm ν moves closer to θ_o^j, namely $\|\theta_d^i(\nu) - \theta_o^j\|$ decreases*
- *Firm ν is more likely to purchase from (o, j)*
- $\Delta \log \left(\chi_{do}^{ij}(\nu)/\chi_{dd}^{ii}(\nu)\right) = -\zeta\bar{t} \cdot \Delta\|\theta_d^i(\nu) - \theta_o^j\|$

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Bilateral Technology Distances Increase in Trade Costs

Proposition

Consider a country-sector (d, i) that is small in the sense that its input and output account for a negligible share of all countries and sectors, including sectors in country d. Then after an x % increase in the cost of (d, i) importing from (o, j):

- *The distance between θ_d^i and θ_o^j change by:*

$$\Delta\|\theta_d^i - \theta_o^j\| = -\frac{\zeta\omega^i\gamma^{ij}\bar{\chi}_{do}^{ij}\|\theta_o^j - \vartheta_d^{ij}\|}{1 + t\zeta\omega^i\sum_{j',o'}\gamma^{ij'}\bar{\chi}_{do'}^{ij'}\|\theta_{o'}^{j'} - \vartheta_d^{ij'}\|} \times \frac{\theta_d^i - \theta_o^j}{\theta_o^j - \vartheta_d^{ij}} \times x,$$

  where $\vartheta_d^{ij} \equiv \sum_m \bar{\chi}_{dm}^{ij}\theta_m^j$ is the average location of the suppliers of (d, i) that is in sector j. Back

- $\|\theta_d^i - \theta_o^j\|$ *increases relative to the expenditure-share weighted distance between θ_d^i and $\theta_{o'}^j$, across $o' = 1, ..., N$. More precisely,*

$$\Delta\|\theta_d^i - \theta_o^j\| - \sum_{o'}\bar{\chi}_{do'}^{ij}\Delta\|\theta_d^i - \theta_{o'}^j\| = \frac{\zeta\omega^i\gamma^{ij}\bar{\chi}_{do}^{ij}\|\theta_o^j - \vartheta_d^{ij}\|}{1 + t\zeta\omega^i\sum_{j',o'}\gamma^{ij'}\bar{\chi}_{do'}^{ij'}\|\theta_{o'}^{j'} - \vartheta_d^{ij'}\|} \times x > 0$$

Externality from Production Linkages in a Closed Economy

Proposition

Consider a closed economy with multiple sectors and each sector with an ex-ante endowment location $\bar{\theta}^i, i = 1, .., N$.

- *The marginal impact of increasing θ^i on the social welfare, $\frac{\Delta \ln(U)}{\Delta \theta^i}$, is given by*

$$\alpha_i \Big[\underbrace{\frac{\exp\big(-\frac{1}{2}\phi(\theta^i - \bar{\theta}^i)^2\big)}{\eta - \sum_i \alpha_i \exp\big(-\frac{1}{2}\phi(\theta^i - \bar{\theta}^i)^2\big)} \phi(\bar{\theta}^i - \theta^i)}_{\text{income effect}} - \underbrace{t \sum_j \tilde{\gamma}^{ij}(\theta^i - \theta^j)}_{\text{sector-i price}} \Big] - \underbrace{t \sum_{j \neq i} \alpha_j \tilde{\gamma}^{ji}(\theta^i - \theta^j)}_{\text{other sector prices}},$$

  where the three terms capture the income effect, the price effect in sector i, and the price effect in all other sectors; $\tilde{\gamma}^{ij}$ is the general equilibrium impact of sector j price on sector i price, defined as $\tilde{\gamma}^{ij} \equiv \sum_m \Omega^{im}\gamma^{mj}$, where Ω^{im} is the (i, m)-th element of $(\mathbb{I}_{NS \times NS} - \Gamma)^{-1}$.

- *If sectors have the same weights in the final consumption and symmetric input-output structure, i.e., for all $i \neq j \neq j'$, $\alpha_i = \alpha_j$, $\gamma^{ii} = \gamma^{jj}$ and $\gamma^{ij} = \gamma^{ij'} = \gamma^{jj'}$, then the equilibrium $||\theta^i - \bar{\theta}^i||$ is too small compared to social optimum. In other words, firms under-invest in technological adaption.*

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Cross-country Spillover of Technology Choice

Proposition

Consider an open economy with one sector with roundabout production and two symmetric countries, country 1 *and* 2*. Assume WOLG that in equilibrium,* $\theta_2 < \theta_1$*. Then the effect of a move of country* 2*'s technology towards country* 1 *from the equilibrium on welfare is:*

$$\frac{\Delta \ln U_2}{\Delta \theta_2} = \frac{\frac{1}{\eta}\exp(-\frac{1}{2}\phi(\theta_2 - \bar{\theta}_2)^2)}{1 - \frac{1}{\eta}\exp(-\frac{1}{2}\phi(\theta_2 - \bar{\theta}_2)^2)}\phi(\bar{\theta}_2 - \theta_2) + t\frac{1-\gamma^L}{\gamma^L}\bar{\chi}_{12}(\theta_1 - \theta_2) > 0$$

$$\frac{\Delta \ln U_1}{\Delta \theta_2} = t\frac{1-\gamma^L}{\gamma^L}\bar{\chi}_{12}(\theta_1 - \theta_2) > 0$$

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