Trade Model with Endogenous Technology Choice

International Trade (PhD), Fall 2024

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Overview of Lecture

- This lecture reviews a multi-industry trade model with endogenous technology choice.
  - there are multiple production technologies
  - firms sort into technologies depending on productivity profile
- Main implications
  - trade integration can encourage the adoption of more productive technologies $\longrightarrow$ larger efficiency gains
  - trade can mitigate distorted technology choices (e.g., there is too little adoption of modern technologies in low-income countries due to inefficient barriers)
- Main References:
  - technology choice in efficient economies: Farrokhi and Pellegrina (2023, JPE)
  - technology choice in distorted economies: Farrokhi, Lashkaripour, Pellegrina (2024, JIE)

Environment

- $n,\ i = 1, ..., N$ countries
- $k = 1, ..., K$ industries
- $t = 1, ..., T$ different types of technology within each industry:
  - technologies differ in their general productivity and factor intensity
- Each industry is populated by a constant measure of managers that sort into technology types and employ their managerial capital and other inputs for production.

Birdseye View of Model

Demand and Supply of Final Goods

- Governed by a multi-industry gravity model, à la Eaton-Kortum or equivalently Armington.

Key Departures from the Standard Multi-Industry Model

- Workers have heterogeneous abilities.
- Different industries within a country offer varying wages.
- Workers sort into industries to maximize their *productivity* $\times$ *wage*, following the Roy model.

Demand and Preferences

- Cobb-Douglas utility aggregator across industries:

$$U_i\left(\mathbf{C}_i\right) = \prod_k \left(\frac{C_{i,k}}{\beta_{i,k}}\right)^{\beta_{i,k}}$$

  implying a constant share $\beta_{i,k}$ of expenditure on industry k goods.

- CES utility aggregator across goods sourced from various industries:

$$C_{i,k} = \left(\sum_n b_{n,k}^{\frac{1}{\sigma_k}} C_{ni,k}^{\frac{\sigma_k - 1}{\sigma_k}}\right)^{\frac{\sigma_k}{\sigma_k - 1}}$$

  - goods are internationally differentiated but homogeneous within countries, irrespective of which technology they are developed with.

Demand and Preferences

- Let $p_{i,k}$ denote the competitive price of goods supplied by firms in country i within industry k.
- The price of these goods sold to destination n after applying the iceberg cost is

$$P_{in,k} = \tau_{in,k} p_{i,k}$$

- Utility maximization s.t. the budget constraint ($\sum_i \sum_k P_{in,k} C_{in,k} = E_n$) implies that country n's expenditure share on country i goods in industry k is

$$\lambda_{in,k}\left(p\right) = \frac{b_{i,k}\left(\tau_{in,k} p_{n,k}\right)^{1-\sigma_k}}{\sum_\ell b_{\ell,k}\left(\tau_{\ell n,k} p_{\ell,k}\right)^{1-\sigma_k}}$$

  - $p \equiv \{p_{n,k}\}_n$ is a vector containing international prices in industry k.
- Total demand for goods originating from country i in industry k:

$$Q_{i,k}^D\left(p\right) \sim \sum_n d_{in,k} C_{in,k} = \frac{1}{p_{i,k}} \sum_n \lambda_{in,k}\left(p\right) \beta_{n,k} E_n$$

Production and Supply

- Each firm ω chooses a technology $t \in \mathbb{T}$.

- The technology choice determines the production function:

$$Q_{i,kt}(\omega) = A_{i,kt} \left(\underbrace{Z_{i,kt}(\omega)}_{\substack{\text{managerial} \\ \text{productivity}}} \underbrace{\frac{H_{i,kt}(\omega)}{\gamma_{kt}}}_{\substack{\text{managerial} \\ \text{capital}}} \right)^{\gamma_{kt}} \left(\underbrace{\frac{L_{i,kt}(\omega)}{1-\gamma_{kt}}}_{\text{labor}} \right)^{1-\gamma_{kt}}$$

- Technologies differ in their general TFP (A) and input intensity (γ)

- Analogous to span-of-control (Lucas, 1978) $\Rightarrow$ Share of profits is γ_{kt}

Technology Choices

- Returns to managerial profit per cost minimization:

$$r_{i,kt}(\omega) = \underbrace{Z_{i,kt}(\omega)}_{\substack{\text{managerial}\\ \text{productivity}}} \times \underbrace{a_{i,kt}\, p_{i,k}^{\frac{1}{\gamma_{kt}}}\, w_i^{\frac{\gamma_{kt}-1}{\gamma_{kt}}}}_{\text{productivity \& prices}}$$

  - $h_{i,kt} \equiv a_{i,kt}\, p_{i,k}^{\frac{1}{\gamma_{kt}}}\, w_i^{\frac{\gamma_{kt}-1}{\gamma_{kt}}}$ is common across firms but Z is manager of firms-specific
  - $a_{i,kt} \equiv (A_{i,kt})^{1/\gamma_{kt}}$ and w_i denotes wages (or the price of labor inputs)

- Every firm ω chooses the technology that maximizes the managerial profit

$$\max\left\{r_{i,kt}(\omega), \quad \text{for } t \in \mathbb{T}\right\}$$

Technology Choices

- Assume $Z_{i,kt}(\omega)$ is drawn from a Fréchet distribution with level parameter
    - Every firm chooses 1 technology
    - Integrate over the continuum of firms to recover the share
- The share of firms choosing technology t is

$$\alpha_{i,kt} = \left(\frac{a_{i,kt} \left(p_{i,k} / w_i \right)^{\frac{1}{\gamma_{kt}}}}{H_{i,k}} \right)^{\theta}, \quad \text{with} \quad H_{i,k} \equiv \left[\sum_{t' \in \mathbb{T}} \left(a_{i,kt'} \left(p_{i,k} / w_i \right)^{\frac{1}{\gamma_{kt'}}} \right)^{\theta} \right]^{1/\theta}$$

Production and Supply: Industry Aggregates

- Managerial profits constitute a fraction γ_{kt} of total sales $\longrightarrow$ total sales are

$$Y_{i,kt} = \frac{1}{\gamma_{kt}} \times \alpha_{i,kt} \times \mid \Omega_{i,k} \mid \times \mathbb{E}\left[Z_{i,kt}\left(\omega\right) \mid \omega \in \Omega_{i,kt}\right] \times a_{i,kt}\, p_{i,k}^{\frac{1}{\gamma_{kt}}}\, w_i^{\frac{\gamma_{kt}-1}{\gamma_{kt}}}$$

  - where $\mid \Omega_{i,k} \mid = 1$ is the measure of firms normalized to one and the average productivity of firms choosing technology t is

$$\mathbb{E}\left[Z_{i,kt}\left(\omega\right) \mid \omega \in \Omega_{ik,t}\right] = \alpha_{i,kt}^{-\frac{1}{\theta}}$$

- Industry-wide supply is the sum of technology-level supply functions, $Q_{i,kt} = Y_{i,kt} / p_{i,k}$:

$$Q^S_{i,k}\left(p_{i,k}\right) = \sum_t \frac{Y_{i,kt}}{p_{i,k}} = \sum_t \frac{a_{i,kt}}{\gamma_{kt}} \left(\frac{p_{i,k}}{w_i}\right)^{\frac{1-\gamma_{kt}}{\gamma_{kt}}} \alpha_{i,kt}\left(p_{i,k}\right)^{\frac{\theta-1}{\theta}},$$

  - the supply elasticity is $\frac{\partial \ln Q^S_{i,k}(p,w)}{\partial \ln p_{i,k}} = \sum_t y_{i,kt}\left[\frac{1-\gamma_{kt}}{\gamma_{kt}} + (\theta-1)\left(\frac{1}{\gamma_{kt}} - \sum_{t'} \frac{\alpha_{i,kt'}}{\gamma_{kt'}}\right)\right]$, where $y_{i,kt} \equiv Y_{i,kt} / Y_{i,k}$ is the share of etechnology t in total output.

General Equilibrium

For a set of parameters, equilibrium is a vector a wages $w \equiv \{w_i\}$ & prices $p \equiv \{p_{i,k}\}$ such that

- the *labor market clearing* condition is satisfied in each country:

$$w_i L_i = \sum_{k=1}^{K} \sum_{t \in \mathbb{T}} (1 - \gamma_{kt}) \, Y_{i,kt} \, (p, w) \, .$$

- *the goods* market clearing condition is satisfied ($Q^S = Q^D$)

$$\underbrace{Y_{i,k} \sim \sum_{t=1}^{T} Y_{i,kt} \, (p, w)}_{p_{i,k} Q^S_{i,k}} = \underbrace{\sum_{n=1}^{N} \lambda_{in,k} \, (p) \, \beta_{n,k} E_n}_{p_{i,k} Q^D_{i,k}} \qquad \text{with} \qquad E_n = \sum_t \sum_k Y_{i,kt} \, (p, w)$$

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$$Y_{i,k} \sim \sum_{t=1}^{T} Y_{i,kt}(p, w) = \sum_{n=1}^{N} \lambda_{in,k}(p) \beta_{n,k} E_n \qquad \text{with} \qquad E_n = \sum_t \sum_k Y_{i,kt}(p, w)$$

- where:

$$Y_{i,kt}(p, w) = \frac{a_{i,kt}}{\gamma_{kt}} \times \alpha_{i,kt}(p, w)^{\frac{\theta-1}{\theta}} \times p_{i,k}^{\frac{1}{\gamma_{kt}}} w_i^{\frac{\gamma_{kt}-1}{\gamma_{kt}}}$$

$$\alpha_{i,kt}(p, w) = \frac{\left(a_{i,kt}(p_{i,k}/w_i)^{\frac{1}{\gamma_{kt}}}\right)^{\theta}}{\sum_{t' \in \mathbb{T}} \left(a_{i,kt'}(p_{i,k}/w_i)^{\frac{1}{\gamma_{kt'}}}\right)^{\theta}} \qquad \lambda_{in,k}(p) = \frac{b_{i,k}(\tau_{in,k} p_{i,k})^{1-\sigma_k}}{\sum_\ell b_{\ell,k}(\tau_{\ell n,k} p_{\ell,k})^{1-\sigma_k}}$$

Performing Counterfactuals using Exact Hat-Algebra

- The welfare change in response to an arbitrary trade cost shock $\{\hat{\tau}_{in,k}\}_{i,n}$:

$$\hat{W}_i = \frac{\hat{E}_i}{\hat{P}_i} \qquad with \qquad \hat{P}_i = \prod_{k=1}^{K} \left[\sum_{n=1}^{N} \lambda_{ni,k} \left(\hat{\tau}_{ni,k} \hat{p}_{n,k} \right)^{1-\sigma_k} \right]^{\frac{\beta_{i,k}}{1-\sigma_k}}$$

- $\hat{E}_i$ and $\hat{p}_{n,k}$ can be calculated given baseline data $\{\alpha_{i,kt}, \lambda_{in,k}, \beta_{i,k}, \gamma_{i,kt}, E_i\}$ via the following system of equations ($Y_{n,kt} = \frac{\alpha_{n,kt}/\gamma_{kt}}{\sum_{t'} \alpha_{n,kt'}/\gamma_{kt'}} Y_{n,k}$, with $Y_{n,k} = \sum \lambda_{ni,k} \beta_{i,k} E_i$):

$$\hat{w}_i w_i L_i = \sum_{k=1}^{K} \sum_{t=1}^{T} \left(1 - \gamma_{kt}\right) Y_{i,kt} \hat{Y}_{i,kt} \qquad \hat{Y}_{i,kt} = \hat{\alpha}_{i,kt}^{\frac{\theta-1}{\theta}} \hat{p}_{i,k}^{\frac{1}{\gamma_{kt}}} \hat{w}_i^{\frac{\gamma_{kt}-1}{\gamma_{kt}}}$$

$$\sum_{t=1}^{T} Y_{i,kt} \hat{Y}_{i,kt} = \sum_{n=1}^{N} \lambda_{in,k} \hat{\lambda}_{in,k} \beta_{n,k} E_n \hat{E}_n, \qquad E_n \hat{E}_n = \sum_{k} \sum_{t} Y_{n,kt} \hat{Y}_{n,kt}$$

$$\hat{\lambda}_{in,k} = \frac{\left(\hat{\tau}_{in,k} \hat{p}_{i,k}\right)^{1-\sigma_k}}{\sum_{\ell} \left(\hat{\tau}_{\ell n,k} \hat{p}_{\ell,k}\right)^{1-\sigma_k}} \qquad \hat{\alpha}_{i,kt} = \frac{\left(\hat{p}_{i,k}/\hat{w}_i\right)^{\frac{\theta}{\gamma_{kt}}}}{\sum_{t'} \alpha_{i,kt'} \left(\hat{p}_{i,k}/\hat{w}_i\right)^{\frac{\theta}{\gamma_{kt'}}}}$$

Application: Compiling Data on Technology Shares

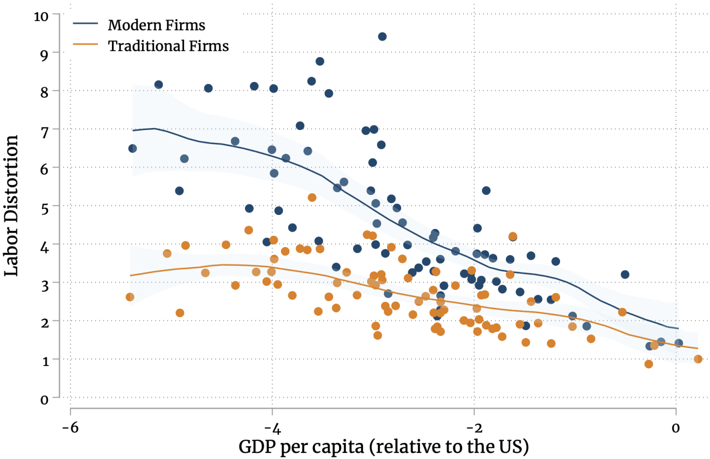
- Counterfactual simulations requires data on the share α of firms using various technologies.
  - technologies are characterized by two parameters: productivity (A) and factor intensity (γ)
  - (A, γ) is unobserved $\longrightarrow$ technology type must be *indirectly* inferred from production/input data.

Example (Farrokhi, Lashkaripour, Pellegrina, 2024)

- Use K-mean clustering to partition firms into two technology groups:
  1. traditional technology (low-productivity, labor intensive)
  2. modern technology (high-productivity, intensive use of traded intermediate inputs)
- The partitioning automatically determines the share α of each technology type
- Technology-specific parameters (γ and A) can be estimated by running a standard production function estimation on each partion of firms.

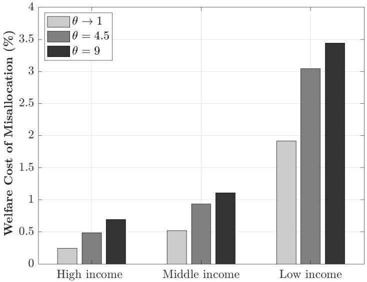
Application: *Farrokhi, Lashkaripour, Pellegrina* (2024, JIE)

Key Regularity: Modern firms face more severe labor input distortions than traditional firms, with this disparity being more pronounced in low-income countries.



Counterfactual Analysis I: Welfare Cost of Misallocation

- Labor market wedges create misallocation through:
  - Reduced adoption of modern technologies across firms (extensive margin)
  - Suboptimal resource allocation to modern firms (intensive margin)
- FLP quantify the welfare costs by simulating removal of labor input wedges across countries



- More misallocation in low-income countries due to larger gap in modern/traditional wedges
- misallocation magnifies when firms have higher technology choice flexibility (higher θ)

Counterfactual Analysis II: Impacts of Trade Integration

Aggregate Welfare Effects

- Compute and decompose the welfare gains from trade under two scenarios
    1. gains from trade relative to autarky (*ex-post*)
    2. gains from piecemeal trade liberalization (*ex-ante*)
- This exercise reveals if trade integration has improved or worsened misallocation

Labor Market Effects

- Compute the counterfactual effects of trade liberalization on *Aggregate Labor Productivity*
- This analysis can shed light on Africa's Manufacturing Puzzle (Diao et al-2021)
    - Despite overall economic growth driven by trade openness, manufacturing labor productivity remains stagnant across many Sub-Saharan African nations

Welfare Gains from Trade: Results

- Gains from Trade relative to Autarky (Ex-post)

	High income	Middle income	Low income
ACR	19.3%	18.0%	16.4%
New Model	21.3%	20.0%	19.2%

- The ACR gains describe welfare effects in a hypothetical misallocation-free economy
- Why does the new model imply larger gains:
  - trade expands access to traded intermediate inputs $\longrightarrow$ increased adoption of modern technologies and reallocation towards modern firms that are intermediate-input-intensive $\longrightarrow$ improvement in allocative efficiency
  - Dix Carneiro, Goldberg, Meghir, Ulyssea (2024) highlight a similar mechasim, but in the conext of trade reducing the prevelance of *informality*

Welfare Gains from Trade: Results

- Piecemeal Trade Liberalization (Ex-ante)

	ACR	Allocative Efficiency	Residual Effects
High income	90.3%	3.0%	6.7%
Middle income	86.6%	5.0%	8.4%
Low income	81.2%	9.2%	9.6%

- The logic for allocative efficiency gains is similar to what was described in the previous slide.
- These results hint that input trade liberalization can be a potentially successful form of *industrial policy* for lower income countries.
  - input tariff liberalization (*e.g.*, tariff exemptions, duty drawback) was an integral part of Taiwan and South Korea's export-oriented industrial policy

Structural DiD Design for Evaluating Labor Market Effects

- The goal is to quantify the effects of trade liberalization (a 20% reduction in trade costs) under the existing labor market distortions, and compare these effects to those in a hypothetical economy without such distortions:

$$\left(\text{With Distortions} : E_0 \rightarrow E_1\right) \quad \text{versus} \quad \left(\text{Without Distortions} : E_0' \rightarrow E_1'\right)$$

		Trade Barriers	
		High	Low
Labor	High	E_0	E_1
Wedges	Low	E_0'	E_1'

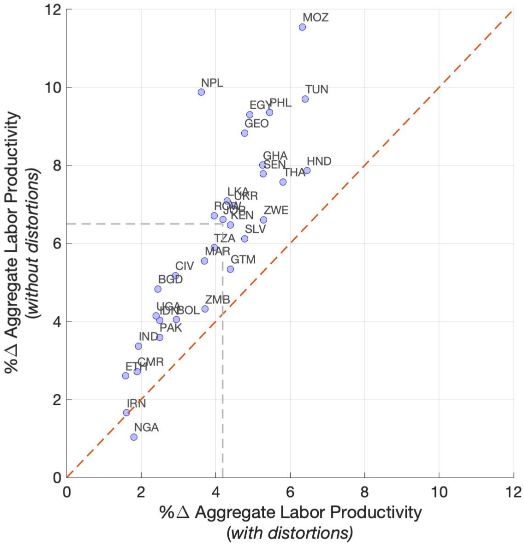
  - E_0 represents the status quo (high trade barriers and labor wedges)
  - E_1, E_0', and E_1' represent counterfactual scenarios
  - Structural *difference-in-differences*: compare $E_0 \rightarrow E_1$ with $E_0' \rightarrow E_1'$

Results: Effects of Trade Liberalization

	Trade Liberalization	
	With Distortions ($E_0 \to E_1$)	Without Distortions ($E'_0 \to E'_1$)
(a) Agg. Labor Productivity	**4.2%**	**6.5%**
(b) Real Wages	7.9%	11.3%
(c) VA per worker in Mfg	8.1%	10.6%
(d) Share of Mfg. Modern Firms	18.4%	5.4%
(e) Mfg. Employment	1.6%	-3.4%
(f) Avg. Mfg. Labor Intensity	-2.2%	-1.1%
(g) Avg. Mfg. Intrm. Input Intensity	7.5%	3.1%

- Trade liberalization spurs technological growth by encouraging modern technology adoption
- But labor market distortions dilute the link between technological growth and labor productivity

Effects of Trade Liberalization on Aggregate Labor Productivity



- Trade increases output per worker
- **Mechansim:** trade improves access to imported intermediate inputs $\rightarrow$ directs resources toward modern technologies that are intermediate input-intensive
- However, in distorted economies, the resulting productivity gains are compromised because modern technologies are disproportionately affected by labor market distortions
- Consequently, these distortions erode 1/3 of the labor productivity gains in low-income countries