14.581 International Macroeconomics — Lecture 17: Fragmentation (Theory) —

Today's Plan

1. Trade in Tasks
2. Sequential Production
3. Multinational Production

Fragmentation of production

Do we really need new theories?

- In the previous lecture, we have discussed how to measure fragmentation using global input-output tables
- **Question:**
  Is "fragmentation" just a fancy name for "trade in intermediate goods"? Can we just relabel final goods as intermediates and recycle existing trade models?
- **Some answer(s):**
  1. It is about trade in intermediate goods, but new models emphasize differences in trade costs across goods (e.g. how routine a particular "task" may be), which previous models abstract from
  2. Sequential nature of production may also introduce new considerations (e.g. the magnification of trade costs that we saw in Yi 2003 and Yi 2010)
  3. It is *not just* about trade in intermediate goods, since "fragmentation" also usually includes a transfer of technology from one country to another (since same firm may be active in multiple countries)
- In the rest of this class we'll discuss a number of neoclassical models aimed to shed light on these new considerations

1. Trade in Tasks

- As in Heckscher-Ohlin model:
  - There are two countries, Home and Foreign
  - There are 2 tradeable goods, $i = 1, 2$
  - There are two factors of production, L and H
- In contrast with Heckscher-Ohlin model:
  - Production process involves a large number of *tasks* $j \in [0, 1]$
- Tasks are of two types:
  - L-tasks which require 1 units of low-skilled labor
  - H-tasks which require 1 units high-skilled labor

Grossman and Rossi-Hansberg (2008)

Offshoring Costs

- Tasks vary in their offshoring costs
  - because some tasks are easier to codify
  - because some services must be delivered personally, while others can be performed at a distance with little loss in quality
- To capture this idea, GRH assume that:
  - H-tasks cannot be offshored
  - L-tasks can be offshored, but amount of low-skilled labor necessary to perform task j abroad is given by $\beta t(j) > 1$
- Under this assumption,
  - β reflects overall feasibility of offshoring at a point in time (e.g. communication technology)
  - $t(j)$ is an increasing function which captures differences in offshoring costs across tasks (e.g. cleaning room vs. call center)

- Suppose that wages for low-skilled labor are higher at Home

$$w_L > w_L^*$$

- Benefit of offshoring$\equiv$ lower wages abroad
- Cost of offshoring$\equiv$ loss in productivity captured by $\beta t(j)$
- In a competitive equilibrium, firm will offshore tasks if and only if:

$$\beta t(j) w_L^* < w_L$$

- Let $J \in [0, 1]$ denote the marginal task that is being offshored

$$\beta t(J) w_L^* = w_L \tag{1}$$

Grossman and Rossi-Hansberg (2008)

Offshoring as Factor Augmenting Technological Change

- The cost of producing one unit of some good is given by

$$c_i = a_{Li}\left[w_L(1-J) + w_L^* \beta T(J)\right] + a_{Hi} w_H \tag{2}$$

  with $T(J) \equiv \int_0^J t(j)dj$, $w_H \equiv$ wage of high-skilled workers at Home
- Substituting (1) into (2), we obtain

$$c_i = a_{Li} w_L \Omega + a_{Hi} w_H$$

  where $\Omega = (1-J) + \frac{T(J)}{t(J)} < 1$
- This looks just like the cost equation of a firm that employs low-skilled workers whose productivity is (inversely) measured by Ω
  - Hence, offshoring is economically equivalent to labor-augmenting technological progress

- **Proposition** *If Home is a small open economy that produces both goods, a decrease in β increases w_L*
- **Proof:**
  1. Zero profit requires:

$$p_i = a_{Li} w_L \Omega + a_{Hi} w_H, \; i = 1, 2$$

  2. Since Home a small open economy, p_i does not depend on β
  3. This implies that $w_L \Omega$ (and w_H) do not depend on β either
  4. Since Ω is decreasing in β, we get w_L increasing in β

- **Productivity effect** implies that workers whose jobs are being offshored benefit from decrease in offshoring costs
- In general, a decrease in offshoring costs would also have:
  1. **Relative-price effect**. If country is not small compared to the rest of the world, changes in β will also affect p_2/p_1
  2. **Labor-supply effect**. If there are more factors than produced goods, changes in β will also affect $w_L\Omega$ and w_H at constant prices
- Simplest way to illustrate labor-supply effect is to consider case where Home is completely specialized in one good
  - this is the effect that has received the most attention in popular discussions
  - empirically, is it more or less important than the other two?

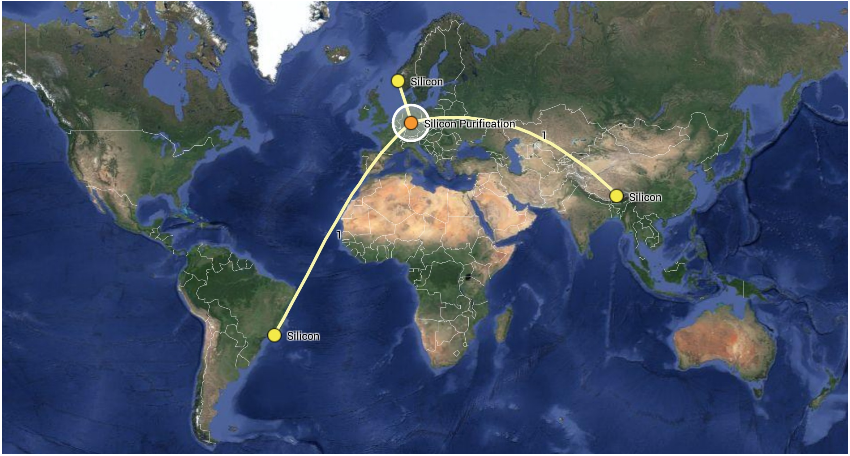
2. Sequential Production

An Example of Sequential Production

Global Semiconductor Industry

An Example of Sequential Production

Global Semiconductor Industry



An Example of Sequential Production

Global Semiconductor Industry

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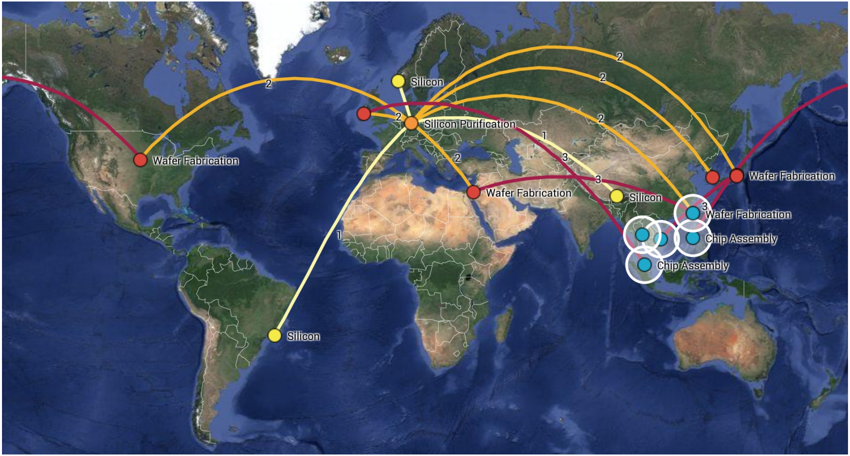

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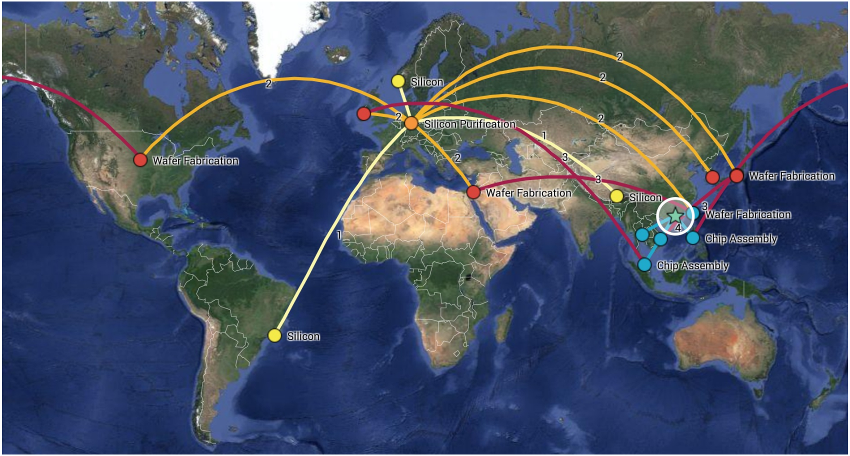

Costinot, Vogel, and Wang (2013)

An elementary theory of global supply chains

- A simple trade model with sequential production:
  - Multiple countries, one factor of production (labor), and one final good
  - Production of final good requires a continuum of intermediate stages
  - Each stage uses labor and intermediate good from previous stage
  - Production is subject to mistakes (Sobel 1992, Kremer 1993)
- Key simplifications:
  - Intermediate goods only differ in the order in which they are performed
  - Countries only differ in terms of failure rate
  - All goods are freely traded

Costinot, Vogel, and Wang (2013)

Basic Environment

- Consider a world economy with multiple countries $c \in \mathcal{C} \equiv \{1, ..., C\}$
- There is one factor of production, labor:
  - Labor is inelastically supplied and immobile across countries
  - L_c and w_c denote the endowment of labor and wage in country c
- There is one final good:
  - To produce the final good, a continuum of stages $s \in \mathcal{S} \equiv (0, S]$ must be performed (more on that on the next slide)
- All markets are perfectly competitive and all goods are freely traded
  - We use the final good as our numeraire

- At each stage, producing 1 unit of intermediate good requires a fixed amount of previous intermediate good and a fixed amount of labor
  - "Intermediate good 0" is in infinite supply and has zero price
  - "Intermediate good S" corresponds to final good mentioned before
- Mistakes occur at a constant Poisson rate, $\lambda_c > 0$
  - λ_c measures total factor productivity (TFP) at each stage
  - Countries are ordered such that λ_c is strictly decreasing in c
- When a mistake occurs, intermediate good is entirely lost
- Formally, if a firm combines $q(s)$ units of intermediate good s with $q(s)ds$ units of labor, the output of intermediate good $s + ds$ is

$$q\left(s+ds\right) = \left(1 - \lambda_c ds\right) q\left(s\right)$$

Costinot, Vogel, and Wang (2013)

Free trade equilibrium

- In spite of arbitrary number of countries, unique free trade equilibrium is characterized by simple system of first-order difference equations
- This system can be solved recursively by:
  1. Determining assignment of countries to stages of production
  2. Computing prices sustaining that allocation as an equilibrium outcome
- Free trade equilibrium always exhibits vertical specialization:
  1. More productive countries, which are less likely to make mistakes, specialize in later stages of production, where mistakes are more costly
  2. Because of sequential production, *absolute productivity differences* are a source of *comparative advantage* between nations
- Cross-sectional predictions are consistent with:
  1. "Linder" stylized facts
  2. Variations in value added to gross exports ratio (Johnson Noguera 12)

Costinot, Vogel, and Wang (2013)

Comparative statics

- Comprehensive exploration of how technological change, either *global* or *local*, affects different participants of a global supply chain
- Among other things, we show that:
  1. Standardization—uniform decrease in failure rates around the world—can cause welfare loss in rich countries: a strong form of immiserizing growth
  2. Spillover effects are different at the bottom and the top of the chain: monotonic effects at the bottom, but not at the top
- **Broad message:** *Important to model sequential nature of production to understand consequences of technological change in developing and developed countries on trading partners worldwide*

Antràs and de Gortari (2017)

Adding General Geography of Trade Costs

- Consider optimal location of production for the different stages in a sequential GVC
- Without trade frictions $\approx$ standard multi-country sourcing model
- With trade frictions, matters become trickier
- Location of a stage takes into account upstream and downstream locations
  - Where is the good coming from? Where is it going to?
  - Need to solve jointly for the optimal path of production

Antràs and de Gortari (2017)

A Multi-Stage Ricardian Model

- Framework will accommodate:
  - Ricardian differences in technology across stages and countries
  - A continuum of final goods
  - Multiple GVCs producing each of these final goods
  - An arbitrary number of countries J and stages N
- Model will **not** predict the path of each specific GVC. Instead:
  - Characterize the relative prevalence of different possible GVC
  - Study average positioning of countries in GVCs
    - Intuitively, countries facing higher trading frictions should tend operate more upstream, where gross output losses associated with those tend to be lower
    - Related to Sobel/Kremer/CVW's channel
  - Trace implications for the world distribution of income

Antràs and de Gortari (2017)

Formal Environment

- Preferences are

$$u\left(\left\{y_i^N(z)\right\}_{z=0}^1\right) = \left(\int_0^1 \left(y_i^N(z)\right)^{(\sigma-1)/\sigma} dz\right)^{\sigma/(\sigma-1)}, \quad \sigma > 1$$

- Technology features CRS and Ricardian technological differences

$$p_j^F(\boldsymbol{\ell}) = \tau_{\ell(N)j} \times \prod_{n=1}^{N-1} \left(\tau_{\ell(n)\ell(n+1)}\right)^{\beta_n} \times \prod_{n=1}^{N} \left(a_{\ell(n)}^n c_{\ell(n)}\right)^{\alpha_n \beta_n}$$

with $\alpha_n =$ share of composite input at stage n and $\beta_n = \prod_{m=n+1}^{N} (1-\alpha_m)$

- Composite input = labor and CES aggregator in $u(\cdot)$
  - $c_i = (w_i)^{\gamma_i} (P_i)^{1-\gamma_i}$, where P_i is the ideal consumer price index

Antràs and de Gortari (2017)

Probabilistic Representation of Technology

- In Eaton and Kortum (2002) with $N = 1$, they assume $1/a^j(z)$ is drawn for each good z independently from the Fréchet distribution

$$\Pr(a_n^j(z) \geq a) = e^{-T_j a^\theta}, \text{ with } T_j > 0$$

- **Problem:** The distribution of the product of Fréchet random variables is **not** distributed Fréchet
  - The same would be true with fixed proportions (sum of Fréchets)
- How can one recover EK's magic in a multi-stage setting?

1. If a production chain follows the path $\{\ell(1), \ell(2), ..., \ell(N)\}$, then

$$\Pr\left(\prod_{n=1}^{N}\left(a^{n}_{\ell j(n)}\right)^{\alpha_n\beta_n} \geq a\right) = \exp\left\{-a^{\theta}\prod_{n=1}^{N}\left(T_{\ell(n)}\right)^{\alpha_n\beta_n}\right\}$$

   - Randomness can be interpreted as uncertainty on compatibility

2. Decentralized equilibrium in which stage-specific producers do not observe realized prices before committing to sourcing decisions

   - Firms observe the productivity levels of their potential direct (or tier-one) suppliers
   - But not of their tier-two, tier-three, etc. suppliers

- Likelihood of a particular GVC ending in j is

$$\pi_{\ell^j} = \frac{\left(\tau_{\ell^j(N)j}\right)^{-\theta} \times \prod_{n=1}^{N-1} \left(\tau_{\ell^j(n)\ell^j(n+1)}\right)^{-\theta\beta_n} \times \prod_{n=1}^{N} \left(\left(c_{\ell^j(n)}\right)^{-\theta} T_{\ell^j(n)}\right)^{\alpha_n\beta_n}}{\Theta_j}$$

  where Θ_j is the sum of the numerator over all possible paths

- Notice that trade costs again matter more downstream than upstream

- Can compute final-good trade shares and intermediate input shares as explicit functions of T_j's, c_j's, and τ_{ij}'s (conditional probabilities)

- Can also express labor market clearing as a function of transformations of these probabilities

- Consider a 'purely-domestic' value chain that performs all stages in a given country j to serve consumers in the same country j
- Such value chain captures a share of country j's spending equal to

$$\pi_{j^N} = \Pr(j, j, ..., j) = \frac{(\tau_{jj})^{-\theta\left(1+\sum_{n=1}^{N-1}\beta_n\right)} \times (c_j)^{-\theta}\, T_j}{\Theta_j}$$

- We can then show

$$\frac{w_j}{P_j} = \left(\kappa\,(\tau_{jj})^{1+\sum_{n=1}^{N-1}\beta_n}\right)^{-1/\gamma_j}\left(\frac{T_j}{\pi_{j^N}}\right)^{1/\left(\theta\gamma_j\right)}$$

- Under autarky $\pi_{j^N} = 1$, so the (percentage) real income gains from trade, relative to autarky, are given by

$$\left(\pi_{j^N}\right)^{-1/\left(\theta\gamma_j\right)} - 1$$

Antràs and de Gortari (2017)

Calibration to World-Input Output Database

- Map multi-country Ricardian framework to world Input-Output Tables
- World Input Output Database: Released in 2016
- 43 countries (86% of world GDP) + ROW
- Yearly: 2000-2014 (use 2014 data)
- Provides information on input and final output flows across countries

		Input use & value added			**Final use**			**Total use**
		Country 1	$\cdots$	Country J	Country 1	$\cdots$	Country J	
Intermediate inputs supplied	Country 1							
	$\cdots$							
	Country J							
Value added								
Gross output								

- Normalizing $\tau_{ii} = 1$, it turns out that

$$(\tau_{ij})^{-\theta} = \sqrt{\frac{\pi_{ij}^F}{\pi_{ii}^F}\frac{\pi_{ji}^F}{\pi_{jj}^F}}$$

- Estimate (T_j, γ_j) for all j and α_n for all n targeting:
    - Diagonal of intermediate input and final-good share matrices
    - Ratio of value added to gross output by country
    - GDP shares by country (also take into account trade deficits)

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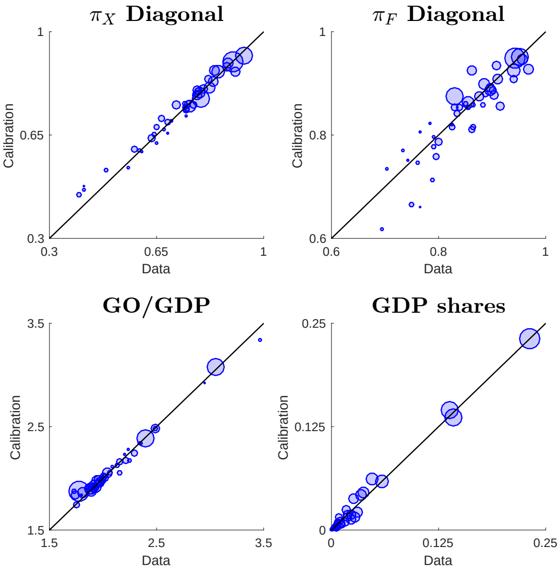
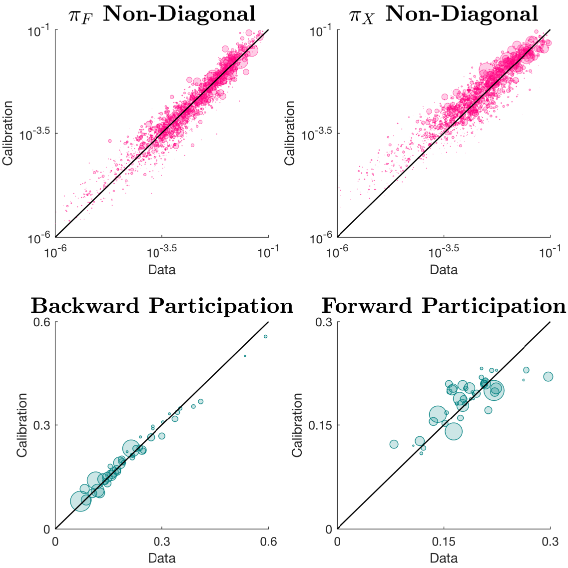
    - Diagonal of intermediate input and final-good share matrices
    - Ratio of value added to gross output by country
    - GDP shares by country (also take into account trade deficits)
- We set $N = 2$ (so far data is 'rejecting' $N > 2$) and $\theta = 5$
- We find $\alpha_2 = 0.16$ (remember $\alpha_1 = 1$ by assumption)
    - Hence, data rejects a standard roundabout model ($\alpha_2 = 1$)

Antràs and de Gortari (2017)

Fit of the Model: Targeted Moments



Fit of the Model: Untargeted Moments



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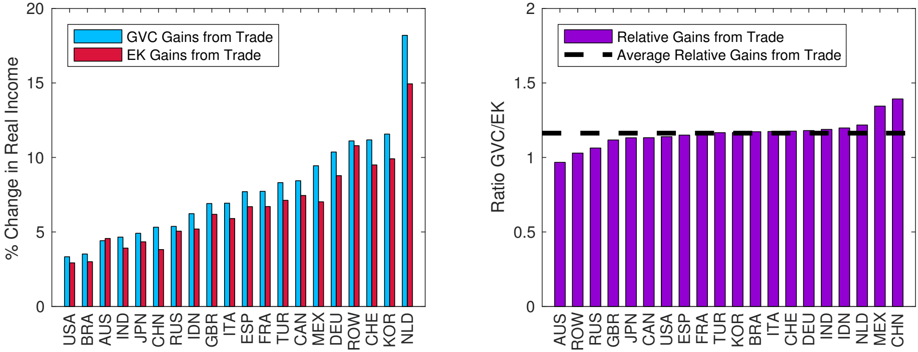
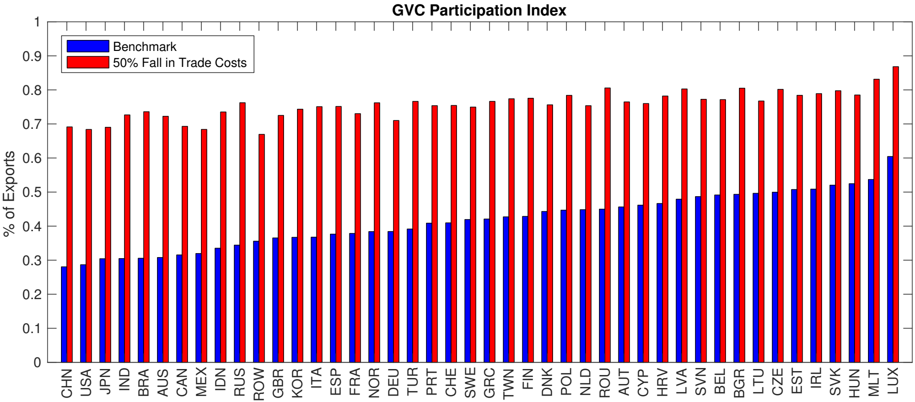
Counterfactuals: Real Income Gains Relative to Autarky



- GVC model with $N = 1$, i.e. EK model, underestimates gains from trade by 17.5% on average

- All countries integrate more



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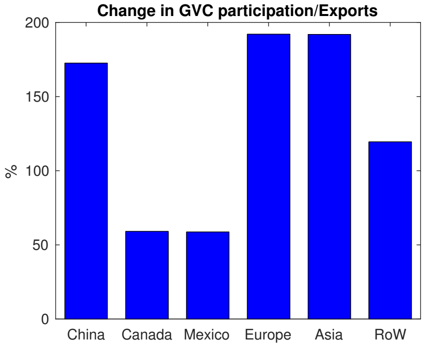
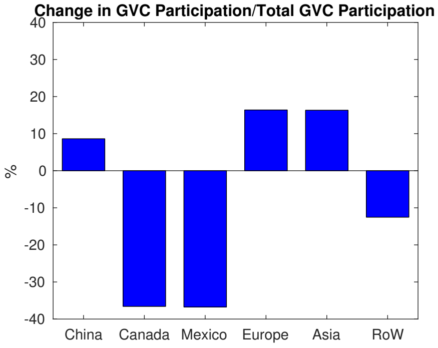
Counterfactuals: 50% Fall in Trade Costs

- USA integrates more with all regions...
- ...but global integration increases relative to regional integration





3. Multinational Production

- Extension of Eaton and Kortum (2002) with both trade and multinational production (MP)
- For each good $v \in (0, 1)$:
  - Ideas gets originated in country $i = 1, ..., I$
  - Production takes place in country $l = 1, ..., I$
  - Consumption takes place in country $n = 1, ..., I$
- Trade versus MP:
  - If $l \neq n$, then good v is traded
  - If $i \neq l$, then MP occurs (in EK, $i = l$)

- Model is Ricardian:
  - Labor is the only factor of production
  - Constant returns to scale
  - (Like EK, full model also includes tradable intermediate goods)
- Constant unit cost of production *and* delivery for a good v given by

$$\frac{d_{nl} h_{li} c_{li}}{z_{li}(v)}$$

  where:
  - $d_{nl} \equiv$ iceberg trade costs from country l to country n
  - $h_{li} \equiv$ iceberg costs from using technology from i in l
  - $c_{li} \equiv$ average unit cost of production for firms from i in country l
  - $z_{li}(v) \equiv$ productivity of firms from i producing good v in country l
- $\mathbf{z}_i(v) \equiv (z_{1i}(v), ..., z_{Ii}(v))$ is drawn from multivariate Fréchet

Ramondo and Rodriguez-Clare (2013)

Results

- **Main result:**
  - Gains from trade are larger in the presence of MP because trade facilitates MP
  - Gains from openness are larger than gains from trade because of MP and complementarity between trade and MP
- A model of MP without a model of MNEs?:
  - in any given country and sector, technology is assumed to be freely available to a large number of price-taking firms
  - discipline only comes from aggregate predictions of the model

More at the Frontier

- **North-North Fragmentation:**
  - In GRH (2008), rationale for offshoring $\equiv$ factor price differences
  - More important for "North-South," but not "North-North" fragmentation
  - In GRH (2012), rationale for offshoring $\equiv$ EES (at the task level)
- **Open Questions:**
  - Can static models really get at sequential nature of GVCs?
    - Kim and Shin (AER, 2012) study payment delays as a way to provide incentives along a supply chain. Interesting connection between GVCs and trade finance
  - How do GVCs affect gains from trade, incentives for trade protection, industrial policy etc.?
    - Blanchard, Bown and Johnson (2016) offer an interesting first attempt. Much more needed