On the Geography of Global Value Chains

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Sequential Global Value Chains

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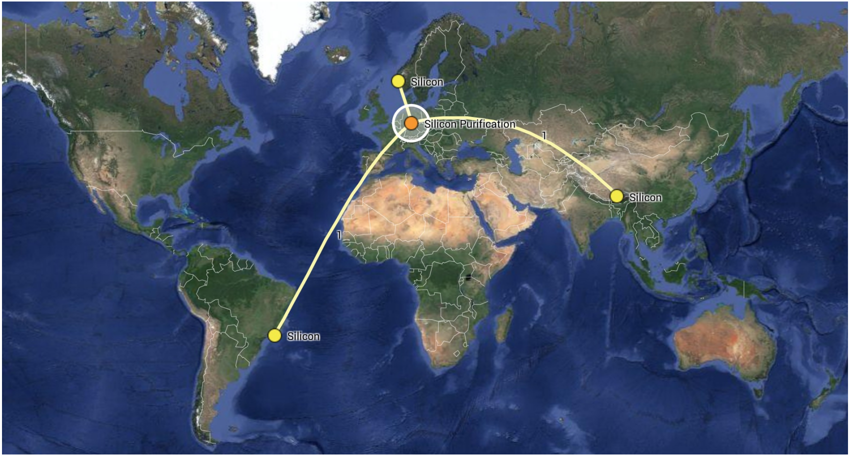

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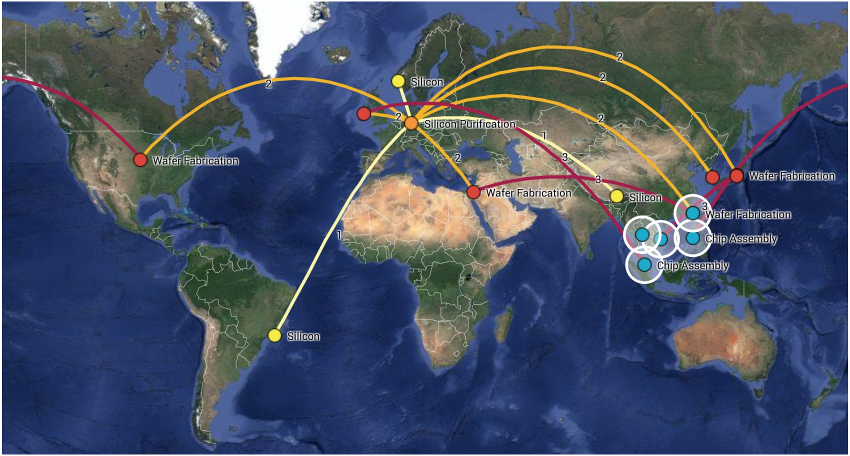

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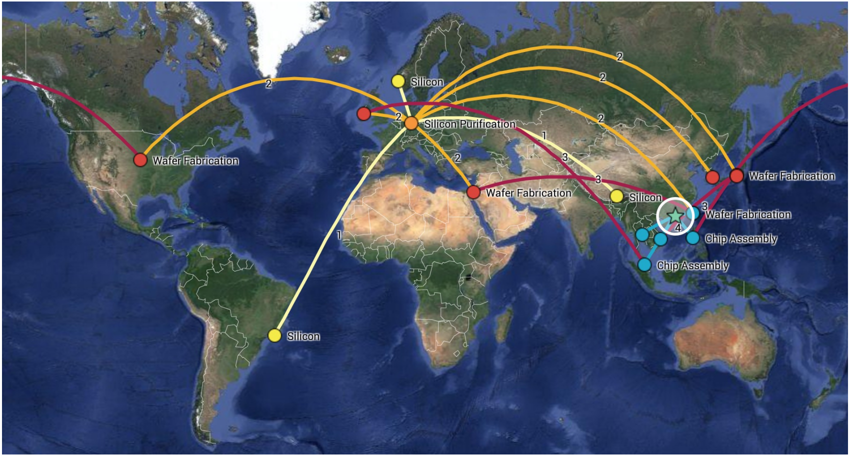

Cool Pictures... But Why Do We Care?

- What are the implications of sequential GVCs for the workings of general-equilibrium models?
  - Location: Harms, Lorz, and Urban (2012), Baldwin and Venables (2013), Costinot *et al.* (2013), Antràs and de Gortari (2016)
  - Organization: Antràs and Chor (2013), Alfaro *et al.* (2015), Kikuchi *et al.* (2014)
  - Both: Fally and Hillberry (2014)
- What are the implications of sequential GVCs for the quantitative consequences of trade cost reductions (e.g., TTIP)
  - Yi (2003), Johnson *et al.* (2014), Fally and Hillberry (2014)

The Geography of Global Value Chains

- Consider optimal location of production for the different stages in a sequential global (multi-country) value chain
- Without trade frictions, not much different from standard multi-country sourcing models
- With trade frictions, matters become trickier
- Location of a stage takes into account geography of upstream and downstream locations
  - Where is the good coming from? Where is it going to?
- Connection with logistics literature (Travelling Salesman Problem)
  - NP-complex problem: curse of dimensionality
- Implications for trade policy if trade barriers are man-made

Contributions of This Paper

- Develop a general-equilibrium model of GVCs with a general geography of trade costs across countries

1. Characterize the optimality of a centrality-downstreamness nexus
    - Consistent with evidence from *Factory Asia*

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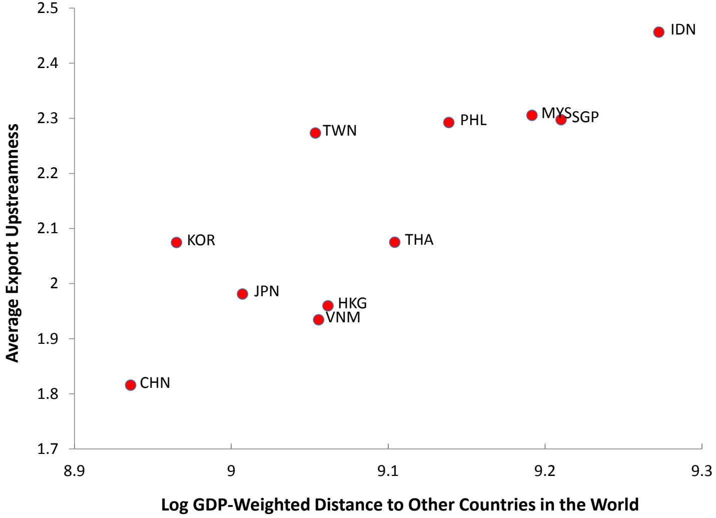


Contributions of This Paper

- Develop a general-equilibrium model of GVCs with a general geography of trade costs across countries

1. Characterize the optimality of a centrality-downstreamness nexus
    - Consistent with evidence from *Factory Asia*
2. Present tools to solve the problem in high-dimensional environments
    - Reformulate problem so it is solvable with LP techniques
    - Useful for illustrating the role of trade frictions in shaping the global versus regional versus local nature of GVCs
3. Develop a tractable multi-stage variant of the Eaton-Kortum (2002) framework for an arbitrary number of sequential stages
    - Opens the door for quantitative analysis using world I-O tables

Road Map

1. General formulation of the problem
2. Special case that isolates the role of trade costs
   - Proximity-concentration tradeoff
   - Application to *Factory Asia*
3. A still special, but less special case
   - Application to Global versus Regional Value Chains
4. A multi-stage Ricardian Model

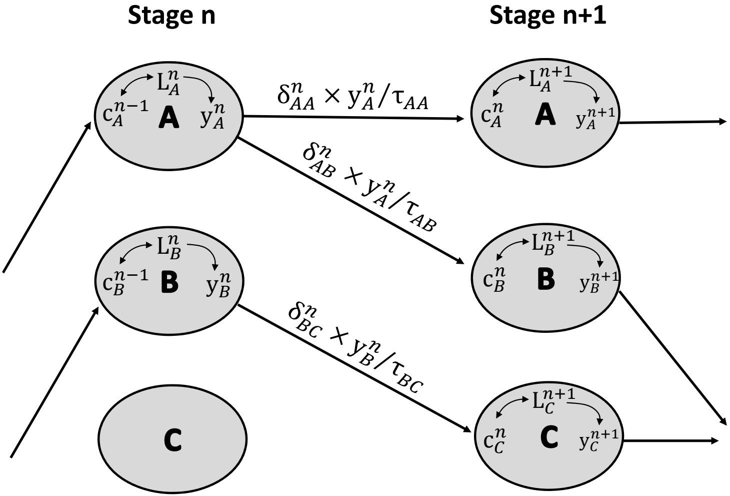
Formal Environment

- There are J countries where consumers derive utility from consuming a set of final-good varieties
- Consumer goods are produced combining N stages that need to be performed sequentially using a unique composite factor (labor)
- The last stage of each production process can be interpreted as assembly and is indexed by N
- Countries differ in their geography, as captured by a $J \times J$ matrix of iceberg trade coefficients τ_{ij}
- We also let countries vary in their size/productivity: each consumer in country i is endowed with L_i efficiency units of labor

Some Notation

- $c_i^N(z)$ = consumption of (assembled) final-good variety z in country i
- $c_i^n(z)$ = quantity of intermediate good z completed up to stage $n < N$ available in country i
- $L_i^n(z)$ = allocation of country i's labor to the production of stage n of good z
- $y_i^n(z)$ = quantity of good z up to stage n produced in country i
- $\delta_{ij}^n(z)$ = share of production $y_i^n(z)$ shipped to country j

Graphical Illustration



Formulation of the Problem

- Rather than specify market structure, focus on planner's problem
- Pareto optimal allocations are the allocations of labor $L_i^n(z)$ and the distribution shares $\delta_{ji}^n(z)$ that solve:

$$\max \quad W = \sum_{i=1}^{J} \lambda_i L_i u\left(\left\{\frac{c_i^N(z)}{L_i}\right\}_{z=0}^{1}\right)$$

$$\text{subject to} \quad c_i^n(z) = \sum_{j=1}^{J} \frac{\delta_{ji}^n(z) y_j^n(z)}{\tau_{ji}}, \text{ for all } n, i, z;\ c_i^0(z) = \underline{c},$$

$$y_i^n(z) = f_{i,z}^{\,n}\left(L_i^n(z), c_i^{n-1}(z)\right), \text{ for all } n, i, z,$$

$$\sum_{i=1}^{J} \delta_{ji}^n(z) = 1, \text{ for all } n, j, z,$$

$$\int_0^1 \sum_{n=1}^{N} L_i^n(z)\, dz = L_i, \text{ for all } n.$$

A Particular Case: Pure Snakes with Agglomeration

- Let us begin by making the following simplifying assumptions

1. There is only one final good
2. Gains from specialization driven purely by external economies of scale

$$f^n\left(L_i^n, c_i^{n-1}\right) = \left(\left(L_i^n\right)^{\phi} L_i^n\right)^{1/n} \left(c_i^{n-1}\right)^{1-1/n}.$$

3. GVCs are **pure snakes**: no 'merging' and no 'splitting' (for $n < N$)

- Then, the unique chain that services consumers in i delivers

$$c_i^N = \delta_{\ell^i(N)i}^N \left(\tau_{\ell^i(N)i}\right)^{-1} \prod_{n=1}^{N-1} \left(\tau_{\ell^i(n)\ell^i(n+1)}\right)^{-\frac{n}{N}} \left(\prod_{n=1}^{N} \left(L_{\ell^i(n)}^n\right)^{\frac{1}{N}}\right)^{1+\phi},$$

where $\ell^i(n)$ is the country producing stage n in that chain

Injective Assignment in the *Even* Case

- Consider the *even* case with $N = J$ and **injective assignment**
  - Then each country must produce exactly one stage and each stage is produced in exactly one country
- Assume also logarithmic utility: $u\left(c_i^N\right) = \ln c_i^N$

Lemma 1 (Modified TSP)

In the even case $N = J$, the optimal injective assignment of stages to countries with logarithmic utility seeks to solve

$$\min_{\{\ell(n)\}_{n=1}^{N}} H\left(\ell\left(1\right), ..., \ell\left(N\right)\right) = \sum_{i=1}^{N} \Lambda_i N \ln \tau_{\ell(N)i} + \sum_{n=1}^{N-1} n \ln \tau_{\ell(n)\ell(n+1)},$$

where $\Lambda_i = \lambda_i L_i / \sum_{i=1}^{J} \lambda_i L_i$.

The Centrality-Downstreamness Nexus

- Assume trade costs can be decomposed as follows:

$$\tau_{ij} = \begin{cases} (\rho_i \rho_j)^{-1} & \text{if } i \neq j \\ \xi (\rho_i \rho_j)^{-1} & \text{if } i = j \text{, with } \xi < 1 \end{cases} \quad (1)$$

Proposition 1 (Centrality-Downstreamness Nexus)

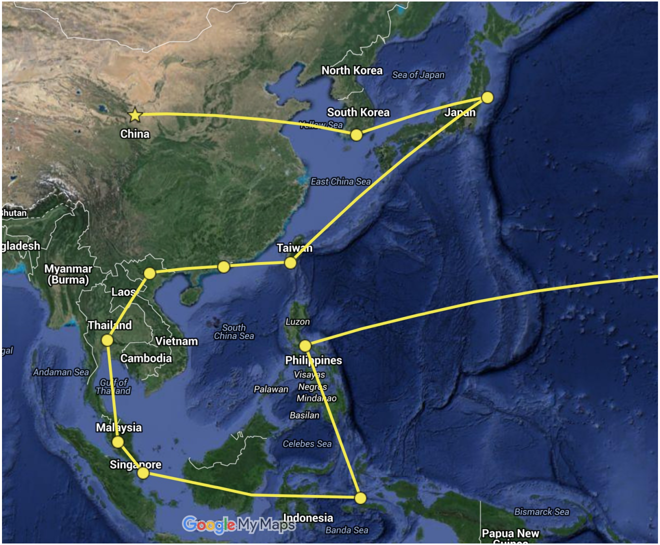
Let countries be ordered according to their centrality so that $\rho_1 < \rho_2 < .... < \rho_N$. Then, as long as cross-country differences in λ_i and L_i are sufficiently small, the optimal injective assignment is such that $\ell(n) = n$, and thus the n-th most central country is assigned the n-th most downstream position in the value chain.

- **Corollary:** conditional on $\ell(N)$, differences in λ_i and L_i are irrelevant
- What if trade costs are not log-separable? Solve modified TSP

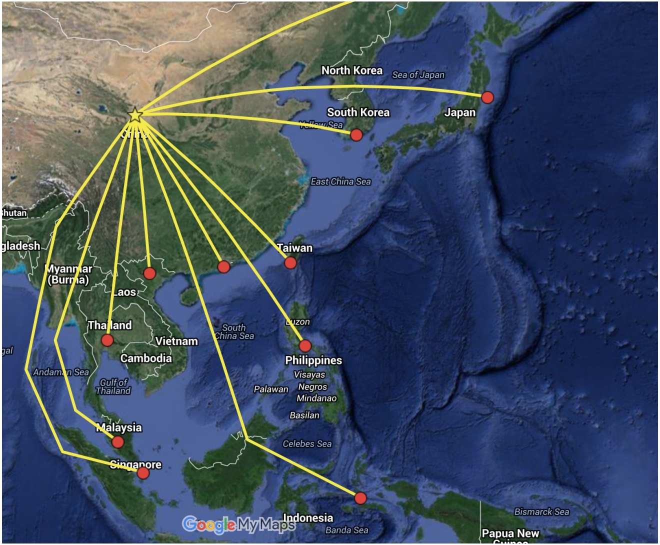
An Application: Factory Asia

- Consider a solution to the modified TSP in Lemma 1 with empirical proxies for bilateral trade costs and population sizes (set $\lambda_i = 1$)
- Choose $J = 12$: 11 largest East and Southeast Asian economies and the U.S.
- Use gravity equation estimates (Head and Mayer, 2014) to back out log trade costs, up to an irrelevant scalar
- Computing $12! \simeq 479$ million permutations brute force takes time
- Instead we express the problem as a zero-one **linear programming** problem (defining dummy variables) and use standard algorithms

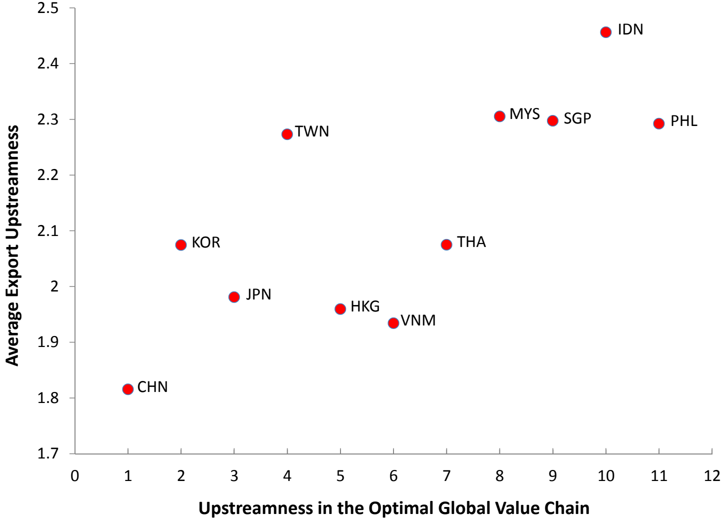
Optimal Pure Snake in Factory Asia: Production



Optimal Pure Snake in Factory Asia: Consumption



Empirical Fit



The Non-Injective Case

- So far, single GVC with each stage produced in a single country
  - Useful for illustrating role of geography
  - Real world: multiple GVCs, countries participating at various stages
- Simplest departure from even case:
  - Still only one homogenous good (aggregate output)
  - There are now J countries and N stages, with potentially $J \neq N$
  - Each country sources the final good from a *single* supply chain and the supply chain follows a *unique* snake path
- Note that countries may now:
  - perform various stages for a given value chain
  - perform different stages for distinct value chains
  - or be in autarky altogether

The Non-Injective Case

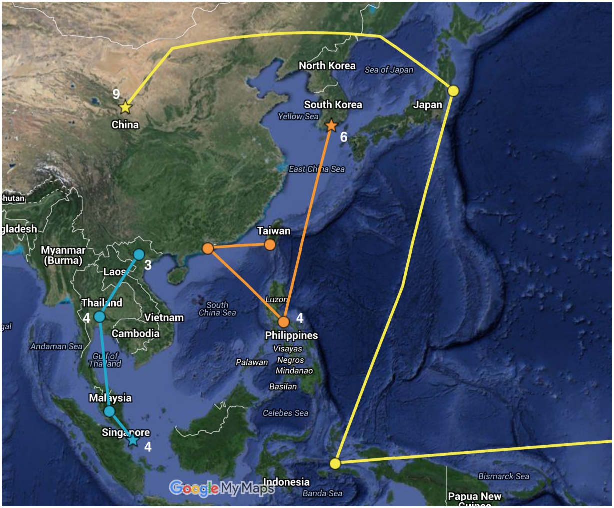
- Various GVCs might now coexist: what do they look like?
- Note that consumption in country i will still satisfy:

$$c_i^N = \delta^N_{\ell^i(N)i} \left(\tau_{\ell^i(N)i}\right)^{-1} \prod_{n=1}^{N-1} \left(\tau_{\ell^i(n)\ell^i(n+1)}\right)^{-\frac{n}{N}} \left(\prod_{n=1}^{N} \left(L^n_{\ell^i(n)}\right)^{\frac{1}{N}} \right)^{1+\phi},$$

- Main new complication is solving for the amount of labor each country devotes to each value chain's stage (i.e., $L^n_{\ell^i(n)}$)
- The lower the trade costs and the higher ϕ, the more 'global' value chains are
- Computationally, can still reduce problem to zero-one LP problem (country-size bins help enhance dimensionality)

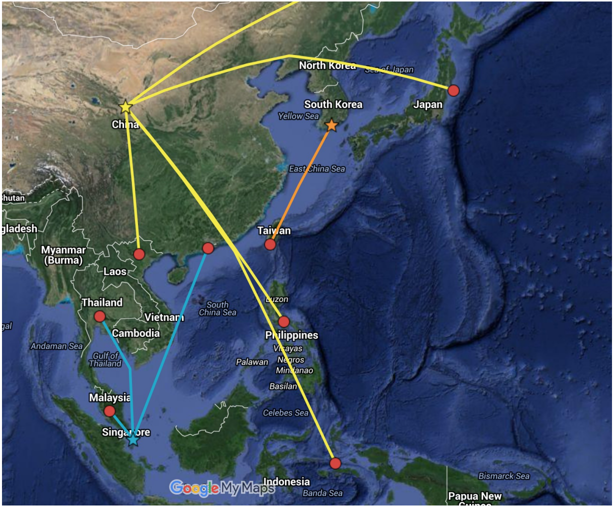
Optimal Non-Injective Assignment in Factory Asia

Production chains with $J = N = 12$



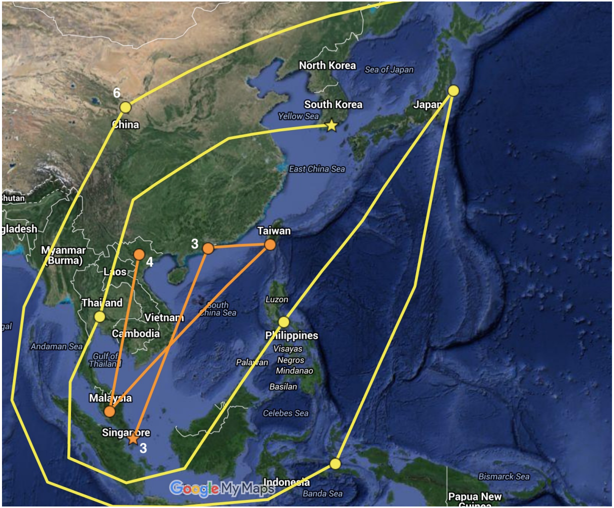
Optimal Non-Injective Assignment in Factory Asia

Assembly and Consumption with $J = N = 12$



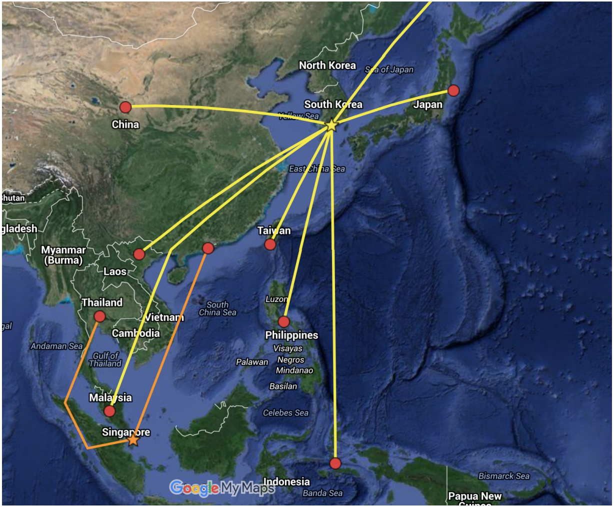
A Reduction in Trade Costs

Production



A Reduction in Trade Costs

Assembly and Consumption



A Multi-Stage Ricardian Extension

- Further generalizations of the previous proximity-concentration framework are very cumbersome
- We next pursue an alternative approach building on the probabilistic approach of Eaton and Kortum (2002)
- The framework will accommodate multiple final goods and multiple GVCs producing each of these final goods
- Model will **not** predict the path of each specific GVCs, but will characterize the relative prevalence of different possible GVCs
- Past work on multi-stage E-K models has focused on low-dimensional environments (namely $N = 2$)
- We propose a new approach that is equally flexible for environments with $N > 2$

Formal Environment

- We go back to our initial general environment with a continuum of final goods. Preferences are now

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

- Technology now features CRS and Ricardian technological differences

$$f_{i,z}^{n}\left(L_i^n(z), c_i^{n-1}(z)\right) = \left(\frac{L_i^n(z)}{a_i^n(z)}\right)^{1/n}\left(c_i^{n-1}(z)\right)^{1-1/n}$$

- Each country j draws productivity levels $1/a_n^j(z)$ for each stage n and each good z independently from the Fréchet distribution

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

The Challenge: An Illustration

- Take the case $N = 2$
- Consider cost-minimizing way to service consumers in country i
- With knowledge of the productivity draws $1/a_1^k(z)$ and $1/a_2^j(z)$, firms would choose $k^*(i)$ and $j^*(i)$ that solve

$$\left(k^*(i), j^*(i)\right) = \arg\min_{(k,j)} \left(a_1^k(z) w_k \tau_{kj} a_2^j(z) w_j (\tau_{ji})^2\right)^{1/2}.$$

- Note that downstream trade costs again carry a higher weight
- **Problem:** the distribution of the product $a_1^k(z) a_2^j(z)$ is **not** Fréchet
  - Eaton-Kortum's magic is gone
  - This is true even when countries draw a common productivity level $1/a_i(z)$ for all stages n in a given value chain

A Feasible Approach

- **E-K:** firms know the precise productivity levels in a value chain for all stages and countries **before** making any location decision
- **Alternative:** Assume instead that firms learn the particular realization of $1/a_i^n(z)$ in different countries i **only** when the location of production of stage $n-1$ has been decided
  - the same results apply under *backward* rather than *forward* learning
- In the $N=2$ case, second stage location now solves

$$j^*(i) = \arg\min_{j \in \mathcal{J}} \left(c_1^k \tau_{kj} a_2^j(z) w_j (\tau_{ji})^2 \right)^{1/2}$$

- The key is that c_1^k is taken as given
- Can iterate for any number of stages and use E-K magic at each stage

Some Results

- Likelihood of a GVC ending in i and flowing through a given sequence of countries is

$$\Pr\left(\ell\left(1\right),\ell\left(2\right),...,\ell\left(N\right);i\right)=\frac{\prod_{n=1}^{N-1}A_{\ell(n)}\left(\tau_{\ell(n)\ell(n+1)}\right)^{-\theta n}\times A_{\ell(N)}\left(\tau_{\ell(N)i}\right)^{-\theta N}}{\Theta_i}$$

  where $A_j=T_j\left(w_j\right)^{-\theta}$ and Θ_i is the sum of the numerator over all possible country permutations

- Notice that $-\ln\Pr\left(\ell\left(1\right),\ell\left(2\right),...,\ell\left(N\right);i\right)$ is

$$\theta N\ln\tau_{\ell(N)i}+\theta\sum_{n=1}^{N-1}n\ln\tau_{\ell(n)\ell(n+1)}+\ln\Theta_i-\sum_{n=1}^{N}\ln A_{\ell(n)},$$

  and is closely related to $H\left(\ell\left(1\right),...,\ell\left(N\right)\right)$ in Lemma 1

The Centrality-Downstreamness Revisited

- Define the average upstreamness $U(\ell; i)$ of production of a given country ℓ in value chains that seek to serve consumers in country i:

$$U(\ell; i) = \sum_{n=1}^{N} (N - n + 1) \times \frac{\Pr(\ell = \ell(n); i)}{\sum_{n'=1}^{N} \Pr(\ell = \ell(n'); i)}$$

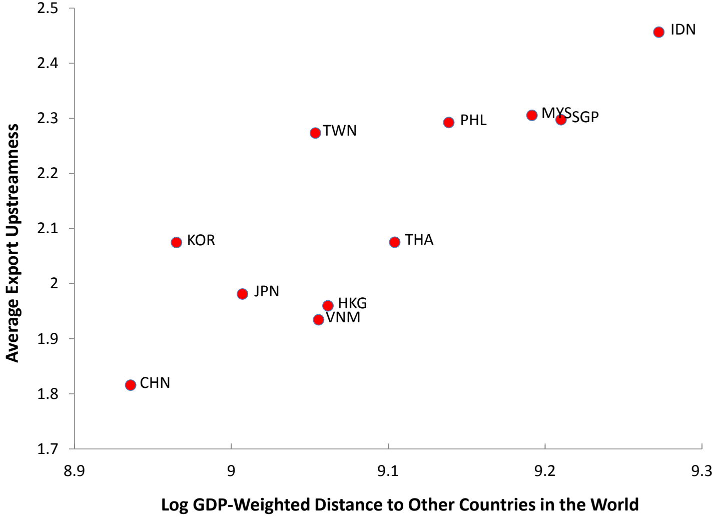
- Closely related to the upstreamness measure proposed by Antràs et al. (2012)

- In the log-separable specification of trade costs , we have that:

Proposition 3 (Centrality-Upstreamness Nexus)

The average upstreamness $U(\ell)$ of a country in global value chains is decreasing in its centrality $\rho(\ell)$.

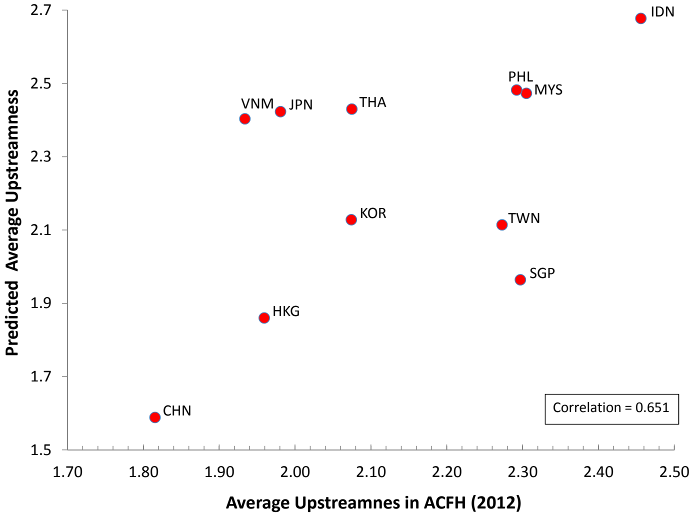
Suggestive Evidence Revisited



Revisiting the Factory Asia Example

- We can also compute average upstreamness with empirical proxies for bilateral trade costs and A_j
- We do this for the same 12 countries as before
- Set $N = 3$
- Again use gravity equation estimates to back out log trade costs (we set $\theta = 5$)
- We back out A_j from the sourcing potential estimates in Antràs, Fort and Tintelnot (2015)

Empirical Fit



Conclusions

- We have studied how trade frictions shape the location of production along GVCs
- We have demonstrated a centrality-downstreamness nexus and have offered suggestive evidence for it
- Our framework can be used to understand the evolution of value chains from local value chains to regional value chains to truly global value chains
- We view our work as a stepping stone for a future analysis of the role of **man-made** trade barriers in GVCs
  - Should countries use policies to place themselves in particularly appealing segments of global value chains?
  - What is the optimal shape of those policies?