# On the Geography of Global Value Chains

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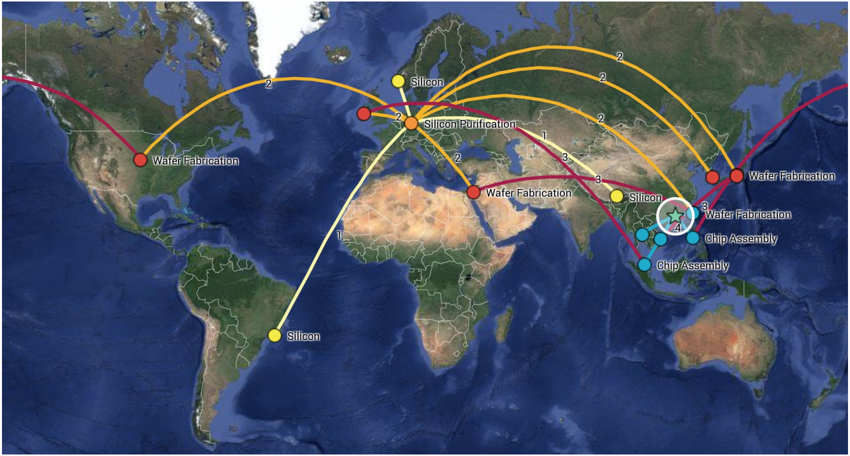
# Global Value Chains

- Value Chain: the series of stages involved in producing a product or service that is sold to consumers, with each stage adding value



# Why Do We Care?

- What are the implications of GVCs for the workings of general-equilibrium models?
  - Harms, Lorz, and Urban (2012), Antràs and Chor (2013), Baldwin and Venables (2013), Costinot *et al.* (2013), Fally and Hillberry (2014), Alfaro *et al.* (2015)
- What are the implications of GVCs for the quantitative consequences of trade cost reductions (or increases!)?
  - Yi (2003, 2010), Johnson and Moxnes (2014), Fally and Hillberry (2014)
- **Past work**: non-existent or very stylized trade costs; generally two-country models

# Adding Realistic Trade Costs Is Tricky

- 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
- Connection with logistics literature

# 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
2. Develop tools to solve the model in high-dimensional environments
3. Show how to map our model to world Input-Output tables
4. Structurally estimate the model and perform counterfactuals

# Model: Partial Equilibrium

# Partial Equilibrium Environment

- There are $J$ countries where consumers derive utility from consuming a final good
- The good is produced combining N stages that need to be performed sequentially (stage $N =$ assembly)
- At each stage $n > 1$, production combines (equipped) labor with the good finished up to the previous stage $n - 1$
- The wage rate varies across countries and is denoted by $w_i$ in $i$
- Countries also differ in their geography $J \times J$ matrix of iceberg trade cost coefficients $\tau_{ij}$
- Technology features constant returns to scale and market structure is perfectly competitive

# Partial Equilibrium: Sequential Production Technology

- Optimal path of production $\boldsymbol{\ell}^j = \left\{ \ell^j(1), \ell^j(2), ..., \ell^j(N) \right\}$ for providing the good to consumers in country $j$ dictated by cost minimization

- We summarize technology via the following sequential cost function associated with a path of production $\boldsymbol{\ell} = \{\ell(1), \ell(2), ..., \ell(N)\}$:

$$p^n_{\ell(n)}(\boldsymbol{\ell}) = g^n_{\ell(n)}\left(w_{\ell(n)}, p^{n-1}_{\ell(n-1)}(\boldsymbol{\ell})\,\tau_{\ell(n-1)\ell(n)}\right), \text{ for all } n.$$

where $p^1_{\ell(1)}(\boldsymbol{\ell}) = g^1_{\ell(1)}\left(w_{\ell(1)}\right)$ for all paths $\boldsymbol{\ell}$

- A good assembled in $\ell(N)$ after following the path $\boldsymbol{\ell}$ is available in any country $j$ at a cost $p^F_j(\boldsymbol{\ell}) = p^N_{\ell(N)}(\boldsymbol{\ell})\,\tau_{\ell(N)j}$

# A Useful Benchmark

- Assume a Cobb-Douglas technology with Ricardian efficiency differences

$$p^n_{\ell(n)}(\boldsymbol{\ell}) = \left(a^n_{\ell(n)} w_{\ell(n)}\right)^{\alpha_n} \left(p^{n-1}_{\ell(n-1)}(\boldsymbol{\ell})\, \tau_{\ell(n-1)\ell(n)}\right)^{1-\alpha_n}, \text{ for all } n,$$

- Iterating, the cost-minimization problem for a **lead firm** is:

$$\boldsymbol{\ell}^j = \arg\min_{\boldsymbol{\ell}\in\mathcal{J}^N} \left\{ \prod_{n=1}^{N} \left(a^n_{\ell(n)} w_{\ell(n)}\right)^{\alpha_n\beta_n} \times \prod_{n=1}^{N-1} \left(\tau_{\ell(n)\ell(n+1)}\right)^{\beta_n} \times \tau_{\ell(N)j} \right\}$$

where

$$\beta_n \equiv \prod_{m=n+1}^{N} (1-\alpha_m)$$

# Two Lessons

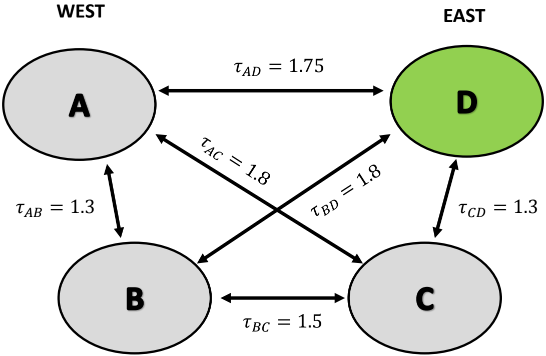
1. Unless $\tau_{\ell(n-1)\ell(n)} = \tau$, one cannot minimize costs stage-by-stage
   - Turns a problem of dimensionality $N \times J$ into a $J^N$ problem
   - But easy to reduce dimensionality with dynamic programming
2. Trade-cost elasticity of the unit cost of serving consumers in country $j$ increases along the value chain $(\beta_1 < \beta_2 < ... < \beta_N = 1)$
   - Incentive to reduce trade costs increases as one moves downstream

- These results hold for any CRS technology

# Decentralization

- What if no lead firm coordinates the whole value chain?
- Assume value chain consists of a series of cost-minimizing stage-specific agents (including consumers in each country)
- Stage $n$ producers in $\ell(n)$ pick $\ell(n-1)$ to min $\left\{ p^{n-1}_{\ell(n-1)} \tau_{\ell(n-1)\ell(n)} \right\}$, regardless of $w_\ell(n)$, productivity $a^n_\ell(n)$, and future path of the good
- With CRS, identity of the specific firms is immaterial $\Longrightarrow$ as if a lead firm used dynamic programming to solve for the optimal path
- Invoking the principle of optimality, we get the exact same optimal path of production than before
- But much lower dimensionality! ($J \times N \times J$ computations)

# An Example: $N = J = 4$




- We explore the implications of shifts in trade costs by letting $\tau'_{ij} = 1 + s(\tau_{ij} - 1)$ for $s > 0$ ▸ Results
- We average across 1 million simulations in which $a^n_j w_j \sim \log \mathcal{N}(0, 1)$

# General Equilibrium

# A Multi-Stage Ricardian Model

- We next embed our framework into a general equilibrium 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
  - Trace implications for the world distribution of income

# Formal Environment

- Preferences are

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

- Technology features CRS and Ricardian technological differences

$$p_{\ell(n)}^{n}(\boldsymbol{\ell},z)=\left(a_{\ell(n)}^{n}(z)\,c_{\ell(n)}\right)^{\alpha_n}\left(p_{\ell(n-1)}^{n-1}(\boldsymbol{\ell})\,\tau_{\ell(n-1)\ell(n)}\right)^{1-\alpha_n},\ \text{for all } n$$

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- Technology features CRS and Ricardian technological differences

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

- Bundle of inputs comprises 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

# Probabilistic Representation of Technology

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

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

- **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 the magic of the Eaton and Kortum in a multi-stage setting?

# The Challenge: Two Solutions

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

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

   - 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

# Some Results: GVC Shares

- Likelihood of a particular GVC ending in $j$ is

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

where $\Theta_j$ is the sum of the numerator over all possible paths

- Notice that trade costs again matter more downstream than upstream
- When $N = 1$

$$\pi_{\ell(N)j} = \frac{T_{\ell(N)} \left( c_{\ell(N)} \tau_{\ell(N)j} \right)^{-\theta}}{\Theta_j},$$

as in Eaton and Kortum (2002)

# Some Results: Mapping to Observables

- With $\pi_{\ell j}$'s can compute final-good trade shares and intermediate input shares as explicit functions of $T_j$'s, $c_j$'s, and $\tau_{ij}$'s (conditional probabilities)

$$\pi_{ij}^F = \sum_{\ell \in \Lambda_i^N} \pi_{\ell j}, \quad \text{where } \Lambda_i^n = \left\{ \boldsymbol{\ell} \in \mathcal{J}^N \mid \ell(n) = i \right\}$$

$$\Pr\left(\Lambda_{k \to i}^n, j\right) = \sum_{\boldsymbol{\ell} \in \Lambda_{k \to i}^n} \pi_{\boldsymbol{\ell} j}, \text{ where } \Lambda_{k \to i}^n = \left\{ \boldsymbol{\ell} \in \mathcal{J}^N \mid \ell(n) = k \text{ and } \ell(n+1) = i \right\}$$

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

$$\frac{1}{\gamma_i} w_i L_i = \sum_{j \in \mathcal{J}} \sum_{n \in \mathcal{N}} \alpha_n \beta_n \times \Pr\left(\Lambda_i^n, j\right) \times \frac{1}{\gamma_j} w_j L_j$$

# Gains from Trade

- 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

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

- We can then show

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

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

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

# The Centrality-Downstreamness Nexus

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

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

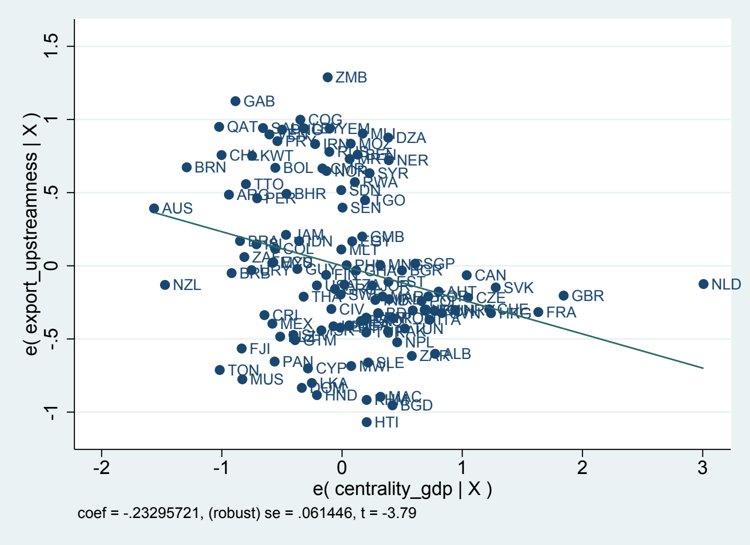
- Closely related to upstreamness measure in Antràs et al. (2012)

- Suppose we can decompose $\tau_{ij} = (\rho_i \rho_j)^{-1}$. Then:

**Proposition (Centrality-Upstreamness Nexus)**

The more central a country $i$ is (i.e., the higher is $\rho_i$), the lower is the average upstreamness $U(i;j)$ of this country in global value chains leading to consumers in any country $j$.

# Centrality and Downstreamness: Suggestive Evidence



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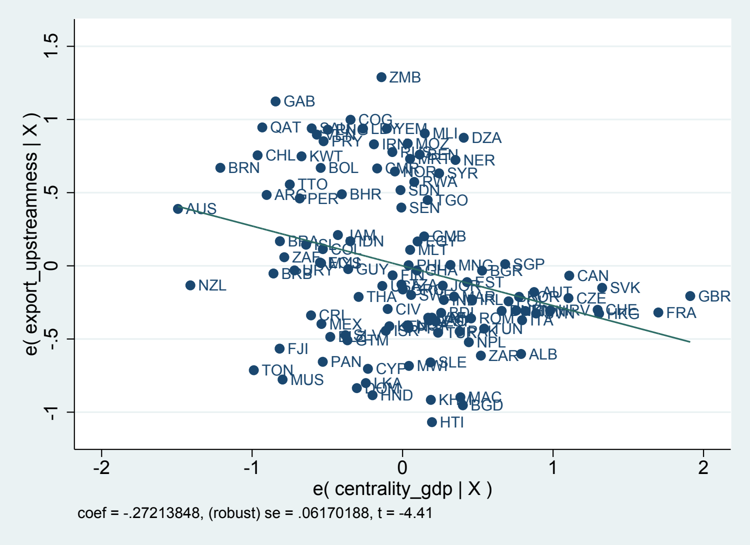


# Increasing Trade Elasticity: Suggestive Evidence

Table 1. Trade Cost Elasticities for Final Goods and Intermediate Inputs

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Distance | -1.111*** | -0.823*** | -1.144*** | -0.851*** | -1.210*** | -0.903*** | -0.794*** |
| | (0.019) | (0.014) | (0.019) | (0.014) | (0.021) | (0.015) | (0.015) |
| Distance × Input | | | | | 0.133*** | 0.106*** | 0.098*** |
| | | | | | (0.006) | (0.006) | (0.006) |
| Continguity | | 2.187*** | | 2.198*** | | 2.287*** | 1.184*** |
| | | (0.111) | | (0.112) | | (0.120) | (0.099) |
| Continguity × Input | | | | | | -0.177*** | -0.054 |
| | | | | | | (0.037) | (0.040) |
| Language | | 0.480*** | | 0.507*** | | 0.596*** | 0.513*** |
| | | (0.026) | | (0.027) | | (0.029) | (0.027) |
| Language × Input | | | | | | -0.179*** | -0.169*** |
| | | | | | | (0.013) | (0.013) |
| Domestic | | | | | | | 5.635*** |
| | | | | | | | (0.187) |
| Domestic × Input | | | | | | | -0.599*** |
| | | | | | | | (0.067) |
| Observations | 32,400 | 32,400 | 64,800 | 64,800 | 64,800 | 64,800 | 64,800 |
| $R^2$ | 0.98 | 0.982 | 0.972 | 0.974 | 0.972 | 0.974 | 0.976 |

# Estimation

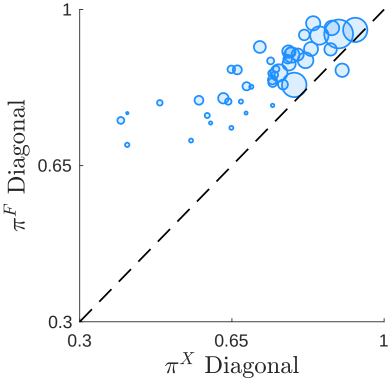
# Calibration to World-Input Output Database

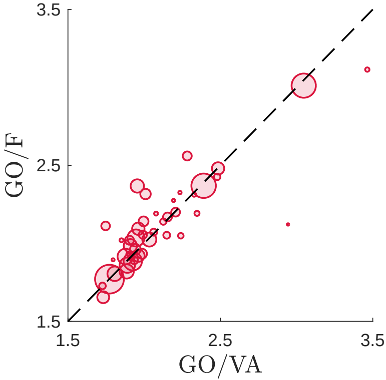
- We next map our multi-country Ricardian framework to world Input-Output Tables
- Core dataset: World Input Output Database (2016 release)
  - 43 countries (86% of world GDP) + ROW; available yearly 2000-2014
  - Provides information on input and final output flows across countries
- Also Eora dataset: 190 countries (but consolidate to 101)

| | | Input use & value added | | | Final use | | | Total use |
|---|---|---|---|---|---|---|---|---|
| | | Country 1 | ··· | Country $J$ | Country 1 | ··· | Country $J$ | |
| **Intermediate inputs supplied** | Country 1 | | | | | | | |
| | ··· | | | | | | | |
| | Country $J$ | | | | | | | |
| **Value added** | | | | | | | | |
| **Gross output** | | | | | | | | |

# Some Key Features

- Asymmetries in input and final-output domestic shares
- Variation in GO/VA and GO/F (+ correlated)



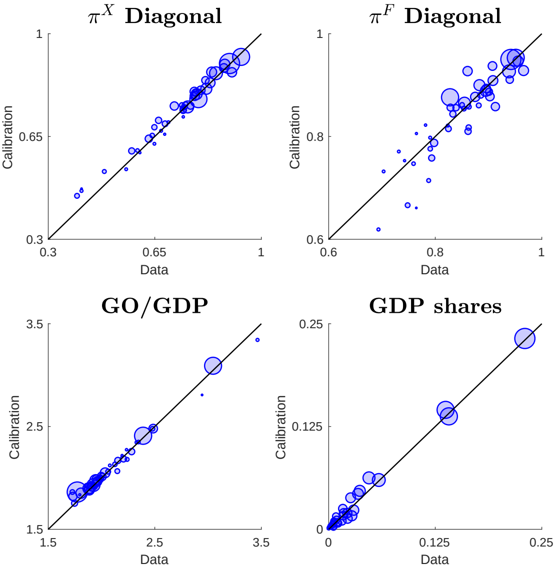
# Empirical Strategy

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

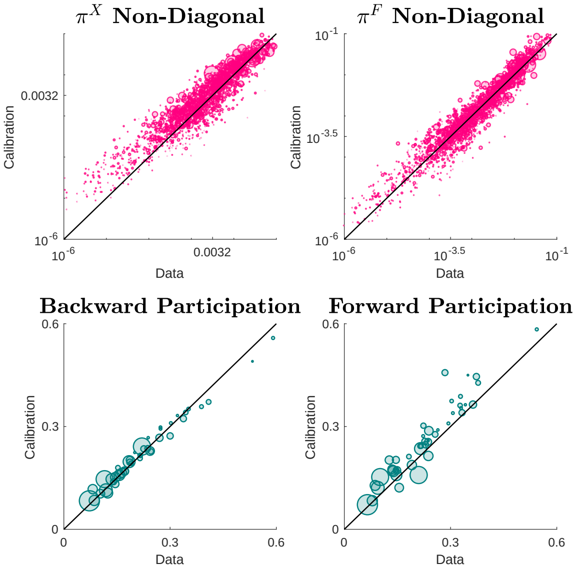
$$(\tau_{ij})^{-\theta} = \sqrt{\frac{\pi_{ij}^F}{\pi_{ii}^F}\frac{\pi_{ji}^F}{\pi_{jj}^F}}$$

- Estimate $(T_j, \gamma_j)$ for all $j$ and $\alpha_n$ 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)
- We set $N = 2$ (data 'rejects' $N > 2$) and $\theta = 5$
- We find $\alpha_2 = 0.16$ (remember $\alpha_1 = 1$); $\alpha_2 = 0.19$ with Eora
  - Hence, data rejects a standard roundabout model ($\alpha_2 = 1$)

# Fit of the Model: Targeted Moments

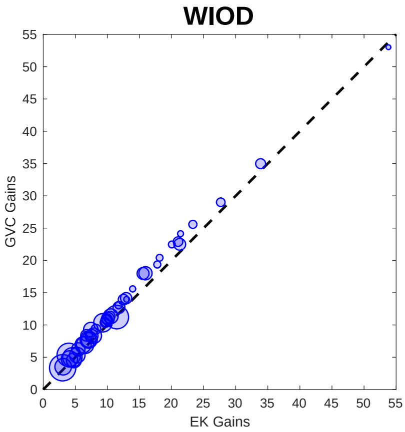


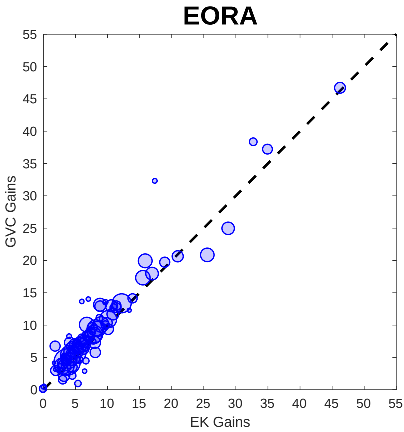
# Fit of the Model: Untargeted Moments



# Counterfactuals

# Counterfactuals: Real Income Gains Relative to Autarky



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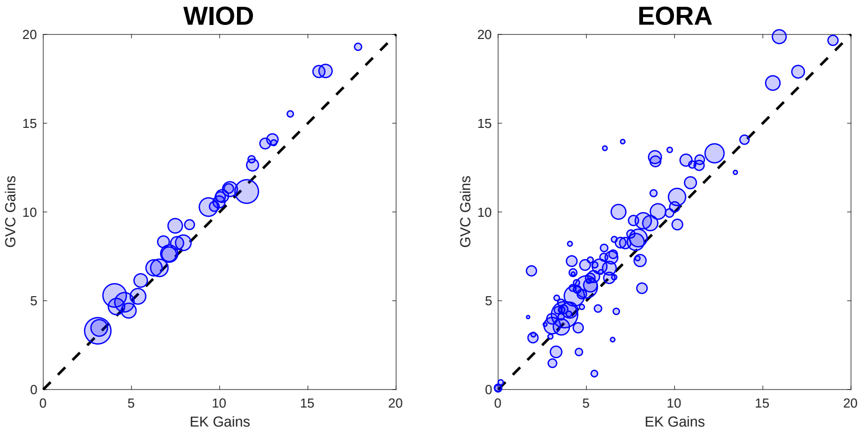

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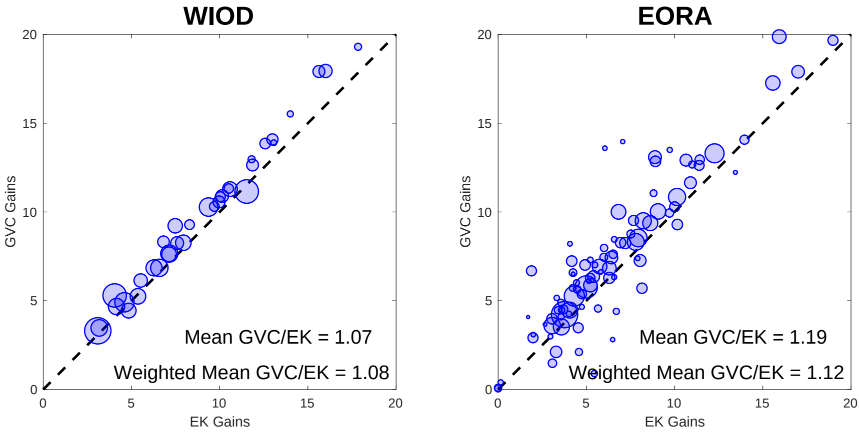

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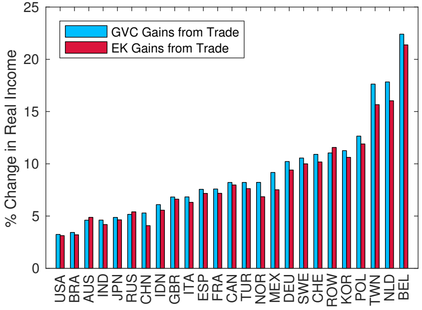
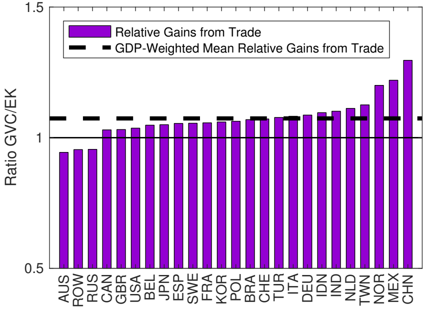
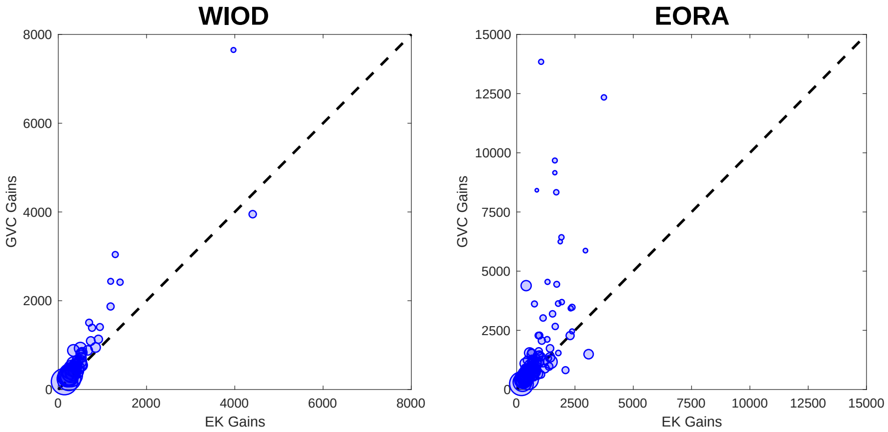



- GVC model with $N = 1$, i.e. EK model, underestimates gains from trade by 8% on average (11% in EORA)

# Counterfactuals: Free Trade Real Income Gains



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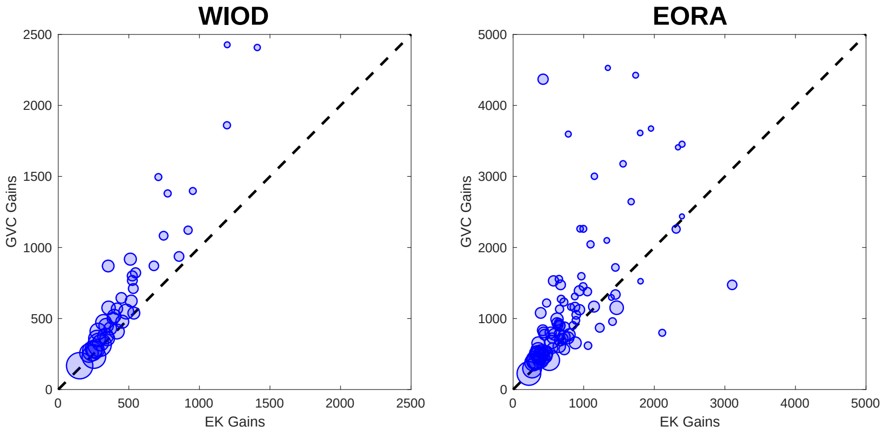

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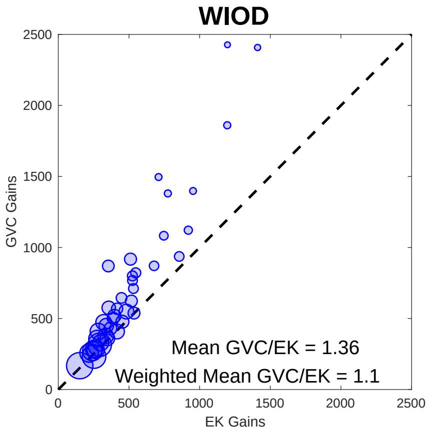
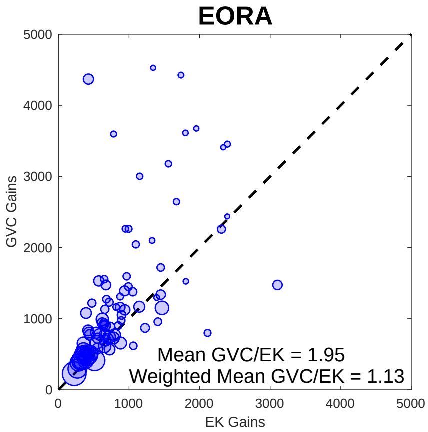
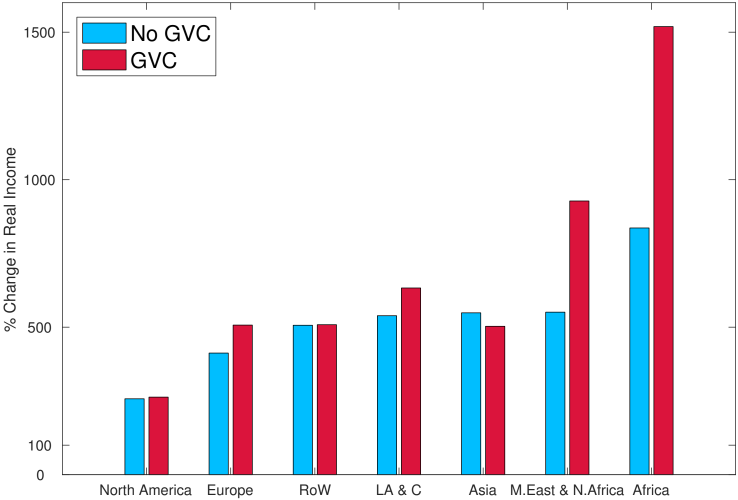


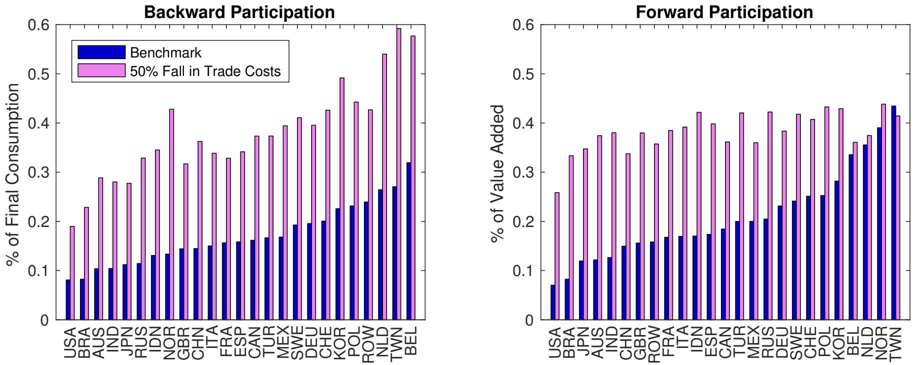



# Counterfactuals: Real Income Gains from Free Trade



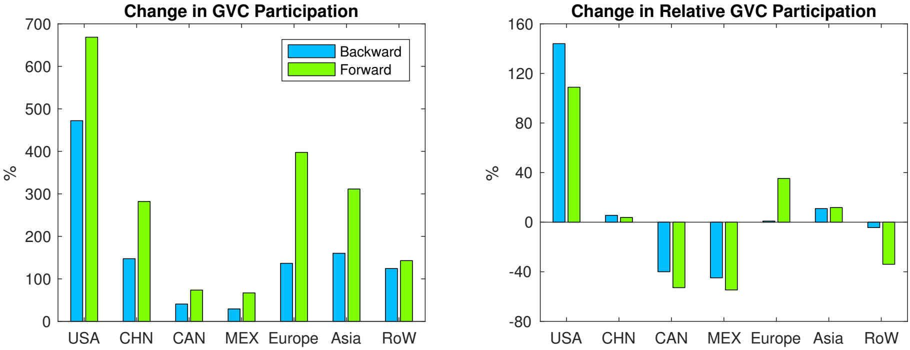
# Counterfactuals: 50% Fall in Trade Costs

- All countries integrate more



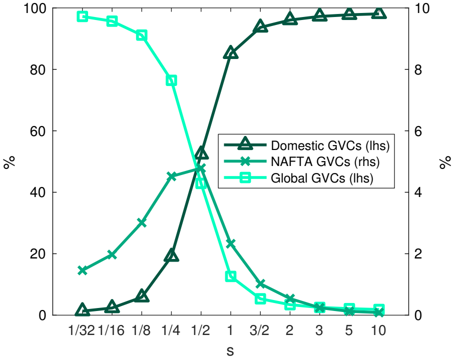
# Counterfactuals: 50% Fall in Trade Costs

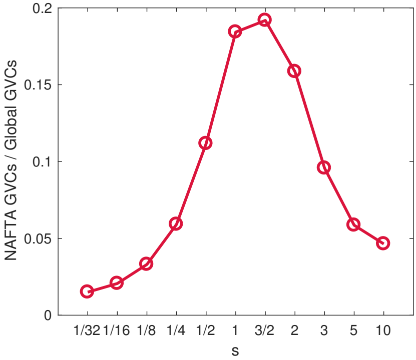
- USA integrates more with all regions...
- ...but global integration increases relative to regional integration



# Counterfactuals: Local vs. Regional vs. Global Chains

- Consider $\tau'_{ij} = 1 + s(\tau_{ij} - 1)$ for $s > 0$
- Very much resembles partial equilibrium model results



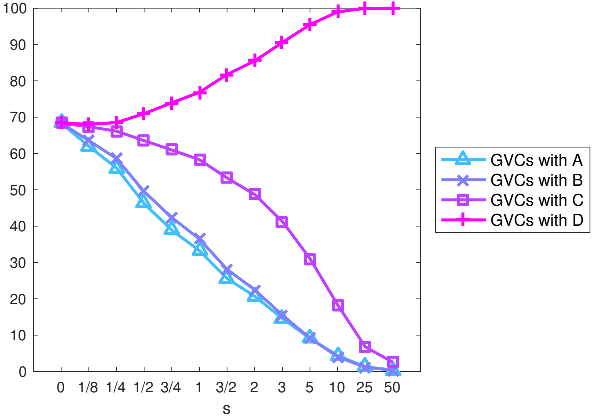



# Conclusions

- 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 quantitatively assess the implications of the rise of GVCs
- 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?

# An Example: Results

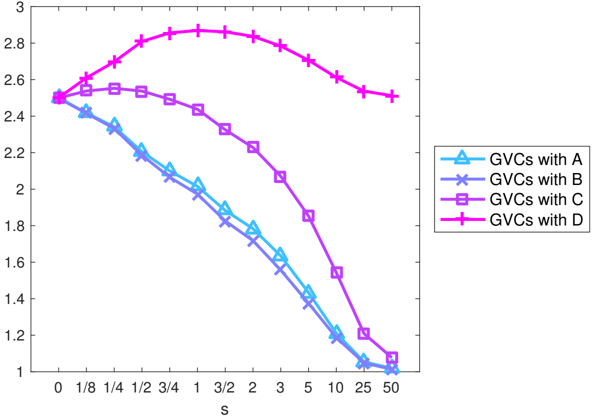
Figure: Average Propensity of Countries in GVCs Leading to Consumption in D




- $B$ appears more often than $A$ in GVCs leading to $D$

# An Example: Results

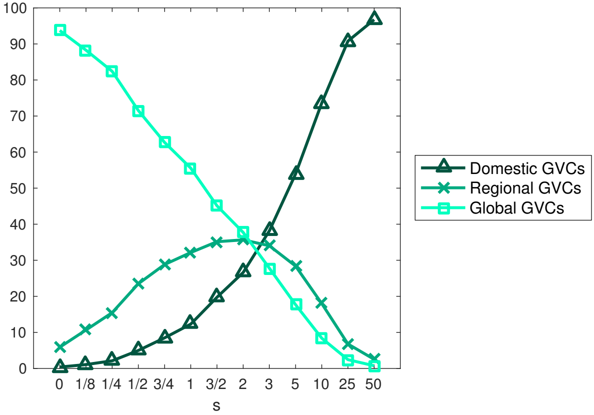
Figure: Average Upstreamness of Countries in GVCs Leading to Consumption in D




- Geography shapes the average position of a country in GVCs

# An Example: Results

Figure: Regional vs Global GVCs Leading to Consumption in D




- GVCs are first local, then regional and finally global

BACK