Global Value Chains and Aggregate Income Volatility

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EASE

Introduction

- Development of Global Value Chains (GVCs) is one of the most important features in the recent world economy
- Increased specialization $\rightarrow$ Aggregate income $\uparrow$
- What about their impact on income volatility?
    - Related question: Supply chain resilience

Motivation

- A shock in one country propagates to other countries through input-output linkages (Boehm, Flaaen, and Pandalai-Nayar, 2019; Caselli, Koren, Lisicky, and Tenreyro, 2020; Kashiwagi, Todo, and Matous, 2018)

- Network structure of GVC may aggregate idiosyncratic "micro" shocks into a "macro" shock (Gabaix, 2011; Acemoglu, Carvalho, Ozdaglar, and Tahbaz-Salehi, 2012; Baqaee and Farhi, 2019; Carvalho, 2014)

What we do

- Develop a framework to quantify the general equilibrium impact of GVC on the level and volatility of aggregate income of the world and countries

- Model
  - A multi-country Ricardian model of GVC with input-output linkages
  - Eaton and Kortum (2002), Caliendo and Parro (2015) +
    - Quality shocks as well as productivity shocks
    - Distinction between final and intermediate goods

- Data
  - Multi-region IO tables: World Input-Output Database
  - Preferential and MFN tariffs: UNCTAD TRAINS
  - 36 countries (88% world GDP), 31 sectors (16 tradable), 14 years (1996-2009)

Departure from Caselli, Koren, Lisicky, Tenreyro (2020)

- Quality shocks as well as productivity shocks
- Enable to shut down only trade of intermediates to examine the impact of GVC
- Level effect as well as volatility effect

Methodology

- $W_{it}(d, r)$: country i's real wage at time t in state (d, r)
  - d: Extent of GVC (treatment variable)

$$d = \begin{cases} 1 & \text{with GVC} \\ 0 & \text{without GVC (intermediates' trade costs} = \infty) \end{cases}$$

  - $r = 0, 1, \cdots$: State of idiosyncratic shocks
  - $(d, r) = (1, 0)$: Actual realization
- Our goal is to estimate

$$M\hat{W}_{it} = \frac{E_r\left[W_{it}(1, r)\right]}{E_r\left[W_{it}(0, r)\right]} = \frac{E_r\left[W_{it}(1, r)/W_{it}\right]}{E_r\left[W_{it}(0, r)/W_{it}\right]} = \frac{E_r\left[\hat{W}_{it}(1, r)\right]}{E_r\left[\hat{W}_{it}(0, r)\right]}$$

$$V\hat{W}_{it} = \frac{\sqrt{Var_r\left[W_{it}(1, r)\right]}}{\sqrt{Var_r\left[W_{it}(0, r)\right]}} = \frac{\sqrt{Var_r\left[\hat{W}_{it}(1, r)\right]}}{\sqrt{Var_r\left[\hat{W}_{it}(0, r)\right]}}$$

Identification of Idiosyncratic Shocks

- Factor analysis (Foerster, Sarte, and Watson, 2011; Choi, Kim, Kim, and Kwark, 2018)
    - Estimate productivity shocks and quality shocks
    - Estimate the stochastic processes of shocks by a factor model
    - Simulate 100 samples of idiosyncratic shocks

Identification of Exogenous Factor of GVC

- Counterfactual analysis of a Ricardian model
  - Identify exogenous main determinants of GVC
  - Technology vs factor endowment vs trade costs
- Find that a reduction in trade costs is the main factor

Main Finding

- Trade cost is the main determinant of GVC.
- Idiosyncratic shocks account for 1/3 of total technology shocks.
- GVC increased both the level and volatility of real wage

	World	Average Country
Mean real wage in 2007	-5.6%	-6.57%
Real wage volatility in 2007	-10.3%	-11.73%

- Impacts are large in low-income and less-populated countries

Model

- $i, n = 1, ..., N$ countries
- $s = 1, ..., S$ industries of Eaton-Kortum type Ricardian
  - $u \in \{f, m\}$: two usages (final goods and intermediate goods)
  - Each usage u in industry s consists of a continuum of varieties $\omega^{su} \in [0, 1]$.
  - Usages differ only in trade costs and share the same technology
- One factor: Labor
- Perfect competition
- Static model where trade balances are exogenously given

Consumers

- Country n representative consumer's utility

$$U_n = \prod_{s=1}^{S} \left(Q_{nt}^{sf} \right)^{\alpha_n^s}, \; Q_{nt}^{sf} = \left[\int_0^1 \underbrace{q_{nt}^{sf*} \left(\omega^{sf} \right)^{\frac{\sigma^{sf}-1}{\sigma^{sf}}}}_{Quality-adjusted\ Consumption} d\omega^{sf} \right]^{\frac{\sigma^{sf}}{\sigma^{sf}-1}}$$

$$q_{nt}^{sf*} \left(\omega^{sf} \right) = \sum_{i=1}^{n} \underbrace{\kappa_{it}^{s}}_{Quality\ Shock} q_{nit}^{sf} \left(\omega^{sf} \right)$$

- Quality normalization

$$\frac{1}{N} \sum_{i=1}^{N} \ln \kappa_{it}^{s} = 0.$$

Producers

- Production of ω^{su} in industry s in country n

$$y_{nt}\left(\omega^{su}\right) = \underbrace{A^s_{nt}}_{TFP\ shock}\ \underbrace{z_n\left(\omega^{su}\right)}_{Frechet}\left({l_{nt}}^{\beta^s_n}\prod_{k=1}^{S} {m^{sk}_{nt}}^{\beta^{sk}_n}\right);\ \beta^s_n + \sum_{k=1}^{S}\beta^{sk}_n = 1$$

$$m^{sk}_{nt} = \left(\int_0^1 \underbrace{\tilde{m}^{*sk}_{nt}\left(\omega^{km}\right)^{\frac{\sigma^{km}-1}{\sigma^{km}}}}_{Quality-adjusted\ input} d\omega^{km}\right)^{\frac{\sigma^{km}}{\sigma^{km}-1}}$$

$$\tilde{m}^{*sk}_{it}\left(\omega^{km}\right) = \sum_{i=1}^{N}\underbrace{\kappa^k_i}_{Quality\ Shock}\ \tilde{m}^{sk}_{nit}\left(\omega^{km}\right)$$

- β_n: from Input-Output tables
- Productivity-quality combined shocks

$$\Lambda^s_{it} \equiv \left(A^s_{it}\kappa^s_{it}\right)^{\theta^s}$$

θ^s: Fréchet parameter.

Equilibrium with the hat algebra

$\left\{\hat{w}_{it}, \hat{c}^s_{it}, \hat{P}^{su*}_{it}, \hat{\pi}^{su}_{int}, \hat{X}^{su}_{nt}\right\}$ satisfy the following conditions:

$$\hat{c}^s_{it} = \hat{w}_{it}^{\beta^s_i} \prod_{k=1}^{S} \left(\hat{P}^{km*}_{it}\right)^{\beta^{sk}_i} \tag{1}$$

$$\left(\hat{P}^{su*}_{nt}\right)^{-\theta^s} = \sum_{h=1}^{N} \pi^{su}_{nh0} \hat{\Lambda}^s_{ht} \left(\hat{c}^s_{ht} \hat{d}^{su}_{nht}\right)^{-\theta^s} \tag{2}$$

$$\hat{\pi}^{su}_{nit} = \frac{\hat{\Lambda}^s_{it} \left(\hat{c}^s_{it} \hat{d}^{su}_{nit}\right)^{-\theta^s}}{\left(\hat{P}^{su*}_{nt}\right)^{-\theta^s}} \tag{3}$$

$$X^{sf\prime}_{nt} = \alpha^s_n \left[\hat{w}_{nt} \hat{L}_{nt} w_{n0} L_{n0} + \sum_{s=1}^{S} \sum_{i=1}^{N} \frac{\tau^{s\prime}_{nit}}{1 + \tau^{s\prime}_{nit}} (\pi^{sf\prime}_{nit} X^{sf\prime}_{nt} + \pi^{sm\prime}_{nit} X^{sm\prime}_{nt}) + TD^{\prime}_{nt}\right] \tag{4}$$

$$X^{sm\prime}_{nt} = \sum_{k=1}^{S} \beta^{ks}_n \left(\sum_{i=1}^{N} \frac{\pi^{kf\prime}_{int}}{1 + \tau^{k\prime}_{int}} X^{kf\prime}_{it} + \sum_{i=1}^{N} \frac{\pi^{km\prime}_{int}}{1 + \tau^{k\prime}_{int}} X^{km\prime}_{it}\right) \tag{5}$$

$$TD^{\prime}_{nt} = \sum_{s=1}^{S} \sum_{i=1}^{N} \left(\frac{\pi^{sf\prime}_{nit} X^{sf\prime}_{nt} + \pi^{sm\prime}_{nit} X^{sm\prime}_{nt}}{1 + \tau^{s\prime}_{nit}} - \frac{\pi^{sf\prime}_{int} X^{sf\prime}_{it} + \pi^{sm\prime}_{int} X^{sm\prime}_{it}}{1 + \tau^{s\prime}_{int}}\right). \tag{6}$$

$$\frac{TD^{\prime}_{nt}}{\sum_i \hat{w}_{it} \hat{L}_{it} w_{i0} L_{i0}} = \frac{TD_{n0}}{\sum_i w_{i0} L_{i0}} \tag{7}$$

Parameter Estimation: θ^s

$$\pi_{nit}^{su} = \frac{\Lambda_{it}^{s} (c_{it}^{s} d_{nit}^{su})^{-\theta^s}}{\Phi_{nt}^{su}}$$

- Trade elasticities: a gravity model

$$\ln \pi_{nit}^{su} = -\theta^s \ln (1 + \tau_{nit}^{s}) + ex_{it}^{s} + im_{nt}^{su} + \sum_{k} TC_{ni,k} \left(\gamma_{kt}^{f} + I_{\{u=m\}} \gamma_{kt}^{m} \right) + \varepsilon_{nit}^{su}$$

for a sub-sample where bilateral tariff τ_{nit}^{s} are available

  - $TC_{ni,k}$: gravity controls (e.g. distance)

Estimated Trade Elasticities

Table: Trade Elasticities (Fréchet Parameters)

WIOD	Industry Description	Theta	Robust SE	n.obs
1	Agriculture, Hunting, Forestry and Fishing	6.26***	(0.54)	36,980
2	Mining and Quarrying	8.05***	(1.60)	33,654
3	Food, Beverages and Tobacco	7.31***	(0.39)	37,101
4	Textile Products, Leather Products and Footwear	6.31***	(0.32)	37,467
6	Wood and Products of Wood and Cork	9.12***	(0.60)	37,133
7	Pulp, Paper, Paper, Printing and Publishing	11.37***	(0.71)	37,394
8	Coke, Refined Petroleum and Nuclear Fuel	6.10***	(0.95)	36,633
9	Chemicals and Chemical Products	6.31***	(0.54)	37,470
10	Rubber and Plastics	6.22***	(0.41)	37,433
11	Other Non-Metallic Mineral	4.78***	(0.47)	37,391
12	Basic Metals and Fabricated Metal	7.78***	(0.54)	37,446
13	Machinery, Nec	7.43***	(0.46)	37,480
14	Electrical and Optical Equipment	9.69***	(0.78)	37,166
15	Transport Equipment	7.13***	(0.40)	36,946
16	Manufacturing, Nec; Recycling	8.01***	(0.52)	37,438

***: 1% significance

Parameter Estimation: Trade costs by the Head and Ries Index

- Use $d^{su}_{nit} = (1 + \tau^{s}_{nit})D^{su}_{nit}$, $\pi^{su}_{nit} = \Lambda^{s}_{it}(c^{s}_{it}d^{su}_{nit})^{-\theta^{s}}/\Phi^{su}_{nt}$, and $D^{su}_{nit} = D^{su}_{int}$
- $\frac{\pi^{su}_{nit}\pi^{su}_{int}}{\pi^{su}_{nnt}\pi^{su}_{iit}} = \frac{\Lambda^{s}_{it}(c^{s}_{it}d^{su}_{nit})^{-\theta^{s}}}{\Lambda^{s}_{nt}(c^{s}_{nt}d^{su}_{nnt})^{-\theta^{s}}}\frac{\Lambda^{s}_{nt}(c^{s}_{nt}d^{su}_{int})^{-\theta^{s}}}{\Lambda^{s}_{it}(c^{s}_{it}d^{su}_{iit})^{-\theta^{s}}}$
- $$\ln d^{su}_{nit} = \frac{1}{2}\ln\left(\frac{1+\tilde{\tau}^{s}_{nit}}{1+\tilde{\tau}^{s}_{int}}\right) + \frac{1}{2\theta^{s}}\ln\frac{\pi^{su}_{nnt}\pi^{su}_{iit}}{\pi^{su}_{nit}\pi^{su}_{int}}$$

  where $\tilde{\tau}^{s}_{int}$ is quasi-bilateral tariffs:

  $$\tilde{\tau}^{s}_{int} = \begin{cases} 0 & \text{if } i = j \text{ or } i \text{ and } j \text{ sign a FTA/CU at } t \\ \text{MFN tariff} & \text{otherwise} \end{cases}$$

Parameter Estimation: Productivity and Quality Shocks

- Estimate the gravity equation:

$$\ln \pi_{nit}^{su} + \theta^s \ln d_{nit}^{su} = ex_{it}^s + im_{nt}^{su} + \varepsilon_{nit}$$

  - $e\hat{x}_{it} = \ln S_{it} - \ln S_{bt} \Rightarrow \frac{1}{N}\sum_i e\hat{x}_{it} = \frac{1}{N}\sum_i \ln S_{it} - \ln S_{bt}$
    - $\pi_{nit}^{su} = \Lambda_{it}^s (c_{it}^s d_{nit}^{su})^{-\theta^s} / \Phi_{nt}^{su}$
    - $S_{it} \equiv \Lambda_{it} c_{it}^{-\theta}$; $\Lambda_{it} = (\kappa_{it} A_{it})^\theta$
- Change in price deflator:

$$d \ln \tilde{P}_{it} = d \ln c_{it} - d \ln A_{it}$$

- Hence

$$\begin{aligned} d \ln S_{it} &= d \ln \kappa_{it}^\theta + d \ln A_{it}^\theta - d \ln c_{it}^\theta \\ &= d \ln \kappa_{it}^\theta - d \ln \tilde{P}_{it}^\theta \end{aligned}$$

- Thus we obtain from $\sum_i \ln \kappa_{it} = 0$ that

$$d \ln S_{it} = d e\hat{x}_{it} - \frac{1}{N}\sum_{i=1}^{N} d e\hat{x}_{it} + \frac{1}{N}\sum_{i=1}^{N} d \ln S_{it}$$

$$= d e\hat{x}_{it} - \frac{1}{N}\sum_{i=1}^{N} d e\hat{x}_{it} - \frac{1}{N}\sum_{i=1}^{N} d \ln \tilde{P}_{it}^\theta$$

Productivity and Quality Shocks

- Change in quality: $d\ln\kappa_{it}^{\theta} = d\ln S_{it} + d\ln\tilde{P}_{it}^{\theta}$
- Change in quality and productivity combined:

$$d\ln\Lambda_{it} = (I - B_i)\left(d\ln\kappa_{it}^{\theta} - d\ln\tilde{P}_{it}^{\theta}\right) + d\ln W_{it}^{\beta\theta} + B_i d\ln\pi_{iit}^{m}$$

  - $$\begin{aligned} d\ln\Lambda_{it} &= d\ln S_{it} + d\ln c_{it}^{\theta} \\ &= d\ln S_{it} + d\ln W_{it}^{\beta\theta} + B_i d\ln P_{it}^{m*\theta} \end{aligned}$$
  - $d\ln P_{it}^{m*\theta} = d\ln\pi_{iit}^{m} - d\ln S_{it} \leftarrow \pi_{iit}^{m} = S_{it}(d_{iit}^{m})^{-\theta}/\Phi_{it}^{m}$
- Change in productivity:

$$d\ln A_{it} = \frac{1}{\theta} d\ln\Lambda_{it} - d\ln\kappa_{it}$$

Factor Analysis

- Three level model

$$
\begin{aligned}
d \ln \tilde{A}^{s}_{it} &= \zeta^{gA}_{is} f^{gA}_{t} + \zeta^{cA}_{is} f^{cA}_{it} + \zeta^{sA}_{is} f^{sA}_{st} + \varepsilon^{A}_{ist} \\
d \ln \tilde{\kappa}^{s}_{it} &= \zeta^{g\kappa}_{is} \underbrace{f^{g\kappa}_{t}}_{Global} + \zeta^{c\kappa}_{is} \underbrace{f^{c\kappa}_{it}}_{Country} + \zeta^{s\kappa}_{is} \underbrace{f^{s\kappa}_{st}}_{Sector} + \underbrace{\varepsilon^{\kappa}_{ist}}_{Idiosyncratic}
\end{aligned}
$$

- Assume $f^{gx}_{t} \perp f^{cx}_{it} \perp f^{sx}_{st} \perp \varepsilon^{x}_{ist}$ for $x \in \{A, \kappa\}$ and
- Extract factors sequentially: $f^{gx}_{t} \to f^{cx}_{it} \to f^{sx}_{st}$

Country-industry of High Volatility

Country	Industry	SD
TWN	Manufacturing, Nec; Recycling	2.5868196
RUS	Coke, Refined Petroleum and Nuclear Fuel	1.9672805
EST	Coke, Refined Petroleum and Nuclear Fuel	1.7173226
RUS	Mining and Quarrying	1.6548905
TUR	Mining and Quarrying	1.3434079
EST	Transport Equipment	1.2471193
EST	Electrical and Optical Equipment	1.19832
TWN	Coke, Refined Petroleum and Nuclear Fuel	1.1458762
BGR	Coke, Refined Petroleum and Nuclear Fuel	1.1320783
RUS	Pulp, Paper, Paper , Printing and Publishing	1.1081882

Variance Decomposition

Variable	Volatility	Variance Share of Component			
		Global	Country	Sector	Idiosyncratic
	(1)	(2)	(3)	(4)	(5)
Productivity	0.517	0.201	0.372	0.165	0.297
Quality	0.676	0.190	0.453	0.109	0.276

note: volatility is standard deviation; Productivity and Quality are multiplied with theta

Re-sampling Idiosyncratic Shocks

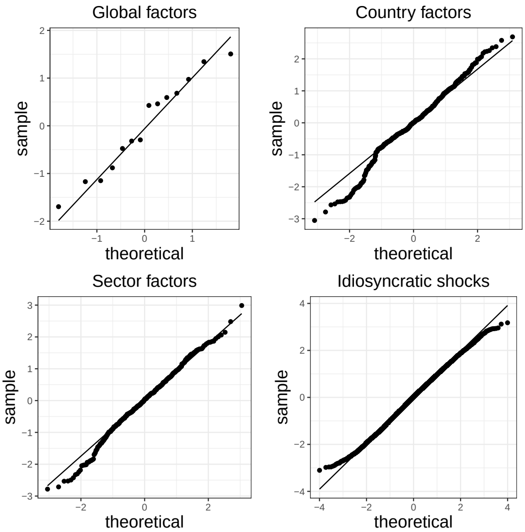
- Simulate 100 re-sampled shocks $\{(\hat{\Lambda}_{it}^{s}(r))_{i=1}^{N}\}_{r=1}^{100}$, assuming iid normal with country-sector specific variances

$$\hat{\varepsilon}_{ist}^{A}(r) \sim N(0, \hat{\sigma}_{Ais}^{2})$$
$$\hat{\varepsilon}_{ist}^{\kappa}(r) \sim N(0, \hat{\sigma}_{\kappa is}^{2})$$

$\hat{\sigma}_{Ais}^{2}$, $\hat{\sigma}_{\kappa is}^{2}$: sample variances over $T = 14$ years

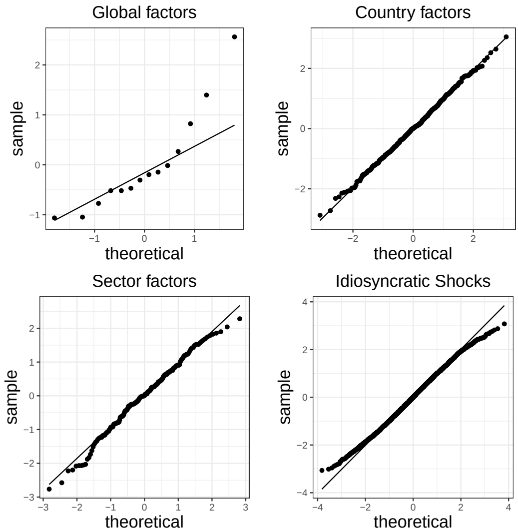
Fitness of the Estimated Shock Distribution: Productivity

Figure: QQ Normality Plots: Productivity

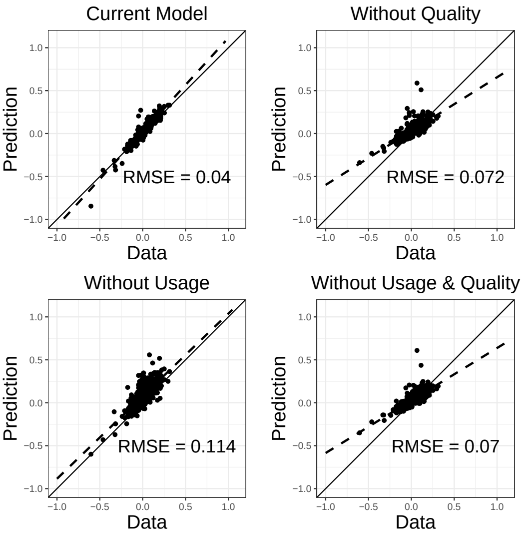


Fitness of the Estimated Shock Distribution: Quality

Figure: QQ Normality Plots: Quality



Model Evaluation: Per Capita Income Growth

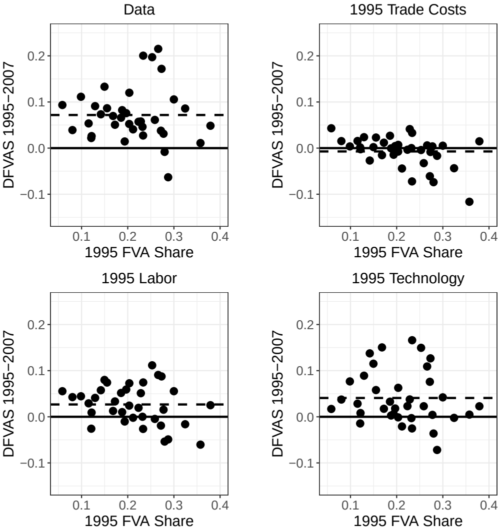


Dashed lines: OLS fits

Identify GVC Drivers

- Measure of GVC integration:
  - FVA share: Foreign value added share in manufacturing value added (Timmer, Erumban, Los, Stehrer, and de Vries, 2014; Los, Timmer, and de Vries, 2015)
- Identification of GVC drivers
  - Counterfactual 2007 FVA share under 1995 technology, endowment and trade costs

GVC Driver = Trade Costs



Dashed lines: OLS fits

GVC's Impacts on Country's Income

		Counterfactual Scenarios			
		Trade Costs 1995	No GVC	No Final Trade	Autarky
Mean Real Wage Change in 2007	Mean	-2.36%	-6.57%	-5.95%	-11.71%
	SE	(0.40)	(0.63)	(0.67)	(1.14)
Real Wage Volatility Change in 2007	Mean	-2.64%	-11.73%	-10.22%	-19.22%
	SE	(1.30)	(1.56)	(1.77)	(2.73)
Number of Countries		35	35	33	33

Role of Country Size

Conclusion

- We incorporate two usages, final and intermediate, for all goods into Caliendo and Parro (2015)
- Use factor analysis to identify shocks
- Generate idiosyncratic shocks to find GVC increases both mean and volatility of real wages
- Future extensions: We examine the effect of supply chain disruption at the HS 3-digit industry level
  - Geopolitical shocks
  - Global shocks that affect trade costs