

Knowledge Spillovers, Innovation and Trade across Countries and Sectors

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¹The views of this presentation do not represent the views of the Federal Reserve Bank of St. Louis or the Federal Reserve System.

Motivation

- ▶ Empirical studies find that export market access and import competition affect firms' innovation outcome. (Bloom, Draca and Van Reenen (2015), Autor, Dorn and Hanson (2016), Coelli, Moxnes and Ulltveit-Moe (2017))

This paper:

- ▶ What is the general equilibrium effect of trade on innovation and welfare?
- ▶ What is the role of knowledge diffusion in shaping the gain from trade?

This paper

- ▶ Develop multi-sector, multi-country model of trade with two endogenous sources of growth:
 - ▶ Innovation: country-sectors differ in innovation efficiency and production productivity
 - ▶ Knowledge spillovers across countries and sectors (Keller 2010, Coe and Helpman 1995, Cai and Li 2018).
- ▶ Solve for BGP of the model.
- ▶ Calibrate model to account for cross-country and cross-sector heterogeneity in productivity, the efficiency of innovation, and knowledge linkages.
- ▶ Quantify trade liberalisation's impact on growth, innovation and welfare.

Preview of Main Findings

What is the impact of trade liberalisation on welfare?

- ▶ Welfare gains from trade between 1.4 and 3 times larger than in static model.
- ▶ Standard gains from trade through specialisation in production and lower prices.
- ▶ Innovation and knowledge spillovers create additional channels for welfare gains:
 - ▶ R&D input reallocates towards sectors with comparative advantage in production and innovation and higher world demand.
 - ▶ Heterogenous Knowledge linkages redistribute the outcome of R&D reallocation.

Preview of Main Findings

What is the role of knowledge networks?

- ▶ If all country-sector pairs learn from each other at the same rate, then all country-sectors have the same productivity.
- ▶ In the calibrated model, country-sector with higher productivity learns preferentially faster from more efficient innovators.
- ▶ More efficient innovators also diffuse their knowledge to other country-sectors faster than other innovators.

Preview of Main Findings

What is the interaction of knowledge linkages and trade liberalization?

- ▶ After trade liberalisation, productivity dispersion enlarges because more efficient innovators create more knowledge than before and previously high productivity country-sectors learn faster from them.
- ▶ Meanwhile, global growth rate is higher after trade liberalisation, because more efficient innovators now create more knowledge and spread knowledge faster to other places than inefficient innovators.
- ▶ If all country-sector pairs learn from each other at the same rate, growth rate increases only a negligible amount.
- ▶ Welfare gain depends crucially on the shape of knowledge networks.

Related papers

- ▶ Model of trade and endogenous technology adoption with symmetric countries to characterise analytically effect of trade on welfare and growth (Perla, Tonetti and Waugh 2015)
- ▶ One-sector quantitative trade model with innovation and diffusion to explain growth miracles (Buera and Oberfield 2017).
- ▶ Multi-sector model of innovation and diffusion within sector to propose a new source of comparative advantage. (Sampson 2018).
- ▶ Multi-sector semi-endogenous growth model of innovation and trade without diffusion to quantify effect of trade on income per capita (Somale 2018).

The Model

The Model: Set-up

- ▶ **Trade block:** Multi-sector and multi-country Ricardian model of trade with Bertrand competition. (Caliendo and Parro (2015))
 - Given distribution of technology and trade frictions, trade block determines static equilibrium of production and trade flow.
- ▶ **Growth block:** Technology evolves through endogenous R&D input and exogenous knowledge spillovers. (Multi-sector version of Eaton and Kortum (1999))
 - Growth block determines endogenous productivity growth and sources of comparative advantage.

The Model

Set-up

- ▶ M countries indexed by i and n .
- ▶ J sectors indexed by j and k .
- ▶ Time is continuous and indexed by t .

Representative household

- ▶ Preferences:

$$U(C_{nt}) = \int_t^{\infty} e^{-\rho(s-t)} \frac{C_{ns}^{1-\gamma}}{1-\gamma} ds$$

- ▶ Chooses consumption and finances innovators; receives labor income and profits from firms.

The Model

- ▶ **Final producer** in each country n :
 - ▶ Demands domestic composite good from each sector, Y_{nt}^j .
 - ▶ Produces non-tradable final good with perfect competition.

$$Y_{nt} = \prod_{j=1}^J \left(Y_{nt}^j \right)^{\alpha^j},$$

with $\alpha^j \in [0, 1]$, and $\sum_{j=1}^J \alpha^j = 1$.

- ▶ **Composite good producer** in each sector j and country n :
 - ▶ Uses traded intermediate products from that sector, r_{nt}^j .
 - ▶ Produces non-tradable composite good, Q_{nt}^j , with perfect competition.

$$Q_{nt}^j = \left(\int r_{nt}^j(\omega)^{1-1/\sigma} d\omega \right)^{\sigma/(\sigma-1)}$$

where $\sigma > 0$.

The Model

- ▶ Continuum of traded **intermediate producers** in each sector j and country n :
 - ▶ Use labor, l_{nt}^j , and domestic composite output from each other sector k in that country, m_{nt}^{jk} .
 - ▶ Heterogeneous in their productivity, z_{nt}^j , and Bertrand competition.

$$q_{nt}^j(\omega) = z_{nt}^j(\omega) [l_{nt}^j(\omega)]^{\gamma^j} \prod_{k=1}^J [m_{nt}^{jk}(\omega)]^{\gamma^{jk}},$$

with $\gamma^j + \sum_{k=1}^J \gamma^{jk} = 1$

- ▶ Trade subject to iceberg transport costs, $d_{ni}^j > 1$.

International Trade

- ▶ Productivity of each intermediate good in country i and sector j , z_i^j , drawn from a Fréchet distribution.

$$F(z_i^j) = Pr [Z \leq z_i^j] = e^{-T_{it}^j z^{-\theta}}$$

with $(T_{it}^j)^{1/\theta}$ the fundamental productivity of sector j in country i .

- ▶ Fraction of goods sector j in country n buys from country i .

$$\pi_{nit}^j = \frac{T_{it}^j (c_{it}^j d_{ni}^j)^{-\theta}}{\Phi_{nt}^j}$$

with c_{it}^j the cost of production, d_{ni}^j iceberg transport costs, and $\Phi_{nt}^j = \sum_{i=1}^M T_{it}^j (c_{it}^j d_{ni}^j)^{-\theta}$.

- ▶ In our model T_{it}^j evolves endogenously through innovation and knowledge spillovers.

Innovation: Knowledge Creation

- ▶ In each sector j , a continuum of entrepreneurs create new ideas to produce an intermediate good with a higher efficiency.
- ▶ Entrepreneurs in sector j and country n invest final output, S_{nt}^j , to create a new idea at rate

$$\lambda_n^j T_{nt}^j (s_{nt}^j)^{\beta_r}$$

with $\lambda_n^j > 0$ the efficiency of innovation, $\beta_r \in (0, 1)$ and $s_{nt}^j = \frac{S_{nt}^j}{Y_{nt}}$.

- ▶ An idea in country n sector j is a blueprint that, if successful, can be used to produce an intermediate good in that country and sector with productivity z_{nt}^j .
- ▶ An idea is successful if it surpasses the productivity of the most productive intermediate producer, which occurs with probability $1/T_{nt}^j$.

The Incentives to Innovate

- ▶ Entrepreneurs choose R&D spending, s_{nt}^j , to maximize

$$\lambda_n^j T_{nt}^j \left(s_{nt}^j \right)^{\beta_r} V_{nt}^j - s_{nt}^j P_{nt} Y_{nt}$$

- ▶ Optimal R&D investment

$$s_{nt}^j = \left(\frac{\beta_r \lambda_{nt}^j T_{nt}^j V_{nt}^j}{P_{nt} Y_{nt}} \right)^{\frac{1}{1-\beta_r}}$$

- ▶ The value of an innovation, V_{nt}^j is given by

$$V_{nt}^j = \int_t^\infty \left(\frac{P_{nt}}{P_{ns}} \right) e^{-\int_t^s r_{nu} du} \frac{1}{T_{ns}^j} \frac{\sum_{i=1}^M \pi_{ins}^j X_{is}^j}{1+\theta} ds$$

with X_i^j total spending of country i sector j .

Knowledge Spillovers

- ▶ Ideas diffuse exogenously across sectors and countries.
- ▶ The diffusion lag of an idea from k, i to j, n is exponentially distributed with parameter ε_{ni}^{jk} .
- ▶ The stock of knowledge, T_{nt}^j , evolves as

$$\dot{T}_{nt}^j = \sum_{i=1}^M \sum_{k=1}^J \varepsilon_{ni}^{jk} \int_{-\infty}^t e^{-\varepsilon_{ni}^{jk}(t-s)} \lambda_i^k T_{is}^k (s_{is}^k)^{\beta_r} ds$$

- ▶ If there were no diffusion (i.e., $\varepsilon_{ni}^{jk} = 0$, for $k \neq j$ and $i \neq n$),

$$\dot{T}_{nt}^j = \lambda_n^j T_{nt}^j (s_{nt}^j)^{\beta_r}$$

Closing the Model

- ▶ Labor market clearing condition

$$W_n L_n = \sum_{j=1}^J \gamma^j \sum_{i=1}^M \pi_{in}^j X_i^j$$

- ▶ Final production

$$Y_n = W_n L_n + \frac{\sum_{j=1}^J \sum_{i=1}^M \pi_{in}^j X_i^j}{1 + \theta}$$

- ▶ Sector production

$$X_n^j = \sum_{k=1}^J \gamma^{kj} \sum_{i=1}^M X_i^k \pi_{in}^k + \alpha^j P_n Y_n$$

- ▶ Resource constraint

$$Y_n = C_n + \sum_{k=1}^J s_n^k Y_n$$

Balanced Growth Path (BGP)

- ▶ Along the BGP variables grow at a constant rate that is common across countries and sectors.

$$g_T = \sum_{i=1}^M \sum_{k=1}^J \frac{\varepsilon_{ni}^{jk}}{g_T + \varepsilon_{ni}^{jk}} \lambda_i^k \frac{\hat{T}_i^k}{\hat{T}_n^j} \left(s_i^k\right)^{\beta_r}$$

- ▶ Knowledge diffusion and Frobenius theorem guarantee the economy converges to a unique BGP, $g_T = \hat{T}_n^j / T_n^j, \forall j, n$.

$$g_T T = \Delta(g_T) T$$

- ▶ We stationarise all variables so that they are constant in the BGP (we denote normalised variables with a hat).

The Mechanism

What is the effect of trade liberalisation on cross-sector R&D allocation?

- ▶ **Case 1 (Autarky):** Suppose all countries are closed from international trade in goods and services. That is, $d_{in}^j \rightarrow \infty, \forall i, n, j$. Relative R&D investment between two sectors j and j' can be rewritten as:

$$\left(\frac{s_n^j}{s_n^{j'}}\right)^{1-\beta_r} = \frac{\lambda_n^j X_{nn}^j}{\lambda_n^{j'} X_{nn}^{j'}}, \quad (1)$$

where X_{nn}^j is total domestic expenditure on sector j product.

- ▶ **Case 2 (Free Trade):** In the case of free trade, $d_{in}^j = 1$. The relative R&D investment between the same two sectors then becomes

$$\left(\frac{s_n^j}{s_n^{j'}}\right)^{1-\beta_r} = \frac{\lambda_n^j \frac{T_n^j (c_n^j)^{-\theta} / \sum_n T_n^j (c_n^j)^{-\theta}}{\lambda_n^{j'} \frac{T_n^{j'} (c_n^{j'})^{-\theta} / \sum_n T_n^{j'} (c_n^{j'})^{-\theta}}}{X^j}{X^{j'}}, \quad (2)$$

where $X^j = \sum_n X_n^j$ denotes the world demand for sector- j good.

Role of ε_{ni}^{jk}

- ▶ Heterogeneity of ε_{ni}^{jk} , generates the dispersion of \hat{T}_n^j .
- ▶ In the calibrated knowledge networks, ε_{jk}^{ni} . Diffusion speed by countries we find that efficient innovating country-sectors both learn from and diffuse knowledge to others faster than inefficient innovators, especially so among efficient innovators.
- ▶ Higher correlation between ε_{ni}^{jk} and $\lambda_i^k T_i^k (s_i^k)^{\beta_r}$ benefits everyone and increases the world growth rate g_T .
- ▶ Higher correlation between ε_{ni}^{jk} and $\lambda_n^j T_n^j (s_n^j)^{\beta_r}$ makes efficient innovators faster learners from other productive innovators at the same time, which causes greater dispersion across \hat{T}_n^j .

Role of Trade Liberalisation

- ▶ Induce higher growth rate
 - ▶ Higher correlation between s_i^k and $\lambda_i^k T_i^k$: reallocate more R&D resources towards country-sectors that are more efficient in research.
 - ▶ Higher correlation between s_i^k and ε_{ni}^{jk} : country-sectors that innovate more also diffuse knowledge faster to others.
- ▶ Enlarge productivity dispersion
 - ▶ Higher correlation between ε_{ni}^{jk} , $\lambda_n^j T_i^k$ and s_i^k : efficient innovators also learn faster from each other.

Calibration

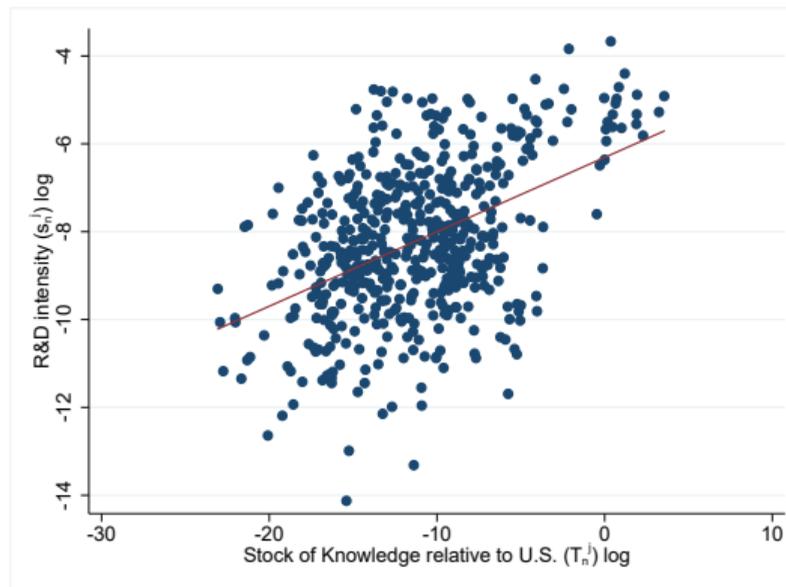
Calibration Strategy

- ▶ $M = 28$, $J = 19$ and $t = 2005$.
- ▶ **List of countries:** Australia, Austria, Belgium, Canada, China, Czech Republic, Estonia, Finland, France, Germany, Hungary, India, Israel, Italy, Japan, Korea, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovenia, Spain, Slovakia, Slovenia, the United Kingdom, and the United States.
- ▶ External parameters
 - ▶ Calibrate production parameters $\{\alpha^j, \gamma^j, \gamma^{jk}\}$ using I/O tables from OECD.
 - ▶ Estimate diffusion parameters ε_{ni}^{jk} using patent citation data.
 - ▶ Fix income per capita growth along the BGP to $g_Y = 0.03$. This implies growth of knowledge stock, $g_T = 0.12$

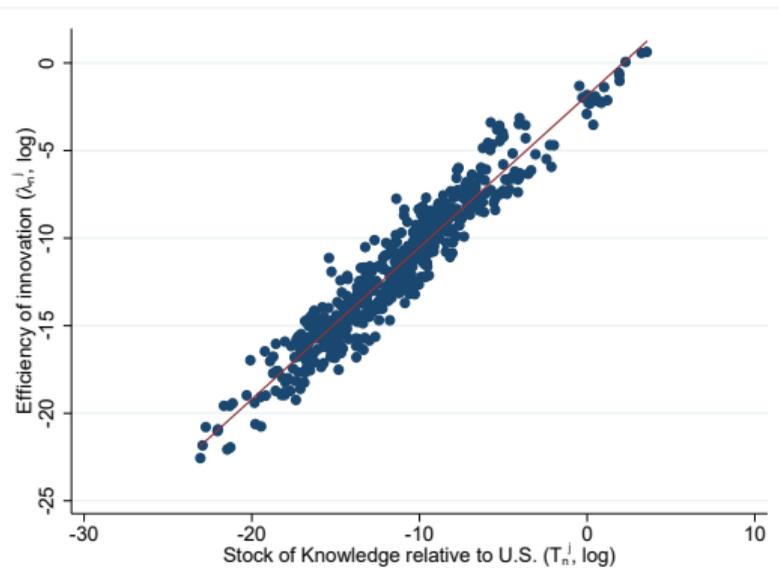
Calibration Strategy: $\{\hat{T}_n^j, d_{in}^j, \lambda_n^j, \beta_r\}$

- ▶ **Trade block:** With calibrated $\{\alpha^j, \gamma^j, \gamma^{jk}\}$, data on trade flows and distance dummies, and $\theta = 4$:
 - ▶ Estimate gravity equation for each sector to recover the distribution of productivity relative to the U.S. (\hat{T}_i^j) and trade barriers d_{ni}^j (Levchenko and Zhang 2016).
 - ▶ Given \hat{T}_n^j and production parameters, use market clearing conditions to obtain static equilibrium: wages, income per capita, prices and trade shares.
- ▶ **Growth block:** Given static equilibrium, recursive algorithm to obtain $\{\lambda_n^j, \beta_r\}$ using:
 - ▶ Data on R&D intensity, s_n^j , is taken from OECD STAN database.
 - ▶ Calibrated knowledge networks, ε_{jk}^{ni} . Diffusion speed by countries and Diffusion speed by sectors
 - ▶ Calibrate β_r from growth rate equation along the BGP to match $g_T = 0.12$.
 - ▶ We obtain $\beta_r = 0.79$.

Stock of knowledge, efficiency in innovation and R&D intensity



R&D intensity and technology



Efficiency of innovation and technology

Quantitative Results

Counterfactual Analysis

- ▶ Start from initial BGP given the estimated distribution of productivity and trade barriers.
- ▶ Uniform reduction in trade barriers ($d_{ni}^j - 1$) of 20%.
- ▶ Compute counterfactual BGP for new distribution of productivity and trade barriers.
- ▶ What is the effect of trade liberalization on growth, innovation and welfare?

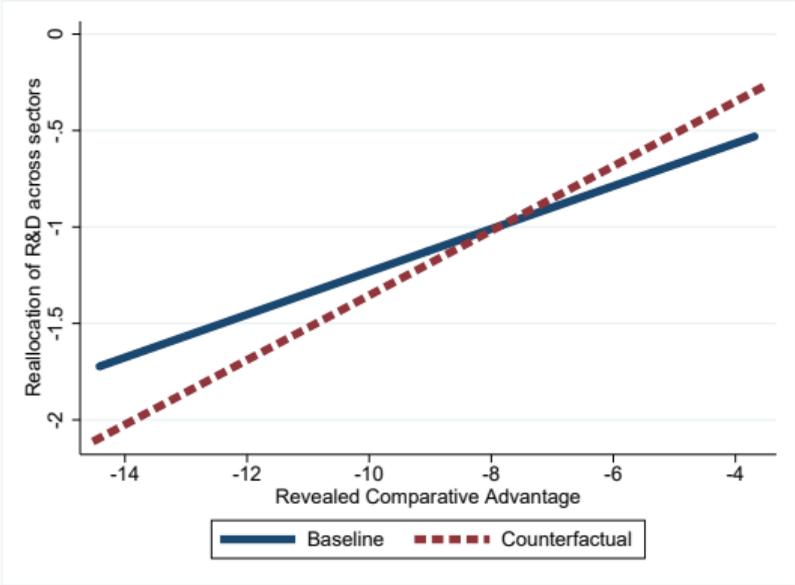
Growth Effects

$$g_T = \sum_{i=1}^M \sum_{k=1}^J \frac{\varepsilon_{ni}^{jk}}{g_T + \varepsilon_{ni}^{jk}} \lambda_i^k \frac{\hat{T}_i^k}{\hat{T}_n^j} \left(s_i^k\right)^{\beta_r}$$

Growth	Baseline	Counterfactual	% Change
g_T	12%	13.4%	11.42%
g_y	3.0%	3.35%	11.67%

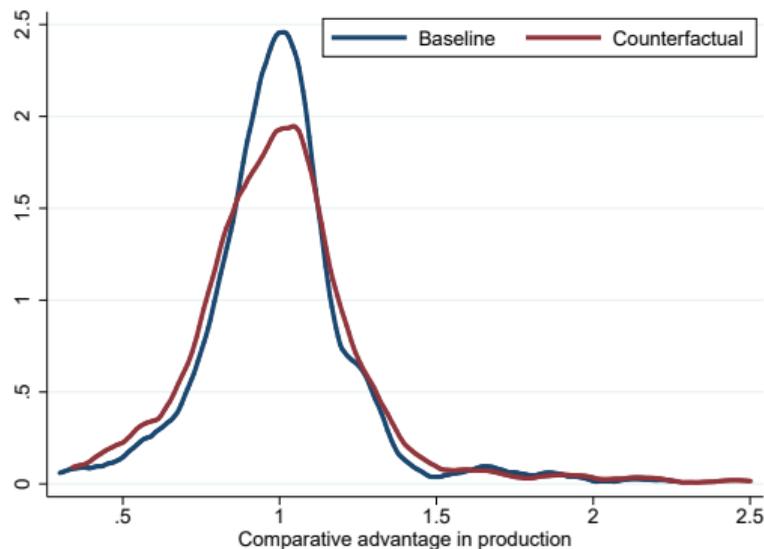
Reallocation of R&D Input

R&D reallocation



Endogenous Comparative Advantage

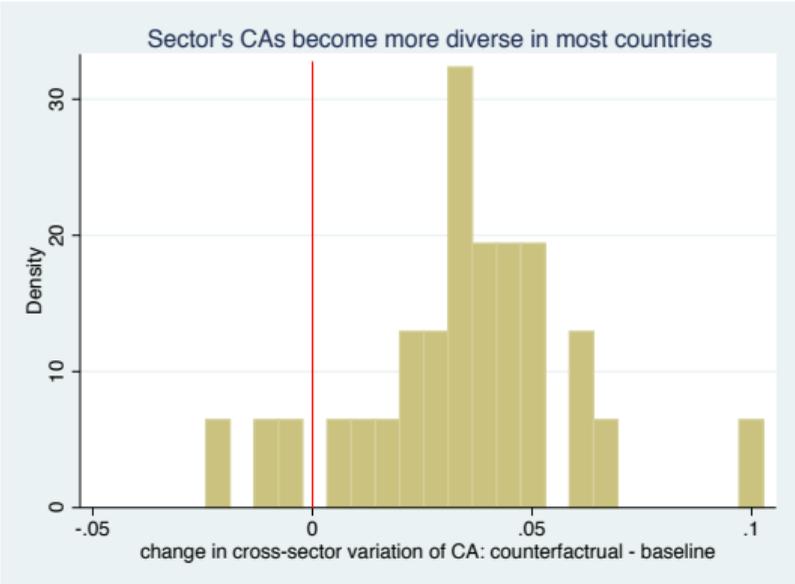
Comparative advantage becomes more disperse after trade liberalisation



Comparative advantage in production calculated as $\frac{\hat{\tau}_n^j / \sum_n \hat{\tau}_n^j}{\sum_j \hat{\tau}_n^j / \sum_j \hat{\tau}_n^j}$

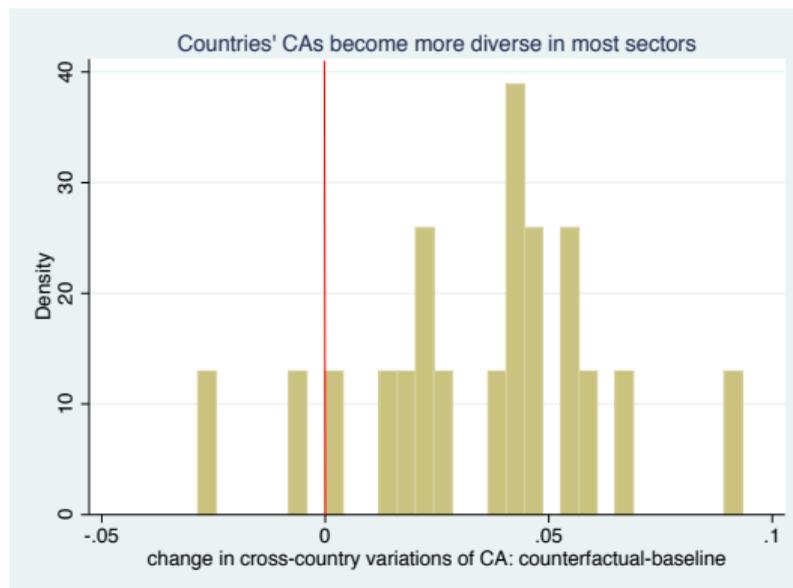
Endogenous Comparative Advantage

Relative productivity within country across sectors



Endogenous Comparative Advantage

Relative productivity within sector across countries



Welfare

- ▶ Welfare gains measured in consumption-equivalent units.
- ▶ Define λ_i : How much additional consumption does the consumer need every period along the baseline BGP to be indifferent between that and the counterfactual BGP.

$$\int_{t=0}^{\infty} e^{-\rho t} u \left(C_{it}^* \frac{1 + \lambda_i}{100} \right) dt = \int_{t=0}^{\infty} e^{-\rho t} u(C_{it}^{**}) dt$$

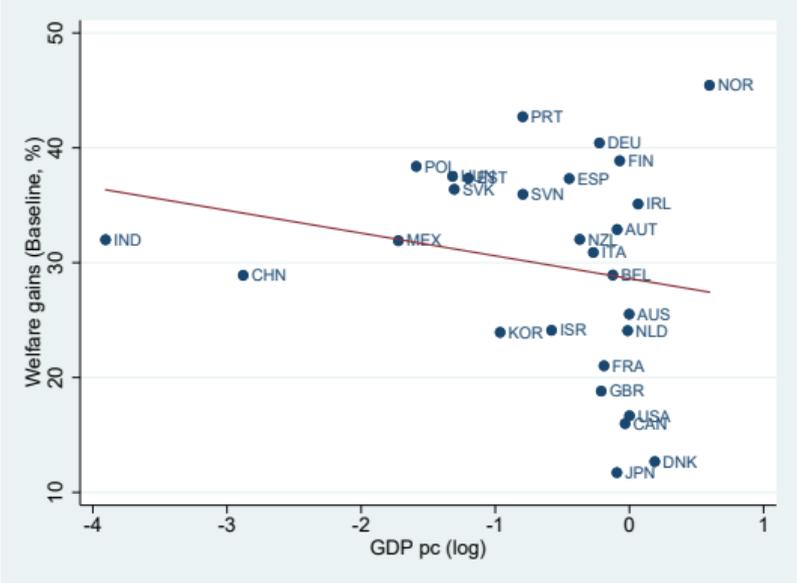
- ▶ Taking into account that consumption growth along BGP

$$\int_{t=0}^{\infty} e^{-\rho t} u \left(\hat{C}_i^* e^{g^* t} \frac{1 + \lambda_i}{100} \right) dt = \int_{t=0}^{\infty} e^{-\rho t} u(\hat{C}_i^{**} e^{g^{**} t}) dt$$

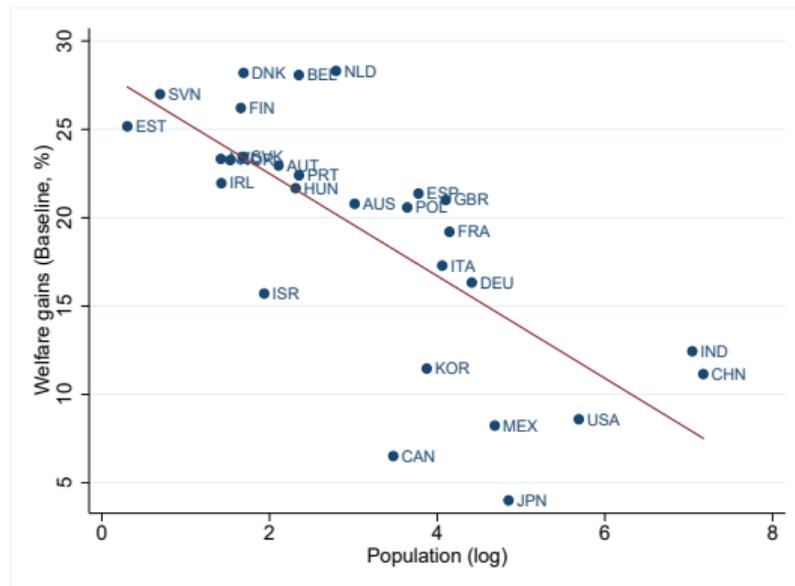
- ▶ Welfare gains:

$$\frac{1 + \lambda_i}{100} = \frac{\hat{C}_i^{**}}{\hat{C}_i^*} \left(\frac{\rho - g^*(1 - \gamma)}{\rho - g^{**}(1 - \gamma)} \right)^{\frac{1}{1-\gamma}}$$

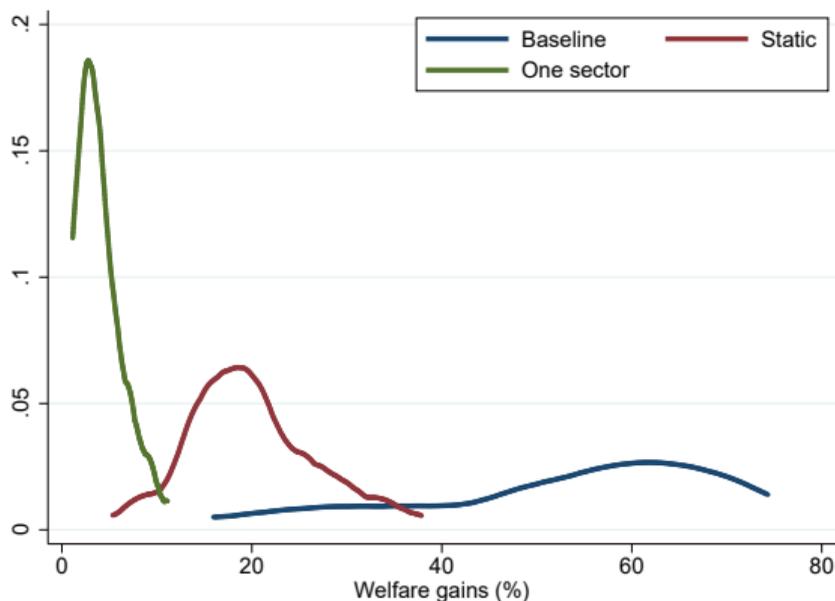
Welfare Gains from Trade by GDP per Capita



Welfare Gains from Trade by Population



Welfare Gains from Trade in Different Senarios



Welfare %	Mean	StDev.	Min	Max
Baseline	53	16	16	74
Static	20	7.0	5.0	38
One sect.	4.0	2.0	1.0	11

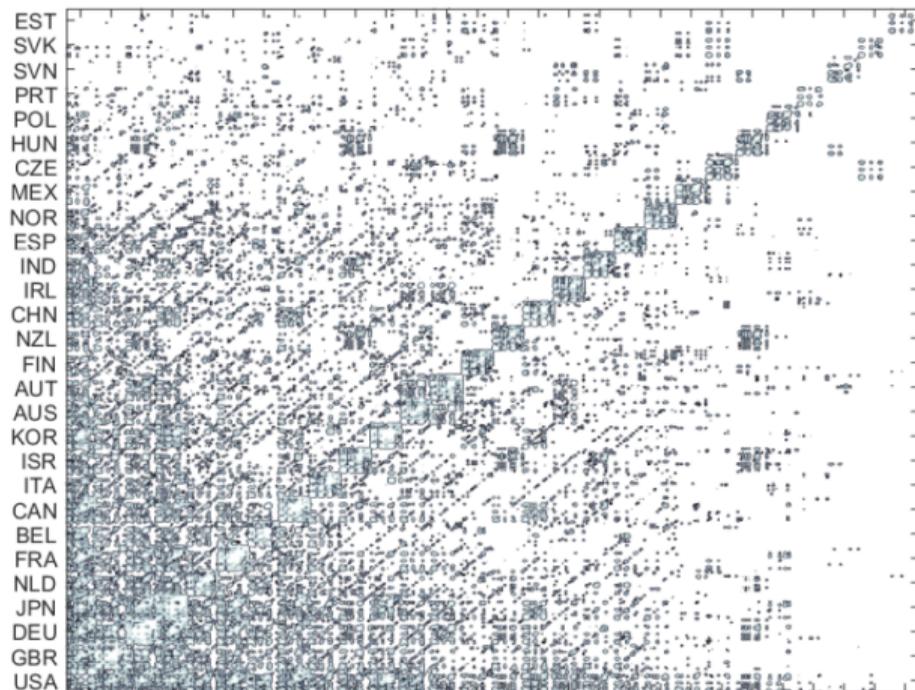
Conclusions

- ▶ We have quantified an endogenous growth multi-sector model of trade with rich heterogeneity in production linkages, innovation and knowledge spillovers.
- ▶ Innovation and knowledge spillovers are sources of comparative advantage and result in welfare gains from trade substantially larger than what static models would predict.
- ▶ We are using our framework to do the following counterfactuals:
 - ▶ Model with no diffusion
 - ▶ Trade war between U.S. and China

Data: Speed of diffusion by country

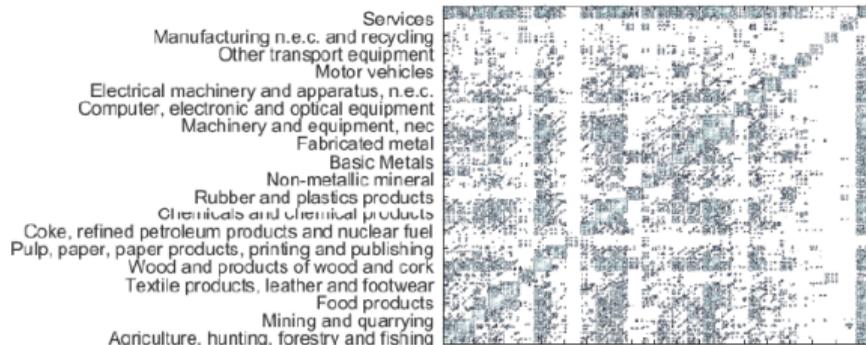
Back to calibration

Back to mechanism



Data: Speed of diffusion by sector

Back to calibration



Agriculture, hunting, forestry and fishing
Mining and quarrying
Food products
Textile products, leather and footwear
Wood and products of wood and cork
Pulp, paper, paper products, printing and publishing
Coke, refined petroleum products and nuclear fuel
Chemicals and chemical products
Rubber and plastics products
Non-metallic mineral
Fabricated metal
Basic Metals
Machinery and equipment, nec
Computer, electronic and optical equipment
Electrical machinery and apparatus, n.e.c.
Other transport equipment
Motor vehicles
Manufacturing n.e.c. and recycling
Services

List of Industries

Sector	ISIC	Industry Description
1	C01T05	Agriculture, Hunting, Forestry and Fishing
2	C10T14	Mining and Quarrying
3	C15T16	Food products, beverages and tobacco
4	C17T19	Textiles, textile products, leather and footwear
5	C20	Wood and products of wood and cork
6	C21T22	Pulp, paper, paper products, printing and publishing
7	C23	Coke, refined petroleum products and nuclear fuel
8	C24	Chemicals and chemical products
9	C25	Rubber and plastics products
10	C26	Other non-metallic mineral products
11	C27	Basic metals
12	C28	Fabricated metal products, except machinery and equipment
13	C29	Machinery and equipment, nec
14	C30T33X	Computer, Electronic and optical equipment
15	C31	Electrical machinery and apparatus, n.e.c.
16	C34	Motor vehicles, trailers and semi-trailers
17	C35	Other transport equipment
18	C36T37	Manufacturing n.e.c. and recycling
19	C40T95	Nontradables