Knowledge Diffusion, Trade and Innovation across Countries and Sectors

Jie Cai [a] Nan Li [b] Ana Maria Santacreu [c,1]

[a]Shanghai University of Finance and Economics

[b]International Monetary Fund

[c]Federal Reserve Bank of St. Louis

June 2019

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

Motivation

Q: What is the effect of trade on innovation, growth and welfare?

Empirical evidence:

- Firm-level data: Trade has a non-negligible effect on innovation.
  (Bloom et al. 2015, Autor et al. 2016, Coell et al. 2016, Santacreu and Varela 2018, . . .)
- Innovation and knowledge flows have effect on patterns of trade.
  (Sampson 2018, Santacreu and Zhu 2018, . . .)

Standard models of trade:

- Static: No productivity dynamics.
- One-sector models predict negligible effects of trade on innovation and welfare (competition effect=market size effect).
  (Buera and Oberfeld 2016, Atkeson and Burstein 2010, Eaton and Kortum 2006)

Motivation

Q: What is the effect of trade on innovation, growth and welfare?

This paper: Two key ingredients:

1. Sector heterogeneity.
2. Innovation and diffusion $\Rightarrow$ Endogenous productivity dynamics.

We find that after trade liberalization:

1. R&D re-allocation towards sectors with a comparative advantage.
2. Higher dispersion in productivity.
3. Higher growth rates.
4. Knowledge spillovers reinforce these effects.

$\Rightarrow$ Amplification of welfare gains from trade.

This Paper

- Develop a novel unified framework to quantify the interactions between trade, innovation and diffusion in a multi-sector environment.
- Calibrate the model to account for cross-country and cross-sector heterogeneity in production, innovation efficiency, and knowledge linkages.
    - 19 OECD countries and 19 sectors (including a nontradable sector).
- Solve for the BGP of the model (abstract from transitional dynamics).
- Quantify effect of trade liberalization on growth, innovation and welfare.

The Model: in a Nutshell

- Multi-sector multi-country Ricardian trade model with Bertrand competition.

  $\Rightarrow$ Static equilibrium, given distribution of technology and trade costs.

- Endogenous growth model. Technology (stock of knowledge) evolves endogenously through innovation and diffusion.

  $\Rightarrow$ Endogenous evolution of comparative advantage and productivity.

Trade Model: Static Equilibrium

- Production input-output linkages.
- Bertrand competition.
- Trade in intermediate goods that are heterogeneous in productivity, z_i^j, distributed Frechet: $F(z_i^j) = \exp\{-T_{it}^j z^{-\theta}\}$.
- Import share country n:

$$\pi_{nit}^j = \frac{T_{it}^j \left(c_{it}^j\right)^{-\theta} \left(d_{ni}^j\right)^{-\theta}}{\sum_{m=1}^M T_{mt}^j \left(c_{mt}^j\right)^{-\theta} \left(d_{nm}^j\right)^{-\theta}}$$

with c_{it}^j country i sector j production cost; $d_{ni}^j > 1$ iceberg transport cost.

- **Growth Model:** T_{nt}^j evolves endogenously over time.

Growth Model: Innovation and Diffusion

- Continuum of firms invest in R&D (s_{nt}^j) to create new ideas.
  - Poisson arrival rate: $\lambda_n^j T_{nt}^j (s_n^j)^{\beta_r}$. with $\beta_r \in (0,1)$.
  - Innovation efficiency: $\lambda_n^j T_{nt}^j$.
- Ideas are realizations of two RVs: the good to which apply and quality.
- Ideas diffuse across *all* country-sectors with speed ε_{ni}^{jk}.
- Innovation and diffusion increase stock of knowledge:

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

Growth Model: Innovation and Diffusion

- Diffused ideas can be adopted to produce an intermediate good in that country, sector with productivity z^j_{nt}.
- An idea is adopted in n, j, if its quality surpasses the productivity of the most productive intermediate producer $(1/T^j_{nt})$.
- Successful adopters in country-sector nj pay to the innovator of that country-sector, V^j_{nt}.

$$V^j_{nt} = \int_t^{\infty} e^{-\int_t^s r_{nu} du} \left(1 - e^{-\varepsilon^{jj}_{nn}(t-s)}\right) \frac{1}{T^j_{ns}} \frac{1}{(1+\theta)} \sum_{i=1}^{M} \pi^j_{ins} X^j_{is} ds$$

BGP

- Normalize variables to be constant on the BGP.
- Positive knowledge spillovers ($\varepsilon_{ni}^{jk} > 0 \ \forall i, k, j, n$) $\Rightarrow$ T_n^j grows at common constant rate $g \ \forall j, n$ (**Perron-Frobenius theorem**).
- BGP growth rate:

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

- Productivity growth.

$$g_y = \frac{1}{\theta}\left(1 + \sum_{j=1}^{J} \alpha_j \Lambda_j\right) g.$$

The Mechanism: Effect of Trade Liberalization

1. **Reallocation of R&D:**

$$\left(s_n^j\right)^{1-\beta_r} \propto \lambda_n^j \sum_{i=1}^{M} \pi_{in}^j \hat{X}_i^j$$

Pre-liberalization: Autarky ($d_{in}^j \to \infty$)

$$\left(\frac{s_n^j/s_n^{j'}}{s_{n'}^j/s_{n'}^{j'}}\right)^{1-\beta_r} = \underbrace{\frac{\lambda_n^j/\lambda_n^{j'}}{\lambda_{n'}^j/\lambda_{n'}^{j'}}}_{\substack{\text{exogenous innovation} \\ \text{comparative advantage}}} \times \underbrace{\frac{\hat{X}_{nn}^j/\hat{X}_{nn}^{j'}}{\hat{X}_{n'n'}^j/\hat{X}_{n'n'}^{j'}}}_{\substack{\text{relative domestic} \\ \text{market size}}},$$

Post-liberalization: Free Trade ($d_{in}^j \to 1$)

$$\left(\frac{s_n^j/s_n^{j'}}{s_{n'}^j/s_{n'}^{j'}}\right)^{1-\beta_r} = \underbrace{\frac{\lambda_n^j/\lambda_n^{j'}}{\lambda_{n'}^j/\lambda_{n'}^{j'}}}_{\substack{\text{exogenous innovation} \\ \text{comparative advantage}}} \times \underbrace{\frac{\hat{T}_n^j(\hat{c}_n^j)^{-\theta}/\hat{T}_n^{j'}(\hat{c}_n^{j'})^{-\theta}}{\hat{T}_{n'}^{j'}(\hat{c}_{n'}^{j'})^{-\theta}/\hat{T}_{n'}^{j'}(\hat{c}_{n'}^{j'})^{-\theta}}}_{\substack{\text{production} \\ \text{comparative advantage}}}.$$

The Mechanism: Effect of Trade Liberalization

2. **Specialization and growth effects**:
   - R&D reallocates towards sectors with comparative advantage in production.
   - From growth rate in BGP, this translates into changes in comparative advantage ($\hat{T}_i^j$) and growth (g).

$\Rightarrow$ Depends on the exact pattern of diffusion.

3. **The role of knowledge spillovers**:
   - If diffusion is stronger for non-innovative country-sectors, it can **dampen** specialization effect as faster productivity convergence makes country-sectors more similar.
   - If diffusion stronger for already innovative countries, it can **amplify** the specialization effect of trade-induced R&D reallocation.

Taking the Model to the Data

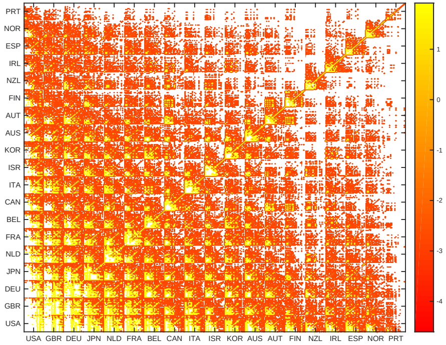
- Data: Trade flows, R&D spending, production and population for 19 OECD countries countries, 19 sectors and year 2005.
- Calibrate standard parameters:
  - Production parameters using I/O tables from OECD.
  - Trade costs from gravity regressions at the sector level.
- Calibrate nonstandard parameters:
  - New!: Estimate diffusion parameters ε_{ni}^{jk} using patent citation data.
  - New!: Recursive algorithm to calibrate $\{\beta_r, \lambda_n^j, \hat{T}_n^j\}$. Parameters

Estimation of Diffusion Speed

- Our solution: New ideas $\simeq$ patents $\Rightarrow$ diffusion $\simeq$ patent citations.
- Patent citations data to estimate a "gravity-type" citations function
  - (Adjusted) number of patents of origin and destination.
  - Propensity to cite and generate spillovers.
  - Obsolescence rate.
  - Probability of learning about a "foreign" idea: **diffusion speed** (ε_{ni}^{jk}.)
- Main findings:
  - Large heterogeneity in cross country-sectors diffusion speed.
  - Large number of country-sector pairs diffuse knowledge very slowly.
  - **Cross-country-sector** mean diffusion lag about 12 years.
  - **Within-country-sector** mean diffusion lag slightly over 1 year.

Faster Diffusion among “Innovative Countries”

- We find that diffusion stronger for already innovative countries ⇒ it can **amplify** the specialization effect of trade-induced R&D reallocation.



Note: Cited country (x-axis); citing country (y-axis). Ranked by average cited speed

Counterfactual: 25% Uniform Trade Liberalization

How does trade liberalization affect innovation, growth and welfare?

- Reallocation effect:
  - *Static* model: Production shifts towards sectors with comparative advantage—"specialization effect".
  - Our *dynamic* model: Reallocation of R&D strengthens countries' comparative advantage, reinforcing the "specialization effect"
    - For the average country: Dispersion of $\hat{T}_n^j$ increases from 0.7 to 0.74.
    - For the average sector: Dispersion of $\hat{T}_n^j$ increases from 0.85 to 0.87.
- Growth effects.
  - Productivity growth increases from 3% to 3.4%.

Results: Welfare Gains from Trade

- Welfare gains measured in consumption-equivalent units.
- λ_i: Additional consumption the consumer needs every period to be indifferent between baseline and counterfactual BGP.

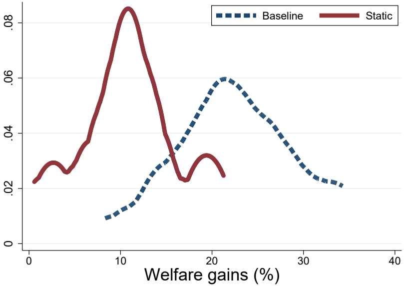
$$\int_{t=0}^{\infty} e^{-\rho t} u\left(C_{it}^{*} \lambda_i\right) dt = \int_{t=0}^{\infty} e^{-\rho t} u\left(C_{it}^{**}\right) dt$$

- Taking into account consumption growth on BGP, welfare gains are:

$$\log\left(\lambda_i\right) = \rho \log\left(\frac{\hat{C}_i^{**}}{\hat{C}_i^{*}}\right) + g_y^{**} - g_y^{*}$$

Results: Welfare Gains from Trade

- Welfare gains from trade model are, on average:
  - 2 times larger than in a static model.
  - 1.2 times larger than in a model with (almost) no diffusion.
- Welfare gains more disperse in the baseline than in a static model.



Conclusions

- We quantify 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.
- Next steps:
  - Effect of tariff changes in specific country-sectors on changes in structure of world production.
  - Model diffusion as a function of distance.

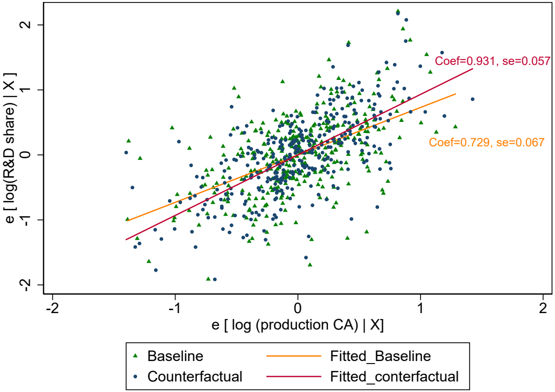
Very Related Papers

- **Perla, Tonetti and Waugh (2015):** Model of trade and diffusion with symmetric countries to characterize effect of trade on welfare and growth.
- **Buera and Oberfield (2017):** One-sector quantitative trade model of innovation, diffusion, and trade to explain growth miracles.
- **Sampson (2018):** Multi-sector trade model of innovation and learning to explain dispersion in relative productivity.
- **Somale (2018):** Multi-sector semi-endogenous growth model of innovation and trade without diffusion to quantify effect of trade on income per capita.

Reallocation of R&D across Sectors

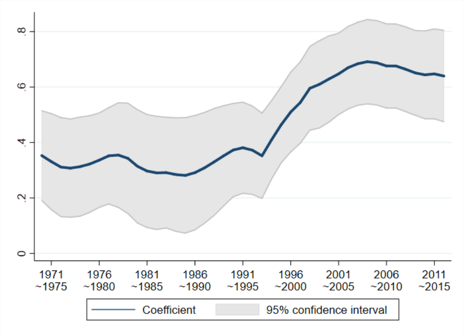
$$\log\left(\frac{s_n^j}{\sum_j s_n^j}\right) = \beta_0 + \beta_1 \log(ICA_n^j) + \beta_2 \log(PCA_n^j) + f_n + f_j + \mu_n^j,$$

where s_n^j is R&D spending, ICA_n is the exogenous comparative advantage in innovation (i.e. based on λ_n^j) and PCA_n^j represents the comparative advantage in production (i.e. based on $T_n^j(c_n^j)^{-\theta}$), both measured by applying the double normalization. Back



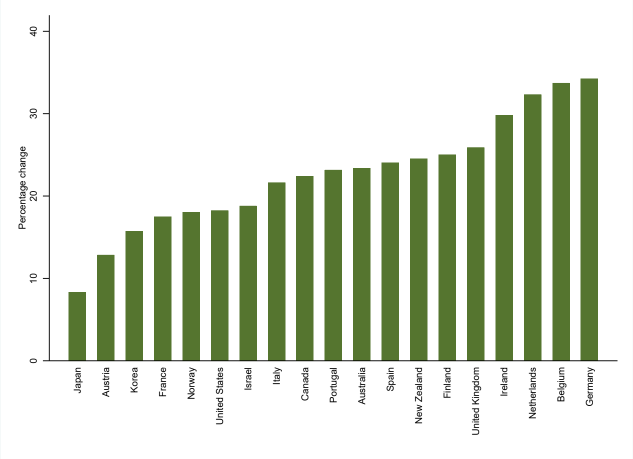
Reallocation of R&D across Sectors: External Validation

$$\log\left(\frac{s^j_{nt}}{\sum_j s^j_{nt}}\right) = \alpha_1 + \alpha_2 \log(RCA^j_{nt}) + f_{nt} + f_{jt} + \mu^j_{nt}.$$



Notes: This figure shows the coefficient of a 5-year rolling window regression of the log of R&D share on the log of revealed comparative advantage, together with 95% confidence intervals.

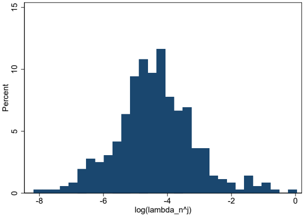
Welfare Gains from Trade



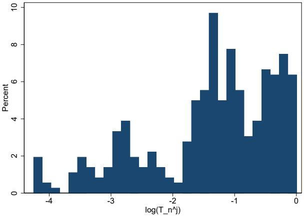
▸ Back

Calibration Results

Parameter	Value	Description
θ	4.00	Trade elasticity
g	0.12	Growth of stock of knowledge
g_y	0.028	Growth of income per capita
ρ	0.90	Discount factor
β_r	0.45	Elasticity of innovation



(a) Efficiency of innovation (λ_n^j)



(b) Stock of knowledge ($\hat{T}_n^j$)

Back

Estimation of Diffusion Speed

- Our solution: New ideas $\simeq$ patents $\rightarrow$ diffusion $\simeq$ patent citations.
- Estimate a "gravity-type" citations function

$$\underbrace{C_{ni}^{jk}(t,s)}_{\text{citations}} = \phi_{n,t}^{j}\delta_{i,s}^{k}\underbrace{(\psi_{i,s}^{k}P_{i,s}^{k})^{\beta_g}(\psi_{n,t}^{j}P_{n,t}^{j})^{\beta_l}}_{\text{(adjusted) patent applications}}\underbrace{e^{-\sum_{\tau=s}^{t}O_{i,\tau}^{k}\tilde{P}_{i,\tau}^{k}}}_{\text{obsolescence rate}}\underbrace{(1-e^{-\varepsilon_{ni}^{jk}(t-s)})}_{\text{prob of seeing the idea}}.$$

- Jointly estimate ε_{ni}^{jk} together with other factors, such as propensity to cite ($\phi_{n,t}^{j}$), spillover effect ($\delta_{i,s}^{k}$), propensity to patent ($\psi_{i,s}^{k}$), obsolescence rate ($O_{i,s}^{k}$). Back

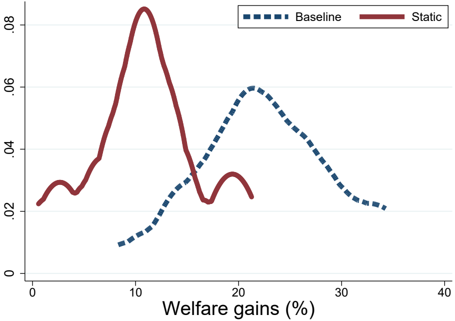
List of Industries

List of countries: Australia, Austria, Belgium, Canada, Finland, France, Germany, Israel, Italy, Japan, Korea, the Netherlands, New Zealand, Norway, Poland, Portugal, Spain, the United Kingdom, and the United States.

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

Back

Results: Welfare Gains from Trade



Model	Mean	Std. Dev.	Min	Max
Baseline	22.63	6.90	8.33	34.27
Static	10.92	5.87	0.58	21.26
No diffusion	18.76	6.80	6.23	30.57

Back