Knowledge Diffusion, Trade and Innovation across Countries and Sectors

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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.

  ⇒ Static equilibrium, given distribution of technology and trade costs.

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

  ⇒ 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, $z^j_i$, distributed Frechet: $F(z^j_i) = \exp\{-T^j_{it}z^{-\theta}\}$.
- Import share country $n$:

$$
\pi^j_{nit} = \frac{T^j_{it} \left( c^j_{it} \right)^{-\theta} \left( d^j_{ni} \right)^{-\theta}}{\sum_{m=1}^{M} T^j_{mt} \left( c^j_{mt} \right)^{-\theta} \left( d^j_{nm} \right)^{-\theta}}.
$$

with $c^j_{it}$ country $i$ sector $j$ production cost; $d^j_{ni} > 1$ iceberg transport cost.

- Growth Model: $T^j_{nt}$ 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: \(\lambda_n^j T_{nt}^j \beta_r\) 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 \(\epsilon_{ni}^{jk}\).

- Innovation and diffusion increase stock of knowledge:

\[
\dot{T}_{nt}^j = \sum_{i=1}^{M} \sum_{k=1}^{J} \int_{-\infty}^{t} \epsilon_{ni}^{jk} e^{-\epsilon_{ni}^{jk}(t-s)} \lambda_i^k T_{is}^k (s_{is}^k)^{\beta_r} ds
\]
Diffused ideas can be adopted to produce an intermediate good in that country, sector with productivity $z_{nt}^j$.

An idea is adopted in $n, j$, if its quality surpasses the productivity of the most productive intermediate producer $(1/T_{nt}^j)$.

Successful adopters in country-sector $nj$ pay to the innovator of that country-sector, $V_{nt}^j$.

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

- Normalize variables to be constant on the BGP.

- Positive knowledge spillovers \( (\varepsilon_{ni}^{jk} > 0 \; \forall i, k, j, n) \Rightarrow T_i^j \) grows at common constant rate \( g \; \forall j, n \) (Perron-Frobenius theorem).

- BGP growth rate:

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

- 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:**

\[
(s^j_n)^{1-\beta_r} \propto \lambda_n^j \sum_{i=1}^{M} \pi_{in}^j \hat{X}_i^j
\]

**Pre-liberalization: Autarky (}^d_{in} \to \infty)\]

\[
\left(\frac{s^j_n}{s^j_n'}\right)^{1-\beta_r} = \left(\frac{s^j_n}{s^j_n'}\right)^{1-\beta_r} \frac{\lambda_n^j / \lambda_n^j'}{\lambda_n^j / \lambda_n^j'} \times \frac{\hat{X}_{nn}^j / \hat{X}_{nn}^j'}{\hat{X}_{nn'}^j / \hat{X}_{nn'}^j'},
\]

exogenous innovation comparative advantage

relative domestic market size

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

\[
\left(\frac{s^j_n}{s^j_n'}\right)^{1-\beta_r} = \frac{\lambda_n^j / \lambda_n^j'}{\lambda_n^j / \lambda_n^j'} \times \frac{\hat{T}_{n}^j (\hat{c}_n^j)^{-\theta} / \hat{T}_{n'}^j (\hat{c}_n'^j)^{-\theta}}{\hat{T}_{n'}^j (\hat{c}_n'^j)^{-\theta} / \hat{T}_{n'}^j (\hat{c}_n'^j)^{-\theta}}.
\]

exogenous innovation comparative advantage

production comparative advantage
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 ($g$).

⇒ 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, 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 $\varepsilon_{ni}^{jk}$ using patent citation data.
  - **New!**: Recursive algorithm to calibrate $\{\beta_r, \lambda_n^j, \hat{T}_n^j\}$. 
Estimation of Diffusion Speed

- Our solution: New ideas ≃ patents ⇒ diffusion ≃ 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 \( \varepsilon_{nk} \)
- 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 $\hat{T}_n^i$ 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.

- $\lambda_i$: Additional consumption the consumer needs every period to be indifferent between baseline and counterfactual BGP.

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

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

$$\log(\lambda_i) = \rho \log\left(\frac{\hat{C}_{i}^{**}}{\hat{C}_{i}^*}\right) + g_{y}^{**} - g_{y}^*$$
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.

![Graph showing welfare gains comparison between Baseline and Static models.](image)
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

\[
\log \left( \frac{s^j_n}{\sum_j s^j_n} \right) = \beta_0 + \beta_1 \log(ICA^j_n) + \beta_2 \log(PCA^j_n) + f_n + f_j + \mu^j_n,
\]

where \( s^j_n \) is R&D spending, \( ICA^j_n \) is the exogenous comparative advantage in innovation (i.e. based on \( \lambda^j_n \)) and \( PCA^j_n \) represents the comparative advantage in production (i.e. based on \( T^j_n(c^j_n) - \theta \)), both measured by applying the double normalization.
Reallocation of R&D across Sectors: External Validation

$$\log \left( \frac{s_{nt}^j}{\sum_j s_{nt}^j} \right) = \alpha_1 + \alpha_2 \log(RCA_{nt}^j) + f_{nt} + f_{jt} + \mu_{nt}^j.$$ 

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
Calibration Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>4.00</td>
<td>Trade elasticity</td>
</tr>
<tr>
<td>$g$</td>
<td>0.12</td>
<td>Growth of stock of knowledge</td>
</tr>
<tr>
<td>$g_y$</td>
<td>0.028</td>
<td>Growth of income per capita</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.90</td>
<td>Discount factor</td>
</tr>
<tr>
<td>$\beta_r$</td>
<td>0.45</td>
<td>Elasticity of innovation</td>
</tr>
</tbody>
</table>

(a) Efficiency of innovation ($\lambda_n^i$)  
(b) Stock of knowledge ($\hat{T}_n^i$)
Estimation of Diffusion Speed

Our solution: New ideas $\simeq$ patents $\rightarrow$ diffusion $\simeq$ patent citations.

Estimate a “gravity-type” citations function

$$C_{ni}^{jk}(t, s) = \phi_{n,t}^{j} \delta_{i,s}^{k} (\psi_{i,s}^{k} P_{i,s}^{k})^{\beta_{g}} (\psi_{n,t}^{j} P_{n,t}^{j})^{\beta_{l}} e^{-\sum_{\tau=s}^{t} O_{i,\tau}^{k} \tilde{P}_{i,\tau}^{k}} \left(1 - e^{-\varepsilon_{ni}^{jk}(t-s)}\right).$$

Jointly estimate $\varepsilon_{ni}^{jk}$ 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 ($O_{i,s}^{k}$).
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.

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

<table>
<thead>
<tr>
<th>Model</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>22.63</td>
<td>6.90</td>
<td>8.33</td>
<td>34.27</td>
</tr>
<tr>
<td>Static</td>
<td>10.92</td>
<td>5.87</td>
<td>0.58</td>
<td>21.26</td>
</tr>
<tr>
<td>No diffusion</td>
<td>18.76</td>
<td>6.80</td>
<td>6.23</td>
<td>30.57</td>
</tr>
</tbody>
</table>