The Composition of Knowledge and Long-Run Growth

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Motivation

- Traditional trade theory: welfare is maximized when countries specialize in sectors that they produce relatively cheaply;
- However, goods with large positive externality may be under-developed.
- **What** a country exports is important
  - Learning by doing, capabilities:
    Krugman (1987), Grossman and Helpman (1991), Hausmann, Hwang and Rodrik (2007)
  - Product network, synergies:
    Hausmann and Hidalgo (2011), Kali, Reys, McGee and Shirrell (2012), Hausmann and Klinger (2007).
- Particularly important for industry policies (e.g. "comparative advantage defying strategies" (Lin, 2009, 2010)).

However, empirical evidence is mixed:

- Difficult to establish causality using commonly adopted regression-based approaches
- Difficult to examine the GE effects of changing production structure
- Difficult to identify sectors with large externalities in the data; existing studies use outcome-based measures.

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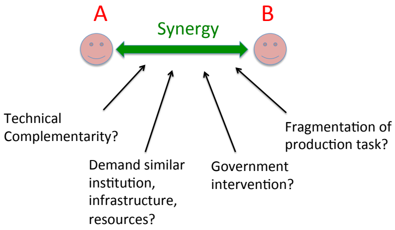
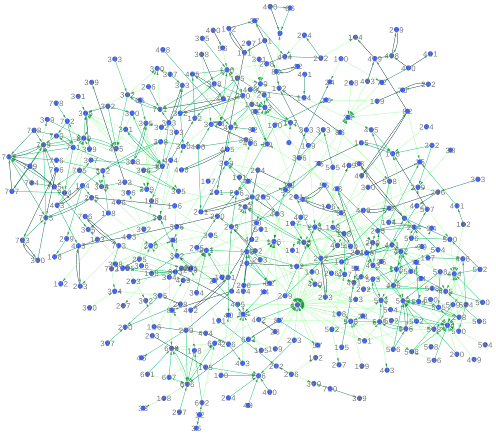
—For example: Previous studies assume sector A and B have synergies if A and B are likely to be co-exported by the same country



This paper: Technical complementarity across sectors

Motivating observation: Research spillovers across sectors are substantial but highly heterogeneous

Figure: Intersectoral Knowledge Flow Network Corresponding to Patent Citations



This paper:

1. Incorporates this network of knowledge complementarities across sectors into a formal model of innovation, trade and growth

- Develops a tractable framework in which a country's composition of knowledge is endogenously determined
- The framework is useful to analyze:
  (Unbiased) trade costs $\Rightarrow$composition of knowledge accumulation $\Rightarrow$ aggregate innovation and growth

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2 Empirically,

- Constructs a quantitative measure of "knowledge applicability" for each sector, based on patent citation network;
- Presents cross-country evidence that broadly supports the model implications:
  – Geographic remoteness has a distributional effect on a country's knowledge composition;
  – A country's initial knowledge applicability is positively and significantly associated with subsequent growth differences.

I. Model

Framework

- Expanding variety model
- Consumers maximize life-time utility and inelastically supply labor
- (Non-traded) final good is a CD combination of sectoral good; sectoral good i is a CES combination of differentiated (home and foreign) goods:

$$Q_t^i = \left[\int_0^{N_t^i + N_t^{i*}} \left(x_{k,t}^i \right)^{\frac{\sigma-1}{\sigma}} dk \right]^{\frac{\sigma}{\sigma-1}}$$

- Continuum of symmetric *multi-sector*, monopolistic competitive firms. Number of varieties per firm in sector i: $n_t^i = N_t^i / M_t$.
- **New:** Firms innovate (create new blueprints) and produce in **all** sectors, where the sectoral knowledge can be adapted to innovate in other sectors. Some knowledge can be easily adapted, while others cannot.
- Study balance growth path (BGP) equilibrium

Differentiated Goods Production

- Identical linear production technology across firms and sectors: $y_t^i = \phi l_t^i$
- Suppose τ is the iceberg transportation cost,

$$p_{ht}^i(k) = \frac{\sigma}{\sigma - 1}\frac{w_t}{\phi}, \quad p_{ft}^i(k) = \tau p_{ht}^i(k)$$

- The firm's (real) profit per variety in sector i is

$$\pi_t^i = \frac{(r_{d,t}^i + r_{x,t}^i)}{\sigma w_t}$$

Firm's R&D Decision

- A firm's *knowledge portfolio*: $\boldsymbol{z}_t = (z_t^1, z_t^2, ..., z_t^K)$, z_t^i is the number of varieties (blue prints, knowledge capital) in sector i

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- **Innovation**: a process of developing new varieties in a given sector using existing knowledge in *all* sectors:

$$\Delta z_t^i = \sum_{j=1}^{K} A^{ij} \left(\bar{z}_t^i R_t^{ij}\right)^{\alpha} \left(z_t^j\right)^{1-\alpha} \tag{2}$$

—A^{ij}: applicability of ideas from $j \to i$
—$\bar{z}_t^i$: researcher efficiency (measured by average knowledge stock in i)

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- Firm's R&D optimization problem:

$$\max_{\{R_t^{ij}\}_{i,j\in\{1,2,\ldots,K\}}} V(\boldsymbol{z}_t) = \sum_{j=1}^{K} \pi_t^j z_t^j - \sum_{i=1}^{K}\sum_{j=1}^{K} R_t^{ij} + \frac{1}{1+r_t} V(\boldsymbol{z}_{t+1})$$

$s.t.$ (1) and (2)

Solution: Firm value

- Firm's value is a linear aggregate of the value of its knowledge capital in all sectors

$$V(\mathbf{z}_t) = \sum_{j=1}^{K} v^j$$

- On the BGP, the market value of the firm's knowledge capital in j

$$v^j = \frac{1}{1-\rho}\left(\pi^j + \sum_{i=1}^{K} \omega^{ij}\right)$$

ω^{ij}: *application value* of the firm's knowledge in sector j to innovation in sector i:

$$\omega^{ij} = \frac{n^j}{n^i}\left(v^i A^{ij} \alpha\rho\right)^{\frac{1}{1-\alpha}} \frac{1-\alpha}{\alpha}$$

- v^i, ω^{ij} and π^i are all time-invariant in the BGP equilibrium

Solution: firm optimal R&D

- Optimal R&D: The firm scales up its R&D by its market share

$$R_t^{ij} = \frac{\alpha}{1-\alpha}\omega^{ij}\frac{z_t^j}{n_t^j}$$

- Closing the model
  - Labor market clearing
  - Balance of trade
  - Free entry

Knowledge Composition and Growth

- **Proposition 1:** At aggregate, R&D resources are allocated according to the value of firm's sectoral knowledge

$$\frac{R^i}{R^j} = \frac{v^i}{v^j}$$

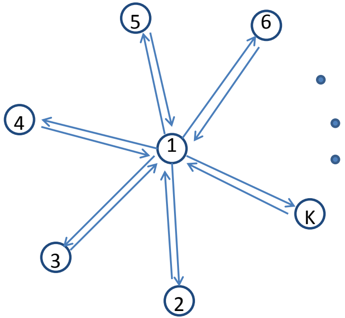
- **Proposition 2:** On the BGP, the aggregate innovation rate increases with the **importance** of firm's knowledge application value $(\frac{\sum_i \sum_j \omega^{ij}}{\sum_i v^i})$:

$$g = \left(\beta(1-\alpha) \frac{\sum_i v^i}{\sum_i \sum_j \omega^{ij}} - 1 \right)^{-1}$$

An illustrative example

Assume two types of sectors: central sectors (c), peripheral sectors (p)
– c: 1.
– p: 2, 3, ...,K

Figure: Star-shaped knowledge complementarity network



Other Parameters: $\beta = 0.98, K = 10, L^* = 50L, \sigma = 6, \alpha = 0.4.$

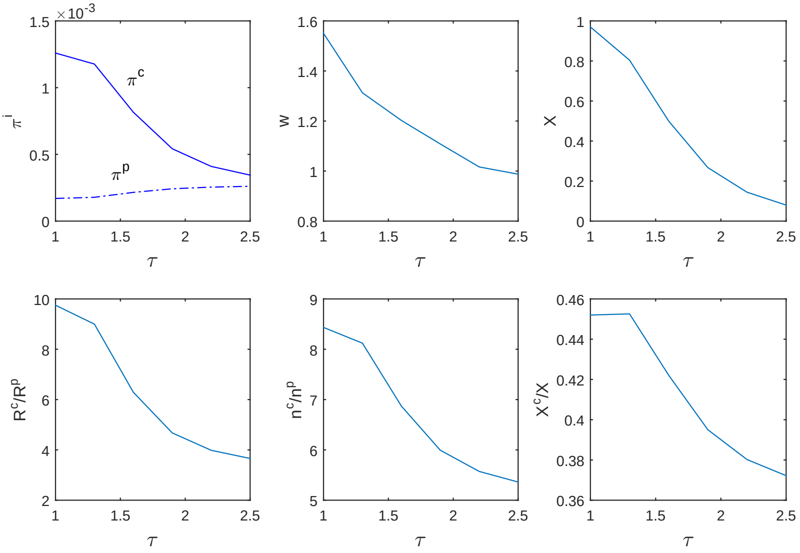
Intuition

- Trade cost $\tau \uparrow \Rightarrow w \downarrow \Rightarrow \uparrow \pi$ (GE effect)
- Trade cost $\tau \uparrow \Rightarrow \downarrow \pi$
- In equilibrium $n^c > n^p$, loss of competitiveness in c sector $\Rightarrow \pi^c \downarrow$, $\pi^p \uparrow$
- $v^j = \frac{1}{1-\rho}\left[\pi^j + \kappa \sum_{i=1}^{K} \frac{n^j}{n^i}\left(v^i A^{i \leftarrow j}\right)^{\frac{1}{1-\alpha}}\right]$ where $A^{c \leftarrow p} = 0, A^{p \leftarrow c} > 0$

$$\Rightarrow \frac{n^c}{n^p}, \frac{v^c}{v^p}, \frac{R^c}{R^p} \downarrow$$

- $\Rightarrow g \downarrow$

Results



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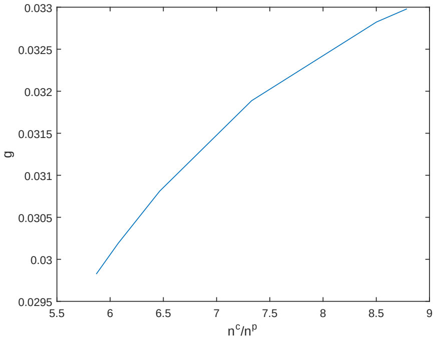

0.033
0.0325
0.032
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0.0305
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7
7.5
8
8.5
9
n^c/n^p

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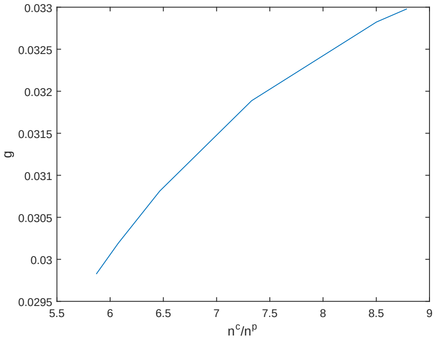


Testable predictions:

- rising τ leads to lower n^c/n^p
- lower n^c/n^p is associated with lower aggregate growth

I. Empirics

Measuring Technology Applicability

Data Source: Patent citation data from US Patent and Trade Office, 1962-2006, SITC 2-digit
– Jaffe et al. (2000), Hall et al. (2001): use patent citations as an indicator of knowledge spillovers

Assume that the knowledge spillover linkages uncovered in the U.S. patent data persist across countries.

- This paper is about the fundamental relationship between technologies
  – Nelson and Winter (1977) *"Innovations follow 'natural trajectories' that have a technological or scientific rationale rather than being fine tuned to changes in demand and cost conditions"*
- 50% of patents applied in U.S. were from foreign inventors
- Due to the territorial principle in the U.S patent laws, anyone intending to claim exclusive rights for inventions is required to file U.S. patents; U.S. has been the largest technology consumption market over the past few decades.

Measuring Technology Applicability

- **Measure of applicability:** $\{aw^i\}_{i=1,..K}$

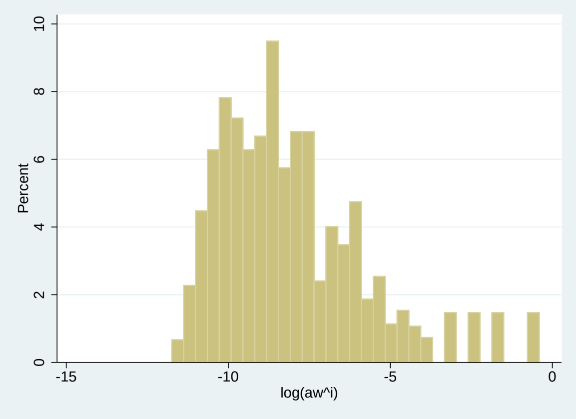
  Apply Kleinberg (1998) algorithm to construct, for each sector, two network-based measures— authority weight (aw) and hub weight (hw).

$$
\begin{aligned}
aw^i &= \lambda^{-1} \sum_j W^{ji} hw^j \\
hw^i &= \mu^{-1} \sum_j W^{ij} aw^j
\end{aligned}
$$

  where W^{ji} = Citations from sector j to sector i

- Compute $\{aw_t^i\}_i$ using cross-sector citations from $[t-10, t]$

Knowledge applicability across sectors is heterogenous and highly skewed



Observation: A small number of sectors are responsible for fostering disproportionately many subsequent innovations

Measuring a country's composition of knowledge

- Can only observe various economic manifestations of the country's composition of knowledge

- Evaluate a country's knowledge composition by its export composition.
  – export share in each sector: $x^i_{c,t} = EX^i_{c,t} / \sum_i EX^i_{c,t}$

- At country level, measures of a country's knowledge applicability:
  - Measure I: export weighted knowledge applicability

$$TA_{c,t} = \sum_i \log(aw^i_t) x^i_{c,t}$$

  - Measure II:The fraction of exports in the most applicable third of all sectors $Perc33$.

- Data source: UN Comtrade sectoral export data, 1972-2013, UN Comtrade sectoral export data.

Determinants of a country's export structure

$$x^i_{c,t} = c + \beta_0 \ln(aw^i_t) + \boldsymbol{\beta_1} \ln(aw^i_t) \times remoteness_c + \beta_2 \ln(aw^i_t) \times \boldsymbol{Z}_{c,t} + \boldsymbol{\beta_3} \boldsymbol{Z}_{c,t} + \mu_c + \eta_i + \varepsilon^i_{c,t}$$

	(1)	(2)	(3)	(4)	(5)
$\log(aw^i_t)$	1.45	1.28	0.97	1.22	1.36
	(3.27)***	(2.84)***	(2.03)**	(2.49)**	(3.17)***
$\mathbf{ln(aw^i_t) \times remoteness_c}$	-0.16	-0.16	-0.15	-0.14	-0.15
	(-3.13)***	(-3.25)***	(-2.88)***	(-2.57)**	(-3.09)***
$\ln(aw^i_t) \times human\ capital_{c,t}$		0.12			
		(3.00)***			
$\ln(aw^i_t) \times capital\text{-}labor\ ratio_{c,t}$		0.02			
		(1.27)			
$\ln(aw^i_t) \times natural\ resource_c$		-0.00			
		(-2.48)**			
$\ln(aw^i_t) \times IPR_{c,t}$			0.06		
			(7.11)***		
$\ln(aw^i_t) \times dist\ from\ equator_c$				0.01	
				(0.87)	
$\ln(aw^i_t) \times regulation\ quality_{c,t}$					0.06
					(2.25)**
Sector FEs	Yes	Yes	Yes	Yes	Yes
Country FEs	Yes	Yes	Yes	Yes	Yes
Six governance variables	No	No	No	No	Yes
Observations	125,727	54,883	23,578	75,057	65,154
R^2	0.45	0.47	0.47	0.46	0.49

Growth Regression

$$(\log y_{c,t} - \log y_{c,0})/t = \beta_0 + \beta_1 \log TA_{c,0} + \beta_2 \log(y_{c,0}) + \boldsymbol{\delta X}_{c,0} + \varepsilon_c$$

	(1)		(2)	
	β	t-statistic	β	t-statistic
Knowledge applicability				
Initial TA	0.42	(2.19)**	0.52	(2.12)**
Country Characteristics				
Initial income	-0.52	(-1.81)	-0.80	(-2.05)**
Initial investment share	0.05	(2.22)**	0.02	(1.04)
Initial human capital	0.80	(1.63)	0.19	(0.47)
Region fixed effects				
Latin America			-0.55	(-1.05)
West Africa			-2.39	(-2.13)**
East Africa			-2.05	(-1.46)
South Central Africa			-3.25	(-2.37)**
East Asia			0.90	(0.90)
South East Asia			0.09	(0.09)
South West Asia			-0.42	(-0.35)
North Africa, Middle East			-0.91	(-1.31)
Eastern Europe			-0.19	(-0.37)
Number of obs	84		84	
R^2	0.16		0.41	

Growth Regression

$$(\log y_{c,t} - \log y_{c,0})/t = \beta_0 + \beta_1 \log TA_{c,0} + \beta_2 \log(y_{c,0}) + \boldsymbol{\delta X}_{c,0} + \varepsilon_c$$

	(1)		(2)		(3)		(4) Perc33	
	β	t-statistic	β	t-statistic	β	t-statistic	β	t-statistic
Knowledge applicability								
Initial TA	0.52	(2.09)**	0.63	(2.84)***	0.66	(2.98)***		
Initial Perc33							2.80	(3.48)***
Country Characteristics								
initial GDP per capita	-0.82	(-2.08)**	-0.91	(-2.40)**	-1.10	(-2.82)***	-1.09	(-2.73)***
Initial investment share	0.02	(1.04)	0.03	(1.31)	0.04	(1.82)	-0.05	(2.04)**
Initial human capital	0.20	(0.49)	0.11	(0.27)	0.39	(0.83)	0.32	(0.69)
Add Openness								
Initial Openness	0.00	(0.34)	0.00	(0.77)	0.00	(0.64)	0.00	(0.66)
Add Other Export Structure								
Initial Diversification			-1.65	(-1.66)	-1.09	(-1.17)	-0.56	(-0.61)
Initial Upstreamness			0.54	(2.00)**	0.52	(1.71)	0.53	(1.81)
Add Geography								
Landlocked					-1.04	(-2.16)**	-1.12	(-2.44)**
Area					0.04	(0.46)	0.03	(0.29)
Distance from the equator					-0.66	(-0.43)	-0.93	(-0.62)
Remoteness					-1.23	(-1.02)	-1.36	(-1.13)
9 region fixed effects	Yes		Yes		Yes		Yes	
Number of obs	84		84		82		82	
R^2	0.42		0.45		0.49		0.50	

Final Remarks

- A systematic analysis to investigate the relationship between the (endogenous) composition of knowledge and growth.
- Questions: How do countries increase the amount of applicable knowledge? Can policy changes such as trade liberalization help to improve the knowledge structure of the economy?
- Our theoretical model is well-suited to answer these questions: Lower trade barriers (besides leading to more trade) increase aggregate innovation productivity by reallocating R&D towards sectors with higher knowledge applicability—"composition effect" of trade cost.
- Further extensions:
  –Endogenous K (adding sectoral entry cost)
  –Imports and cross-country knowledge spillovers (technology adoption)
  –Quantitative analysis