Technology Flows

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Overview

- Naive attitude is to expect all useful innovations to diffuse more or less instantaneously across countries

- Obviously this does not happen: why?

- Biggest empirical challenge is to "observe" diffusion

- Today review some very reduced-form empirical approaches to international technology diffusion

- See Jonathan's part of the course for more structural approaches

Approach 1: TFP growth as a function of foreign R&D

- Two influential papers by Coe and Helpman (1995) and Coe, Helpman, Hoffmaister (1997).

- Endogenous growth model with innovation and imitation. Leads to following reduced-form equation for non–OECD-country TFP:

  $\log(A_i) = \alpha + \alpha^S \log(S_i) + \alpha^M M_i + \alpha^{SM} [\log(S_i) M_i] + \alpha^E E_i + \alpha^{SE} [\log(S_i) E$

  - $A_i = Y_i/(K^{0.4} L^{0.6})$ (hence A includes effect of human capital!).

  - S_i "R&D" capital of country $i's$ industrialized trading partners. (R&D spillovers).

    * $S_i = \sum_{k \in \text{OECD}} \psi_{ik} (\text{R\&D})_k$, where

      · $(\text{R\&D})_k =$"R&D capital" of country k (computed with R&D spending data and perpetual inventory method). (OECD data)

      · $\psi_{ik} =$ imports of machinery and equipment from country k as share of Y_i.

- M_i total machinery and equipment imports from OECD as share in GDP. (UN data).

- E_i human capital (eases technology adoption), measured by secondary enrollment rate (!).

- $[\log(S_i)\, M_i]$ embodied tech. greater if coming from high R&D countries and/or R&D spillovers take place through machinery trade.

- $[\log(S_i)\, E_i]$ spillovers greater if receptive "students".

- Method:
  - 1997 paper looks at 77 non-OECD countries (1995 paper is intra-OECD)
  - Panel data: 1975-1990; 5-year intervals.
  - WLS in first differences (nets out country-specific intercepts).
  - Fixed effects and time dummies (allows for country-specific trends).

Total Factor Productivity Estimation Results

(Pooled data, four observations for 77 countries, 308 observations, standard errors in parentheses)

Coefficient	Variable	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)
α^S	$\Delta \log S$	0·751	−1·827	0·648	−1·875	0·029	−0·276	—	—	—	—
		(0·220)	(0·898)	(0·233)	(0·895)	(0·151)	(0·184)	—	—	—	—
α^M	ΔM	0·231	0·139	−9·525	−9·657	−10·104	−12·332	−9·598	−9·960	−10·498	−9·853
		(0·129)	(0·117)	(3·027)	(3·027)	(3·087)	(3·142)	(3·054)	(3·067)	(3·067)	(3·043)
α^{SM}	$\Delta(M \cdot \log S)$	—	—	0·811	0·809	0·877	1·058	0·819	0·846	0·893	0·837
				(0·247)	(0·250)	(0·255)	(0·259)	(0·252)	(0·254)	(0·255)	(0·252)
α^E	ΔE	0·243	0·259	−0·773	0·301	−0·880	−0·810	−1·915	0·740	0·359	0·247
		(0·093)	(0·098)	(1·219)	(1·866)	(1·266)	(1·940)	(1·182)	(1·875)	(0·094)	(0·096)
α^{SE}	$\Delta(E \log S)$	—	—	0·084	−0·003	0·095	0·083	0·178	−0·014	—	—
				(0·095)	(0·151)	(0·099)	(0·156)	(0·092)	(0·151)	—	—
Total elasticities of F with respect to:											
$S\,(\alpha^S + \alpha^{SM}\bar{M} + \alpha^{SE}\bar{E})$		—	—	0·728	−1·819	0·117	−0·179	0·108	0·047	0·062	0·058
				(0·226)	(0·892)	(0·138)	(0·154)	(0·030)	(0·045)	(0·017)	(0·017)
$M\,(\alpha^M + \alpha^{SM}\log\bar{S})$		—	—	0·287	0·242	0·510	0·464	0·305	0·275	0·311	0·279
				(0·151)	(0·132)	(0·145)	(0·127)	(0·154)	(0·133)	(0·155)	(0·132)
$E\,(\alpha^E + \alpha^{SE}\log\bar{S})$		—	—	0·248	0·270	0·265	0·192	0·235	0·259	—	—
				(0·111)	(0·105)	(0·114)	(0·109)	(0·112)	(0·106)	—	—
Time effects		Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Fixed effects		No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Standard error		1·026	1·009	1·029	1·010	1·033	1·015	1·030	1·010	1·031	1·010
R^2		0·182	0·184	0·228	0·246	0·156	0·149	0·209	0·229	0·200	0·228
R^2 adjusted		0·166	0·162	0·207	0·219	0·142	0·134	0·191	0·205	0·184	0·208
F tests											
No time effects		—	—	—	—	3·577**	3·408*	—	—	—	—
No fixed effects		1·417*	—	1·540**	—	1·582*	—	1·618**	—	1·628**	—
Equal coefficients on											
$\Delta \log S$		2·620**	1·319	2·851**	1·318	2·719**	1·091	—	—	—	—
ΔM		0·964	1·009	0·984	1·030	0·975	1·086	0·141	0·795	0·173	0·797
ΔE		1·741**	1·194	1·830**	1·286	1·643**	1·131	1·131	0·842	1·508*	0·845
Interaction terms		—	—	1·430*	1·055	1·317*	0·931	0·931	1·600*	0·223	0·808

The dependent variable is $\Delta \log F$. Δ indicates the 4-year change to 1975, and 5 year changes to 1980, 1985 and 1990.

* [**] indicates reject null hypothesis of no effects or equal coefficients across countries at the 5 [1]% significance level.

Definitions: F is total factor productivity in developing countries; S is the foreign R & D capital stock; M is the ratio of imports of machinery and equipment from 22 industrial countries to GDP in each developing country; and E is the ratio of secondary-school enrolment to secondary-school-age population. A bar over a variable indicates sample mean, with $\log \bar{S} = 12·10$, $\bar{M} = 0·07$, and $\bar{E} = 0·29$.

- Results without fixed effects sensible, but those with fixed effects puzzling.

- Dropping log(S) not really very legitimate

- Keller (EER 1998) finds that *random* ψ_{ik}s lead to stronger effects from foreign R&D than the actual ones!

- Interpretation difficult anyway. E.g. R&D and TFP are procyclical and Mexico's business cycle is influcenced by US'.

Further developments

- Keller (JEG 2002) adds industry dimension to data (among other things) and gets more robust results.

- Keller (AER 2002) looks at the role of geographical distance

- Estimating equation:

$$\log(A_{cit}) = \alpha_{ci} + \alpha_t + \beta \log \left[R_{cit} + \gamma \left(\sum_{g \in G5} R_{git} e^{-\delta D_{cg}} \right) \right] + \varepsilon_{cit}$$

  where D_{cg} is geographical distance, normalized to 1 for GER-NET distance (235 KM).

- 9 receiving countries (AUS, CAN, DEN, FIN, ITA, NET, NOR, SPA, SWE) and 5 (G5) "sending" countries (FRA, GER, JAP, UK, USA). i is only receiving. 12 manufacturing industries. 1970-1995.

- Method: NLS

- Finds $\beta = 0.078^*$, $\gamma = 0.843^*$, and $\delta = 1.005^*$. Implies that half of knowledge sent out has melted after 163Km*

- But when looking at sub-periods finds much less localization in recent times (half-life as large as 2000Km in 1983-1995)

- Still interpretation issues: events in German car industry influence more Dutch car industry than Spanish car industry, but is it ideas?

- Other work adds spillovers from the spillovers, etc. (Keller has big survey in JEL).

*Looking for D^* such that $e^{-\delta D^*} = 0.5$. That's 0.69, corresponding to 163Km due to normalization.

Approach 2: TFP growth and distance from frontier

- Nelson and Phelps (1966):

Most growth theory assumes that human capital increases efficiency units of labor, *permanently* (later called "skill in use"). NP argue that most operations become routinized, so HC only important during technological change ("skill in adoption"). A big empirical literature on this in agriculture, where educated farmers adopt first but others eventually follow. NP link this with the idea of technology catch-up, which says that those with the most to catch up will grow faster.

- Model:
  - Output
$$Q(t) = F[k(t), A(t)l(t)].$$
  - Technology frontier
$$T(t) = T_0 e^{\lambda t}.$$
  - Technology in use
$$\frac{\dot{A}(t)}{A(t)} = \Phi(h(t)) \left[\frac{T(t)}{A(t)} - 1 \right]$$

- Assume h constant. Then, in steady state,

$$\frac{A^*(t)}{T^*(t)} = \frac{\Phi(h)}{\Phi(h) + \lambda}$$

hence

  - A increases in human capital.
  - Distance from frontier falls as λ falls.
  - Elasticity of A to human capital increasing in λ. One implication is that inequality across workers *and across countries* should increase during periods of fast technical change and decline during periods of stagnation.

- Benhabib and Spiegel (JME 1994) found support for the NP idea (catch-up plus human-capital interaction)

- Benhabib and Spiegel (Handbook of Ec Growth, forth.) propose an alternative formulation:

$$\frac{\dot{A}(t)}{A(t)} = \Phi(h(t)) \left[1 - \frac{A(t)}{T(t)}\right],$$

  which is logistic. (Whereas the original NP formulation was "confined exponential").

- Same interpretation but different steady state implications. In particular:

$$\frac{A^*(t)}{T^*(t)} = \max\left(\frac{\Phi(h) - \lambda}{\Phi(h)}, 0\right)$$

- I.e. countries with initial h below a certain thresholds will *fall back* (convergence clubs)!

- Microfoundation
  - Version of Barro and Sala-i-Martin's diffusion model with cost of imitation, η, a function of h.
  - Depending of functional forms can generate both confined exponential and logistic diffusion dynamics.
  - (Not a full microfoundation but relatively easy to write model where imitation uses skilled labor and skilled wage higher when skilled labor is scarce).
  - Howitt and Mayer and Foulkes (2002) have something along similar lines (but more complicated).

- Empirical Implementation
  - Estimate equation for TFP growth that nests confined exponential and logistic.
  - Data is cross-section of countries 1960-1995.
  - Fairly robust evidence in support of $h-$technology gap interaction.
  - Weak support for logistic over confined exponential.

- Lots of data and identification problems, and in particular:
  - Measurement of TFP in 1960 (to calculate growth rate).
  - h may be picking up all sorts of correlated things.

Approach 3: Analysis of patent data

- Eaton and Kortum (JIE 1996). Empirical determinants of country i's propensity to take patents in country j (OECD sample). Countries patent more in nearby countries (more similar tastes and hence greater value of protection? easier imitation and hence greater need for protection?), in countries with high human capital, and in poorer countries. They do not patent more in countries where they export a lot.

- Peri (RESTAT 2005). Cross-regional patent citations. Stronger results pertain to intense localization, similar to Keller.

- Cross-border patenting and cross-border citation patterns obviously more direct measures of knowledge flows.

Approach 4: Embodied technology flows

- To the extent that technology is embodied in specific equipment, can learn about technology flows by looking at equipment imports.

- Again, I let Jonathan talk about his own important work here.

- Also, Giorgio has a nice paper with Soloaga using the unit-value of equipment imports – relative to the unit-value of equipment imports in the US – as a proxy for the technological sophistication of various countries' imports.

- Caselli and Coleman (AER 2000). Look at computer imports as proxy for adoption:
  - Recent
  - Embodied
  - Produced in Few Countries

- Data Set 1
  - *imports of automatic data processing machines and units thereof; magnetic and optical readers, machines for transcribing data onto data media in coded form and machines for processing such data, n.e.s..*
  - I.e. assembled computers and key components (central processing units, memory chips, storage devices, peripherals...).
  - From 1970-1990.
  - From (initially) 155 countries.
  - from Feenstra, Lipsey, and Bowen (1997).
  - Divided by labor force, from World Bank (1998).

- Data Set 2
  - Same but only if no computer exports.

- Data Set 3
  - OCAM data (Office Computing and Accounting Machinery)
  - Production + Imports - Exports
  - Production from UNIDO
  - From 1977-1990
  - Fewer Countries

- Method
  - Regression

$$\log(I_c^{it}) = \alpha + \boldsymbol{\delta}^t \beta + \mathbf{X}^{it} \gamma + \eta^i + u^{it} \tag{1}$$

  - 5 Year Dummies.
  - 7 Regional Dummies.
  - Country Random Effects

- Summary of Results
  - Always Significant (3 Samples)
    - ∗ Human Capital
      - · New in Cross-Country Setting
      - · Skill in Use vs. Skill in Adoption
    - ∗ Manufacturing Imports from OECD
      - · Knowledge Externalities?

- Often Significant (2 Samples)
  - Agriculture Share of GDP
  - Investment per Worker
    - Embodied Technology
  - Property Rights Protection
  - Government Share of GDP.

- Sometimes Significant
  - Manufacturing Share of GDP
  - Some Export Variables
- Never Significant
  - Fraction Speaking English.

- Caselli and Wilson (JME 2004). Generalizes to a cross-section of types of capital.

- Composition of K-imports (and hence,presumably, K) varies dramatically across countries. Shares in total capital imports

	Metal Prod.	Non-Elec.	OCAM	Elec. Eq.	Comm. Eq.	Motor Veh.	Other Transp.	Aircraft	Prof. Goods
Mean	.08	.21	.06	.14	.11	.24	.03	.05	.07
Std. Dev.	.06	.08	.05	.07	.05	.10	.04	.09	.03
Min	.01	.03	.01	.01	.01	.01	.00	.00	.01
Max	.55	.48	.41	.59	.37	.55	.34	.88	.23
Y Corr	-.25	-.14	.53	.27	.20	-.32	-.41	.14	.33
R&D	202	887	1170	848	2280	1810	57	1880	801

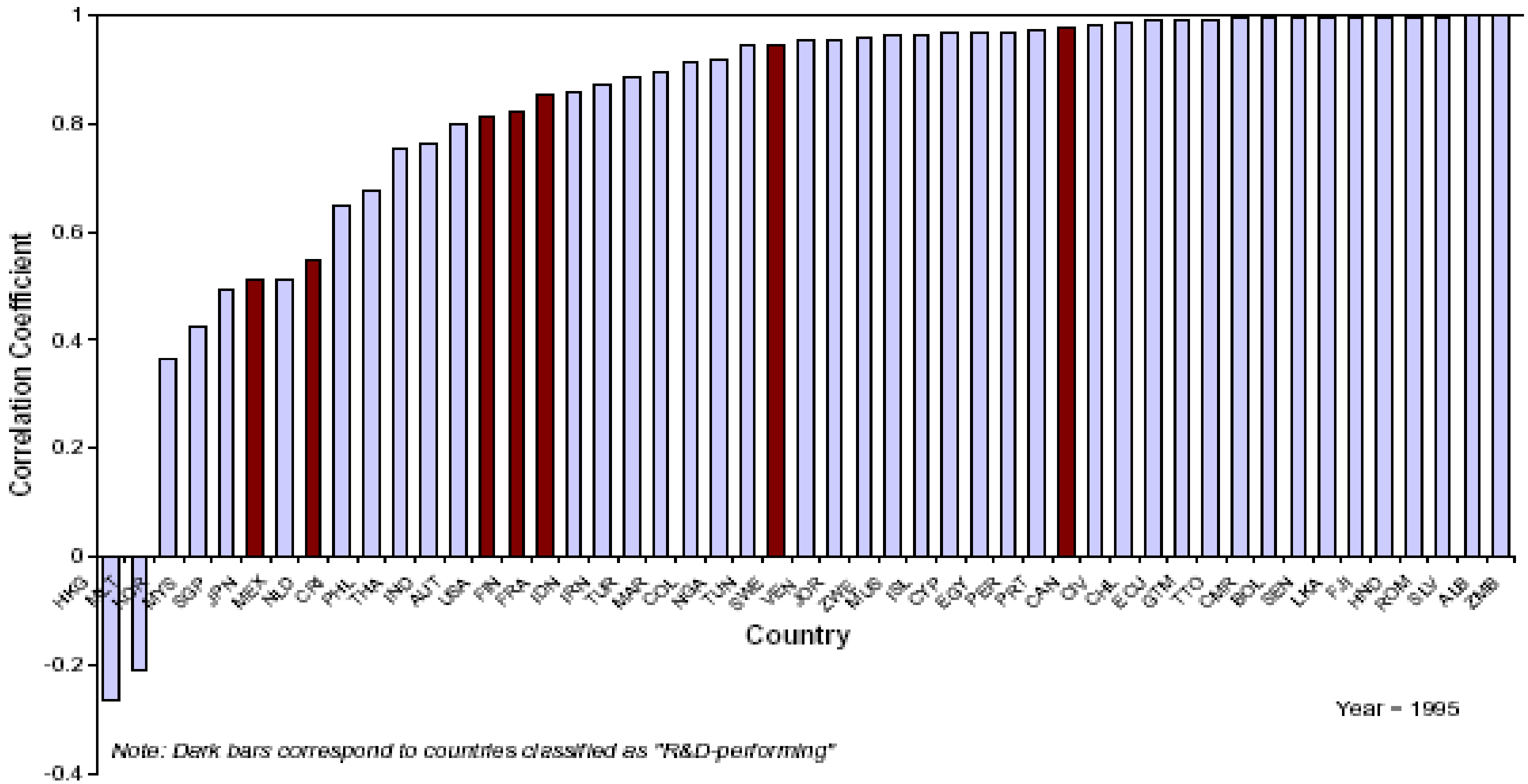

Fig. 1. Correlations between import shares and investment shares, by country.

- Two Questions
  - Why does K Composition Vary?
  - Does it Matter for Var(Y)?

- Sketch of a Model

$$Y^i = B^i \left[\sum_{p=1}^{P} \left(x_p^i \right)^\gamma \right]^{\frac{1}{\gamma}} \qquad \gamma < 1,$$

$$x_p^i = A_p^i \left(L_p^i \right)^{1-\alpha} \left(K_p^i \right)^\alpha \qquad 0 < \alpha < 1,$$

  - K_p^i is Market Value of Capital Type p
  - A_p^i is both Type and Country Specific

- Model Solution

  – With Sectoral Labor Mobility and Investment Arbitrage

$$\frac{K_p^i}{K^i} = \frac{\left(A_p^i\right)^{\frac{\gamma}{1-\gamma}}}{\sum_j \left(A_j^i\right)^{\frac{\gamma}{1-\gamma}}}.$$

  – Determinants of country-type productivity:

$$A_p^i = A_p \prod_c \left(z_c^i\right)^{\delta_{c,p}}.$$

  – Regression:

$$\frac{K_p^i}{K_p^1} = \beta_p \prod_c \left(z_c^i\right)^{\beta_{c,p}} \varepsilon_p^i$$

  where $\beta_p = (A_p/A_1)^{\gamma/(1-\gamma)}$ and $\beta_{c,p} = (\delta_{c,p} - \delta_{c,1})\gamma/(1-\gamma)$.

  – $p = 1$ is fabricated metal products

Table 4
Type-by-type relative imports regression

	2	3	4	5	6	7	8	9
Variable	Non-elec eqp	Computers	Elec eqp	Comm eqp	Other transport	Motor vehicles	Aircraft	Prof goods
Panel A—Dependent variable = Relative imports								
Intercept	1.665**	−3.404**	−1.426**	−2.390**	0.155	1.175**	−3.712**	−0.765
Time Trend	−0.221	2.693**	2.045**	2.870**	−0.803	−0.041	3.518**	0.864
Inward FDI	−0.120**	−0.077	−0.061**	−0.038	−0.111**	−0.057**	−0.159**	−0.107**
Outward FDI	0.028**	0.035*	0.017	0.002	0.019	0.001	0.053**	0.011
Gov't share	−0.324**	−0.570**	−0.450**	−0.140	−0.205	−0.040	0.095	−0.285
Industrial share	0.680**	0.384	0.188	−0.384	0.451	0.337	−0.121	0.138
Services share	−0.259	−0.253	−1.027**	−0.827*	0.556	0.676*	−0.567	0.111
Human capital	0.134	0.487*	0.286*	0.561**	−0.043	0.248**	0.142	0.417**
Income per capita	−0.040	0.460**	0.407**	0.170	−0.403	−0.041	−0.230	0.114
Pseudo-R_2	0.108	0.168	0.134	0.103	0.031	0.026	0.112	0.056
N	205	205	205	205	205	205	205	205
# countries	40	40	40	40	40	40	40	40

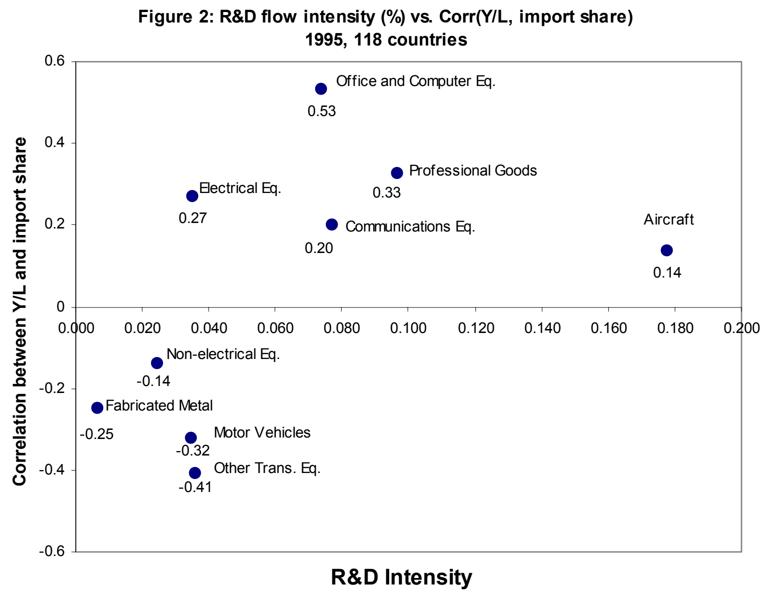

Figure 1: Capital Composition and Income

- Embodied-technology regressions:

$$A_p = a(R_p)^\sigma$$

$$\delta_{c,p} = b_c \log(R_p)$$

$$\frac{K_p^i}{K_1^i} = a\left(\frac{R_p}{R_1}\right)^\phi \prod_c (z_c^i)^{\phi_c \log(R_p/R_1)} \varepsilon_p^i$$

Table 5
Embodied R&D regressions

Independent variable	1	2	3	4	5
	Dependent variable				
	Relative imports				
Constant	1.847**	1.856**	1.848**	1.735**	1.685**
$LOG(R_P/R_1)$	−0.663**	−0.700**	−0.705**	−0.580**	−0.660**
Time trend	0.008**	0.010**	0.010**	0.008**	0.009**
Inward FDI	−0.036**	−0.041**	−0.042**	−0.031**	−0.029**
Outward FDI	0.007**	0.009**	0.008**	0.007**	0.001
Industrial share	0.032	−0.028	−0.027	0.074	0.149*
Services share	−0.254**	−0.378**	−0.355**	−0.095	0.260*
Gov't share	−0.102**	−0.024	−0.042	−0.031	−0.039
Human capital	0.174**	0.074*	0.091**	0.024	−0.063
Income per capita	0.049	0.094**	0.082**	−0.052	0.002
Remoteness		0.375**	0.383**	0.302**	0.349**
Fin. development			0.039	−0.027	−0.076*
Property rights				0.049**	0.041**
IPR					0.057
N	1176	1176	1136	824	808
# Countries	40	40	39	39	38

Note: For each of the country-specific factors above, it is the log of the factor interacted with $\log(R_p/R_1)$ that is included in the regression.

- Back to Model

$$Y^i = B^i \left[\sum_p \left(A_p^i \right)^{\frac{\gamma}{1-\gamma}} \right]^{\frac{1-\gamma}{\gamma}} \left(K^i \right)^{\alpha} \left(L^i \right)^{1-\alpha}$$

Compare with Standard Development Accounting

$$Y^i = TFP^i \left(K^i \right)^{\alpha} \left(L^i \right)^{1-\alpha}$$

Fraction of Income variance Explained by Quality

γ	Log-Var	90-10 Ratio	Corr with Y
0.25	4.9	4.8	.3
0.50	0.5	0.7	.3
0.75	0.1	0.4	.3

- K Composition Varies a Lot

- Why

  K-type Characteristics (Embodied Technology)

  Country Characteristics (Appropriate Technology)

- Does it Matter for Var(Y)

  Theory: Definitely Yes

  Data: Tentatively Yes