# The impact of educated labor on technology adoption and comparative advantage

Serge Shikher
Research Division
U.S. International Trade Commission

March 2017

## Introduction

- There are patterns in trade and development at the industry level:
  - Rich countries tend to produce and export certain types of machinery, such as medical equipment
  - Poor countries tend to produce and export textile, basic metals, and food products
- Understanding the pattern in production and trade is important for
  - International trade
  - Development economics
  - Competitiveness trends
- Big question: what explains these patterns?

Contributions of this paper:

- Estimate fundamental productivities for a large set of countries and industries
- Characterize the pattern of productivities and comparative advantages
- Break productivities into country and industry components
  - Using a new, very general empirical approach
- Provide evidence of complementarity of productivities with respect to industry and country characteristics
  - This complementarity is a fundamental characteristic of neoclassical theory of trade
- Link productivities to country and industry characteristics
  - Capital, labor, institutions, innovation, and others
  - Focus on labor with different levels of education
  - Account for quality of education
- Provide insight for development accounting from the industry dimension

Related literatures:

- Exogenous productivity differences matter for trade (Harrigan, 1997; Davis and Weinstein, 2001; Eaton and Kortum, 2002, 2012)
- Productivity differences matter for differences in per capita income (Hall and Jones, 1999; Caselli, 2005)
- Some productivity differences can be explained by a combination of country-specific endowments and industry-specific intensities (Trefler, 1995; Harrigan, 1997; Romalis, 2004)
- Some productivity differences can be explained by institutions (Nunn, 2007; Levchenko, 2007; Costinot, 2009; Chor, 2010)
- Educated labor plays a key role in technology adoption (Nelson and Phelps, 1966; Benhabib and Spiegel, 2005)
- Human capital has an effect on trade and specialization (Romalis, 2004; Ciccone and Papaionnaou, 2009; Baldwin, 1979)
- Measure of human capital is important
    - Previous papers: years of schooling, workers with secondary education, skilled workers, non-production workers
    - This paper focuses on workers with post-secondary education

## Estimation of productivities

- Follow a standard approach, using an extension of the Eaton-Kortum (2002) methodology to multiple industries and factors
- Each industry has many goods produced with different productivities
- With trade, each country only produces a subset of all goods
- Comparative advantage of an industry is based on the productivity of all goods (in autarky), not just those currently produced
- We need to estimate the mean productivity of all goods, $A$, called fundamental productivity or state of technology

- Fundamental productivity can be obtained using trade, output, and factor price data from the following expression:

$$\log\left(\frac{A_{ij}}{A_{us,j}}\right) = \frac{1}{\theta} D_{ij}^{exp} + \log\left(\frac{c_{ij}}{c_{us,j}}\right)$$

- $i$ is country, $j$ is industry
- $D_{ij}^{exp}$ is the competitiveness of country $i$ in industry $j$ in exports, estimated from a gravity equation
- $c_{ij}$ is the cost of production
- $\theta$ is a parameter

More detail

$D_{ij}^{exp}$ is estimated from the gravity equation

$$\log \frac{X_{nij}}{X_{nnj}} = -\theta \left( \text{DIST}_{knij} + \text{BORDER}_{nij} + \text{LANG}_{nij} + \text{FTA}_{nij} \right) + \\ + D_{ij}^{exp} + D_{nj}^{imp} + \varepsilon_{nij}$$

$X_{nij}$: industry $j$ imports from country $i$ by country $n$, obtained from data
$X_{nnj}$: spending on own country goods (domestic trade), calculated as output-exports
$\text{DIST}_{knij}$ $(k = 1, ..., 6)$ is the effect of distance lying in the $k$th interval
$\text{BORDER}_{nij}$: common border
$\text{LANG}_{nij}$: common language
$\text{FTA}_{nij}$: free trade area
$D_{ij}^{exp}$ and $D_{nj}^{imp}$: exporter and importer fixed effects
$\varepsilon_{nij}$ includes all other trade barriers
$\theta$: parameter (elasticity of imports with respect to the relative price of imports), taken from literature (8.28; robustness checks in appendix)

- 4 factors of production: capital and 3 types of labor (with primary or less, secondary, and tertiary education)

$$c_{ij} = r_i^{\alpha_j} \left( \prod_e w_{ei}^{\lambda_{ej}} \right) P_{ij}^{1-\alpha_j-\beta_j}$$

- Different types of labor are not perfect substitutes
- $r$ is the rate of return of capital in country $i$
- $w_e$ is the wage of labor with of type $e$
- $\lambda_{ej}$ is the share of that type of labor in industry $j$
- $\beta_j = \sum_e \lambda_{ej}$ is total labor share
- $P$ is the cost of intermediate goods bundle: $P_{ij} = \prod_m p_{im}^{\eta_{jm}}$, $p$ is the industry price index
- Robustness checks include a translog production function

## Accounting for education quality differences

- Education quality varies across countries and helps explain productivity differences
  - International test scores (Hanushek and Kimko, 2000; Kaarsen, 2014)
  - Earnings of immigrants (Hendricks, 2002; Schoellman, 2012)
  - Models of human capital accumulation (Manuelli and Seshadri, 2010; Erosa et al, 2007)
- So wages $w_{ei}$ are not directly comparable across countries
- We must account for differences in education quality

## Accounting for education quality differences (cont'd)

- Observed wage

$$w_{ei} = \widetilde{w}_i h_{ei} = \widetilde{w}_i e^{f(s_e, q_i)}$$

  $\widetilde{w}_i$ is the base wage in country $i$
  $h_{ei}$ is the human capital of labor with education level $e$ in country $i$.
  $s_e$ is the number of year of education of level $e$
  $q_i$ is the quality of education in country $i$

- $f(s_e, q_i) = \dfrac{\xi (s_e q_i)^\rho}{\rho}$, where $\xi$ and $\rho$ are parameters.
- Motivation: Bils and Klenow (2000) have this functional form, but without $q$
  - To fit the cross-country data on Mincerian returns to education
- Schoellman (2012): adds quality of education $q_i$
  - Education quality and years of schooling are positively correlated if $0 < \rho < 1$
- The values of parameters $\rho$ and $\xi$ are estimated
  - Schoellman (2012) from earnings of immigrants
  - Kaarsen (2014) from international test scores.

- The wages observed in data are $w_{ei}^{i}$
  superscript represents the quality of education that workers received.
- Need to compare wages at the same education quality level
  - I compare wages at the U.S. quality level
  - Need to adjust observed $w_{ei}^{i}$ to $w_{ei}^{us}$
- Multiply the observed $w_{ei}^{i}$ by $w_{ei}^{us} / w_{ei}^{i}$

$$\log \frac{w_{ei}^{us}}{w_{ei}^{i}} = \log \frac{\widetilde{w}_i h_{e,us}}{\widetilde{w}_i h_{ei}} = \log \frac{h_{e,us}}{h_{ei}} = f(s_e, q_{us}) - f(s_e, q_i) =$$

$$= \frac{\xi s_e^{\rho}}{\rho} \left[ q_{us}^{\rho} - q_i^{\rho} \right]$$

$s_e$ is number of years of education for level $e = 1, 2, 3$

## Estimation of productivities: summary

1. Estimate $D_{ij}^{exp}$ from a gravity equation
2. Calculate trade costs using factor prices and shares
   - Adjust wages for quality of education differences
3. Calculate productivities $\frac{A_{ij}}{A_{us,j}}$

## Data sources

- 53 countries, including many developing, poor, and very poor countries
- 15 manufacturing industries
- Year 2005
- Bilateral trade data is from COMTRADE
- Output data is from IndStat
- Gravity variables are from CEPII
- Factor shares are from OECD, WBES, ACS
  (World Bank Enterprise Surveys, American Community Survey)
- Wages are from OWW (Occupational Wages Around the World database)
- Several assumptions tested for rates of return

## What do estimated productivities $A_{ij} / A_{us,j}$ tell us?

1. Some countries have higher productivities than others in all industries. These are absolute advantages.
2. In each country, productivities vary significantly across industries. These are comparative advantages.

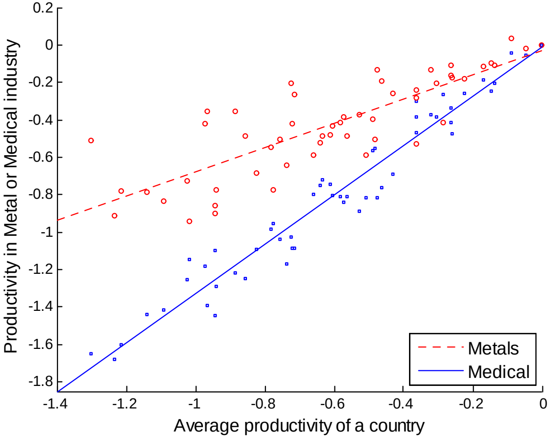
| | China | Ecuador | Ethiopia | Germany | Indonesia | Korea | Mexico | Turkey | Vietnam |
|---|---|---|---|---|---|---|---|---|---|
| Food | 0.66 | 0.62 | 0.48 | 0.88 | 0.62 | 0.60 | 0.57 | 0.67 | 0.56 |
| Textile | 0.80 | 0.43 | 0.42 | 0.96 | 0.60 | 0.91 | 0.59 | 0.78 | 0.54 |
| Wood | 0.74 | 0.49 | 0.33 | 0.98 | 0.60 | 0.60 | 0.47 | 0.53 | 0.46 |
| Paper | 0.59 | 0.34 | 0.25 | 0.95 | 0.49 | 0.73 | 0.49 | 0.49 | 0.33 |
| Chemicals | 0.66 | 0.40 | 0.39 | 0.91 | 0.48 | 0.72 | 0.62 | 0.59 | 0.37 |
| Rubber | 0.60 | 0.40 | 0.27 | 0.94 | 0.48 | 0.93 | 0.52 | 0.60 | 0.40 |
| Nonmetals | 0.71 | 0.36 | 0.30 | 1.01 | 0.49 | 0.77 | 0.53 | 0.66 | 0.40 |
| Metals | 0.77 | 0.46 | 0.46 | 0.98 | 0.53 | 0.90 | 0.62 | 0.69 | 0.42 |
| Metal products | 0.62 | 0.36 | 0.25 | 0.98 | 0.39 | 0.76 | 0.53 | 0.59 | 0.35 |
| Machinery, other | 0.58 | 0.34 | 0.21 | 0.97 | 0.41 | 0.75 | 0.54 | 0.54 | 0.31 |
| Machinery, e&c | 0.67 | 0.35 | 0.22 | 0.97 | 0.49 | 0.89 | 0.59 | 0.60 | 0.38 |
| Medical | 0.50 | 0.28 | 0.20 | 0.95 | 0.31 | 0.66 | 0.47 | 0.41 | 0.24 |
| Transport | 0.58 | 0.38 | 0.28 | 0.98 | 0.42 | 0.89 | 0.55 | 0.63 | 0.40 |
| Other | 0.67 | 0.37 | 0.26 | 0.91 | 0.50 | 0.76 | 0.54 | 0.59 | 0.41 |
| AVERAGE | 0.65 | 0.40 | 0.31 | 0.95 | 0.49 | 0.78 | 0.54 | 0.60 | 0.40 |

## What do estimated productivities $A_{ij}/A_{us,j}$ tell us?

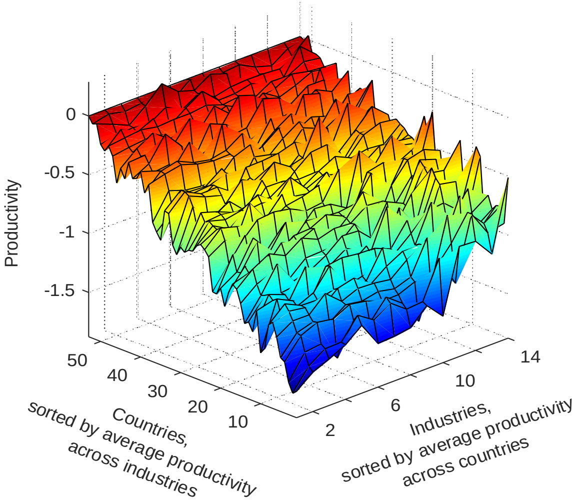
1. Some countries have higher productivities than others in all industries. These are absolute advantages.
2. In each country, productivities vary significantly across industries. These are comparative advantages.

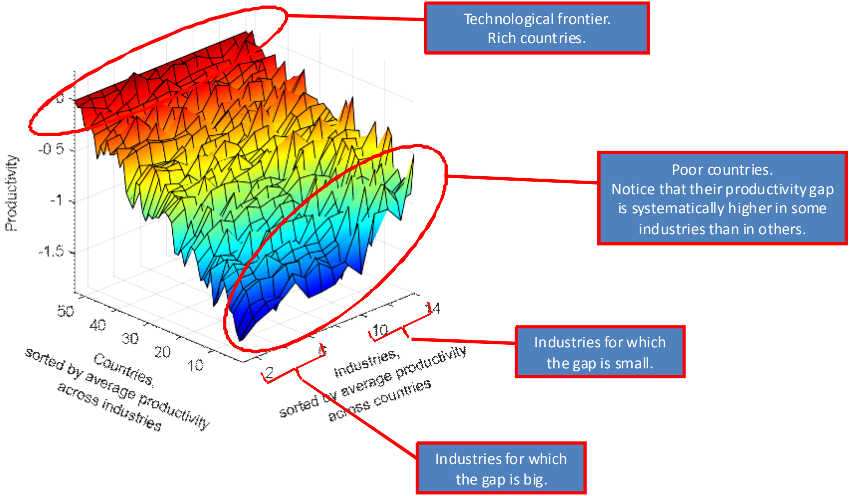
| | China | Ecuador | Ethiopia | Germany | Indonesia | Korea | Mexico | Turkey | Vietnam |
|---|---|---|---|---|---|---|---|---|---|
| Food | 0.66 | 0.62 | 0.48 | 0.88 | 0.62 | 0.60 | 0.57 | 0.67 | 0.56 |
| Textile | 0.80 | 0.43 | 0.42 | 0.96 | 0.60 | 0.91 | 0.59 | 0.78 | 0.54 |
| Wood | 0.74 | 0.49 | 0.33 | 0.98 | 0.60 | 0.60 | 0.47 | 0.53 | 0.46 |
| Paper | 0.59 | 0.34 | 0.25 | 0.95 | 0.49 | 0.73 | 0.49 | 0.49 | 0.33 |
| Chemicals | 0.66 | 0.40 | 0.39 | 0.91 | 0.48 | 0.72 | 0.62 | 0.59 | 0.37 |
| Rubber | 0.60 | 0.40 | 0.27 | 0.94 | 0.48 | 0.93 | 0.52 | 0.60 | 0.40 |
| Nonmetals | 0.71 | 0.36 | 0.30 | 1.01 | 0.49 | 0.77 | 0.53 | 0.66 | 0.40 |
| Metals | 0.77 | 0.46 | 0.46 | 0.98 | 0.53 | 0.90 | 0.62 | 0.69 | 0.42 |
| Metal products | 0.62 | 0.36 | 0.25 | 0.98 | 0.39 | 0.76 | 0.53 | 0.59 | 0.35 |
| Machinery, other | 0.58 | 0.34 | 0.21 | 0.97 | 0.41 | 0.75 | 0.54 | 0.54 | 0.31 |
| Machinery, e&c | 0.67 | 0.35 | 0.22 | 0.97 | 0.49 | 0.89 | 0.59 | 0.60 | 0.38 |
| Medical | 0.50 | 0.28 | 0.20 | 0.95 | 0.31 | 0.66 | 0.47 | 0.41 | 0.24 |
| Transport | 0.58 | 0.38 | 0.28 | 0.98 | 0.42 | 0.89 | 0.55 | 0.63 | 0.40 |
| Other | 0.67 | 0.37 | 0.26 | 0.91 | 0.50 | 0.76 | 0.54 | 0.59 | 0.41 |
| AVERAGE | 0.65 | 0.40 | 0.31 | 0.95 | 0.49 | 0.78 | 0.54 | 0.60 | 0.40 |

3. Key observation: as the overall productivity of a country declines the productivities of individual industries decline at different rates.



# Pattern of industry productivities




Technological frontier.
Rich countries.
Poor countries.
Notice that their productivity gap is systematically higher in some industries than in others.
Industries for which the gap is small.
Industries for which the gap is big.
Productivity
0
-0.5
-1
-1.5
50
40
30
20
10
Countries, sorted by average productivity across industries
2
6
10
14
Industries, sorted by average productivity across countries

## Formal analysis

- Let's see if we can decompose productivity differences into
  - industry-specific components $\gamma_j^k$, $k = 1, ..., M$ and
  - country-specific components $\phi_i^k$, $k = 1, ..., M$, where $M$ is the number of components
- Use the following functional form:

$$\log \frac{A_{ij}}{A_{US,j}} = -\sum_{k=1}^{M} \gamma_j^k \log \frac{\phi_i^k}{\phi_{US}^k}$$

or in matrix form

$$\underset{N\times J}{\mathbf{A}} = \underset{N\times M}{\mathbf{U}} \cdot \underset{J\times M}{\mathbf{V}}^{\mathsf{T}},$$

- Each row of **U** contains the values of $M$ country-level determinants
- Each row of **V** contains the values of $M$ industry-level determinants

$$\log \frac{A_{ij}}{A_{US,j}} = -\sum_{k=1}^{M} \gamma_j^k \log \frac{\phi_i^k}{\phi_{US}^k}$$

The functional form is called log-supermodular (Costinot, 2009)

- Log-supermodularity is a mathematical property of a function:
  - A type of complementarity between two inputs of a function
  - Impact from increasing one input of is greater when other inputs are high
- Log-supermodularity is the key unifying feature of the neoclassical trade theory
  - More general than the Heckscher-Ohlin model
  - Can be applied to an arbitrary number of countries, factors, and industries
  - Example: countries with more skilled workers have greater output in sectors which use skilled workers more intensively

Why do this decomposition?

- To see if the pattern of productivities can be described parsimoniously
- The decomposition will help us understand the reasons for productivity differences
- The industry-specific component can help us understand what kind of industries see the highest drop in productivity when the average productivity falls

- To decompose $A$ we can use Singular Value Decomposition (SVD)
- A variant of principal component analysis
- SVD decomposes $\mathbf{A}$ (in the least squared sense) into

$$\mathbf{A} = \mathbf{U}\boldsymbol{\Sigma}\mathbf{V}^{\mathsf{T}}$$

where $\boldsymbol{\Sigma}$ is a diagonal $M \times M$ matrix with each element showing the importance or weight of each factor

- SVD tries to explain as much as possible of $\mathbf{A}$ by the first factor, then uses the other factors to tweak the fit
- Consider for example this equation with $M = 1$:

$$\log \frac{A_{ij}}{A_{us,j}} = -\gamma_j^1 \log \frac{\phi_i^1}{\phi_{US}^1} + \varepsilon_{ij},$$

  where $\varepsilon_{ij}$ is the residual.
- We can use SVD to estimate $\gamma_j^1$ and $\phi_i^1$ that would best explain the variation of productivities $A_{ij}$ (in the least squared sense).

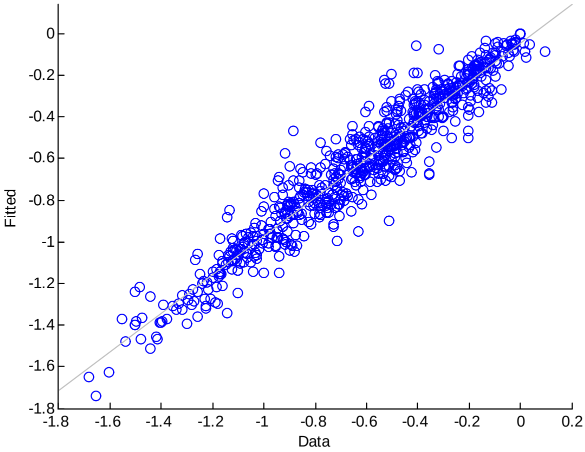
More detail

Estimated diagonal elements of $\mathbf{\Sigma}$

| | |
|---|---|
| 1 | 19.16 |
| 2 | 1.43 |
| 3 | 1.30 |
| 4 | 1.05 |
| 5 | 0.95 |
| 6 | 0.67 |
| 7 | 0.52 |
| 8 | 0.46 |
| 9 | 0.45 |
| 10 | 0.39 |
| 11 | 0.36 |
| 12 | 0.34 |
| 13 | 0.28 |
| 14 | 0.21 |

- Key finding: the first factor has a much greater weight than the rest
- The $R^2$ of the fit with only the first factor is 0.92

# Fitted vs actual productivities



Ranking of industries according to the first industry-specific factor $\gamma_j^1$:

| |
|---|
| Metals |
| Food |
| Textile |
| Chemicals |
| Wood |
| Machinery, e&c |
| Rubber |
| Nonmetals |
| Transport |
| Other |
| Paper |
| Machinery, other |
| Metal products |
| Medical |

Link to Krugman (1986) model:

- Technological gap between developed and developing countries varies systematically across industries
- There is a "ladder" for development: as they develop, countries move from manufacturing one bundle of goods to another
- Technological progress is a vector rather than a number
- Developed countries have comparative advantages in "technology-intensive" goods
- This paper presents evidence for the above
- Relates technological intensity to human capital intensity

## In search of key determinants of productivity

Looking for correlates with the country and industry determinants estimated by SVD

- Physical capital
- Labor, distinguished by education
- Institutions
  - Quality of institutions varies by country
  - Institutional reliance varies by industry

## Country-specific determinants

- Physical capital, per capita
  - Data source: Penn World Tables
- Labor with primary, secondary, and tertiary education, adjusted for quality of education
  - Data sources for attainment: Barro-Lee and IIASA/VID
  - Data sources for quality: Schoellman and Kaarsen
- Institutions:
  - Two measures from Nunn (2007): rule of law in 1998 from Kaufmann (2003), quality of legal system in 1995 from Gwartney and Lawson (2003)
  - World Bank's Doing Business report (overall DTF 2010, individual DTF scores 2006)

Correlations with $\phi_i^1/\phi_{US}^1$
(endowment of the first factor estimated by SVD)

| | |
|---|---|
| GDP per capita | 0.8 |
| Capital stock per capita | 0.75 |
| Labor with primary education | (-0.23)-(-0.09) |
| Labor with primary education (outliers removed) | (-0.31)-(-0.18) |
| Labor with secondary education | 0.48-0.55 |
| Labor with secondary education (outliers removed) | 0.56-0.69 |
| Labor with tertiary education | 0.55-0.65 |
| Labor with tertiary education (outliers removed) | 0.67-0.76 |
| Rule of law | 0.69 |
| Quality of legal system | 0.65 |
| WB Doing Business Overall Distance To Frontier 2010 | 0.7 |
| WB Doing Business Distance To Frontier 2006 | 0.26-0.61 |

- Ranges show correlations for different data sources
- For labor with tertiary education, Russia, Ukraine, and Kazakhstan, and Bulgaria are outliers

## Regressing $\phi_i^1 / \phi_{US}^1$ on factor endowments and institutions:

| Source of educational quality data | Schoellman | Shoellman | Kaarsen |
|---|---|---|---|
| Source of institutions data | DTF10 | DTF10 | qc |
| Constant | -0.043 | -0.044 | -0.049 |
| | (0.000) | (0.000) | (0.000) |
| Physical capital per capita | 0.030 | 0.032 | 0.022 |
| | (0.001) | (0.000) | (0.047) |
| Fraction of population with primary education, quality adjusted | 0.001 | 0.000 | 0.001 |
| | (0.552) | (0.814) | (0.497) |
| Fraction of population with secondary education, quality adjusted | -0.014 | -0.006 | 0.011 |
| | (0.342) | (0.627) | (0.363) |
| Fraction of population with tertiary education, quality adjusted | 0.019 | 0.023 | 0.017 |
| | (0.052) | (0.012) | (0.045) |
| Institutions | 0.104 | 0.027 | 0.030 |
| | (0.037) | (0.654) | (0.276) |
| R squared | 0.65 | 0.71 | 0.71 |
| N | 53 | 49 | 47 |

p-values in parentheses

Source of educational attainment data is IIASA

DTF10 is Overall distance to frontier in 2010 from WB

qc is Quality of Legal System in 1995 from Gwartney and Lawson (2003)

## Industry-specific determinants

- Shares of physical capital and three types of labor
- Contract intensity (relationship specificity): the fraction of inputs not sold on organized exchange or reference priced (from Nunn, 2007)
  - Greater contract intensity implies greater dependence on institutions
- $1 -$ Herfindalh index of intermediate input use: measures the concentration of inputs across industries
  - An industry with less concentration of inputs will depend more on institutions (also from Nunn, 2007)
- External financial dependence (from Do and Levchenko, 2007)
  - An industry that required more external financing is more dependent on the financial sector
- Job complexity (from Costinot, 2009)
  - A measure of on-the-job training

## Correlation with $\gamma_j^1$ (share of the first factor estimated by SVD)

| | |
|---|---|
| Capital | 0.27 |
| Labor, primary | -0.08 |
| Labor, secondary | 0.51 |
| Labor, tertiary | 0.88 |
| Contract intensity, $z^{rs1}$ | 0.65-0.69 |
| Contract intensity, $z^{rs2}$ | 0.76-0.78 |
| Input concentration | 0.67 |
| External financial dependence | 0.53 |
| Job complexity | 0.47 |

$z^{rs1}$: fraction of inputs not sold on exchange and not ref priced

$z^{rs2}$: fraction of inputs not sold on exchange

Input concentration: one minus the Herfindahl index of intermediate input use

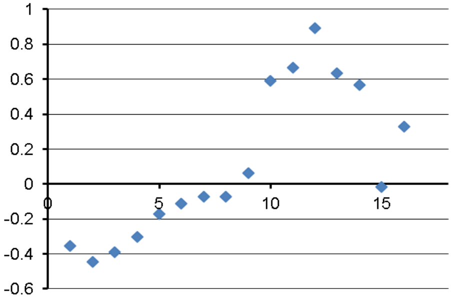
Regressing $\gamma_j^1$ on factor shares and institutional intensity:

| | |
|---|---|
| Constant | -0.018<br>(0.796) |
| Share of physical capital | 0.107<br>(0.763) |
| Share of labor with primary education | 0.439<br>(0.855) |
| Share of labor with secondary education | 0.228<br>(0.743) |
| Share of labor with tertiary education | 1.634<br>(0.008) |
| Contract intensity* | 0.150<br>(0.228) |
| R squared | 0.89 |
| N | 14 |

p-values in parentheses

Measure of contract intensity is z_rs2 (conservative)

## Correlation between $\gamma_j^1$ and shares of 16 types of labor (from the U.S. ACS data)




| | |
|---|---|
| 1 | No school completed |
| 2 | Nursery school to grade 4 |
| 3 | Grade 5 or grade 6 |
| 4 | Grade 7 or grade 8 |
| 5 | Grade 9 |
| 6 | Grade 10 |
| 7 | Grade 11 |
| 8 | Grade 12 no diploma |
| 9 | High school graduate |
| 10 | Some college, but less than 1 year |
| 11 | One or more years of college, no degree |
| 12 | Associate's degree |
| 13 | Bachelor's degree |
| 14 | Master's degree |
| 15 | Professional school degree |
| 16 | Doctorate degree |

## Evidence on occupations

Industries that are more education-intensive use more educated workers in all occupations (administrators, engineers, maintenance workers, production workers, technicians, sales people)

## Summary of regression results

- Physical capital, educated labor, and institutions are correlated with the first country principal component
- In regressions, only physical capital and labor with tertiary education are robust and statistically significant
- Institutions are only significant when the four Eastern European countries are included
- For cross-industry variation of productivities, only the share of labor with tertiary education is significant
- Labor with tertiary education can explain both cross-country and cross-industry variations of productivities

How does labor with tertiary education affect productivity?

- It cannot be the differences in cost of this labor
  - Heckscher-Ohlin or Becker-Mincer effects
  - Already accounted for
- There must be an externality associated with this type of labor
- Previous literature: the main role of human capital is to enable technology adoption
  - Nelson-Phelps model; Doms et al (1997)

# Motivation for the technology adoption story: evidence on technology adoption f

- Use of licensed foreign technology (World Bank data)
- Average share of enterprises using of foreign licensed technology: 16%

Pattern of foreign technology licensing:

| | | Country income | | | |
|---|---|---|---|---|---|
| | | Upper middle income | Lower middle income | Low income | |
| Education intensity | high | 34% | 13% | 13% | |
| | low | 15% | 12% | 14% | |
| | | | | | |
| Correlation between education intensity and use of licensed foreign technology | | | | | |
| | | 0.84 | -0.07 | 0.06 | |

- Steep drop-off in licensing rates in high-$\lambda_3$ industries, but not others
- If appropriability (theft) were a problem due to poor enforcement of IP rights, we would have seen low technology adoption in all industries
- Suggests inability to use licensed technology in high-$\lambda_3$ industries

- Why are workers not properly compensated?
- Possible explanations (more research needed):
    - Externality is outside the firm (e.g. learning from others: Rosenzweig, 2004)
    - Local market effects (Moretti, 2004)
    - Labor market imperfections (e.g. high search costs)

## Explaining the variation of productivities by human capital

- Frontier technology is available to all countries
- As in Krugman (1986), countries vary in their ability to use technologies
- As in the Nelson-Phelps model, technology adoption is enabled by educated labor
  - More sophisticated technology requires more workers with post-secondary education
- The average productivity in industry $j$ of country $i$ relative to the U.S. is a function of
  1. Stock of labor with tertiary education in country $i$, $H_i$, relative to the stock of labor with tertiary education in the U.S., $H_{us}$
  2. Industry $j$ requirement for educated labor, $\lambda_{3j}$

$$\frac{A_{ij}}{A_{us,j}} = \mu \left( \frac{H_i}{H_{us}} \right)^{\psi \lambda_{3j}}, \tag{1}$$

where $\mu$ and $\psi$ are (scaling) parameters

Model fit

We perform the regression

$$\log \frac{A_{ij}}{A_{us,j}} = \log \mu + \psi \lambda_{3j} \log \frac{l_{3i}^{us}}{l_{3,us}^{us}}$$

Educational attainment is from IIASA/VID
Educational quality is from Schoellman
Four outlier countries are omitted

| | |
|---|---|
| Constant | -0.300 (0.000) |
| Slope | 3.812 (0.000) |
| $R^2$ | 0.496 |
| N | 686 |

p-values in parentheses

Benchmark: first principal component; $R^2 = 0.92$

## Development account with an industry dimension

Accounting for productivity gaps between most and least productive countries in each industry, $\max_i(A_{ij}) / \min_i(A_{ij})$

| | Data | | | Model | |
|---|---|---|---|---|---|
| | Capital and one type of labor | Separate labor into threee types | Account for education quality differences | SVD model | Model of technology adoption |
| Food | 3.2674 | 3.2898 | 3.1022 | 2.6612 | 2.0321 |
| Textile | 3.2953 | 3.2108 | 3.1023 | 2.8145 | 2.3038 |
| Wood | 4.3952 | 4.595 | 4.4043 | 3.3772 | 2.2078 |
| Paper | 5.3935 | 5.0616 | 4.397 | 4.3327 | 3.9901 |
| Chemicals | 3.9759 | 4.07 | 3.5507 | 3.1509 | 3.2084 |
| Rubber | 4.9151 | 4.6598 | 4.4547 | 3.9274 | 3.2261 |
| Nonmetals | 4.4479 | 4.7023 | 4.5192 | 3.9839 | 2.6246 |
| Metals | 2.7285 | 2.9035 | 2.6517 | 2.4534 | 1.8672 |
| Metal products | 5.7059 | 5.5716 | 4.6663 | 4.3951 | 3.7926 |
| Machinery, other | 6.5219 | 6.1072 | 4.7247 | 4.3347 | 4.7456 |
| Machinery, e&c | 5.9477 | 5.6134 | 4.4857 | 3.7738 | 3.6474 |
| Medical | 7.281 | 6.8272 | 5.3689 | 5.7039 | 7.7386 |
| Transport | 5.0003 | 4.858 | 4.0313 | 4.04 | 2.8288 |
| Other | 5.3357 | 4.9919 | 4.5029 | 4.0596 | 3.0777 |

# Summary of the results

- As average productivity of a country declines, productivities in some industries decline faster than in others
- Matrix of productivities can be decomposed into industry and country components by SVD
- Rich countries have comparative advantages in education-intensive industries
- Labor with tertiary education, especially with an equivalent of an Associate's degree is the most important determinant of productivity in manufacturing
- Education quality differences matter
- Technology adoption is important for determining productivity differences
- The key role of educated labor is to enable technology adoption
- Labor with tertiary education can explain up to 50% of variation in industry-level productivities
    - The estimated principal component can explain 92% of variation

Eaton-Kortum model

- Each industry $j$ has a continuum of goods
- Indexed by $u \in [0, 1]$ and produced productivity $\chi_{nj}(u)$
- Productivities are the result of the R&D process and probabilistic
- Drawn independently from the Fréchet distribution
- The cdf of this distribution is $F_{ij}(\chi) = e^{-T_{ij}\chi^{-\theta}}$
- Parameters $T_{ij} > 0$ and $\theta > 1$, with $\theta$ being the dispersion parameter

- Share of country $i$ in country $n$'s spending on $j$

$$\frac{X_{nij}}{X_{nj}} = \frac{T_{ij}\left(c_{ij}d_{nij}\right)^{-\theta}}{\sum_m T_{mj}\left(c_{mj}d_{nmj}\right)^{-\theta}}$$

- $X_{nij}$ are imports of industry $j$ goods by country $n$ from country $i$
- $X_{nj}$ is spending by country $n$ on industry $j$ goods
- $c_{ij}$ is the cost of production inputs
- $d_{nij}$ is the "iceberg" trade cost

- Dividing trade shares by their domestic counterpart, we obtain

$$\frac{X_{nij}}{X_{nnj}} = \frac{T_{ij} c_{ij}^{-\theta}}{T_{nj} c_{nj}^{-\theta}} d_{nij}^{-\theta}$$

- The mean productivity in industry $j$ of country $i$ is denoted by $A_{ij} \equiv T_{ij}^{1/\theta}$
- Taking logs of the above and using the definition of $A_{ij}$ we obtain

$$\log \frac{X_{nij}}{X_{nnj}} = \theta \log \left( A_{ij} / c_{ij} \right) - \theta \log \left( A_{nj} / c_{nj} \right) - \theta \log d_{nij},$$

- Trade cost $d_{nij}$ is represented by the following trade cost function:

$$\log d_{nij} = \text{DIST}_{kj} + \text{BORDER}_j + \text{LANG}_j + \text{FTA}_j + \text{DEST}_{nj} + \delta_{nij}$$

- $\delta_{nij}$ is the sum of geographic barriers that are due to all other factors
- As typical in trade literature, international trade cost is measured relative to domestic trade cost: $\log d_{iij} \equiv 0$

- Plugging the trade cost function into the gravity equation we obtain

$$\log \frac{X_{nij}}{X_{nnj}} = -\theta \text{DIST}_{kj} - \theta \text{BORDER}_j - \theta \text{LANG}_j - \theta \text{FTA}_j - \theta \text{DEST}_{nj} - \\ -\theta \delta_{nij} + \theta \log \left( A_{ij} / c_{ij} \right) - \theta \log \left( A_{nj} / c_{nj} \right)$$

- Collecting terms that become parts of importer and exports fixed effects, we get a gravity equation

$$\log \frac{X_{nij}}{X_{nnj}} = -\theta \text{DIST}_{kj} - \theta \text{BORDER}_j - \theta \text{LANG}_j - \theta \text{FTA}_j + D_{ij}^{exp} + D_{nj}^{imp} + \varepsilon_{nij}$$

- $D_{ij}^{exp} = \theta \log \left( A_{ij} / c_{ij} \right)$ is the exporter fixed effect
- $D_{nj}^{imp} = -\theta \text{DEST}_{nj} - \theta \log \left( A_{nj} / c_{nj} \right)$ is the importer fixed effect
- $\varepsilon_{nij} = -\theta \delta_{nij}$ is the error term
- The following normalization is used: $D_{us,j}^{exp} = D_{us,j}^{imp} = 0$

Back

- A singular value and a pair of singular vectors of a rectangular matrix $\mathbf{A}$ are a nonnegative scalar $\sigma$ and nonzero vectors $u$ and $v$ such that $\mathbf{A}v = \sigma u$ and $\mathbf{A}^{\mathsf{T}} u = \sigma v$
- In matrix form: $\mathbf{AV} = \mathbf{U}\,\circ$ and $\mathbf{A}^{\mathsf{T}}\mathbf{U} = \mathbf{V}\,\circ^{\mathsf{T}}$
- $\circ$ is a matrix that is zero except on its main diagonal that contains the singular values of $\mathbf{A}$
- Matrices $\mathbf{U}$ and $\mathbf{V}$, whose columns are the singular vectors, are orthogonal
- Note that singular values and eigenvalues are related:
  - the singular values of matrix $\mathbf{A}$ are the positive square roots of the nonzero eigenvalues of $\mathbf{A}^{\mathsf{T}}\mathbf{A}$
  - If $\mathbf{A}$ is a real symmetric $N \times N$ matrix with non-negative eigenvalues, then its eigenvalues and singular values are the same.
- SVD decomposes $\mathbf{A}$ (in the least squared sense) into $\mathbf{A} = \mathbf{U}\,\circ\,\mathbf{V}^{\mathsf{T}}$
- SVD can be performed in MATLAB using the SVD command

Back

## Evidence from patents

- Data: number of patents granted by the U.S. Patent and Trademark Office during 1963-2008 or 1999-2008, scaled by industry output or employment
- Correlation between number of patents and $\lambda_3$ is 0.75-0.81.
- Examples: number of patents per $1mil. of output
    - Food: 0.04, Metals: 0.19
    - Medical: 2.99, Other Machinery: 4.29
- Innovation is accelerating in education-intensive industries
- Data: fraction of all patents granted in 1963-2008 which were granted during the last 10 years 1999-2008
- Correlation with $\lambda_3$ is 0.69.
- Examples:
    - Metals: 0.21, Food: 0.24 (almost no acceleration of innovation)
    - Other Machinery: 0.41, Medical: 0.41