PREM Learning Week

World Bank Institute Course on Knowledge-Based Growth and Competitiveness

Knowledge and Development

An Empirical Analysis

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Knowledge and Development: A Cross-Section Approach

(jointly with Carl J. Dahlman)

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Introduction and Motivation

- Large volume of literature on the determinants of total factor productivity as channels to increase long-term economic growth
- Knowledge is seen to be one of the key determinants of TFP
- Various dimensions of knowledge have been shown to be individually important in affecting growth
- Due to interdependence and complementarities, important to consider the various dimensions of knowledge together

Objective

- To empirically investigate to contribution of knowledge to long-term economic growth
- Focus on three dimensions of knowledge:
  - Human capital or education & training
  - Innovation and technological adoption
  - Information and communications technologies (ICTs) usage

Human Capital

- Human capital in the form of an educated and skilled labor force
  - Crucial for creation, acquisition, diffusion and utilization of knowledge
- Numerous empirical cross-country studies on economic growth include human capital as an independent variable
  - Various proxies for human capital have been used

Human Capital

Barro (QJE, 1991)

- Primary and secondary enrollments rates had positive effects growth of real GDP per capita

Mankiw et al. (QJE, 1992)

- Robust effects of secondary school enrollment rates on growth of GDP per capita.

Benhabib and Spiegel (JME, 1994)

- Human capital stock levels has positive effects on the growth of income per capita

Cohen and Soto (OECD, 2001)

- Educational attainment has positive effects on the growth of real GDP per capita

Innovation

- Innovation and technological adoption – creation of new knowledge and using new knowledge - a major source of productivity growth
- Barro and Sala-i-Martin (2004)
  - recent studies on international income differences suggest that income variation is largely explained by the differences in technology employed in each country

Innovation

- Adams (JPE, 1990)
  - Count of academic scientific papers (as a proxy for new knowledge) contributed to TFP growth of U.S. manufacturing industries.
- Guellec and van Pottelsberghe (OECD, 2001)
  - Business, public and foreign R&D had positive effects on productivity growth for OECD countries.
- Lederman and Maloney (WB, 2003)
  - Uses a panel data set for 53 countries, show that the share of R&D expenditure in GDP has statistically significant positive effects on growth rate of GDP

Human Capital and Innovation

- Doms et al. (QJE, 1997)
  - Better educated workers are more likely to adopt new technologies
- Kalaitzidakis et al. (JEG, 2001)
  - post primary education important for the absorption of new technologies, and hence economic growth
- Lloyd-Ellis and Roberts (JEG, 2002); Mukoyama (JEG, 2004)
  - Develop models showing that skills or human capital can affect technological innovation and diffusion

ICTs

- Recently recognized as effective tool for knowledge diffusion, hence promotes economic development
- Allows knowledge and information to be transmitted
  - Inexpensively
  - Over great distances
  - Promptly
- Various studies have produced empirical evidence that ICT usage have led to productivity gains
  - For the U.S. and other OECD countries
    - Whelan (FRB, 2000), Oliner and Sichel (JEP, 2000), Jorgenson and Stiroh (BPEA, 2000), Schreyer (OECD, 2000)

Knowledge Economy Framework

The Four KE Pillars

- Educated, creative and skilled labor force
- Effective national innovation system
- Modern and developed information infrastructure
- Economic incentive and institutional regime

Pillars are complements and are therefore interdependent

Overview

- Analytical framework
- Description of data
- Cross-section regression results
- Conclusions

Analytical Framework

Analytical Framework

Assume the existence of an economy aggregate production function

$$Y = A\,F(K, L) \qquad (1)$$

where

Y is the level of aggregate output or GDP

K is the level of the capital stock

L is the size of the labor force

A is total factor productivity (TFP)

F(.) represents a mathematical function

Analytical Framework

Typical example of an explicit form of equation (1) is the Cobb Douglas specification,

$$Y = A K^{\alpha_K} L^{\alpha_L} \qquad (2)$$

Where

α_K is the elasticity of output to capital

α_L is the elasticity of output to labor

Analytical Framework

From equation (2), it can be shown that

$$\frac{\Delta Y}{Y} = \alpha_K \frac{\Delta K}{K} + \alpha_L \frac{\Delta L}{L} + \frac{\Delta A}{A} \qquad (3)$$

Or

Growth rate of GDP depends on

1. the growth rate of capital
2. the growth rate of the labor force
3. the growth rate of total factor productivity

Analytical Framework

From equation (2), with the additional assumption of constant returns to scale, it can be shown that

$$\frac{\Delta\left(Y/L\right)}{Y/L} = \alpha_K \frac{\Delta\left(K/L\right)}{K/L} + \frac{\Delta A}{A} \qquad (4)$$

Or

Growth rate of GDP per worker depends on

1. the growth rate of capital per worker
2. the growth rate of total factor productivity

Analytical Framework

We postulate education, innovation & technological adoption, and the level of ICT infrastructure are fundamental determinants of TFP

Mathematically,

$$Y = A(E, R, I)K^{\alpha_K} L^{\alpha_L} \qquad (5)$$

where

E - level of education & training of the population

R - country's level of domestic innovation and/or technological adoption

I - country's information & communication infrastructure

Analytical Framework

Given equation (5), our estimating equation thus become either

$$\frac{\Delta Y}{Y} = \alpha_K \frac{\Delta K}{K} + \alpha_L \frac{\Delta L}{L} + \beta_E E + \beta_R R + \beta_I I$$

OR (6)

$$\frac{\Delta\left(Y/L\right)}{Y/L} = \alpha_K \frac{\Delta\left(K/L\right)}{K/L} + \beta_E E + \beta_R R + \beta_I I$$

(7)

where

β_i - will be the estimated coefficient of TFP determinant *i*

Data: Human Capital

Data: Educational Attainment

Human Capital Stock

- Need to measure the stock of knowledge embodied within the labor force
- Used average years of schooling as the basic measure of human capital stock
  - Barro-Lee (OEP, 2001)
  - Cohen and Soto (OECD, 2001)
- Stock variable – reflects the accumulated educational investment embodied by the current labor force

Data: Educational Attainment

Problems with average years of schooling as a proxy for human capital stock

- Does not account for differences in quality of schooling
- Does not take into account increasing or decreasing returns to education

Quality of education

- Assumes that an additional year of schooling, regardless of the country in which it took place, increases the human capital by the same amount

Data: Educational Attainment

Returns to education

- Assumes that each additional year of schooling raises the human capital stock by a constant amount
- Productivity differentials among workers are assumed to be proportional to their years of schooling
- Micro-studies have found decreasing returns to education

Data: Human Capital Stock

Human Capital Stock

- From a measure of education measured in units of time into the stock of human capital expressed in units of money
- Based on the Mincer specification
  - Log-linear relationship between earnings and schooling
  - Each year of schooling is weighted by the return it generates in the labor market

$$H = e^{rs}$$

H is the human capital stock

r is the return to education, *s* is the years of education

Data: Returns to Education

2 different series for returns to education

- Country specific returns to education provided by the literature
  - Psacharopoulos (WD, 1994)
  - Bil and Klenow (AER, 2000)
  - 64 countries
- Returns to education world average of 0.095 for all countries

Data: Educational Quality

Hanushek and Kimko (AER, 2000)

- Developed indices of educational quality for 38 countries for the period 1965 - 1991
- Based on scores on 6 international tests of academic performance in science and mathematics
  - 4 IEA tests – International Association for the Evaluation of Educational Achievement
  - 2 IAEP tests – International Assessment of Educational Progress
  - Used U.S. National Assessment of Education Progress (NAEP) trend assessments to combine international test scores

Data: Educational Quality

To further expand the data set:

- Estimated a statistical relationship for 30 countries between educational quality and schooling inputs
  - Schooling inputs: Primary school enrollment, adult average years of schooling, total expenditure on education (% of GDP), annual population growth, regional dummies
  - Accounted for 65% of observation cross-country variation in educational quality
  - Used predicted data to expand data set:
    - 90 countries, years 1965-2001, averaged values over period

Data: Innovation and Technological Adoption

Patent Data

USPTO Patent Count

- Includes utility patents, design patents, plant patents, etc.
- Basic measure of innovation
- U.S. patents increasingly reflect innovation around the world
- Adhere to one set of minimum standards
- Information available by country of residence of first inventor
- For many countries from 1977 to 2001, annual basis

Patent Data

USPTO Utility Patent Count

- Hall, Jaffe and Trajtenberg (2002)
- Largest category of patents – more than 90 percent in 1999
- for each patent - information available by country of residence of first inventor
- Available for many countries from 1963 to 2001, annual basis
- Includes information number of patent citations received and made (1975 – 1999)

Patent Data

USPTO Utility Patent Citations Received

- Hall, Jaffe and Trajtenberg (2002)
- Patents vary largely in terms of quality and economic importance
- Frequency of citations provides an indication of the importance of the cited patent

Innovation Data

Number of Scientific and Technical Journal Articles

- SIMA database
- Available for many countries from 1960 to 2001, annual basis
- Includes fields such as physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, earth and space sciences
- Focuses not only on innovations that have commercial and economic value

Innovation Data

Royalty Payments and Receipts

- SIMA database
- Sum of royalty receipts and payments
- Indicates the amount of innovation or new knowledge that is “exported” and “imported”
- Available for many countries from 1960 to 2001, annual basis
- Measure of technological innovation and adaptation

Data: ICTs

ICT Data

Obtained from SIMA

- Computers
- Internet users
- Internet hosts
- Number of phones (fixed lines and mobile)

Other Data

Other Data

Capital / Capital per Worker

- Perpetual inventory method generate capital stock
- Gross Investment data (Gross Capital Formation)
- See Appendix A of working paper

Labor Force

Initial Income

- Poorer countries tend to grow faster than wealthier countries
- Ratio of country's GDP per capita in 1960 to that of the U.S. in 1960; PPP terms.

Cross-Section Regression Results

Table 1

Dependent Variable: Growth Rate of Real GDP
Educational Pillar Indicators

Years : 1960 - 2000	Reg 1.1	Reg 1.2
Growth of Capital	0.2128***	0.2118***
Growth of Labor	0.5694***	0.5867***
Initial GDP (1960)	-3.8747***	-3.8384***
HC15	4.3613**	
Sq of HC15	-1.0208**	
HC25		3.7916*
Sq of HC25		-0.9286**
Log (Educational Quality)	0.2933	0.3671
Log (Patents)	0.1909***	0.1955***
Phones	0.0033***	0.0035***
Constant	-3.6660*	-3.2783
R squared	0.6137	0.6078
Number of Countries	85	84

Table 1a

Dependent Variable: Growth Rate of Real GDP Per Worker
Educational Pillar Indicators

Years : 1960 - 2000	Reg 1a.1	Reg 1a.2
Growth of Capital per worker	0.2119***	0.2095***
Initial GDP (1960)	-3.7103***	-3.7197***
HC15	4.4661**	
Sq of HC15	-1.0965**	
HC25		3.8946*
Sq of HC25		-0.9925**
Log (Educational Quality)	0.3719	0.4324
Log (Patents)	0.1956***	0.1984***
Phones	0.0040***	0.0040***
Constant	-4.5304**	-4.066*
R squared	0.5912	0.5842
Number of Countries	85	84

Table 2

Dependent Variable: Growth Rate of Real GDP
Innovation Pillar Indicators

Years : 1960 - 2000	Reg 2.1	Reg 2.2	Reg 2.3	Reg 2.4	Reg 2.5
Growth of Capital	0.2128***	0.2157***	0.2252***	0.2033***	0.2141***
Growth of Labor	0.5694***	0.5775***	0.5948***	0.5703***	0.5933***
Initial GDP (1960)	-3.8747***	-3.9019***	-3.6842***	-3.8133***	-3.6067***
HC15	4.3613**	4.5361**	3.9374**	2.2266	2.8968*
Sq of HC15	-1.0208**	-1.0544**	-0.9253**	-0.4574	-0.6273*
Log (Educational Quality)	0.2933	0.3338	0.4639	0.4720	0.3980
Log (Patents)	0.1909***				
Log (Utility Patents)		0.1759**			
Log (Journals)			0.2254***		
Log (Royalties)				0.0253*	
Royalties per capita					0.000004***
Phones	0.0033***	0.0036***	0.0032***	0.0046***	0.0044***
Constant	-3.6660*	-4.0111*	-4.7967**	-2.4736	-2.5903
R squared	0.6137	0.6071	0.646	0.6318	0.6320
Number of Countries	85	85	85	84	84

Table 2a

Dependent Variable: Growth Rate of Real GDP Per Worker
Innovation Pillar Indicators

Years : 1960 - 2000	Reg 2a.1	Reg 2a.2	Reg 2a.3	Reg 2a.4	Reg 2a.5
Growth of Capital Per Worker	0.2119***	0.2147***	0.2251***	0.2020***	0.2150***
Initial GDP (1960)	-3.7103***	-3.7533***	-3.5395***	-3.6375***	-3.4059***
HC15	4.4661**	4.6428**	4.0179**	2.2785	2.9533*
Sq of HC15	-1.0965**	-1.1303**	-0.9878**	-0.5215	-0.6932*
Log (Educational Quality)	0.3719	0.4121	0.5337	0.5610	0.4750
Log (Patents)	0.1956***				
Log (Utility Patents)		0.1839**			
Log (Journals)			0.2295***		
Log (Royalties)				0.0268**	
Royalties per capita					0.000005***
Phones	0.0040***	0.0041***	0.0037***	0.0052***	0.0049***
Constant	-4.5304**	-4.8463**	-5.5338**	-3.3607	-3.4270
R squared	0.5912	0.5854	0.6248	0.5999	0.6042
Number of Countries	85	85	85	84	84

Table 3
Dependent Variable: Growth Rate of Real GDP
Information and Communications Technologies (ICT) Pillar Indicators

Years : 1960 - 2000	Reg 3.1	Reg 3.2	Reg 3.3	Reg 3.4
Growth of Capital	0.2264***	0.2251***	0.2310***	0.2128***
Growth of Labor	0.4614***	0.4617***	0.4521***	0.5694***
Initial GDP (1960)	-4.0288***	-3.4424***	-3.4300***	-3.8747***
HC15	3.7100***	4.9953**	5.4972***	4.3613**
Sq of HC15	-0.9508***	-1.1712**	-1.2625**	-1.0208**
Log (Educational Quality)	0.3848	0.3147	0.4798*	0.2933
Log (Patents)	0.2252***	0.2366***	0.2411***	0.1909***
Computers	0.0082***			
Internet Users		0.0082***		
Hosts			0.0017**	
Phones				0.0033***
Constant	-2.8603	-4.1496**	-5.2290***	-3.666*
R squared	0.6646	0.6114	0.6034	0.6137
Number of Countries	81	85	85	85

Table 3a
Dependent Variable: Growth Rate of Real GDP Per Worker
Information and Communications Technologies (ICT) Pillar Indicators

Years : 1960 - 2000	Reg 3.1	Reg 3.2	Reg 3.3	Reg 3.4
Growth of Capital per worker	0.2293***	0.2298***	0.2360***	0.2119***
Initial GDP (1960)	-3.5813***	-2.9514***	-2.9244***	-3.7103***
HC15	3.9910***	5.2399**	5.7432***	4.4661**
Sq of HC15	-1.0697***	-1.2780**	-1.3677***	-1.0965**
Log (Educational Quality)	0.5363	0.4788	0.6516	0.3719
Log (Patents)	0.2474***	0.2586***	0.2636***	0.1956***
Computers	0.0086***			
Internet Users		0.0084***		
Hosts			0.0017***	
Phones				0.0040***
Constant	-4.4327**	-5.7535***	-6.8771***	-4.5304**
R squared	0.6165	0.5779	0.5687	0.5912
Number of Countries	81	85	85	85

Data: Economic Regime and Institutional Quality

Economic Regime

Sachs and Warner (BPEA, 1995)

- Developed a zero-one indicator for trade openness
- 80 countries for the period 1960-1992
- Country had an open trade policy for specific year if it DID NOT have
  - Nontariff barriers covering 40% or more of trade
  - Average tariff rates of 40 percent or more
  - Black market exchange rate depreciated by 20% or more relative to the official exchange rate (average in the 1970s or 1980s)
  - Socialist economic system
  - State monopoly on major exports.

Economic Regime

Sachs and Warner (BPEA, 1995)

- Trade liberalization is generally just one portion of a government's overall reform plan
- Usually correlated with price liberalization, budget restructuring, extensive privatization, deregulation, attempting macroeconomic stability
- Openness measure serves as a proxy for an array of features that are characteristic of a healthy economy

Institutional Quality

Knack and Keefer (E&P, 1995)

- Examined the effects of property rights on economic growth
- Used as proxies indicators from Business Environmental Risk Intelligence (BERI) for 1982, and the International Country Risk Guide (ICRG) for 1972
- ICRG data
  - expropriation risk
  - rule of law
  - repudiation of contracts by the government
  - corruption in government and the quality of the bureaucracy.
- For this paper, we use the simple average of the ICRG indicators as a measure of institutional quality.

Table 4

Dependent Variable: Growth Rate of Real GDP
Regressions with Economic Openness and Institutions

Years : 1960 - 2000	Reg 2.1	Reg 2.3	Reg 2.5	Reg 3.1	Reg 3.2	Reg 4.1	Reg 4.2	Reg 4.3	Reg 4.4	Reg 4.5
Growth of Capital	0.2128***	0.2252***	0.2141***	0.2264***	0.2251***	0.2384***	0.2380***	0.2510***	0.2348***	0.2344***
Growth of Labor	0.5694***	0.5948***	0.5933***	0.4614***	0.4617***	0.3999***	0.4411***	0.4059***	0.4293***	0.4315***
Initial GDP (1960)	-3.8747***	-3.6842***	-3.6067***	-4.0288***	-3.4424***	-3.6513***	-3.4613***	-3.4498***	-3.8702***	-3.8524***
Economic Openness						0.4979**	0.6255**	0.4578*	0.4189*	0.4595*
Institutions						3.6920***	2.6259**	3.8409***	3.0583***	3.6058***
Education Variables										
HC15	4.3613**	3.9374**	2.8968*	3.7100***	4.9953**	1.7563	1.7059	1.8216	1.7856	1.6176
Sq of HC15	-1.0208**	-0.9253**	-0.6273*	-0.9508***	-1.1712**	-0.2906	-0.3056	-0.2981	-0.3561	-0.2435
Log (Educational Quality)	0.2933	0.4639	0.3980	0.3848	0.3147	0.6176	0.7633*	0.6182	0.6166	0.6348
Innovation Variables										
Log (Patents)	0.1909***			0.2252***	0.2366***	0.0703			0.0723	0.0600
Log (Journals)		0.2254***					0.1431***			
Royalties per capita			0.000004***					0.000002*		
ICT Variables										
Phones	0.0033***	0.0032***	0.0044***			-0.0011	-0.0009	-0.0008		
Computers				0.0082***					0.0012	
Internet Users					0.0082***					-0.0027
Constant	-3.6660*	-4.7967**	-2.5903	-2.8603	-4.1496**	-4.0649**	-4.6608***	-4.2734**	-3.6728*	-4.0212**
R squared	0.6137	0.646	0.632	0.6646	0.6114	0.8194	0.8387	0.8185	0.8220	0.8192
No. of Countries	85	85	84	81	85	72	72	72	70	72

Table 4a

Dependent Variable: Growth Rate of Real GDP Per Worker

Regressions with Economic Openness and Institutions

Years : 1960 - 2000	Reg 2a.1	Reg 2a.3	Reg 2a.5	Reg 3.1	Reg 3.2	Reg 4a.1	Reg 4a.2	Reg 4a.3	Reg 4a.4	Reg 4a.5
Growth of Capital per worker	0.2119***	0.2251***	0.2150***	0.2293***	0.2298***	0.2304***	0.2317***	0.2486***	0.2322***	0.2304***
Initial GDP (1960)	-3.7103***	-3.5395***	-3.4059***	-3.5813***	-2.9514***	-3.4913***	-3.2936***	-3.2002***	-3.4618***	-3.4694***
Economic Openness						0.5622*	0.6986**	0.5128*	0.5783*	0.6223**
Institutions						3.7204***	2.5559**	3.7322***	3.5433***	4.0038***
Education Variables										
HC15	4.4661**	4.0179**	2.9533*	3.9910***	5.2399**	2.2976	2.1616	2.3235	1.9538	1.8594
Sq of HC15	-1.0965**	-0.9878**	-0.6932*	-1.0697***	-1.2780**	-0.5218	-0.5091	-0.5264	-0.4551	-0.3699
Log (Educational Quality)	0.3719	0.5337	0.4750	0.5363	0.4788	0.7383	0.8826*	0.7408	0.7875	0.7930
Innovation Variables										
Log (Patents)	0.1956***			0.2474***	0.2586***	0.0719			0.0791	0.0696
Log (Journals)		0.2295***					0.1543***			
Royalties per capita			0.000005***					0.000003***		
ICT Variables										
Phones	0.0040***	0.0037***	0.0049***			0.0003	0.0003	0.0005		
Computers				0.0086***					0.0008	
Internet Users					0.0084***					-0.0025
Constant	-4.5304**	-5.5338**	-3.4270	-4.4327**	-5.7535***	-5.7956***	-6.2132***	-5.8668***	-5.5098***	-5.8155***
R squared	0.5912	0.6248	0.6042	0.6165	0.5779	0.7980	0.8202	0.8023	0.8006	0.7990
No. of Countries	85	85	84	81	85	72	72	72	70	72

Table 4b

Table of Correlation Coefficients: Knowledge Economy Variables

	Openness	Institutions	HC15	Square of HC15	HC25	Square of HC25	Log (Educational Quality)	Log (Patents)	Log (Journals)	Royalties per capita	Phones	Computers	Internet Users
Openness	1.0000												
Institutions	0.7308	1.0000											
HC15	0.6538	0.8372	1.0000										
Square of HC15	0.6315	0.8304	0.9931	1.0000									
HC25	0.6527	0.8450	0.9974	0.9937	1.0000								
Square of HC25	0.6310	0.8360	0.9875	0.9974	0.9931	1.0000							
Log (Educational Quality)	0.5743	0.6663	0.6609	0.6410	0.6582	0.6346	1.0000						
Log (Patents)	0.6152	0.8468	0.8245	0.8252	0.8333	0.8311	0.5984	1.0000					
Log (Journals)	0.5048	0.7948	0.7056	0.7049	0.7106	0.7084	0.4856	0.9044	1.0000				
Royalties per capita	0.3851	0.4940	0.4525	0.4451	0.4593	0.4476	0.3002	0.4396	0.3750	1.0000			
Phones	0.7408	0.9099	0.8889	0.8927	0.9004	0.9011	0.6728	0.8483	0.7391	0.4495	1.0000		
Computers	0.6452	0.8660	0.8651	0.8799	0.8783	0.8908	0.6466	0.7648	0.6416	0.4867	0.9219	1.0000	
Internet Users	0.6638	0.8243	0.8443	0.8601	0.8520	0.8659	0.6417	0.7410	0.6186	0.4267	0.9087	0.9279	1.0000

Conclusions

Conclusions

- Provided empirical evidence showing that 3 different aspects of knowledge are positively correlated with long-term economic growth
- Results are relatively robust; similar results with various indicators for each aspect of knowledge
- Expand study to use panel regression analysis
  - Explore interaction effects
  - Employ measures to correct for endogeneity, etc.

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