

Valuable Skills, Innovation and Technology Diffusion

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This study

- estimates the market value of education quality (HC)
- re-examines the role of HC in (a) innovation, and (b) technology diffusion
- runs a horse-race of 5 alternative measures of HC
- accounts for 'model uncertainty' (i.e., HC effect, production function, endogeneity)

Motivation:

- Pritchett (2001) *Where has all the education gone?*
- Most of GDP growth due to TFP (technology) growth
- Do nations learn from each other?
- If yes, why not free-ride on other nations' R&D?
- If IP rights limit free-riding (Schumpeter 1934), how is knowledge transmitted?
- What role of Education? What kind of education?

Technology Diffusion: Theory

A general production function:

$$Y_{jt} = f(A_{jt}, X_{1t}, X_{2t}, \dots, X_{njt})$$

Y = Output; X_1, X_2, \dots, X_n = Inputs (n production factors);

A = Technology (know-how) or Disembodied knowledge or TFP

Ex: (a) Y = # medical procedures; (b) Y = # customers in a restaurant

Endogeneous technology growth: 4 Models

Model 1: Nelson and Phelps (1966)

$$Y_t = (A_0 \varepsilon_t) K_t^\alpha L_t^\beta$$

$$\Delta \ln(A_t) = \Delta a_t = mh_t \left[\frac{A_t^{\max} - A_t}{A_t} \right] + \varepsilon_t$$

h_t = Human capital stock; K_t = Physical capital stock; L_t = Labour force

A^{\max} = Technology Leader; j = country or sector; t = time period

Technology Diffusion: Theory

Model 2: Benhabib and Spiegel (1994);

'exponential diffusion'

$$\Delta a_t = gh_t + mh_t \left[\frac{A_t^{\max} - A_t}{A_t} \right] + \varepsilon_t \quad (2)$$

- g is the local innovation/diffusion effect
- m is the foreign technology absorption/diffusion effect

Model 3: Dowrick and Rogers (2002)

$$\Delta a_t = \underbrace{\beta \ln(Y_0)}_{\substack{\text{classical} \\ \text{convergence}}} + mh_t \ln \left[\frac{A_t^{\max}}{A_t} \right] + u_t \quad (4)$$

exponential diffusion

- HC (h_t) does not contribute to local innovation
- HC also enters the production function directly → growth effects

Technology Diffusion: Theory

Model 4: Benhabib and Spiegel (2005); 'logistic diffusion'

$$\Delta a_t = \underbrace{gh_t}_{\text{local innovation}} + mh_t \left[\underbrace{\frac{A_t^{\max} - A_t}{A_t}}_{\substack{\text{exponential} \\ \text{diffusion}}} \right] \underbrace{\left[\frac{A_t}{A_t^{\max}} \right]}_{\substack{\text{barriers to} \\ \text{absorption}}} + e_t \quad (5)$$

1 4 4 4 4 2 4 4 4 4 4 3
logistic diffusion

Model 4 simplifies to:

$$\Delta a_t = \gamma h_t - mh_t \left[\frac{A_t}{A_t^{\max}} \right] + e_t \quad (5)$$

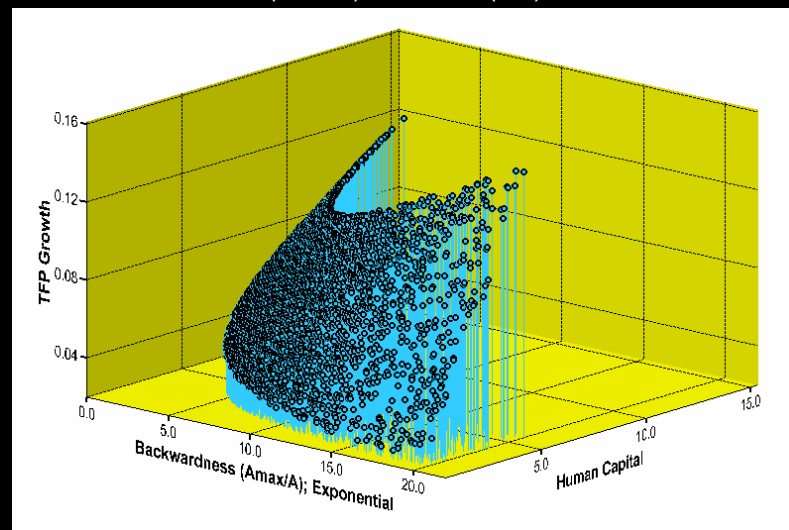
Note:

- predictions: (a) $\gamma > 0$, (b) $m < 0$, (c) $\gamma = (g + m) > m$

Technology Diffusion: Theory

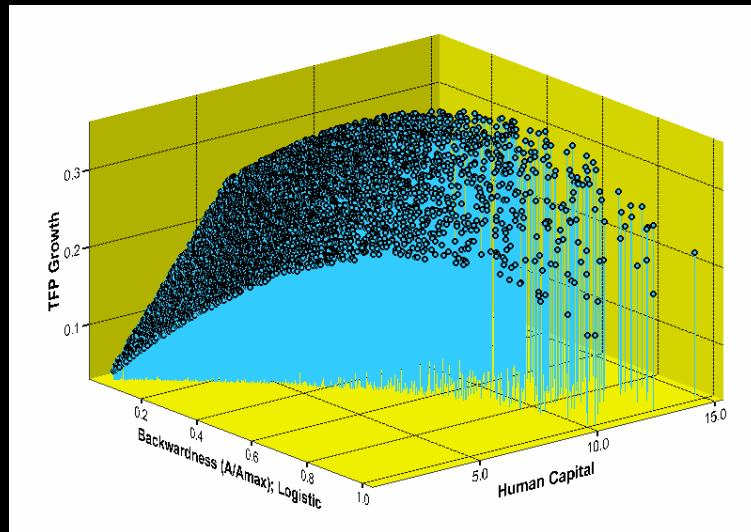
Model 2: Benhabib and Spiegel (1994)

Simulation: $B = (A/A^{\max}) = \text{Gamma}(2,9)$; $h = 18B - 8B^2 + 5u$



Technology Diffusion: Theory

Model 4: Benhabib and Spiegel (2005)



Empirical method

DATA: 70 countries; 1970-2003

METHOD:

1. We estimate a new latent index of 2 key components: (i) cognitive skills; (ii) education value → 'valuable skills' (VS)
2. We use VS to test 3 models: Benhabib-Spiegel (1994); Dowrick-Rogers (2002); Benhabib-Spiegel (2005) (Not presented; Benhabib-Spiegel (2005) model fits data best)
3. We use panel GMM to compare the performance of VS in a horse-race with 5 existing alternative measures of HC in the Benhabib-Spiegel (2005) model (Cobb-Douglas function)
4. Sensitivity analysis:
 - (a) alternative indicators in latent factor estimation;
 - (b) alternative production functions (CES and Translog)

1. A New Index of HC: Background

Quantity measures: attainment; years of schooling

- Cross-country quality differences

Quality measures: TIMSS; (Teacher/Pupil) ratios; IQ

- Facilitate international comparisons
- Less likely to be endogeneous
- Uni-dimensional measures (demand? depreciation? learning on the job?)

Beyond formal education

- Market value (Schultz 1961; Mincerian tradition)
- Latent factor (Dagum and Slottje 2000)

1. A New Index of HC: Estimation

Step 1: Lagged Test Scores ($TIMSS_{t-2}$); imputed

Step 2: Factor analysis in 5-year periods

Table 2. Human Capital as a Latent Factor: Factor Analysis

		Indicators				Eigenvalue		EV
		TIMSS imputed	SciP	BKS	OPEN	F1	F2	
1970-	Loading	0.75	0.93	0.92	0.72	2.79	0.68	0.70
	Scores	0.11	0.44	0.36	0.10			
1975-1979	Loading	0.80	0.93	0.91	0.72	2.84	0.62	0.71
	Scores	0.13	0.46	0.32	0.09			
1980-1984	Loading	0.84	0.94	0.94	0.69	2.96	0.69	0.74
	Scores	0.13	0.41	0.40	0.06			
1985-1989	Loading	0.87	0.95	0.96	0.78	3.17	0.53	0.79
	Scores	0.15	0.34	0.44	0.07			
1990-1994	Loading	0.88	0.95	0.97	0.82	3.29	0.46	0.82
	Scores	0.13	0.31	0.48	0.08			
1995-	Loading	0.90	0.95	0.97	0.86	3.39	0.38	0.85
	Scores	0.14	0.29	0.47	0.09			
2000-2003	Loading	0.91	0.95	0.97	0.87	3.43	0.33	0.86
	Scores	0.15	0.26	0.48	0.10			

TIMSS: imputed test scores; SciP: pc scientific publications in sciences; BKS: pc books published; OPEN: openness to trade. All are in logs. Scores are normalised (0, 1). F1 and F2 are principal component factors 1 and 2. EV stands for explained variation.

1. A New Index of HC: Estimation

- Step 3: One optimal Factor, 'valuable skills'
- Step 4: Save scores
- Step 5: Re-scale factor scores using FGLS to make it comparable to 'education' (i.e., units of equivalent years of education)

3. HC measures compared: Reliability tests

Five existing measures of HC:

- **EDU_BL**: Average years of education by Barro & Lee (2001)
- **EDU_CS**: Average years of education by Cohen & Soto (2007)
- **TIMSS (original)**: International Test Scores in Maths & Science by 13-14 years old secondary school students
- **TIMSS_{t-2} (imputed)**: TIMSS lagged 2 periods (i.e., 10 years) as a better measure of cognitive skills of the working population
- **IQ**: IQ scores by Lynn & Vanhanen (2002); cross-section only

3. HC measures compared: Reliability tests

Table 3. Six Measures of Human Capital Compared

A: Reliability Ratios: $R_i = \text{Cov}(h_i, h_j) / \text{Var}(h_i)$

	Obs.	VS_1	EDU (BL)	EDU (CS)	TIMSS original	TIMSS _{t-2} imputed	IQ
Conditional: 1995-99	67	0.602	0.508				
	60	0.519		0.538			
	52	0.688			0.448		
	67	0.813				0.746	
	67	0.857					0.500

B: Reliability Tests: Bivariate Regression: Coefficient estimates

Conditional: 1995-99	67	0.602** (0.114)	0.508** (0.108)				
	60	0.531** (0.101)		0.538** (0.127)			
	52	0.953** (0.179)			0.448** (0.077)		
	67	0.813** (0.078)				0.746** (0.075)	
	67	0.857** (0.179)					0.500* (0.060)

C: Predictive Power on conditional ln(GDP): Coefficient estimates

ly cond	67/52	0.657** (0.101)	0.321** (0.113)	0.342* (0.132)	0.220** (0.072)	0.501** (0.102)	0.486* (0.069)
$\Delta(\text{ly cond})$	67/52	0.170** (0.052)	0.089* (0.040)	0.081 (0.042)	0.109** (0.026)	0.122** (0.042)	

Significance levels: * = 5%; ** = 1 %

3. HC measures compared: Time trends

Figure 1. Education and Valuable Skills: 1970-2003

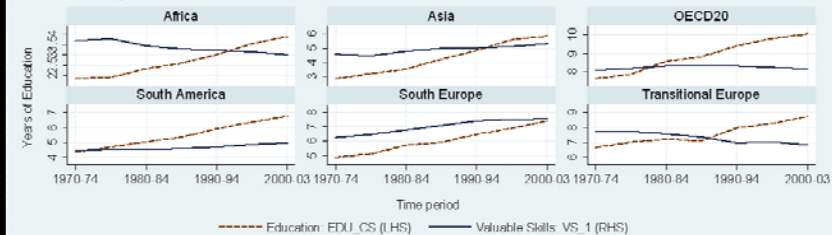
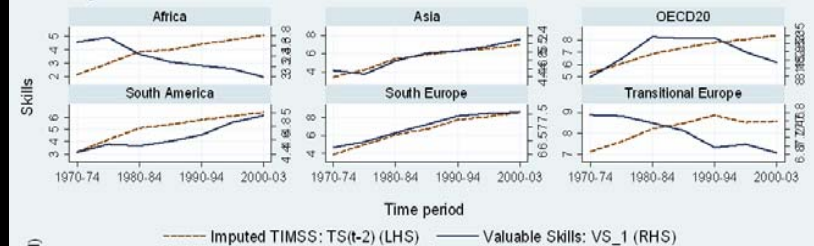
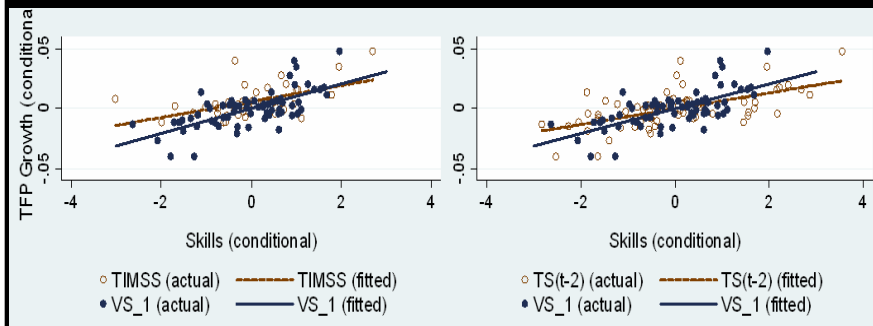


Figure 1. TIMSS Scores and Valuable Skills: 1970-2003



3. HC measures compared: TFP Growth



3. HC measures: Panel GMM in CD Technology

$$\Delta a_t = \gamma h_t - m h_t \left[\frac{A_t}{A_t^{\max}} \right] + e_t \quad (5)$$

Table 4. Logistic Technology Diffusion (Benhabib and Spiegel 2005): Alternative Human Capital Measures

Explanatory Variables	Education		Cognitive skills		Valuable skills
	EDU BL	EDU CS	TIMSS original	TIMSS _{t-2} imputed	VS 1
	(1)	(2)	(3)	(4)	(5)
Constant	0.073 (0.046)	0.019 (0.035)	-1.150** (0.386)	-0.035 (0.047)	-0.124 (0.072)
h	-0.009 (0.010)	0.001 (0.010)	0.167** (0.047)	0.012 (0.011)	0.058** (0.018)
$h(A_t/A_t^{\max})$	0.010 (0.008)	0.005 (0.010)	-0.023* (0.009)	-0.001 (0.008)	-0.048** (0.014)
Observations	409	362	106	405	404
AB AR(1)	2.65**	2.59**	0.81	2.99	3.63**
AB AR(2)	1.24	0.43	0.02	0.68	0.82
Hansen: χ^2	40.39*	29.61	5.97	37.63	32.05

Significance levels: * = 5%; ** = 1 %

3. HC measures compared: Poverty Traps

Benhabib and Spiegel (2005) have derived the HC condition or threshold for catch-up (logistic diffusion):

$$h_t^* = \exp\left(\frac{g \ln(h_t^{\max})}{g + m}\right) \quad (7)$$

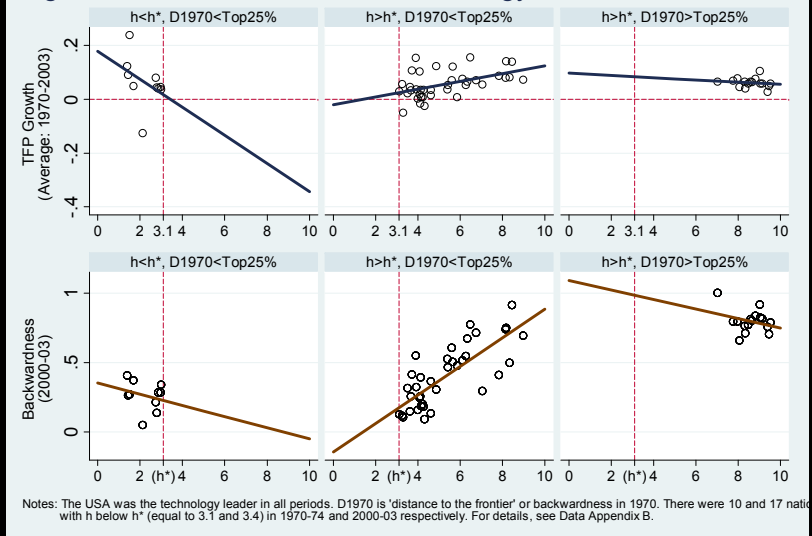
Note:

- $h_j \geq h^* \Rightarrow$ country j is **able** to catch-up
- $h_j < h^* \Rightarrow$ country j is **unable** to catch-up (poverty trap)
- As g or $h^{\max} \uparrow \Rightarrow$ It gets **harder** to catch-up
- As $m \uparrow \Rightarrow$ It gets **easier** to catch-up, given

$$\Delta a_t = (g + m)h_t - mh_t \left[\frac{A_t}{A_t^{\max}} \right] + e_t \quad (5)$$

3. HC measures compared: Catching-up & Traps

Figure 2. Valuable Skills and Technology Diffusion: 1970-2003



4. Sensitivity Analysis: Latent Index composition

Using only TS, BKS & OPEN in factor analysis (SciP excluded)
 ⇒ Latent Index No.2 (VS_2)

Table 4. Logistic Technology Diffusion (Benhabib and Spiegel 2005): Alternative Human Capital Measures

Explanatory Variables	Education		Cognitive skills		Valuable skills	
	EDU BL	EDU CS	TIMSS original	TIMSS _{t-2} imputed	VS 1	VS 2
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.073 (0.046)	0.019 (0.035)	-1.150** (0.386)	-0.035 (0.047)	-0.124 (0.072)	-0.156* (0.073)
h	-0.009 (0.010)	0.001 (0.010)	0.167** (0.047)	0.012 (0.011)	0.058** (0.018)	0.066** (0.016)
$h(A_i/A^{max})$	0.010 (0.008)	0.005 (0.010)	-0.023* (0.009)	-0.001 (0.008)	-0.048** (0.014)	-0.055** (0.013)
Observations	409	362	106	405	404	404
AB AR(1)	2.65**	2.59**	0.81	2.99	3.63**	3.77**
AB AR(2)	1.24	0.43	0.02	0.68	0.82	1.24
Hansen: χ^2	40.39*	29.61	5.97	37.63	32.05	27.87

Result: VS_1 ⇒ $h^* = 3.1$ (1970-74); $h < h^*$ in 10 nations
 VS_2 ⇒ $h^* = 3.5$ (1970-74); $h < h^*$ in 14 nations

4. Sensitivity Analysis: Latent Index composition

Using TS, SciP, BKS & EDU_CS in factor analysis
 ⇒ Latent Index No.3 (VS_3)

Table 4. Logistic Technology Diffusion (Benhabib and Spiegel 2005): Alternative Human Capital Measures

Explanatory Variables	Education		Cognitive skills		Valuable skills	
	EDU BL	EDU CS	TIMSS original	TIMSS _{t-2} imputed	VS 1	VS 3
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.073 (0.046)	0.019 (0.035)	-1.150** (0.386)	-0.035 (0.047)	-0.124 (0.072)	-0.089 (0.071)
h	-0.009 (0.010)	0.001 (0.010)	0.167** (0.047)	0.012 (0.011)	0.058** (0.018)	0.050* (0.021)
$h(A_i/A^{max})$	0.010 (0.008)	0.005 (0.010)	-0.023* (0.009)	-0.001 (0.008)	-0.048** (0.014)	-0.051* (0.020)
Observation	409	362	106	405	404	360
AB AR(1)	2.65**	2.59**	0.81	2.99	3.63**	2.93**
AB AR(2)	1.24	0.43	0.02	0.68	0.82	0.76
Hansen: χ^2	40.39*	29.61	5.97	37.63	32.05	29.73

Result: VS_3 ⇒ $h^* = 0.9$ (1970-74); $h < h^*$ in 1 nation
 $h^* = 0.9$ (2000-03); $h < h^*$ in 0 nations! (endogeneity?)

4. Sensitivity Analysis: CES Technology

Capital-Skill Complementarity (CSC)

(Duffy, Papageorgiou and Perez-Sebastian 2004)

$$Y_t = A_t \left\{ a \left[(bK_t^\theta + (1-b)S_t^\theta)^{\rho/\theta} + (1-a)N_t^\rho \right]^{1/\rho} \right\} e_t$$

S = skilled labour = γL

N = unskilled labour = $(1-\gamma)L$

ρ, θ = elasticity of substitution parameters

Note: Iff $\rho > \theta \Rightarrow$ capital-skill complementarity

If ρ or $\theta = 0 \Rightarrow$ Cobb-Douglas production function

We focus on TFP growth ($\Delta\alpha$), assume CSC and calibrate on (Krusell *et al.* 2000) estimates.

4. Sensitivity Analysis: CES Technology

Table 5. CES Technology in Benhabib and Spiegel (2005) model: Alternative Human Capital Measures

Explanatory Variables	Education		Cognitive skills		Valuable skills	
	EDU BL	EDU CS	TIMSS original	TIMSS _{t-2} imputed	VS 1	VS 2
	(1)	(1)	(3)	(4)	(5)	(6)
Constant	0.129* (0.059)	0.066 (0.059)	-2.117* (0.990)	-0.002 (0.089)	-0.144* (0.048)	-0.177** (0.043)
<i>h</i>	0.000 (0.013)	0.016 (0.013)	0.305* (0.130)	0.026 (0.017)	0.082* (0.014)	0.091** (0.013)
$h(A_i/A^{\max})$	0.017 (0.014)	0.003 (0.013)	-0.031 (0.031)	0.002 (0.014)	-0.063* (0.014)	-0.073** (0.015)
Observation	407	360	106	403	402	402
AB AR(1)	3.49**	3.51**	1.20	3.53**	3.85**	3.95**
AB AR(2)	2.59*	2.22*	0.38	2.12*	2.35*	2.80**
Hansen: χ^2	32.54	30.32	6.40	44.08*	32.53	27.43

Significance levels: * = 5%; ** = 1 %

4. Sensitivity Analysis: Translog Technology

CSC and Skilled-Biased-Technical-Change (SBTC)
(Papageorgiou and Chmeralova 2005)

$$\Theta_S = \alpha_S + \gamma_K \ln(K/Y) + \gamma_S \ln(W_S/W_N) + \gamma_Y \ln Y + \gamma_A \ln A \quad (12)$$

Θ_S = skilled labour income share

(K/Y) = capital-output ratio

(W_S/W_N) = relative price of skilled labour

Following Young (1992):

$$\ln A = \ln Y - \left[\alpha \ln(K) + (1 - \alpha) (\Theta_S \ln(S) + (1 - \Theta_S) \ln(N)) \right] \quad (13)$$

4. Sensitivity Analysis: Translog Technology

**Table 6. Translog Production Technology and Logistic Diffusion:
Alternative Human Capital Measures**

Explanatory Variables	Education		Cognitive skills		Valuable skills	
	EDU_BL	EDU_CS	TIMSS original	TIMSS _{t-2} imputed	VS_1	VS_2
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.005 (0.061)	-0.022 (0.042)	-1.311** (0.373)	-0.043 (0.068)	-0.151** (0.046)	-0.165* (0.072)
<i>h</i>	0.004 (0.014)	0.011 (0.010)	0.189** (0.043)	0.013 (0.016)	0.062** (0.015)	0.069** (0.017)
<i>h</i> (A/A^{\max})	0.003 (0.011)	0.000 (0.010)	-0.029** (0.009)	-0.002 (0.012)	-0.051** (0.015)	-0.062** (0.015)
Observations	397	357	100	397	397	397
AB AR(1)	2.95**	2.93**	2.22*	3.02**	3.65**	3.70**
AB AR(2)	1.25	1.17	0.30	0.89	0.92	1.46
Hansen: χ^2	34.30	32.17	6.11	34.46	30.11	29.13

Note: See Tables 3-4 for definitions and notation. S and N in equation (12) are calculated as $S = s * POP$ where *s* is VS_1 re-scaled on the basis of share of the population (POP) who have attained primary school (PRIM).

Significance levels: * = 5%; ** = 1 %

4. Sensitivity Analysis: Translog Technology

We estimate Papageorgiou and Chmeralova (2005)

$$\Theta_S = \alpha_S + \gamma_K \ln(K/Y) + \gamma_S \ln(W_S/W_N) + \gamma_Y \ln Y + \gamma_A \ln A \quad (12)$$

Nested hypotheses:

$\gamma_K > 0 \Rightarrow$ CSC (Capital-Skill-Complementarity)

$\gamma_K < 0 \Rightarrow$ CSS (Capital-Skill-Substitution)

$\gamma_S > 0 \Rightarrow$ SNC (Skill-Unskilled-Complementarity)

$\gamma_S < 0 \Rightarrow$ SNS (Skill-Unskilled-Substitution)

$\gamma_Y = 0 \Rightarrow$ Homothetic production

$\gamma_A > 0 \Rightarrow$ SBTC (Skilled-Biased-Technical-Change)

$\gamma_A < 0 \Rightarrow$ New technology favours Unskilled Labour

4. Sensitivity Analysis: CSC & SBTC

Results:

(a) CSC; (b) SNC; (c) SBTC;

(d) SBTC was higher in developed nations in the 1980s

Table 7. Translog Technology, Complementarity and Skill Bias

Explanatory Variables	FGLS		Quantile Regressions					
			1970-1979		1980-1989		1990-1999	
			Q25	Q75	Q25	Q75	Q25	Q75
Constant	-0.931** (0.036)	-0.733** (0.245)	-1.139** (0.185)	-0.686** (0.181)	-0.930** (0.128)	-0.863** (0.149)	-1.019** (0.182)	
ln(K/Y)	0.164** (0.006)	0.135** (0.035)	0.171** (0.047)	0.148** (0.021)	0.176** (0.032)	0.153** (0.022)	0.155** (0.035)	
ln(W _S /W _N)	0.464** (0.015)	0.452** (0.093)	0.565** (0.112)	0.387** (0.064)	0.428** (0.058)	0.455** (0.073)	0.491** (0.065)	
ln(Y/L)	-0.165** (0.010)	-0.161** (0.043)	-0.126 (0.077)	-0.148** (0.037)	-0.238** (0.058)	-0.151** (0.030)	-0.155** (0.060)	
ln(A)	0.418** (0.013)	0.377** (0.075)	0.401** (0.113)	0.351** (0.053)	0.547** (0.083)	0.379** (0.043)	0.423** (0.070)	
Observations	475	132	132	134	134	139	139	
Pseudo R ²		0.36	0.48	0.47	0.36	0.47	0.56	

Summary

Research Questions

- Does human capital facilitate technology transfer?
- Is a latent index (VS) better?
- Are the results robust to
 - (a) different indicators for the latent factor?
 - (b) CES and Translog production functions?
- Can the new HC estimate shed light on CSC & SBTC?

The evidence:

- It is consistent with the Logistic diffusion model
- The VS Index outperforms all other measures of HC
- The role of HC in innovation and diffusion seems robust to alternative forms of production technologies