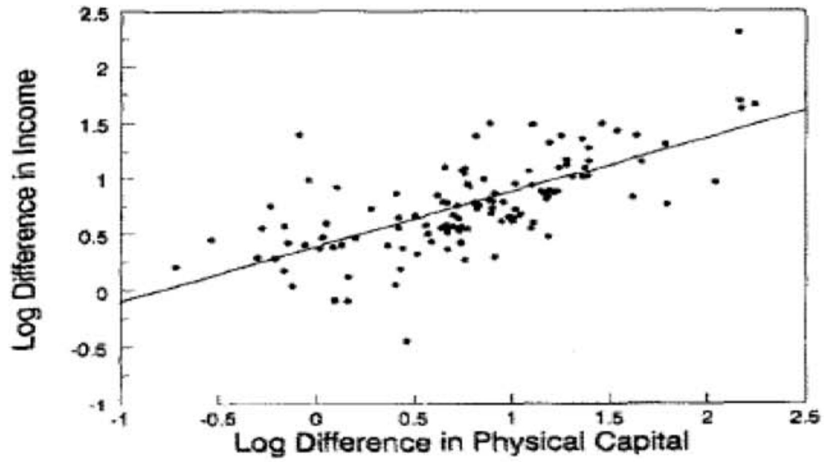
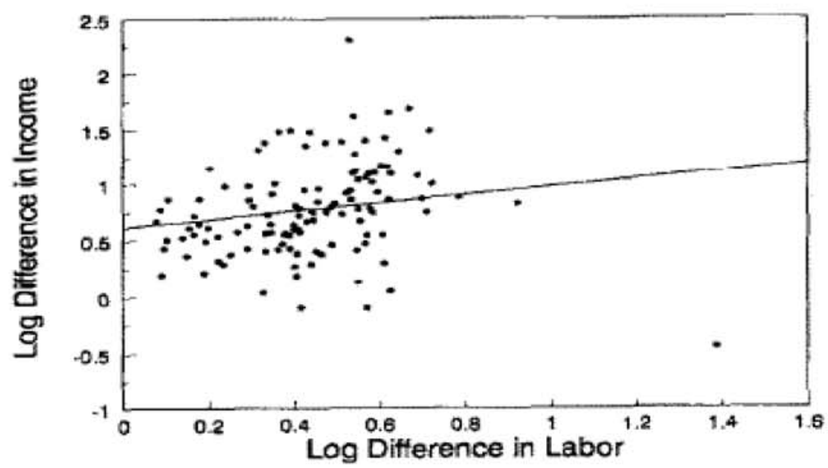
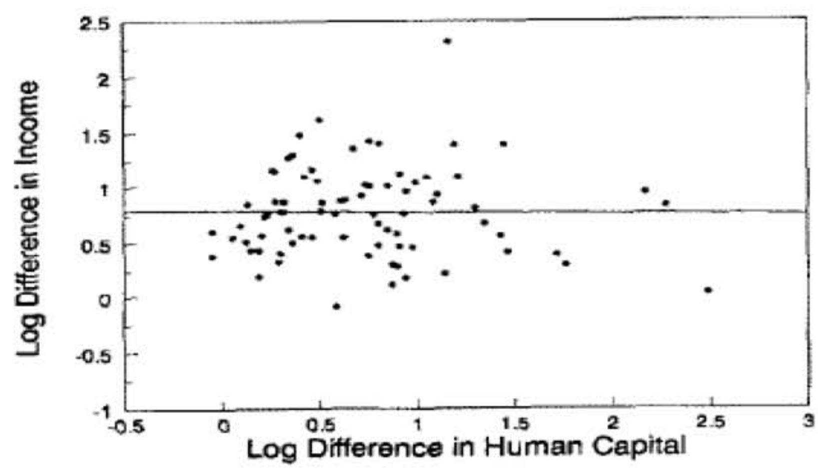
(1) Income vs. physical capital



(2) Income vs. labor



(3) Income vs. human capital (Kyriacou data)



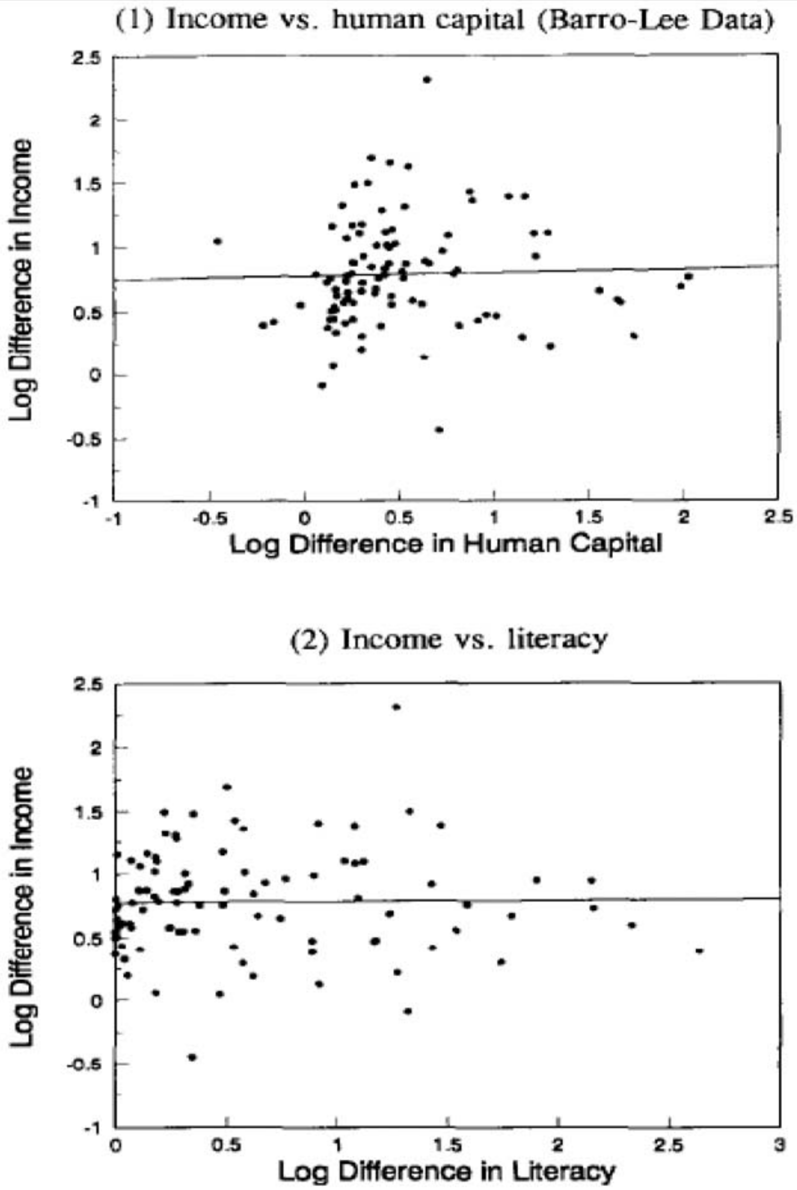


Fig. 2. Alternative measures of human capital.

Cross-country growth accounting results: Standard specification[a] – dependent variable: DY 1965–1985

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Const.	0.269[b]	1.947[b]	1.871[b]	1.968[b]	1.127[b]	1.654[b]
	(0.090)	(0.322)	(0.349)	(0.398)	(0.287)	(0.296)
DK	0.457[b]	0.545[b]	0.555[b]	0.530[b]	0.607[b]	0.472[b]
	(0.085)	(0.066)	(0.068)	(0.088)	(0.064)	(0.056)
DL	0.209	0.130	0.164	0.225	0.362[c]	0.219
	(0.207)	(0.163)	(0.164)	(0.192)	(0.156)	(0.138)
DH	0.063	− 0.059	− 0.043	− 0.080	− 0.028	− 0.031
	(0.079)	(0.058)	(0.066)	(0.064)	(0.065)	(0.059)
$LOGY_0$	—	− 0.190[b]	− 0.185[b]	− 0.190[b]	− 0.143[b]	− 0.152[b]
		(0.036)	(0.038)	(0.041)	(0.038)	(0.030)
OIL		—	− 0.097	—	—	
			(0.141)			
$AFRICA$	—	—	—	− 0.024	—	—
				(0.144)		
$LAAMER$	—	—	—	− 0.107		—
				(0.065)		
MID	—	—	—	—	0.675	—
					(0.761)	
PIQ	—	—	—	—	—	− 0.057
						(0.057)
Obs.	78	78	78	78	40	67
F-stat.	26.609	37.693	30.228	25.610	27.740	22.736

[a]dX refers to the log difference in variable X. Standard errors are in parentheses.

[b]1% confidence level.

[c]5% confidence level.

Table 3
Cross-country income determination in levels[a] – dependent variable: *LOGY*

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Const.	0.744	0.584	0.569	2.399[b]	2.196[b]	2.250[b]
	(0.568)	(0.391)	(0.521)	(0.325)	(0.350)	(0.385)
LOGK	0.853[b]	0.871[b]	0.866[b]	0.643[b]	0.692[b]	0.694[b]
	(0.064)	(0.048)	(0.049)	(0.038)	(0.038)	(0.030)
LOGL	0.153[c]	0.136[b]	0.155[b]	0.365[b]	0.319[b]	0.318[b]
	(0.066)	(0.055)	(0.051)	(0.041)	(0.042)	(0.033)
LOGH	0.050	—	—	0.217[b]	—	—
	(0.071)			(0.076)		
LOGHB	—	0.015	—	—	0.039	—
		(0.047)			(0.078)	
LOGLIT	—	—	0.037	—	—	0.080
			(0.049)			(1.003)
Obs.	80	97	115	109	101	102
F-stat.	893.10	1284.68	1197.91	1218.24	1130.18	1173.73

[a]Models 1, 2, and 3 use 1965 data, with the exception of Model 3 for which LOGLIT refers to 1960 literacy rates. Models 4, 5, and 6 use 1985 data.

[b]1% confidence level.

[c]5% confidence level.

Alternative Specification

$$\frac{\dot{A}}{A} = g(H_i) + c(H_i)\left(\frac{\max_j A_j - A_i(t)}{A_i(t)}\right)$$

$$= g(H_i) + c(H_i)\left(\frac{A_m(0)e^{g(H_m)t} - A_i(t)}{A_i(t)}\right)$$

$$A_i(t) = [A_i(0) - \Omega A_m(0)]e^{[g(H_i)-c(H_i)]t} + \Omega A_m(0)e^{g(H_m)}$$

$$\Omega = \frac{c(H_i)}{c(H_i) + g(H_m) - g(H_i)}$$

$$Lim_{t\to\infty} \frac{A_i(0) - \Omega A_m(0)}{A_m(0)} e^{[g(H_i)-c(H_i)-g(H_m)]t} + \Omega = \Omega$$

since $[g(H_i) - c(H_i) - g(H_m)] < 0.$

Catch up! Asymptotically growth rates converge.

$$
\begin{aligned}
\ln Y_T - \ln Y_0 = {} & (\ln A_T - \ln A_0) \\
& + \alpha(\ln K_T - \ln K_0) \\
& + \beta(\ln L_T - \ln L_0) \\
& + \gamma \frac{1}{T}\left(\sum_{t=0}^{T} H_t\right) + \ln \varepsilon_T - \ln \varepsilon_0
\end{aligned}
$$

Table 4
Cross-country growth accounting results: Human capital in log levels[a] – dependent variable: *DGDP* 1965–1985

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Const.	0.416[b]	2.093[b]	2.065[b]	2.044[b]	1.176[b]	1.730[b]
	(0.103)	(0.326)	(0.345)	(0.392)	(0.391)	(0.308)
DK	0.495[b]	0.500[b]	0.505[b]	0.479[b]	0.594[b]	0.440[b]
	(0.100)	(0.075)	(0.079)	(0.094)	(0.077)	(0.063)
DL	0.132	0.253	0.260	0.391[c]	0.385[c]	0.303
	(0.218)	(0.166)	(0.169)	(0.191)	(0.174)	(0.150)
LOGH	– 0.079	0.128[c]	0.121[c]	0.167[c]	0.045	0.089
	(0.060)	(0.055)	(0.059)	(0.054)	(0.101)	(0.058)
$LOGY_0$	—	– 0.233[b]	– 0.230[b]	– 0.235[b]	– 0.161	– 0.179[b]
		(0.043)	(0.045)	(0.046)	(0.067)	(0.036)
OIL	—	—	– 0.032	—	—	—
			(0.127)			
AFRICA	—	—	—	0.007	—	—
				(0.133)		
LAAMER	—	—	—	– 0.135[c]	—	—
				(0.065)		
MID	—	—	—	—	0.746	—
					(0.747)	
PIQ	—	—	—	—	—	– 0.045
						(0.053)
Obs.	78	78	78	78	40	67
F-stat.	27.551	41.225	32.583	29.198	27.832	23.830

[a] d*X* refers to the log difference in variable *X*. Standard errors are in parentheses.

[b] 1% confidence level.

[c] 5% confidence level.

A more structural specification:

$$
\begin{aligned}
\ln Y_T - \ln Y_0 &= c + gH_i + mH_i\left(\frac{Y_{\max} - Y_i}{Y_i}\right) \\
&\quad + \alpha(\ln K_T - \ln K_0) \\
&\quad + \beta(\ln L_T - \ln L_0) \\
&\quad + \gamma\frac{1}{T}\left(\sum_{t=0}^{T} H_t\right) + \ln\varepsilon_T - \ln\varepsilon_0 \\
&= c + (g-m)H_i + mH_i\frac{Y_{\max}}{Y_i} \\
&\quad + \alpha(\ln K_T - \ln K_0) \\
&\quad + \beta(\ln L_T - \ln L_0) \\
&\quad + \gamma\frac{1}{T}\left(\sum_{t=0}^{T} H_t\right) + \ln\varepsilon_T - \ln\varepsilon_0
\end{aligned}
$$

Table 5

'Structural specification' cross-country growth regressions[a] – dependent variable: DY 1965–1985

	Model 1	Model 2[b]	Model 3[c]	Model 4[d]	Model 5
Const.	0.1627	– 0.2268	0.0528	0.2324	0.0538
	(0.1142)	(0.2822)	(0.2246)	(0.2483)	(0.1345)
H	– 0.0136	0.0439[g]	– 0.0003	– 0.0736	0.0021
	(0.0144)	(0.0224)	(0.0366)	(0.0586)	(0.0154)
$H(Y_{max}/Y)$	0.0011[e]	0.0003	– 0.0001	0.0012[e]	0.0007[f]
	(0.0002)	(0.0009)	(0.0009)	(0.0003)	(0.0003)
dK	0.4723[e]	0.5076[e]	0.5517[e]	0.5233[e]	0.5005[e]
	(0.0717)	(0.0944)	(0.1226)	(0.1431)	(0.0771)
dL	0.1880	0.1720	0.5389	0.2901	0.2045
	(0.1640)	(0.2325)	(0.3884)	(0.5069)	(0.1558)
Y_{max}/Y	—	—	—		0.0014
					(0.0010)
Obs.	78	26	26	26	78
F-stat.	45.245	9.778	11.136	18.471	37.667

[a]Ordinary least squares. White's heteroskedasticity correction used. Standard errors are in parentheses.

[b]Wealthiest third of sample; per capita GDP in 1965 greater than \$2520.

[c]Middle third of sample; per capita GDP in 1965 less than \$2520 and greater than \$1250.

[d]Poorest third of sample; per capita GDP less than \$1250.

[e]1% confidence level.

[f]5% confidence level.

[g]10% confidence level.

Human Capital and Technology Diffusion

Jess Benhabib, Mark M. Spiegel

"Our view suggests that the usual, straightforward insertion of some index of educational attainment in the production function may constitute a gross mis-specification of the relation between education and the dynamics of production."

Nelson and Phelps, AER, 1966

Technology Diffusion raises two questions

1. Why undertake costly innovation rather than sit back and enjoy the technology flow? This question has been extensively discussed in the literature.

2. **a**) Why doesn’t technology diffuse instantly, and **b**) What factors account for its rate of its diffusion?

i) Vintage models are one possible explanation for slow diffusion (Chari-Hoppenhayn, Comin-Hobijn)

ii) A more widely used approach, not precluding the other, stipulates that the rate of diffusion depends on "appropriate" distance of TFP, (Output?) to frontier technology.(Gershenekron,Nelson-Phelps, Benhabib-Spiegel, Barro-Sala-i Martin, Eaton-Kortum, Howitt). Microfoundations of such models (e.g. Barro-Sala-i Martin) are about economic decisions, given that diffusion depends on distance.

There is a literature outside mainstream economics that offers two basic views about why technology diffusion is logistic, and not instantaneous.

A) epidemiology models **B**) probit models (Griliches' hybrid corn model)

There are theories about the factors that affect the rate of catch-up: Profitability (Griliches), Human Capital (Nelson-Phelps..), Institutions (Prescott-Parente...)

In this paper we focus NOT on factors that affect the rate of catch-up, but on the "distance to the leader."

(See also Basu-Weil)

Nelson-Phelps: Confined Exponential

$$\frac{\dot{A}_i(t)}{A_i(t)} = g(H_i(t)) + c(H_i(t))\left(\frac{A_m(t)}{A_i(t)} - 1\right)$$

$$\frac{A_m(t)}{A_i(t)} \to \infty, \ \frac{\dot{A}_i(t)}{A_i(t)} \to \infty; \lim_{t\to\infty} \frac{A_i(t)}{A_m(t)} = \frac{c_i}{c_i + g_m - g_i}$$

Logistic Diffusion

$$\frac{\dot{A}_i(t)}{A_i(t)} = g(H_i(t)) + c(H_i(t))\left(1 - \frac{A_i(t)}{A_m(t)}\right)$$

$$= g(H_i(t)) + c(H_i(t))\left(\frac{A_i(t)}{A_m(t)}\right)\left(\frac{A_m(t)}{A_i(t)} - 1\right)$$

$$As \ \frac{A_m(t)}{A_i(t)} \to \infty, \ \frac{\dot{A}_i(t)}{A_i(t)} \to g_i + c_i$$

$$\lim_{t\to\infty} \frac{A_i(t)}{A_m(t)} = \begin{cases} \frac{(c_i + g_i - g_m)}{c_i} & \\ \frac{A_i(0)}{A_m(0)} & if \\ 0 & \end{cases} \quad \begin{matrix} (c_i + g_i - g_m) > 0 \\ (c_i + g_i - g_m) = 0 \\ (c_i + g_i - g_m) < 0 \end{matrix}$$

Which model is correct?

A Nested Specification

To test this nested specification empirically we can specify it as:

$$\Delta a_{it} = \left(g + \frac{c}{s}\right)h_{it} - \frac{c}{s}h_{it}\left(\frac{A_{it}}{A_{mt}}\right)^{s}.$$

where Δa_{it} is the growth of TFP for country i, h_{it} is its initial or average human capital and $\left(\frac{A_{it}}{A_{mt}}\right)$ is the ratio of the country′s TFP to that of the leader.

Note that this specification nests the logistic $(s = 1)$, Gompertz $(s = 0)$, and exponential $(s = -1)$ diffusion models.

“The Catch-Up Condition” (for $s > 0$) :

$$c^{*} = 1 + \frac{c}{sg} > \frac{h_{mt}}{h_{it}}$$

Countries for which $\left(\frac{h_{mt}}{h_{it}}\right) > c^{*}$ will not converge to the leader’s growth rate unless they invest in "human capital / institutions" to reverse this inequality.

Table 2

Regression Results: Log H_{1960}

	Model 1	Model 2	Model 3	Model 4
C	0.0083**	–	0.0085**	–
	(0.0016)		(0.0016)	
$\ln(H_{1960})$	0.0080**	0.0116**	0.0100**	0.0134**
	(0.0019)	(0.0016)	(0.0023)	(0.0025)
$\ln(H_{1960}) * \left(\frac{TFP_i}{TFP_m}\right)^s$	-0.0086**	-0.0085**	-0.0089**	-0.0072**
	(0.0032)	(0.0039)	(0.0036)	(0.0025)
s	2.304*	3.164*	1	1
	(1.405)	(1.892)		
# of observations	84	84	84	84
log likelihood	264.5	252.4	263.9	263.9
Wald P-value	0.00	0.00	0.00	0.00

note: Estimation by maximum likelihood with standard errors presented in parentheses. ** denotes statistical significance at the 5% confidence level while * denotes statistical significane at the 10% confidence level.

Table 3

Regression Results: Log $\overline{H}_{1960-1995}$

	Model 1	Model 2	Model 3	Model 4
C	-0.0030	–	-0.0030	–
	(0.0024)		(0.0024)	
$\ln(\overline{H}_{1960-1995})$	0.0175**	0.0150**	0.0184**	0.0159**
	(0.0046)	(0.0039)	(0.0026)	(0.0017)
$\ln(\overline{H}_{1960-1995}) * \left(\frac{TFP_i}{TFP_m}\right)^s$	-0.0129**	-0.0116**	-0.0135**	-0.0122**
	(0.0039)	(0.0036)	(0.0031)	(0.0029)
s	1.151	1.192	1	1
	(0.783)	(0.862)		
# of observations	84	84	84	84
log likelihood	274.5	273.7	274.4	273.6
Wald P-value	0.00	0.00	0.00	0.00

note: Estimation by maximum likelihood with standard errors presented in parentheses. ** denotes statistical significance at the 5% confidence level while * denotes statistical significane at the 10% confidence level.

Table 4

Regression Results: Log $\overline{H}_{1960-1995}$ and Geo-Political Variables

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
C	-0.0671	–	-0.0778*	–	-0.1394**	–
	(0.0463)		(0.0461)		(0.0488)	
$\ln(\overline{H}_{1960-1995})$	0.0077	0.0070	0.0072	0.0067*	0.0092	0.0080**
	(0.0061)	(0.0043)	(0.0054)	(0.0038)	(0.0077)	(0.0038)
$\ln(\overline{H}_{1960-1995})$	-0.0196**	-0.0164**	-0.0194**	-0.0159**	-0.0213**	-0.0142**
$*\left(\frac{TFP_i}{TFP_m}\right)^s$	(0.0066)	(0.0045)	(0.0059)	(0.0041)	(0.0082)	(0.0043)
s	0.9302	1.1380*	0.9866*	1.2250*	0.8375	1.2780
	(0.5796)	(0.6534)	(0.5621)	(0.6414)	(0.5857)	(0.7953)
ssafrica	-0.0041	-0.0049*	–	–	-0.0047	-0.0065**
	(0.0030)	(0.0030)			(0.0032)	(0.0033)
access	-0.0018	-0.0027	-0.0026	-0.0038	0.0002	-0.0015
	(0.0027)	(0.0026)	(0.0026)	(0.0026)	(0.0029)	(0.0030)
tropics	-0.0070**	-0.0074**	-0.0073**	-0.0078**	-0.0086**	-0.0096**
	(0.0026)	(0.0026)	(0.0026)	(0.0026)	(0.0027)	(0.0028)
life1	0.0201*	0.0031**	0.0228*	0.0031**	0.0393**	0.0044**
	(0.0117)	(0.0007)	(0.0117)	(0.0007)	(0.0123)	(0.0008)
ethling	0.0001	0.0000	0.0000	-0.0000	0.0001*	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
openess	0.0128**	0.0140**	0.0128**	0.0143**	–	–
	(0.0027)	(0.0026)	(0.0027)	(0.0026)		
# of observations	75	75	75	75	78	78
log likelihood	259.8	258.7	258.8	257.4	261.2	257.3
Wald P-value	0.00	0.00	0.00	0.00	0.00	0.00

note: Estimation by maximum likelihood with standard errors presented in parentheses. ** denotes statistical significance at the 5% confidence level while * denotes statistical significane at the 10% confidence level. See text for definitions of the conditioning variables.

Table 5
Point Estimates

H_{1960}

	Model 1	Model 2	Model 3	Model 4
g	-0.0006	0.0031	0.0012	0.0063
c	0.0198	0.0268	0.0089	0.0072
s	2.3040	3.1645	1	1
H_{60}^{*}	n.a.	1.78	1.29	2.75
H_{95}^{*}	n.a.	1.95	1.35	3.22

$\overline{H}_{1960-1995}$

	Model 1	Model 2	Model 3	Model 4
g	0.0046	0.0034	0.0049	0.0037
c	0.0149	0.0138	0.0135	0.0122
s	1.1515	1.1921	1	1
H_{60}^{*}	1.76	1.63	1.78	1.65
H_{95}^{*}	1.93	1.76	1.95	1.79

note: g, c, and s are obtained from the point estimates presented in Tables 2 and 3. H_{60}^{*} and H_{95}^{*} represent the minimal initial estimated stock of human capital needed for positive predicted growth relative to the leader nation.

Table 6
Nations with Slow TFP Growth (1960)

Country	H_{1960}	(TFP Growth$_i$) – (TFP Growth$_{USA}$)
Nepal	0.07	-0.0072
Mali	0.17	-0.0199
Niger	0.20	-0.0297
Mozambique	0.26	-0.0307
Togo	0.32	-0.0172
Central African Republic	0.39	-0.0295
Iran	0.63	-0.0050
Pakistan	0.63	0.0063
Ghana	0.69	-0.0067
Bangladesh	0.79	-0.0084
Algeria	0.97	-0.0067
Syria	0.99	0.0034
Uganda	1.10	-0.0090
Indonesia	1.11	0.0095
Papua New Guinea	1.13	-0.0057
Kenya	1.20	-0.0061
Cameroon	1.37	-0.0169
Jordan	1.40	-0.0082
Guatemala	1.43	-0.0067
India	1.45	0.0013
Botswana	1.46	0.0168
Zimbabwe	1.54	-0.0002
Senegal	1.60	-0.0198
Zambia	1.60	-0.0238
Honduras	1.69	-0.0122
Malawi	1.70	-0.0070
El Salvador	1.70	-0.0116

Countries with 1960 human capital levels below 1.78, minimum for TFP catchup per Model 2 in Table 2.

Table 7
Nations with Slow TFP Growth (1995)

Country	H_{1995}	$\frac{TFP_{1995i}}{TFP_{1995USA}}$
Mali	0.69	0.1188
Niger	0.69	0.1152
Mozambique	1.01	0.1499
Nepal	1.53	0.1489

Countries with 1995 human capital levels below 1.95, minimum for TFP catchup according to Model 2 in Table 2. For the full 84 country sample, $\overline{\frac{TFP_{1995i}}{TFP_{1995USA}}} = 0.4377$

Figure 1
TFP Growth vs Initial Human Capital

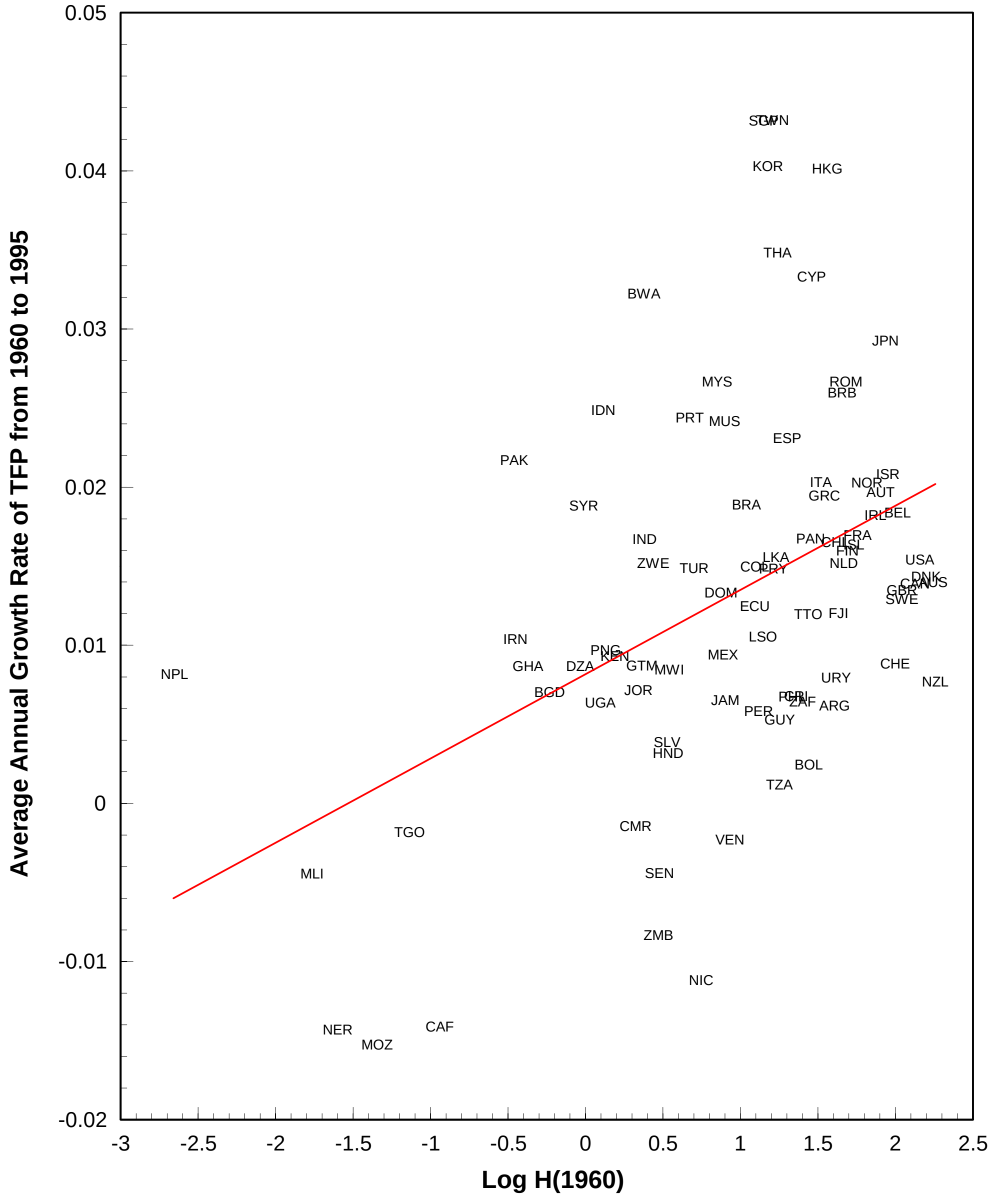
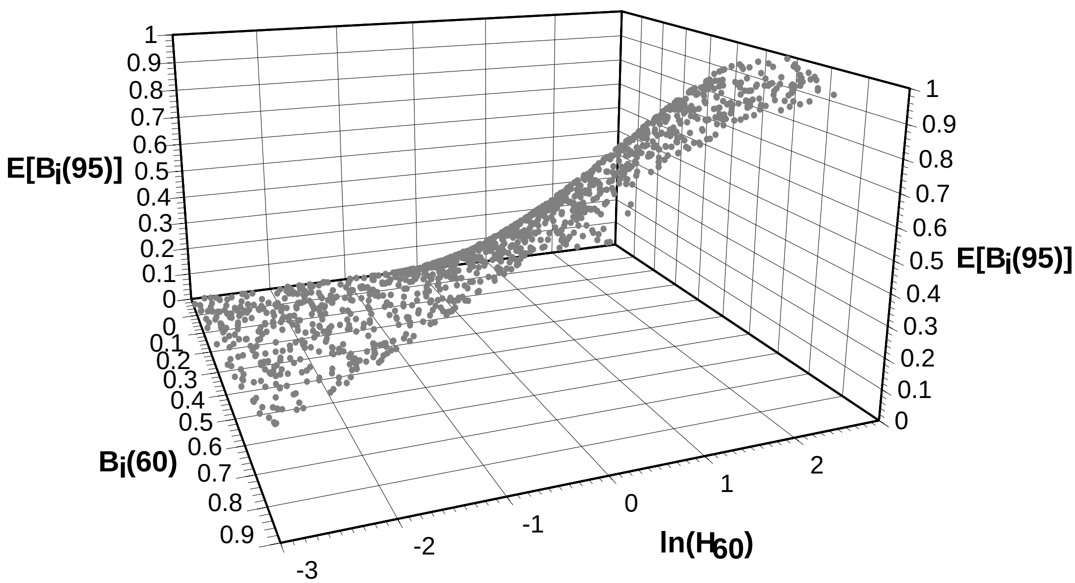


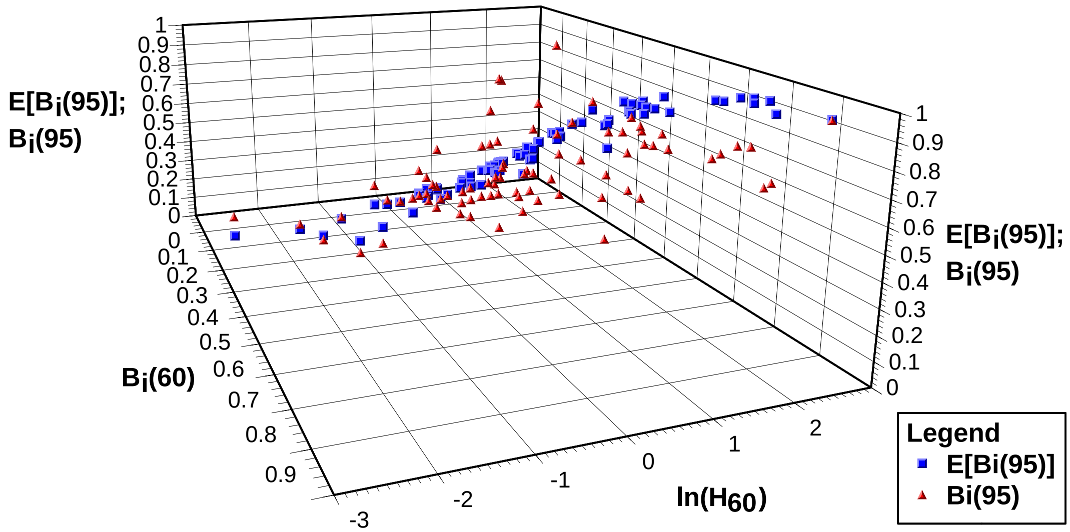
Figure 2
Predicted Values of $B_i(1995)$[1]



[1] Predicted values of $B_i(95)$ are based on initial backwardness in TFP, $B_i(60)$, and the log of initial stock of human capital. $B_i(t)$ represents the ratio of TFP in country i to TFP in the leader country (United States) at time t. The sample encompasses the entire range of values for backwardness and human capital.

Figure 3

Predicted and Actual Values of $B_i(1995)$[1]



[1]Predicted values of $B_i(95)$are based on initial backwardness in TFP, $B_i(60)$, and the log of initial stock of human capital. $B_i(t)$represents the ratio of TFP in country $i$to TFP in the leader country (United States) at time t. The sample includes observed data points only.