2011

The effects of human capital composition on technological convergence

James B Ang, *Nanyang Technological University*


Volume 33, Issue 3
September 2011
ISSN 0164-0704
ELSEVIER
Journal of MACROECONOMICS
CONTENTS
H. Bi and M. Kumhof, Jointly optimal monetary and fiscal policy rules under liquidity constraints 373
B. Heer, A. Maußner and P.D. McNelis, The money-age distribution: Empirical facts and the limits of three monetary models 390
B. Russell, Non-stationary inflation and panel estimates of United States short and long-run Phillips curves 406
H. Berger, M. Ehrmann and M. Fratzscher, Geography, skills or both: What explains Fed watchers' forecast accuracy of US monetary policy? 420
A. Minniti, Knowledge appropriability, firm size, and growth 438
A. López-Villavicencio and V. Mignon, On the impact of inflation on output growth: Does the level of inflation matter? 455
J.B. Ang, J.B. Madsen and Md. Rabiul Islam, The effects of human capital composition on technological convergence 465
L. Aguiar-Conraria and M. Joana Soares, Business cycle synchronization and the Euro: A wavelet analysis 477
In collaboration with the E.J. Ourso College of Business, Louisiana State University
Available online at www.sciencedirect.com
ScienceDirect

Journal of Macroeconomics 33 (2011) 465–476

Contents lists available at ScienceDirect

Journal of Macroeconomics

journal homepage: www.elsevier.com/locate/jmacro

The effects of human capital composition on technological convergence

James B. Ang *, Jakob B. Madsen, Md. Rabiul Islam

Department of Economics, Monash University, Australia

ARTICLE INFO

Article history:
Received 3 September 2010
Accepted 3 March 2011
Available online 16 March 2011

JEL classification:
I20
O30
O40

Keywords:
Human capital composition
Innovation
Convergence

ABSTRACT

This paper empirically investigates whether the contribution of human capital to productivity growth depends on the composition of human capital and proximity to the technology frontier in a panel of 87 sample countries over the period 1970–2004. It tests the hypothesis that primary and secondary education is more suitable for imitation whereas tertiary education is more appropriate for innovation. The results show that the growth enhancing effects of higher education increase with proximity to the technology frontier only for high and medium income countries.

1. Introduction

Although human capital has been widely regarded as an important driver for innovative growth in the theories of endogenous growth (Romer, 1990; Aghion and Howitt, 1992, 1998; Acemoglu, 1996; Acemoglu et al., 2002), empirical findings regarding its direct contribution to growth are at best mixed.[1] On the other hand, building on the earlier work of Nelson and Phelps (1966) that suggests that a more educated workforce facilitates the adoption of new technologies, a number of recent studies have consistently found that human capital not only enhances the ability of a country to develop its own technological innovation but also increases its capacity to adopt technologies already developed elsewhere and thereby facilitates convergence (see Griffith et al., 2004; Benhabib and Spiegel, 2005; Kneller and Stevens, 2006; Madsen et al., 2010, among others).

However, despite finding a dual role for human capital in promoting growth, these studies do not resolve the empirical puzzle that human capital enhances growth only for those countries with the lowest level of education, as found by Krueger and Lindahl (2001). In an attempt to resolve this issue, Vandenbussche et al. (2006) argue that human capital does not affect innovation and imitation uniformly. In their model, unskilled human capital facilitates imitation or diffusion of existing technology, whereas skilled human capital promotes the innovation of new technology. Their theoretical model proposes that tertiary education should become increasingly important and primary and secondary education less important for growth as a country moves closer to the technology frontier.

* Corresponding author. Address: Department of Economics, Monash University, 900 Dandenong Road, Caulfield East, Vic 3145, Australia. Tel.: +61 3 99034516; fax: +61 3 99031128.

E-mail address: James.Ang@buseco.monash.edu.au (J.B. Ang).

[1] For instance, Mankiw et al. (1992) find a positive and significant direct effect of human capital on growth, whereas Islam (1995) finds the reverse using a different estimator. Caselli et al. (1996) also obtain significant negative coefficients of human capital whereas Knowles and Owen (1995), Pritchett (2001) and Radelet et al. (2001) find insignificant associations between human capital and growth.

0164-0704/$ - see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.jmacro.2011.03.001

Using aggregate data for 19 OECD countries over the period 1960–2000 and state level data for the US, the empirical analyses of Vandenbussche et al. (2006), henceforth VAM, and Aghion et al. (2009) find evidence in favor of the predictions of VAM's model. However, whether these predictions are valid for medium and low income developing countries remains untested. There are three reasons why it is important to test their hypothesis for developing countries. First, the VAM model so far has only been tested for high income countries. The sample countries typically have the highest levels of human capital accumulation in the world. Second, knowledge of the social returns to different categories of education is important from a budgetary perspective. If developing countries are mainly technology followers and thereby absorb foreign technologies by adapting them to local conditions and applying them to alternative uses, the social returns to lower skilled workers exceed those of higher skilled workers. Conversely, if human capital predominantly fosters technological innovations in developed countries and thereby generates income growth by making capital and labor more productive, the social returns to highly skilled workers may exceed those of lower skilled workers (Aghion et al., 2009). This suggests that the way human capital composition affects growth may vary depending on the developmental stage of a country, and therefore highlights the importance of segregating the sample into different income groups. Third, Caselli and Coleman (2006) argue that skilled and unskilled workers are imperfect substitutes and that the skill premium differs substantially between developed and developing countries. If this is the case, the sample of developing countries will give insight into the general validity of the model of VAM.

This paper contributes to the growth and development literature in three respects. First, the hypothesis of VAM is tested for low income, middle income and high income countries. Second, in addition to utilizing the widely used human capital datasets of Barro and Lee (2001), we also use the new educational datasets compiled by Cohen and Soto (2007) and Lutz et al. (2007). Third, only a few studies, if any, have made a cross-country analysis of the growth effects of human capital for various educational groups. *A priory* there is no reason why the growth effects of different categories of human capital are the same or that the social returns to human capital for different educational groups are the same as the private returns, as is often assumed when different educational groups are combined together in macroeconomic studies.

The next section establishes the empirical framework and Section 3 explains the data and construction of variables. The analysis is conducted based on a large panel of 87 countries (including 28 high, 37 middle and 22 low income countries) over the period 1970–2004 using the system GMM method. Section 4 presents the results and the last section concludes.

2. Empirical framework

The discussions above suggest that the composition of human capital has a direct effect on TFP growth: skilled human capital is important for innovation, whereas unskilled human capital is better suited for imitation. The effect of proximity (inverse of distance) to the technology frontier is expected to have a negative effect on TFP growth, following the prediction of the hypothesis of the advantage of backwardness by Gerschenkron (1962). That is, countries which are further behind the technology frontier should experience higher TFP growth due to lower effective costs of innovation, thereby allowing a more rapid catch-up to the technology frontier. The effects of skilled human capital on TFP growth should increase with proximity to the technology frontier since innovation is a skill-intensive activity. However, the contribution of unskilled human capital to TFP growth should decrease with proximity to the technology frontier since imitation requires mostly physical capital and less educated (or unskilled) human capital (VAM; Aghion et al., 2007, 2009).

Accordingly, the following empirical specification is adopted to test the above hypotheses (see VAM):

$$\Delta \ln A_{it} = \beta \ln \left(\frac{A_{i,t-1}}{A_{t-1}^{\mathrm{US}}} \right) + \gamma' H_{i,t-1} + \delta' H_{i,t-1} \ln \left(\frac{A_{i,t-1}}{A_{t-1}^{\mathrm{US}}} \right) + \theta' X_{it} + c_i + t_t + \varepsilon_{it} \tag{1}$$

where $\Delta \ln A$ is TFP growth, $\frac{A_{i,t-1}}{A_{t-1}^{\mathrm{US}}}$ is the relative TFP gap between country i and the US (technology leader), which measures proximity to the technology frontier, H is a vector of human capital decomposed into different educational groups, X is a vector of control variables (which includes the rate of inflation, trade openness, the inflows of FDI, financial development and geographical location), c_i captures the time-invariant unobserved country-specific fixed effects, t_t captures the unobservable individual invariant time effects, and ε_{it} is the stochastic error term. The variables are measured as the average within the period that is covered by the differences.

The focus variables in the VAM model are human capital and the interaction between human capital and proximity to the frontier. The model predicts that the signs of the coefficients of these variables vary across educational groups. Importantly, VAM argues that the growth effects of the interaction between human capital and proximity are positive for tertiary education but negative for primary and secondary education. The interaction effect is negative for primary and secondary education because these educational groups imitate the innovations in the frontier country. The further the country is from the frontier the larger is the imitation effect because the effective costs of imitation are lower. Furthermore, the model predicts that the growth effects of primary and secondary education are insignificant but significantly positive for tertiary education because this is the only educational group that innovates.

3. Estimation method and data

The empirical estimates are based on the system GMM estimator for a panel of 87 countries covering the period 1970–2004. The system GMM estimator has been widely used to deal with unobserved heterogeneity and endogeneity biases in estimation. In the presence of heteroskedasticity the system GMM estimator is more efficient than the simple IV estimator (Baum et al., 2003). Furthermore, Bond et al. (2001) show that the system GMM estimator is the preferred approach for estimation of empirical growth models due to its superior ability in exploiting stationarity restrictions (see also Durlauf et al., 2005). Eq. (1) is estimated in 5-year intervals (except for the period 2000–2004, which covers only four years), as dictated by the availability of educational data and to filter out the influence of business cycles.

In addition to the default internal instruments (lagged levels and first-differences of the explanatory variables), the following external instruments are used for human capital: real public educational expenditures per capita on primary, secondary and tertiary education, life expectancy, and effectiveness of legislature. External instruments are used to cater for the possibility of feedback effects from productivity growth to human capital. Public expenditure on schooling is influential on the part of schooling that is financed publicly while it does not influence the privately financed schooling decision and, as such, is unaffected by growth. Life expectancy influences the schooling decision because it increases the present value of schooling and is, at the same time, independent of growth. Acemoglu and Johnson (2007) find that growth is independent of life expectancy. Finally, the effectiveness of legislature is included as an institutional variable promoting schooling. All these instruments are highly correlated with human capital and its interaction with proximity to the frontier and are orthogonal to the residuals. Tests for orthogonality are performed using the "Hansen" and "difference-in-Hansen" tests.

The sample is divided into 28 high, 37 middle and 22 low income countries, where the low income countries are assumed to imitate and the high income countries to innovate. Whether the middle income group innovates or imitates is an empirical issue. This country classification is based on the 2008 GNI per capita data in current US$, following the World Bank's approach. An alternative country classification is also considered where the total sample is divided equally into three groups based on the 2008 GDP per capita data in constant 2005 international dollars valued at PPP. This results in 29 countries in each group. However, the results were unaffected by this alternative classification (see Table A1 in Appendix A). The principal results are unaltered if the same country classification method based on 1980, 1990 or 2000 (data for 1970 are not available) per capita income valued at PPP is used instead (not reported).

The following three different data sets on educational attainment are used: Barro and Lee (2001), henceforth 'BL', Cohen and Soto (2007), henceforth 'CS', and Lutz et al. (2007), which is from the International Institute for Applied Systems Analysis (IIASA) and the Vienna Institute of Demography (VID), henceforth 'IV'.[2] The CS educational data are interpolated geometrically since they are available only in 10-year intervals. The advantage of using different data sources is that educational attainment is decomposed differently and, therefore, gives greater insights into the growth effects of different educational grouping.

Human capital is constructed in the following three different ways: (1) the average number of years of primary (*YPRI*), secondary (*YSEC*) and tertiary (*YTER*) education for the population aged 15 years and above; (2) the number of years of education of the skilled (*YSK*) and unskilled (*YUSK*) population aged 15 years and above; and (3) the fraction of the population over the age of 14 having primary (*PRI*), secondary (*SEC*) and tertiary (*TER*) education. Data sources and the construction of these variables are discussed in the next section.

The approach of VAM is used to categorize the variables. The discussion below is based on the IV education dataset, which is available in 4 non-overlapping categories: no schooling (0), primary (6), secondary (6) and tertiary (4) education, where the figures in the brackets indicate the number of years (n) required for completing a particular category of education. Accordingly, the first set of human capital composition variables is constructed as: $YPRI = (p_2 + p_3 + p_4)n_2$, $YSEC = (p_3 + p_4)n_3$ and $YTER = p_4 n_4$, where p_i is the percentage of the population (aged 15 and above) who have completed the ith category of education.[3]

VAM also considers the following composition of human capital: $YSK = p_4\sum_{j=0}^{4} n_j$ and $YUSK = \sum_{i=1}^{3}\left(\sum_{j=1}^{i} n_j\right)p_i$, where *YSK* (*YUSK*) indicates the number of years of skilled (unskilled) education of the population (aged 15 and above). Skilled

[2] Education data are also available from de la Fuente and Doménech (2006), but are only for 21 high income OECD countries. The estimated results for the OECD using this dataset are consistent with our results for high income countries, but they are not reported here for brevity.

[3] Barro and Lee (2001) provide 7 categories of schooling data: no schooling (p_1), some primary (p_2), complete primary (p_3), some secondary (p_4), complete secondary (p_5), some tertiary (p_6) and complete tertiary (p_7) so that $(n_1, n_2, n_3, n_4, n_5, n_6, n_7) = (0, 3, 3, 3, 3, 2, 2)$. Thus, $YPRI = (p_2 + p_3 + p_4 + p_5 + p_6 + p_7)n_2 + (p_3 + p_4 + p_5 + p_6 + p_7)n_3$; $YSEC = (p_4 + p_5 + p_6 + p_7)n_4 + (p_5 + p_6 + p_7)n_5$; and $YTER = (p_6 + p_7)n_6 + p_7 n_7$. A similar approach is used for the Cohen-Soto dataset.

Table 1
Descriptive statistics.

	$\Delta \ln A_{it}$	$(A_i/A^{US})_{t-1}$	IIASA & VID (IV)			Cohen and Soto (CS)			Barro and Lee (BL)		
			$YPRI_{i,t-1}$	$YSEC_{i,t-1}$	$YTER_{i,t-1}$	$YPRI_{i,t-1}$	$YSEC_{i,t-1}$	$YTER_{i,t-1}$	$YPRI_{i,t-1}$	$YSEC_{i,t-1}$	$YTER_{i,t-1}$
All countries (87)											
Obs.	606	607	609	609	609	504	504	504	516	516	518
Mean	3.66	43.70	4.10	2.21	0.24	4.03	1.83	0.26	3.67	1.57	0.22
St. Dev.	13.18	25.47	1.74	1.72	0.24	1.71	1.42	0.27	1.55	1.15	0.24
Min.	−61.24	6.09	0.07	0.02	0.00	0.07	0.02	0.00	0.15	0.02	0.00
Max.	51.48	100.00	6.02	6.00	1.28	6.01	5.14	1.46	5.90	5.15	1.45
High income countries (28)											
Obs.	196	196	196	196	196	175	175	175	182	182	182
Mean	7.03	71.16	5.54	4.04	0.46	5.71	3.27	0.49	5.15	2.66	0.40
St. Dev.	10.09	14.36	0.87	1.50	0.24	0.53	1.17	0.28	0.55	1.00	0.27
Min.	−40.53	30.04	2.11	0.67	0.06	3.31	0.50	0.04	3.09	0.35	0.03
Max.	51.34	100.00	6.02	6.00	1.28	6.01	5.14	1.46	5.90	5.15	1.45
Middle income countries (37)											
Obs.	257	257	259	259	259	217	217	217	222	222	224
Mean	3.22	39.83	4.20	1.78	0.20	3.81	1.42	0.20	3.47	1.28	0.17
St. Dev.	13.23	16.34	1.28	0.93	0.16	1.05	0.78	0.16	1.04	0.67	0.14
Min.	−38.83	7.39	0.84	0.29	0.00	0.87	0.12	0.01	1.08	0.23	0.00
Max.	39.36	97.43	6.01	4.99	0.85	5.47	3.94	1.01	5.77	3.28	0.70
Low income countries (22)											
Obs.	153	154	154	154	154	112	112	112	112	112	112
Mean	0.07	15.22	2.10	0.63	0.03	1.82	0.39	0.02	1.68	0.39	0.02
St. Dev.	15.45	7.24	1.24	0.54	0.03	1.10	0.34	0.03	0.87	0.32	0.02
Min.	−61.24	6.09	0.07	0.02	0.00	0.07	0.02	0.00	0.15	0.02	0.00
Max.	51.48	57.06	4.96	2.87	0.17	4.55	1.33	0.13	4.15	1.41	0.12

Notes: *YPRI*, *YSEC* and *YTER* are expressed in years. TFP growth rates (in percentages) are averaged over a 5-year period.

education refers to tertiary education whereas unskilled education includes both primary and secondary education. Under this approach, it is assumed that one year of higher education is sufficient to transform all previous 12 years of unskilled education into 12 years of skilled education. Hence, a university graduate contributes 16 years to *YSK* but 0 years to *YUSK*.

Finally, the last set of human capital composition measures is constructed simply by considering the percentage of the population who have completed primary (*PRI*), secondary (*SEC*) and tertiary (*TER*) education. This approach, however, gives rise to some interpretation problems given that an increase in *SEC*, for instance, implies a reduction in *PRI*. The first two approaches are preferred as they are not subject to this limitation.

TFP is estimated as a residual of the aggregate production function: $Y/(K^{\alpha}L^{1-\alpha})$, where Y is real GDP, K is physical capital stock, L is the labor force, and α is the share of income that goes to capital stock and is set to 0.3. The initial capital stock is estimated using the Solow model steady-state value of $I_{i0}/(\delta + g_i)$, where I_0 is the initial real investment, δ is the rate of depreciation (assumed to be five percent) and g is the growth rate in real investment over the sample period. The capital stock series is then constructed using the perpetual inventory method with the same depreciation rate. The data are collected from Penn World Tables 6.2. Proximity to the technology frontier is measured as the relative TFP gap between the sample country and the US.

As noted above, the following control variables are included in the regressions: the rate of consumer price inflation, trade openness (imports plus exports over GDP), the ratio of foreign direct investment inflows to GDP, financial development (the ratio of private credit to GDP) and geographical location (landlockedness). Growth is assumed to be negatively related to landlockedness because landlocked countries are disadvantaged by their lack of access to the sea and therefore incur larger transportation costs.[4]

Table 1 presents descriptive statistics for TFP growth, proximity to the frontier, and education decomposed into primary, secondary and tertiary. TFP growth during the data period (1970–2004) differs substantially between countries. The low income countries have hardly experienced any growth and the high income countries have had growth rates more than twice as high as the middle income countries. Not surprisingly the high income countries have higher years of schooling in each category of education than the middle and low income countries. The educational attainments differ

[4] Except for data on *landlockedness* which are obtained from the '2009 Doing Business in Landlocked Economies database' (see http://www.doingbusiness.org/reports/special-reports/landlocked-economies-2009), all other data are gathered from the World Development Indicators (2010).

Table 2
TFP growth estimates based on average years of educational attainment.

	All countries (87)			High income (28)			Middle income (37)			Low income (22)		
	IV 1(a)	CS 1(b)	BL 1(c)	IV 2(a)	CS 2(b)	BL 2(c)	IV 3(a)	CS 3(b)	BL 3(c)	IV 4(a)	CS 4(b)	BL 4(c)
$YPRI_{i,t-1}$	0.06*	0.06*	0.16*	0.05	0.11	0.19	0.01	−0.01	−0.01	−0.03	−0.28	0.12
	(1.82)	(1.71)	(1.93)	(1.38)	(1.15)	(1.46)	(0.72)	(−0.16)	(−0.04)	(−0.27)	(−1.09)	(0.67)
$YSEC_{i,t-1}$	0.06*	0.08*	−0.09	−0.02	−0.04	−0.08	0.01	−0.04	0.03	0.55	1.40	0.10
	(1.81)	(1.74)	(−0.90)	(−1.00)	(−1.22)	(−1.27)	(0.42)	(−0.33)	(0.43)	(1.38)	(0.92)	(0.19)
$YTER_{i,t-1}$	−0.27	−0.23	0.30*	0.13*	0.08*	0.14*	0.24**	0.56*	0.44*	−1.03	4.94	5.33
	(−1.35)	(−1.36)	(1.81)	(1.80)	(1.74)	(2.04)	(2.26)	(2.03)	(1.82)	(−0.21)	(0.31)	(0.60)
$\ln(A_i/A^{US})_{t-1}$	−0.21***	−0.23***	−0.32**	−0.61*	−1.45*	−1.75*	−0.22***	−0.05	−0.25**	−0.24**	−0.32**	−0.30**
	(−2.78)	(−3.41)	(−2.28)	(−1.77)	(−1.71)	(−1.74)	(−3.82)	(−0.19)	(−2.15)	(−2.78)	(−2.56)	(−2.60)
$YPRI_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	−0.01	0.01	0.05	0.06	0.24	0.37	0.01	−0.04	−0.01	−0.03	−0.11	0.04
	(−0.08)	(0.24)	(0.60)	(0.83)	(1.45)	(1.43)	(0.53)	(−0.48)	(−0.09)	(−0.43)	(−0.90)	(0.41)
$YSEC_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	0.07*	0.03	−0.08	−0.04	−0.09	−0.18	−0.02	−0.07	0.01	0.29	0.55	0.10
	(1.67)	(0.68)	(−0.59)	(−0.86)	(−1.56)	(−1.46)	(−0.83)	(−0.56)	(0.17)	(1.49)	(0.80)	(0.44)
$YTER_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	−0.25	−0.11	0.33*	0.49**	0.44**	0.30**	0.36***	0.86***	0.60**	−0.80	3.78	2.72
	(−1.17)	(−0.46)	(1.71)	(2.63)	(2.23)	(2.61)	(3.82)	(2.94)	(2.78)	(−0.34)	(0.45)	(0.60)
Inflation_{it}	−0.01***	−0.01***	−0.01**	−0.92***	−0.90***	−1.01***	−0.01***	−0.01***	−0.01***	−0.22***	−0.20**	−0.20***
	(−3.06)	(−3.98)	(−2.47)	(−5.34)	(−4.34)	(−3.43)	(−3.23)	(−3.34)	(−4.01)	(−5.36)	(−2.51)	(−2.98)
$\text{Trade openness}_{it}$	0.12	0.04	0.03	0.01	0.02	−0.01	0.01	0.02	0.01	−0.06	−0.24	−0.26
	(1.47)	(0.70)	(0.44)	(0.45)	(0.73)	(−0.01)	(0.40)	(0.44)	(0.34)	(−0.46)	(−1.16)	(−1.33)
$\text{FDI inflows over GDP}_{it}$	0.65*	0.89**	0.93	0.01	−0.03	0.41	0.85**	1.54*	1.26**	1.14	5.67*	3.48
	(1.68)	(2.03)	(1.59)	(0.02)	(−0.17)	(1.03)	(2.34)	(1.83)	(2.12)	(1.48)	(2.04)	(1.56)
$\text{Financial development}_{it}$	0.01	−0.02	−0.01	−0.03	−0.01	−0.04	0.04	0.01	0.05	−0.12	0.88	−0.48
	(0.08)	(−0.43)	(−0.09)	(−1.32)	(−0.32)	(−1.63)	(1.31)	(0.07)	(1.13)	(−0.63)	(1.51)	(−0.97)
$\text{Landlockedness}_{it}$	−0.07*	−0.07*	−0.05	−0.01	−0.01	0.02	−0.03**	−0.01	−0.04	−0.02	−0.05	−0.03
	(−1.88)	(−1.87)	(−1.35)	(−0.51)	(−0.19)	(0.65)	(−2.19)	(−0.48)	(−1.56)	(−0.68)	(−0.79)	(−0.82)
Hansen (*p*-val)	0.33	0.42	0.26	0.98	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99
Diff-in-Hansen (*p*-val)	0.57	0.62	0.23	0.98	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99
AR(2) (*p*-val)	0.60	0.16	0.84	0.58	0.18	0.23	0.22	0.11	0.13	0.18	0.17	0.25

Notes: *YPRI*, *YSEC* and *YTER* indicate average years of schooling for the population aged 15 years and above at primary, secondary and tertiary levels, respectively. A_i/A^{US} = proximity to the technology frontier. The Hansen test examines the validity of the instruments where the null hypothesis is that the instruments are uncorrelated with the residuals. The "Difference-in-Hansen" test examines the exogeneity of the instrument subsets with the null hypothesis that the subsets of instruments are exogenous. The null hypothesis of the AR(2) test is that the error terms in the 1st-differenced regression exhibit no 2nd order serial correlation. In most cases, 2nd and 3rd lags of the explanatory variables are taken as instruments for the differenced equation whereas 1st differences of the explanatory variables are taken as instruments for the level equation. The regressions also include three sets of external instruments: (1) real public educational expenditures per capita at primary, secondary and tertiary level; (2) life expectancy; and (3) effectiveness of legislature. Constant and time dummies are included but not reported for brevity. The numbers in parentheses are *t*-statistics and are based on robust standard errors.

* Indicates 10% level of significance.

** Indicates 5% level of significance.

*** Indicates 1% level of significance.

Table 3
TFP growth estimates based on years of skilled and unskilled education.

	All countries (87)			High income (28)			Middle income (37)			Low income (22)		
	IV 1(a)	CS 1(b)	BL 1(c)	IV 2(a)	CS 2(b)	BL 2(c)	IV 3(a)	CS 3(b)	BL 3(c)	IV 4(a)	CS 4(b)	BL 4(c)
$YUSK_{i,t-1}$	0.04**	0.05***	0.06***	−0.01	0.01	0.01	0.01	−0.01	0.01	0.11	−0.02	0.19
	(2.32)	(2.88)	(3.63)	(−0.14)	(0.42)	(1.00)	(0.73)	(−0.50)	(0.41)	(1.41)	(−0.21)	(1.02)
$YSK_{i,t-1}$	0.01	0.02	0.01	0.04**	0.02***	0.02*	0.10**	0.11*	0.13**	−0.18	3.47	0.88
	(0.40)	(0.75)	(1.11)	(2.58)	(3.00)	(1.71)	(2.62)	(2.04)	(2.15)	(−0.18)	(1.15)	(0.51)
$\ln(A_i/A^{US})_{t-1}$	−0.16**	−0.19***	−0.20***	−0.35*	−0.33*	−0.52**	−0.21**	−0.05	−0.26**	−0.31**	−0.36**	−0.39**
	(−2.61)	(−2.79)	(−3.06)	(−1.69)	(−1.73)	(−2.30)	(−2.44)	(−0.30)	(−2.10)	(−2.61)	(−2.36)	(−2.66)
$YUSK_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	−0.01	−0.01	0.02	−0.01	−0.01	0.02	−0.01	−0.04	0.01	0.04	−0.01	0.07
	(−0.35)	(−0.08)	(1.18)	(−0.51)	(−0.31)	(0.74)	(−0.67)	(−1.43)	(0.01)	(0.92)	(−0.06)	(0.80)
$YSK_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	0.03	0.03	0.01	0.14***	0.11***	0.05**	0.11**	0.17***	0.14**	−0.01	1.93	0.69
	(0.72)	(0.52)	(0.03)	(2.97)	(6.46)	(2.29)	(2.66)	(3.13)	(2.66)	(−0.01)	(1.23)	(0.73)
Hansen (*p*-val)	0.28	0.13	0.39	0.98	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99
Diff-in-Hansen (*p*-val)	0.35	0.41	0.32	0.94	0.99	0.93	0.96	0.99	0.98	0.99	0.99	0.99
AR(2) (*p*-val)	0.46	0.21	0.51	0.65	0.20	0.29	0.14	0.11	0.16	0.17	0.28	0.37

Notes: *YUSK* indicates years of unskilled educational attainment for the population aged 15 years and above whereas that of *YSK* indicates years of skilled educational attainment. Constant and control variables are included but not reported for brevity. See also notes to Table 2.

Table 4
TFP growth estimates based on sex-wise average years of educational attainment.

	All countries (87)		High income (28)		Middle income (37)		Low income (22)	
Gender	Male	Female	Male	Female	Male	Female	Male	Female
$YPRI_{i,t-1}$	0.07*	0.04*	0.05	0.07	0.01	0.01	0.07	0.21
	(1.93)	(1.82)	(1.37)	(1.59)	(0.69)	(0.22)	(1.01)	(1.64)
$YSEC_{i,t-1}$	0.06*	0.04*	−0.02	−0.03	0.01	0.01	0.31	0.04
	(1.70)	(1.68)	(−0.95)	(−1.50)	(0.43)	(0.09)	(1.32)	(0.08)
$YTER_{i,t-1}$	−0.28	−0.22	0.11*	0.13*	0.23**	0.35**	−2.65	−0.62
	(−1.28)	(−1.33)	(1.79)	(1.92)	(2.22)	(2.67)	(−1.02)	(−0.07)
$\ln(A_i/A^{US})_{t-1}$	−0.24**	−0.19***	−0.75*	−0.76*	−0.22***	−0.23***	−0.29**	−0.33***
	(−2.42)	(−3.35)	(−1.68)	(−1.82)	(−2.83)	(−3.62)	(−2.73)	(−4.59)
$YPRI_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	−0.01	0.01	0.08	0.13	0.01	0.01	0.02	0.09
	(−0.05)	(0.13)	(0.82)	(1.48)	(0.35)	(0.37)	(0.54)	(1.40)
$YSEC_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	0.09*	0.04	−0.02	−0.08	−0.02	−0.03	0.18	0.05
	(1.78)	(1.19)	(−0.61)	(−1.51)	(−0.84)	(−0.54)	(1.57)	(0.17)
$YTER_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	−0.34	−0.17	0.44**	0.43**	0.37***	0.42***	−1.55	−0.86
	(−1.55)	(−0.86)	(2.56)	(2.37)	(3.79)	(3.70)	(−1.08)	(−0.20)
Hansen (*p*-value)	0.35	0.16	0.98	0.99	0.98	0.99	0.99	0.99
Diff-in-Hansen (*p*-val)	0.28	0.44	0.98	0.99	0.99	0.99	0.99	0.99
AR(2) (*p*-value)	0.57	0.58	0.54	0.77	0.23	0.16	0.20	0.14

Notes: The estimates are based on the IV dataset. Constant and control variables are included but not reported for brevity. See also notes to Table 2.

between the data sets; however, the relativities between the educational groups are quite consistent among the data sets.[5] Finally, the standard deviation of tertiary education is very small in the low income countries, thus yielding low identifying variations in the data. Similarly, given that almost the entire labor force has had at least some primary education in the high income countries in the sample period, the identifying variations in these data will tend to bias the corresponding coefficient estimates towards zero.

4. Results

Table 2 presents the TFP growth estimates of Eq. (1). The system GMM estimates satisfy a battery of diagnostic checks, including the Hansen's and difference-in-Hansen's tests for instrument validity, the *F*-test for the joint significance of the coefficients, AR(1) and AR(2) tests for 1st order and 2nd order serial correlation, respectively, for both the full and subsamples. The *F*-test and AR(1) test results are not reported to conserve space. All equations perform very well on the basis of the diagnostic checks.

First, consider the results for the full sample (columns (1a) to (1c)). Primary and particularly secondary education influence growth positively. However, there is only a weak positive growth effect from tertiary education using the BL dataset. The coefficients of interaction between proximity to the frontier and the fraction of the population with different levels of educational attainment are insignificant in most cases. In all cases, technological proximity ($\ln(A/A^{US})$) is a significant determinant of productivity growth, supporting the evidence that there is productivity convergence independent of human capital. All the coefficients of inflation and some of those of FDI and landlockedness are significant and with their expected signs. The coefficients of trade openness and private credit over GDP, however, are consistently insignificant.

Turning to the results for high income and middle income countries, the estimates give some remarkable results (columns 2(a) to 2(c) and 3(a) to 3(c)). Tertiary education consistently has a significant positive effect on growth, whereas primary and secondary education are unimportant for growth. This result is important for two reasons. First, it explains why educational attainment, measured as the joint effects of primary, secondary and tertiary education, is an insignificant determinant of growth in a large body of the empirical literature – the insignificance of primary and secondary schooling overrides the positive growth effects of tertiary education.

Second, these results make intuitive sense. Growth can only be sustained if the labor force continues to invent higher quality products, makes more efficient use of the capital stock and finds new and more efficient methods of production. It is unlikely that individuals with only primary and secondary education are in a position to achieve these. The insignificance of primary and secondary education does not, of course, imply that individuals not educated beyond these levels do not enhance productivity. Here we are only testing whether educational attainment has permanent growth effects, not temporary ones that may well be positive for adults with primary and secondary education.

The coefficients of the interaction between the average years of tertiary education for population aged 15 years and above and proximity to the technology frontier are positive and significant but they are insignificant for the other educational groups. The overall growth effects of tertiary education depend on distance to the frontier for the high income countries. The closer a country is to the frontier the stronger are the growth enhancing effects from tertiary education. For a sufficiently backward country the interaction effects may outweigh the direct effects.

The results imply that adults with tertiary education are more important for growth in high income and middle income countries when they move closer to the technology frontier. In other words, the effect of proximity to the frontier on growth is less negative for countries with more highly skilled populations. Thus, advanced and semi-advanced economies are more likely to engage in innovating new technologies which require highly educated human capital. Overall the results for these two groups are consistent with the predictions of the VAM model.

For low income countries the effect of proximity to the frontier is found to be negative and highly significant, implying that countries that are further from the technology frontier will grow faster. Education, however, is unimportant for growth at any educational level. The coefficients of educational attainment and their interaction with the distance to the frontier are also insignificant at any educational category. Thus, education is not influential for growth for sufficiently poor countries. Although the educational attainment among the population above the age of 15 barely exceeds two years (see Table 1) for these countries, the impact and quality of teaching is likely to be low for these countries because teachers and students are often absent from the classroom and students' alertness is likely to be very low because of their extraordinarily high burden of tropical diseases such as malaria, parasitic worms, diarrhea and AIDS (Sachs, 2001).

Table 3 provides the estimates of Eq. (1) in which education is decomposed into skilled and unskilled. The skilled category of education (*YSK*) refers to the number of years of skilled education of the population that may facilitate the innovation of new technology, whereas the unskilled category (*YUSK*) indicates the number of years of unskilled

[5] Population aged 15 years and above is used here. The regression results are unaltered when population aged 25 and above, 15 to 64 or 25 to 64 is used instead.

education of the population which may facilitate the adoption of existing technology. On the whole, the results are fairly consistent with the baseline specification in Table 2. Specifically, skilled education has dual effects in promoting growth – direct and indirect – in both high and middle income countries. However, such effects are not found for low income countries. Moreover, the main results are also robust to the use of the third set of human capital composition variables (i.e., *PRI-SEC-TER*) where the fraction of the population having tertiary education has consistently been found to enhance growth directly and indirectly in both high and middle income countries (see Table A2 in Appendix A).

Next, consider the growth effects of different categories of educational attainment decomposed into gender groups (Table 4). The results for high and middle income countries are the same as previously. The productivity effects for educated men and women are almost the same for high income countries, although slightly larger effects of female tertiary education are found for middle income countries. For low income countries the growth effects of education remain insignificant.

5. Concluding remarks

Human capital is generally regarded as an important driver for economic growth, although the empirical evidence so far is mixed. Some argue that human capital should enter the production function as an input which thereby affects output directly while others argue that human capital contributes to higher technological progress by facilitating innovation, diffusion and adoption of new technologies and thus affects productivity growth indirectly. It is also plausible that different types and levels of human capital may have different effects on growth.

Considering that technological progress is a dual mechanism comprising innovation and imitation and that primary and secondary education are more suitable for imitation, whereas higher education is more appropriate for innovation, this study has investigated whether the contribution of human capital to productivity growth depends on the composition of human capital and proximity to the technology frontier in a panel of 87 sample countries over the period from 1970 to 2004. It used different levels of educational attainment based on several education datasets and also examined the effects of human capital composition on growth across gender.

The results show that the growth enhancing effects of tertiary education attainment or skilled human capital increase when high and medium income countries move closer to the technology frontier. In other words, those economies that concentrate more on innovation than imitation and thus invest more in higher education are able to accelerate TFP growth as their technological gap narrows. On the other hand, human capital is not contributing to growth in low income countries, suggesting that they neither innovate nor imitate. That human capital is unimportant for growth in developing countries is likely to reflect a low quality of teaching and that schools are badly resourced. The students are often absent, physically and mentally, from the classes due to a high burden of disease (Sachs, 2001). Finally, there is evidence of technology convergence independent of human capital in low income countries, implying that being far from the frontier allows one to experience faster TFP growth.

The findings of this study have some important policy implications for high, medium and low income countries. High and medium income countries – those that invest more in tertiary education – will continue to grow as they move closer to the frontier. These results support the model of Vandenbussche et al. (2006) in which growth is driven by innovations by highly educated people. Low income countries, by contrast, have only low growth prospects because growth is independent of educational attainment. Thus, the growth prospects in these countries are likely to remain low because the only source of growth is the distance to the technology frontier.

Acknowledgments

Helpful comments and suggestions from participants at the 38th Australasian Conference of Economists, 2009 Monash University HDR Workshop, and Asia-Pacific Week 2010 & South Asian Studies Summer School are gratefully acknowledged. Jakob B. Madsen acknowledges support from ARC Discovery grants from the Australian Research Council.

Appendix A

See Tables A1 and A2.

Table A1
TFP growth estimates based on alternative country classification.

	High Income (29)			Middle Income (29)			Low Income (29)		
	IV	CS	BL	IV	CS	BL	IV	CS	BL
	2(a)	2(b)	2(c)	3(a)	3(b)	3(c)	4(a)	4(b)	4(c)
$YPRI_{i,t-1}$	−0.01	0.12	−0.01	0.04	−0.05	−0.08	0.01	0.04	0.03
	(−0.10)	(1.22)	(−0.01)	(0.76)	(−0.48)	(−0.93)	(0.11)	(0.29)	(0.25)
$YSEC_{i,t-1}$	0.01	−0.04	−0.04	0.01	0.04	0.04	0.26	0.62	0.25
	(0.82)	(−1.26)	(−0.78)	(0.37)	(0.42)	(0.36)	(1.08)	(1.37)	(1.02)
$YTER_{i,t-1}$	0.14*	0.09*	0.17*	0.23**	0.42*	0.46*	−1.53	−4.83	−0.50
	(1.77)	(1.88)	(2.04)	(2.71)	(1.94)	(1.99)	(−1.16)	(−1.32)	(−0.32)
$\ln(A_i/A^{US})_{t-1}$	−0.19	−1.41*	−0.45	−0.37*	−0.03	−0.03	−0.19**	−0.25**	−0.29**
	(−0.51)	(−1.69)	(−0.61)	(−1.91)	(−0.11)	(−0.14)	(−2.58)	(−2.57)	(−2.57)
$YPRI_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	−0.08	0.23	0.09	0.03	−0.07	−0.09	0.01	0.02	0.02
	(−1.15)	(1.41)	(0.56)	(0.57)	(−0.69)	(−0.99)	(0.10)	(0.32)	(0.29)
$YSEC_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	0.06	−0.09	−0.12	−0.01	0.02	0.05	0.14	0.28	0.15
	(1.31)	(−1.58)	(−1.42)	(−0.38)	(0.17)	(0.45)	(1.07)	(1.09)	(1.05)
$YTER_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	0.52**	0.47**	0.34**	0.37***	0.66***	0.66**	−1.04	−2.40	−0.27
	(2.62)	(2.37)	(2.21)	(2.94)	(2.97)	(2.33)	(−1.17)	(−1.10)	(−0.23)
Hansen (*p*-val)	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Diff-in-Hansen (*p*-val)	0.98	0.96	0.98	0.96	0.99	0.99	0.99	0.99	0.99
AR(2) (*p*-val)	0.93	0.18	0.32	0.12	0.11	0.17	0.22	0.21	0.29

Notes: The total sample is divided into high income, middle income and low income countries of equal size according to the 2008 GDP per capita data, in constant 2005 international dollars, valued at PPP. Constant and control variables are included but not reported for brevity. See also notes to Table 2.

Table A2
TFP growth estimates based on the fraction of educational attainment.

	All countries (87)			High income (28)			Middle income (37)			Low income (22)		
	IV 1(a)	CS 1(b)	BL 1(c)	IV 2(a)	CS 2(b)	BL 2(c)	IV 3(a)	CS 3(b)	BL 3(c)	IV 4(a)	CS 4(b)	BL 4(c)
$PRI_{i,t-1}$	0.30**	0.23	0.24	0.27	−0.12	0.28	0.08	−0.20	−0.49	0.41	−2.60	−1.58
	(2.10)	(1.20)	(0.82)	(1.37)	(−0.68)	(0.64)	(0.72)	(−0.68)	(−0.94)	(0.44)	(−1.23)	(−1.21)
$SEC_{i,t-1}$	0.51***	0.57**	0.52***	0.19	−0.07	0.29	0.16	0.09	0.66	2.75	3.65	3.16
	(3.27)	(2.46)	(3.12)	(0.99)	(−0.26)	(1.23)	(1.19)	(0.13)	(0.91)	(1.25)	(0.27)	(1.35)
$TER_{i,t-1}$	−0.42	−0.23	0.74*	0.66**	0.18*	0.95**	1.10***	1.68*	3.01**	3.38	96.40	32.17
	(−0.83)	(−0.83)	(1.93)	(2.29)	(1.72)	(2.13)	(2.92)	(1.81)	(2.15)	(0.12)	(1.19)	(1.15)
$\ln(A_i/A^{US})_{t-1}$	−0.18***	−0.19***	−0.10*	−0.60*	−0.11	−0.68**	−0.23***	−0.18	−0.21***	−0.32**	−0.32**	−0.26***
	(−3.00)	(−2.67)	(−1.89)	(−1.74)	(−0.37)	(−2.48)	(−3.82)	(−1.50)	(−2.86)	(−2.79)	(−2.89)	(−4.00)
$PRI_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	0.08	0.14	−0.32	0.33	−0.35	0.48	0.06	−0.15	−0.52	0.24	−1.08	−0.70
	(0.77)	(0.81)	(−0.73)	(0.74)	(−0.83)	(0.55)	(0.53)	(−0.54)	(−1.12)	(0.52)	(−0.99)	(−1.13)
$SEC_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	0.18	0.21	0.04	0.17	−0.44	0.64	−0.07	−0.10	0.38	1.54	1.29	1.79
	(1.27)	(0.89)	(0.15)	(0.49)	(−0.66)	(1.34)	(−0.73)	(−0.16)	(0.64)	(1.36)	(0.21)	(1.41)
$TER_{i,t-1} \times \ln(A_i/A^{US})_{t-1}$	−0.49	−0.01	0.67	2.05**	1.60**	2.22**	1.37***	2.42***	3.62**	−2.03	53.14	16.36
	(−0.86)	(−0.01)	(1.29)	(2.68)	(2.72)	(2.68)	(3.83)	(3.38)	(2.39)	(−0.14)	(1.32)	(1.00)
Hansen (*p*-val)	0.29	0.30	0.23	0.98	0.99	0.99	0.85	0.99	0.99	0.99	0.99	0.99
Diff-in-Hansen (*p*)	0.40	0.33	0.42	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
AR(2) (*p*-val)	0.44	0.32	0.28	0.58	0.27	0.85	0.22	0.11	0.13	0.24	0.42	0.63

Notes: *PRI*, *SEC* and *TER* indicate fraction of the population aged 15 years and above having studied primary, secondary and tertiary levels of education, respectively. Constant and control variables are included but not reported for brevity. See also notes to Table 2.

References

Acemoglu, D., 1996. A microfoundation for social increasing returns in human capital accumulation. Quarterly Journal of Economics 111, 779–804.
Acemoglu, D., Aghion, P., Zilibotti, F., 2002. Distance to frontier, selection, and economic growth. Journal of the European Economic Association 4, 37–74.
Acemoglu, D., Johnson, S., 2007. Disease and development: the effect of life expectancy on economic growth. Journal of Political Economy 115, 925–985.
Aghion, P., Boustan, L., Hoxby, C., Vandenbussche, J., 2007. Exploiting States' Mistakes to Identify the Causal Impact of Higher Education on Growth. Harvard University, mimeo.
Aghion, P., Boustan, L., Hoxby, C., Vandenbussche, J., 2009. The Causal Impact of Education on Economic Growth: Evidence from US. Harvard University, mimeo.
Aghion, P., Howitt, P., 1992. A model of growth through creative destruction. Econometrica 60, 323–351.
Aghion, P., Howitt, P., 1998. Endogenous Growth Theory. MIT Press, Cambridge.
Barro, R.J., Lee, J.W., 2001. International data on educational attainment: updates and implications. Oxford Economic Papers 53, 541–563.
Baum, C.F., Schaffer, M.E., Stillman, S., 2003. Instrumental variables and GMM: estimation and testing. The Stata Journal 3, 1–31.
Benhabib, J., Spiegel, M.M., 2005. Human capital and technology diffusion. In: Aghion, P., Durlauf, S. (Eds.), Handbook of Economic Growth. Elsevier, Amsterdam, pp. 935–966.
Bond, S.R., Hoeffler, A., Temple, J., 2001. GMM Estimation of Empirical Growth Models. Centre for Economic Policy Research Discussion Paper No. 3048.
Caselli, F., Coleman, W.J., 2006. The world technology frontier. American Economic Review 96, 499–522.
Caselli, F., Esquivel, G., Lefort, F., 1996. Reopening the convergence debate: a new look at cross-country empirics. Journal of Economic Growth 1, 363–389.
Cohen, D., Soto, M., 2007. Growth and human capital: good data, good results. Journal of Economic Growth 12, 51–76.
de la Fuente, A., Doménech, R., 2006. Human capital in growth regressions: how much difference does data quality make? Journal of the European Economic Association 4, 1–36.
Durlauf, S., Johnson, P., Temple, J., 2005. Growth Econometrics. In: Aghion, P., Durlauf, S. (Eds.), Handbook of Economic Growth. North-Holland, Amsterdam, pp. 555–677.
Gerschenkron, A., 1962. Economic Backwardness in Historical Perspective. Belknap Press of Harvard University Press, Cambridge.
Griffith, R., Redding, S., Reenen, Jv., 2004. Mapping the two faces of R&D: productivity growth in a panel of OECD industries. Review of Economics and Statistics 86, 883–895.
Islam, N., 1995. Growth empirics: a panel data approach. Quarterly Journal of Economics 110, 1127–1170.
Kneller, R., Stevens, P.A., 2006. Frontier technology and absorptive capacity: evidence from OECD manufacturing industries. Oxford Bulletin of Economics and Statistics 68, 1–21.
Knowles, S., Owen, P.D., 1995. Health capital and cross-country variation in income per capita in Mankiw–Romer–Weil model. Economics Letters 48, 99–106.
Krueger, A.B., Lindahl, M., 2001. Education for growth: why and for whom? Journal of Economic Literature 39, 1101–1136.
Lutz, W., Goujon, A., Samir, K.C., Sanderson, W., 2007. Reconstruction of populations by age, sex and level of educational attainment for 120 countries for 1970–2000. Vienna Yearbook of Population Research 2007 8, 193–235.
Madsen, J.B., Islam, M.R., Ang, J.B., 2010. Catching up to the technology frontier: the dichotomy between Innovation and Imitation. Canadian Journal of Economics 43, 1389–1411.
Mankiw, G., Romer, D., Weil, D.N., 1992. A contribution to the empirics of economic growth. Quarterly Journal of Economics 107, 407–437.
Nelson, R.R., Phelps, E.S., 1966. Investment in humans, technological diffusion, and economic growth. American Economic Review 56, 69–75.
Pritchett, L., 2001. Where has all the education gone? The World Bank Economic Review 15, 367–391.
Radelet, S., Sachs, J., Lee, J.-W., 2001. The determinants and prospects of economic growth in Asia. International Economic Journal 15, 1–29.
Romer, P.M., 1990. Endogenous technological change. Journal of Political Economy 98, S71–S102.
Sachs, J., 2001. Tropical Underdevelopment. NBER Working Paper No. 8119.
Vandenbussche, J., Aghion, P., Meghir, C., 2006. Growth, distance to frontier and composition of human capital. Journal of Economic Growth 11, 97–127.