Journal of Economic Cooperation and Development, **38**, 4 (2017), 123-154

Nonlinear Effects of Human Capital on TFP: Evidence from Eight ASEAN Countries

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The purpose of this paper is to investigate the nonlinear relationship between TFP growth rate and human capital in 8 ASEAN countries over the period from 1990 to 2014. Using two-way fixed-effect Benhabib-Spiegel model, this study finds that human capital, denoting the innovation term, is negatively related with TFP growth rate. Meanwhile, the catch-up term, denoted by the interaction between human capital and the technology gap, has a positive effect on TFP growth rate. This study further uses threshold-seeking procedure proposed by Hansen (1999) and finds that there are two thresholds in the innovation term and a single threshold in the catch-up term, i.e. in terms of human capital.

1. Introduction

Since 1960, East Asian countries and regions such as Hong Kong, Singapore and Taiwan have experienced a huge growth; while other countries of South East Asian had also shown a persistent growth (Park, 2012). Meanwhile, Park (2012) indicated that the 12 Asian countries' national incomes were 12% of the world's total in 1995 and 20% in 2006. Besides, according to the World Bank's World Development Indicator (WDI, 2013), during the period from 1981 to 2011, the average growth rate of five Asian countries (Indonesia, Malaysia, Philippines,

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Thailand, Vietnam) was 5.379%; much more than that of OECD countries during the corresponding period. Prior to this, the so-called "Asia's Miracle" took the Western world by surprise; but later suffered from many incredulous attitudes mainly owing to the input-driven growth and the over-planned market. In fact, as for "Asia's Miracle", Krugman (1994) emphasized that the sustainable economic growth should be sourced from the progress of total factor productivity rather than the input-driven growth.

Nelson and Phelps (1966) theoretically indicated that the growth rate of total factor productivity (hereafter written as TFP) mainly relies on implications of domestic innovation and imitation from the technological frontier. For developing countries, the speed of convergence to the technological frontier is actually a catch-up process which heavily depends upon the level of human capital. Based on the endogenous growth model led by Romer (1986) and Lucas (1988), studies concerning the effect of human capital upon economic growth are continuously undertaken. Human capital, as an important carrier of knowledge and technology progress, does not only play a crucial role in impelling the economic growth but is considered as the leading force to aiding developing countries in catching up with developed countries. In the neoclassical growth theory, human capital is regarded as a factor input incorporated into the production function. Naturally, the existence of the relationship between economic growth and human capital is quite understandable. The alternative thought, instead of seeing human capital as a factor input, there is a notion that human capital mainly contributes to economic growth through two channels (Aghion and Howitt, 1990; Benhabib and Spiegel, 1994). The first is that human capital decides the level of capacity of technological innovation (Romer, 1990), and the second one is about technology diffusion (Nelson and Phelps, 1966). Both the mentioned channels worked through the technological transmission mechanism.

However, empirical evidences indicate that human capital does not significantly affect growth, even though theoretically it is quite clear

(Sunde and Vischer, 2011; Zaman, 2012). Generally, there are two types of testing results. The first one indicates a weak relationship between human capital and economic growth (Benhabib and Spiegel, 1994; Vandenbussche, 2006; Zaman, 2012; Delpachitra and Dai, 2012; Stöllinger, 2013); and the second one proves a positive relationship between the two (Mankiw et al., 1992; Bowlus et al., 2005; Krammer, 2008; Emmanuel et al., 2014). Similar to the empirical results that contradict the theoretical expectation in the relationship between human capital and economic growth, the effect of human capital upon TFP growth rate does not empirically meet the theory either. For example, Miller and Upadhyay (2002), Kumar and Kober (2012) and Danquah and Ouattara (2014) found no association between human capital and TFP growth.

In light of inconclusive empirical evidences, this study attempts to contribute to the existing literature in the following aspects. First and foremost, this study attempts to contribute to the existing literature of measuring TFP growth rate for ASEAN countries by using a newly extended growth-accounting method proposed by Feenstra, et al. (2013) and Inklaar and Timmer (2013). This method, compares the information across countries (Inklaar and Diewert, 2016), and does not impose a production function (e.g. the Cobb-Douglas function). Second, the benchmark model in this study is based on the Logistic technology diffusion model put forward by Benhabib and Spiegel (2005). Unlike the widely used confined exponential model proposed by Benhabib and Spiegel (1994), which is identifying absolute technology convergence to the technological frontier, the former would allow the occurrence of absolute divergence within technological followers under a certain condition, which better fits the reality. Third, literature seldom investigates the effects of human capital upon TFP growth rate using the panel threshold estimation proposed by Hansen (1999) for ASEAN countries. If the level of human capital meets a certain requirement in achieving sufficient technology diffusion, the pulling effects sourced from leader countries would be effective (Benhabib and Spiegel, 2005). Otherwise, the gap between the leader and the followers would not be narrowed; meaning that the follower countries could not catch up with the leader countries, and therefore, club convergence would ultimately emerged. The study will give the influences of different intervals in terms of innovation term denoted by human capital and the catch-up term split by the threshold(s) found on the growth rate of TFP. Therefore, not only does this study fills in the void in the literature but also systematically analyzes nonlinear-type effects of the human capital on the TFP growth for ASEAN countries.

This paper is organized as follows. Section 2 presents the literature review. Section 3 introduces the theoretical framework, relative model specifications. Section 4 displays empirical findings, and section 5 concludes.

2. Literature Review

Nelson and Phelps (1966) proposed a hypothesis of technology-driven growth that posits education will generate a positive effect when technology keeps on progressing. This hypothesis has two parts. First, the growth in the current technology frontier represents the pace of technological advances. TFP growth rate of a nation would depend on the implications of those technological advances and the distance between the current technology level and the frontier. The second part of the hypothesis indicates that the speed of convergence to the technology frontier is determined by the human capital level. In the framework of Nelson-Phelps technological diffusion, Benhabib and Spiegel (1994) generalized the catch-up model by incorporating the idea of Romer (1990), which assumes that human capital takes charge in the determinate role of the technology innovation; and thereby directly affecting TFP growth rate. Benhabib and Spiegel (1994) indicated that absolute convergence would exist in the TFP growth across different economies; and even though different countries hold their own economic characteristics such as initial human capital level and technological level, technology diffusion would help the following countries to catch up with the advanced technology frontier at balanced growth path. However, Basu and Well (1998) argued that absolute convergence for those followers may not be valid, for advances in technology cannot be applied immediately when the technological gap between the follower and the leader is overlarge. Thus, Benhabib and Spiegel (2005) proposed the logistic exponential technology diffusion model which allows the possibility of club convergence.

Serranito (2014) applied TFP growth rate from the PWT 8.0 to examine multiple effects sourced from the human capital by using logistic diffusion model for African and Middle-East countries from 1970 to 2010. Using the generalized method of moments (hereafter written as GMM) panel estimation, the author found that; firstly, the interacting variables (human capital and technology gap) representing the catch-up term negatively influenced TFP growth rate; hence, supporting the convergence hypothesis. Second, the human capital is positively associated with the growth rate of TFP. In addition, following the idea of Aghion et al. (2005) the author incorporated technology gap into the model and proved that absolute convergence does not exist in those countries of low technological level.

Cheng et al. (2013) also made use of the TFP growth rate from the PWT 7.0 and logistic diffusion model to examine the importance of human capital to technology growth for 16 Asian countries over the period of 1970 to 2009. Through the random effect model, the findings showed that the catch-up term is expected to negatively correlate with TFP growth rate; but unexpectedly, the human capital has a negative and significant effect upon the growth rate of TFP. Furthermore, the authors took into account the composition of human capital and individually examined both the relationships between educational attainments (primary, secondary and tertiary level) and the corresponding catch-up terms and TFP growth rate. The results showed that the biggest effect of the innovation term is from the tertiary education, and that of the catch-up term from the secondary education. Madsen et al. (2010) also emphasized on the importance of technology imitation for developing countries by using the confined exponential technology diffusion model.

Similar to the estimation results of the innovative capacity in the paper of Cheng et al. (2013), Madsen et al. (2010) gave no positive evidence in regard to the effect of technology innovation on TFP growth rate for developing countries.

Di Liberto et al. (2011) regressed the Mankiw et al.'s (1992) model with the consideration of Islam (1995) by using methods such as least square dummy variable model (LSDV), as well as Kiviet-corrected LSDV and GMM for robustness. They also examined the existence of technology convergence through the utilization of logistic model for 76 countries from 1960 to 2003. The empirical findings indicated that there was no TFP convergence to the leader country (the U.S.) for the majority of countries all around the world. In addition, the hypothesis of positive effects sourced from a certain level of human capital was not empirically supported. The authors mentioned that one possible explanation for the both results is that the TFP leader (the U.S.) is distancing itself away from the followers. Sawada et al. (2012) also examined technology convergence worldwide using logistic diffusion model. The difference is that Sawada et al. (2012) supported the existence of technology catch-up for the majority of a sample of 85 countries. It is worth noting that they did not only take the human capital as the medium interacting with the technology gap but also considered foreign direct investment (hereafter written as FDI), external trade and technology cooperation aid.

Stöllinger (2013) examined how technology innovation and imitation function in the production function by using a panel of 76 nations over the period from 1980 to 2009. The author obtained the TFP level by the means of Cobb-Douglas growth function in the tradition of Hall and Jones (1999), and the innovation term was represented by the ratio of gross expenditure on R&D over the aggregate output. Except for expected effects generated by the variables like physical capital and labor force, the interests of this paper were not satisfied. The innovation term was negative and insignificant in 4 of 5 specifications and the catch-up term was positive; which means all countries will fall into the technology convergence club. Also, Stöllinger (2013) found the existence of non-linearity effect in the catch-up term by using the panel threshold estimation proposed by Hansen (1999); and thereby dividing different regimes of human capital and expected influences on economic growth.

3. Methodology

3.1 Model Specification

To investigate the relationship between TFP growth and human capital, this study will firstly follow the Benhabib and Spiegel's (2005) logistic technology diffusion to examine the existence of the catch-up effect (technology diffusion) . Meanwhile, as human capital is the main channel to TFP growth, the effect of the innovation term in 8 ASEAN countries is another interest in this study. Thus, the model in this study will be briefly discussed as below:

$$\Delta logA_{it} = \beta_1 H_{it} - \beta_2 H_{it}\left(1 - \frac{A_{it}}{A_{mt}}\right) + \boldsymbol{\Gamma X}'_{it} + \delta_t + \eta_i + \varepsilon_{it} \quad (1)$$

where, the term of $\Delta logA_{it}$ denotes the TFP growth rate in the i^{th} country respectively at the t^{th} period. H_{it} is human capital denoting the innovation term, and its interaction term, $H_{it}\left(1 - \frac{A_{it}}{A_{mt}}\right)$, represents the catch-up term. Then, the variable vector contains relative control variables, denoted as $\boldsymbol{X}'_{i,t}$. Correspondingly, $\boldsymbol{\Gamma}$ is a vector of coefficients of control variables. In addition, as the panel model is considered, δ_t and η_i are fixed effects in terms of years and countries.

When the human capital reaches a specific level, it will make the catch-up effect work for the following countries within the process of technology diffusion. Unlike the traditional way of building up the threshold value such as exogenously separating samples into different regimes by means of subjective consideration (Borensztein et al., 1998) and the group-specific dummies (Xu, 2000); endogenously estimating the threshold value in the basis of Hansen (1999) will be much more reliable statistically (Fu and Li, 2009). Thus, by using the threshold seeking procedures proposed by Hansen (1999), the human capital level will be divided into several regimes; and thereby generating the non-linear catch-up effects when the technology gap is multiplied with different human capital regimes. The threshold regression model for panel data will be expressed as follows (taking an example of the single threshold model):

$$\Delta logA_{it} = \beta_1 H_{it} + \Phi_1 I(H_{it} \leq \gamma)\left(1 - \frac{A_{it}}{A_{mt}}\right) + \Phi_2 I(H_{it} > \gamma)\left(1 - \frac{A_{it}}{A_{mt}}\right)$$

$$+\boldsymbol{\Gamma X}'_{it} + \delta_t + \eta_i + \varepsilon_{it} \qquad (2)$$

$$\Delta logA_{it} = \Psi_1 H_{it} \mathrm{I}(\mathrm{q}_{it} \leq \gamma) + \Psi_2 H_{it} \mathrm{I}(\mathrm{q}_{it} \leq \gamma) - \beta_2 H_{it}\left(1 - \frac{A_{it}}{A_{mt}}\right)$$

$$+\boldsymbol{\Gamma X}'_{it} + \delta_t + \eta_i + \varepsilon_{it} \qquad (3)$$

where, $I(\cdot)$ is the indicator function in both equations and the term γ in the bracket of the indicator function is the threshold value of the selected variable. In the Eq. (2), given that there is a single threshold being found, the technology gap will be splitting into two groups in accordance with the threshold of human capital. Similar to Eq. 2, the Eq. (3) particularly concentrates on the innovation term affecting the mechanism of TFP growth in the framework of the threshold regression in terms of human capital itself.

3.2 Variable Selection and Calculation

3.2.1 Dependent Variable: TFP Growth Rate Measurement

The representation of TFP growth rate is given by the left side of Eq. (2),

$\Delta log A_{it}$. The following algebraic identities are given by:

$$\frac{A_i(t)}{A_i(t)} = \frac{dlogA_i(t)}{dt} = \frac{A_i(t+1) - A_i(t)}{A_i(t)} = \frac{A_i(t+1)}{A_i(t)} - 1$$

TFP growth rate is an interest to this study. Its measurement will partly be used to measure the TFP level across countries or over time in PWT 8.1. Obviously, algebraic identities show that the TFP level, $\frac{A_i(t+1)}{A_i(t)}$, is the focal point. According to Inklaar and Timmer (2013) and Feenstra et al., (2013), firstly, the TFP level is defined as:

$$\frac{TFP_{jt}}{TFP_{jt-1}} = \frac{GDP_{jt}}{GDP_{jt-1}} / Q_{j,t,t-1} \quad (4)$$

where, $\frac{TFP_{jt}}{TFP_{jt-1}}$, the TFP level is obtained by calculating the combination of inputs in real terms such as real gross domestic product (hereafter written as GDP) and real capital stock at constant national price (2005 = 1) over observed periods. More importantly, $Q_{j,t,t-1}$ is the Törnqvist index of factor endowments, which is given by:

$$Q_{j,t,t-1} = \frac{1}{2}(\alpha_t + \alpha_{t-1}) \left(\frac{L_{jt}}{L_{jt-1}} \frac{H_{jt}}{H_{jt-1}}\right) + [1 - \frac{1}{2}(\alpha_t + \alpha_{t-1}) \left(\frac{K_{jt}}{K_{jt-1}}\right)] \quad (5)$$

where, L_{jt}, H_{jt} and K_{jt} are respectively representing the number of employed labor, human capital and real capital stock. All elements, except for the labor share, α_t or α_{t-1}, where its data may not be available for every country, could be easily found in the many databases.

No matter which method of measuring TFP growth rate or level is taken into account, to approximate capital stock will be a common prerequisite.

With no doubt, the widely-used perpetual inventory method (hereafter written in PIM) makes efforts to estimate the capital stock with depreciation rates varying across countries and over time. Basically, the formula of the PIM will be given by:

$$K_t = (1 - \delta_t)K_{t-1} + I_t \tag{6}$$

where capital stock depends upon three components, namely, δ_t, the depreciation rate, K_{t-1}, the capital stock at previous period, and I_t, the investment is usually measured by the gross capital formation. Even though PWT 8.1 also provides the series of real capital stock over time or across countries from 1950 to 2011, it is not appropriate for this study in terms of capital stock measurement for the researching period of this study which ranges from 1990 to 2014. In addition, initial capital stock, which plays a crucial role in estimating the rest of capital stock, would be totally different from the one used in existing data in PWT 8.1. Meanwhile, PWT 8.1 uses the initial capital/output ratio to calculate the initial capital stock (like Eq. 8). This study follows the way proposed by Harberger (1978), i.e. approximating the initial capital stock by considering the sum of the investment growth rate at the balanced-growth path and the depreciation rate as the denominator (like Eq. 7).

$$K_0 = \frac{I_0}{g+\delta} \tag{7}$$

$$K_0 = Y_0 \times k \tag{8}$$

After obtaining capital stock using the method described above, together with other elements, Törnqvist index of factor endowments, $Q_{j,t,t-1}$, can be calculated.

3.3.2 Independent Variable: Catch-up term Measurement

The catch-up term in the model is denoted by the interaction of human capital and the technology gap, $H_{it}\left(1 - \frac{A_{it}}{A_{mt}}\right)$. Apparently, the term $\frac{A_{it}}{A_{mt}}$

is represented by the ratio of TFP level of technological followers over that of the leader country. Thus, comparable information across countries in terms of output, inputs as well as corresponding price data is very important in obtaining accurate technology gap. This study will carry out method similar to the TFP measurement mentioned in previous subsection. The core function is given by:

$$\frac{TFP_{it}}{TFP_{USAt}} = \frac{GDP_{it}}{GDP_{USAt}} / Q_{iUSAt} \tag{9}$$

where the difference between Eqs. 4 and 9 is that the dominator in Eq. 9 becomes the U.S instead of one-period-lagged follower countries themselves in Eq. 4. In view that technology gap does only measure the technological distance to the frontier, the price effects upon the sequences of GDP are not taken into account. Meanwhile, Törnqvist index of factor endowments, Q_{iUSAt}, will be expressed as:

$$Q_{iUSAt} = \frac{1}{2}(\alpha_{it} + \alpha_{USAt})\left(\frac{L_{it}}{L_{USAt}} \frac{H_{it}}{H_{USAt}}\right) + [1 - \frac{1}{2}(\alpha_{it} + \alpha_{USAt})\left(\frac{K_{it}}{K_{USAt}}\right)] \tag{10}$$

With regard to capital stock, it will be obtained through the PIM approach, following the way proposed by Harberger (1978) to deal with the initial capital stock as mentioned above. Then, by simply multiplying human capital with the difference between 1 and the technology gap, the catch-up term is obtained.

3.4. Data Description

The appropriate measurement of human capital can be bewildering. This is because biasness probably caused by the way of estimating the human capital is considerably influential to the whole investigation (Wößmann, 2003); which would be more serious when considering that "human capital is generally poorly proxied" (Teixeira & Fortuna 2010). By now, it is still premature to conclude on the standard measurement for human capital. There are many proxies for human capital, such as school enrolment rates, educational attainment, adult literacy rates and international test scores and so on (Teixeira 2005). Due to data availability, school enrolment and adult literacy rates have also been widely entered into the production growth model. However, Teixeira & Fortuna (2010) indicated that these two proxies are not suitable to be the measure of human capital stock for they are flow indicators. The last one (international test score) is limited to its availability and coverage for countries. Education, which usually takes charge on the important role of human capital formation both in “specific” and “general” points of view, is extensively being used as the measure of human capital. However, educational attainment is criticized for of its ignorance of quality (Wößmann, 2003). This study uses educational attainment from Barro & Lee (2013) database as a proxy of human capital. This is because it overcomes measurement error to some extent and takes into account the issue of the homogenous mortality rate, as criticized by Cohen & Soto (2007) compared with the Barro & Lee's (1993) data.

Data for other parameters estimation and model specification are mainly sourced from two databases, namely PWT 8.1 and the WDI 2016. The labor share, α_t, and the depreciation rate, δ_t, were collected from PWT 8.1. Both are time- and country- specific. However, this variation in labor share is not available for Cambodia, Laos and Vietnam. The assumptions of the labor share value within existing literature are based upon the considerations to the country’s circumstances (Kim and Lau, 1994; Harrison, 1996; Delpachitra and Pham Van Dai, 2012). According to Delpachitra and Dai’s (2012) assumptions for selected ASEAN country, the labor shares for these three countries are assumed to be 0.6. Except for FDI, other variables, such as the labor force, urbanization, openness in trade, real GDP per capita as well as gross capital formation and so on, are all sourced from WDI 2016. FDI is an exception because its data are unavailable for some countries over the entire observed periods. FDI inward stock collected from World Investment Report 2016 is used as a proxy for FDI. Table 1 presents definitions, the way of calculation as well as descriptive summaries for all variables.

Table 1: Descriptive statistics

Variable	Definition	Calculation	N	Mean	St.d
TFP	TFP Growth rate	a newly extended growth-accounting method developed by Feenstra, et al., (2013)	192	-0.003	0.03
HC	Education attainment	Data from Barro-Lee, (2010) dataset	192	6.258	2.18
Pri	Primary education	Percentage of population with primary education from Barro-Lee, (2010)	192	41.729	14.86
Sec	Secondary education	Percentage of population with secondary education from Barro-Lee, (2010)	192	29.172	14.17
Ter	tertiary education	Percentage of population with secondary education from Barro-Lee, (2010)	192	10.073	9.29
Catch-up	Technology gap with HC	$H_{it}\left(1-\frac{A_{it}}{A_{mt}}\right)$	192	2.240	2.60
Catch-up (primary)	Technology gap with Primary education	$pri_{it}\left(1-\frac{A_{it}}{A_{mt}}\right)$	192	21.348	17.38
Catch-up (secondary)	Technology gap with secondary education	$sec_{it}\left(1-\frac{A_{it}}{A_{mt}}\right)$	192	10.044	13.21
Catch-up (tertiary)	Technology gap with secondary education	$ter_{it}\left(1-\frac{A_{it}}{A_{mt}}\right)$	192	2.799	6.32
Gov	Government expenditure	the share of government consumption in real PPP-GDP	192	0.089	0.03
Openness	Openness in trade	the sum of exports and imports in real PPP-GDP	192	1.351	0.91
Ur	Urbanization	the share of non-rural population in total population	192	0.450	0.25
FDI	FDI inward stock	the share of inward FDI stock in real PPP-GDP	192	0.502	0.59

4 Empirical Finding

4.1 Two-way Fixed-Effect Estimation

Table 2: Panel estimation of the growth effect of Human Capital and its composition

VARIABLES	**Panel model (1)**	**(2)**	**(3)**	**(4)**
HC	-0.0141***			
	(0.005)			
Catch-up	0.0191***			
	(0.004)			
Primary education		0.0005		
		(0.000)		
Catch-up(primary)		-0.0001		
		(0.000)		
VARIABLES	**Panel model (1)**	**(2)**	**(3)**	**(4)**
Secondary education			-0.00193**	
			(0.001)	
Catch-up(secondary)			0.0029***	
			(0.001)	
Tertiary education				0.0011
				(0.001)
Catch-up(tertiary)				0.0045***
				(0.002)
Government expenditure	0.121	0.0332	0.0862	0.138
	(0.131)	(0.122)	(0.126)	(0.152)
Openness	-0.0004	0.0103	0.0013	0.0191**
	(0.008)	(0.009)	(0.009)	(0.008)
Urbanization	-0.0775	-0.119*	-0.0910	-0.1622**
	(0.079)	(0.067)	(0.070)	(0.081)
FDI	0.0219***	-0.00586	-0.0047	-0.0053
	(0.008)	(0.007)	(0.007)	(0.0106)
Constant	1.043***	1.011***	1.044***	1.013***
	(0.026)	(0.030)	(0.027)	(0.025)
Country dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Hausman	67.8***	19.09***	31.58***	43.41***
Observations	192	192	192	192
R-squared	0.556	0.483	0.511	0.518
Number of id	8	8	8	8
F	6.689	4.998	5.590	5.734

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2 reports the results of panel estimation. Significant Hausman statistics support the choice of panel regression with two-way fixed effects. The first column shows the results using a model with innovation term denoted by the human capital, the catch-up term, as well as other control variables. Human capital is found to be negatively and significantly associated with TFP growth rate. This is in line with results of Cheng et al.'s (2013) study in that human capital negatively affects the TFP growth rate in a panel of 16 Asian countries, and the Stöllinger's (2013) work which took human capital as the innovation term in the same way and found the negative relationship of it with economic growth. As mentioned in the introductory section of this paper, the importance of human capital to TFP growth rate is obvious for it is highly related with knowledge or technology which is being repeatedly involved in many economic growth theories. Indeed, negative relationship between human capital and TFP growth is confusing. Human capital is further proxied by a ratio of population aged 25 and over with a certain educational level. From column 2 to 4, there are three educational levels, namely primary, secondary and tertiary education, independently and separately entering the estimation. Secondary education gives rise to the downside to the TFP growth rate, whereas primary and tertiary educations cannot provide significant positive effects. Thus, this may be a cause of why the estimates of human capital went against the expectation and be an indication of the existence of nonlinearity in human capital.

The catch-up term is another interest of this study. The estimates in all columns are as expected. The panel model (1) yields a positive coefficient for the catch-up term. More specifically, given the distance of follower country to the technology frontier, an increase in human capital level raises absorptive capacity; and therefore, boosts the TFP growth. The result of the catch-up term in column 2 of Table 3 favors Benhabib & Spiegel's (2005) study in which they pointed that if human capital is too low to make the catch-up process occur. As an indicator of low human capital level, primary education interacting with the objective technology gap has no response to TFP growth rate. In addition, the technology gap which individually multiplied with secondary and tertiary education significantly activates the catch-up process in TFP growth rate. Besides, the latter generates more effects than the former.

Data limitation causes only four control variables to enter into the panel models. As main channels of transferring advanced technologies, openness and FDI are quite important for they effectively bridge the domestic market with external development; and therefore, are more likely to absorb advances by means of capital transferring, managerial training or competition in commodity selling. However, the first column (Panel model (1)) shows different situations in which FDI is positively associated with TFP growth; and the coefficient of openness, even though it is not significant, has a negative sign. Positive association of FDI with TFP growth rate is in line with most literature, especially Piyaareekul's (2008) study for five ASEAN countries. The finding of no impact of openness on TFP growth rate is similar to what Mahmood and Talat (2008) found in a panel of five East Asian countries including three ASEAN countries namely, Indonesia, Malaysia and Thailand; contradicting the common belief. In general, although human capital, as a proxy of innovation term, is found to be negatively associating with TFP growth rate, the results of its composition unveiled that this negative relationship is not linear and may not represent the real situation across ASEAN countries. Thus, using panel threshold regressions to examine the nonlinearity of human capital is necessary.

4.2. Panel Threshold Estimation

4.2.1 Threshold(s) in human capital for innovation term

It has been shown that innovation term generates inconsistent effects upon TFP growth rate when percentages of population with different educational levels are used to proxy different levels of human capital. Meanwhile, although human capital is often observed to weakly or insignificantly affecting the economic growth regression and the TFP growth model, the empirical finding which contradicts theoretical expectation is possible. This is because these positive effects generated by one part of human capital are counteracted/overwhelmed by the other part. Thus, the purpose of this section is to find empirical evidence of the regime of innovation term that boosts TFP growth rate. Table 3 gives the result of the number of thresholds in terms of human capital. According to bootstrap p-values, corresponding statistics, F_1, F_2 and F_3, will suggest the number of thresholds. Tests for the single threshold F_1 and the double threshold F_2 are strongly significant, with bootstrap p-values of 0.019 and 0.020 respectively. Although the test for statistics F_3 shows possibility of the existence of a triple threshold model, the point estimates of the plot of $LR_3(\gamma)$ (Figure 1. (c)), the concentrated likelihood ratio function, are all below the dotted line, which means the statistic F_3 is invalid. On the other hand, the plots of $LR_1^r(\gamma)$ and $LR_2^r(\gamma)$ in Figures 1 (a) and (b) individually showed the valid value of ratio hitting the zero axis.

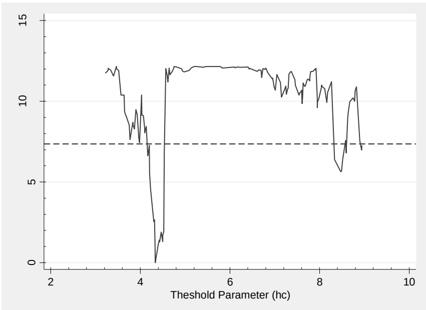
Table 3: Tests for threshold effects

Test for single threshold	
F_1	12.501**
P-value	0.019
(1%, 5%, 10% critical values)	(14.241, 8.946, 6.482)
Test for double threshold	
F_2	13.250**
P-value	0.020
(1%, 5%, 10% critical values)	(14.236, 8.874, 6.412)
Test for triple threshold	
F_3	4.881*
P-value	0.089
(1%, 5%, 10% critical values)	(10.246, 6.262, 4.574)

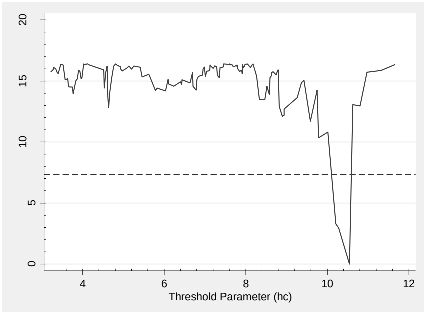
Note: 1. 1000 bootstrap replications were used for each of the three bootstrap tests.

2. *** p<0.01, ** p<0.05, * p<0.1

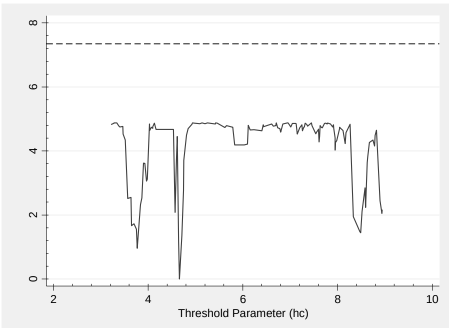
Figure 1: Likelihood ratio of the threshold/thresholds



(a)



(b)



(c)

Table 4 gives two threshold estimates and their own asymptotic 95% confidence interval. Since educational attainment is a proxy of innovation term, the first threshold estimate is 4.336 years of schooling and the second is 10.542 years of schooling. Thus, the three regimes separated by these point estimates are 'low human capital', 'medium human capital' and 'high human capital'.

Table 4: Threshold estimates

	Estimate		**95% confidence interval**
$\hat{\gamma}^1$	4.336		[4.164, 8.942]
$\hat{\gamma}^2$	10.542		[10.208, 10.542]

The three regimes of human capital were entered into the threshold panel regression. Table 5 displays the coefficient of each split of human capital by using the two-way fixed-effect threshold procedure developed by Lian et al. (2006). The 'low human capital' that includes a sample of countries with no more than 4.336 years of schooling positively affects TFP growth rate; while a sample of countries in the 'medium human capital' negatively associates with TFP growth rate. More importantly, it is different from the empirical evidence of the weak relationship between human capital and TFP growth, and generally meets theoretical expectations-for the 'high human capital' indeed positively affects TFP growth. Do note that the effect of 'high human capital', even together with that of 'low human capital', is still much less than the absolute value of the medium regime of human capital.

Table 5: Threshold Panel regression (Threshold(s) in human capital)

VARIABLES	**Threshold model (1)**
HC(low)	0.00505***
	(0.002)
HC(medium)	-0.0210***
	(0.005)
HC(high)	0.00344***
	(0.001)
Catch-up	0.0265***
	(0.004)
Government expenditure	0.160
	(0.125)
Openness	0.00175
	(0.008)
Urbanization	-0.0145
	(0.076)
FDI	0.0225***
	(0.007)
Constant	1.022***
	(0.026)
Country dummies	Yes
Year dummies	Yes
Observations	192
R-squared	0.606
Number of id	8
F	7.604

Note: 1. 1000 bootstrap replications were used for each of the three bootstrap tests. 2. *** p<0.01, ** p<0.05, * p<0.1

Despite the two thresholds categorizing human capital into three regimes, the significant estimate of each regime proves the existence of nonlinear effects upon TFP growth rate. Table 6 shows countries in each regime of human capital at different observed period. In 1991, three countries, namely Malaysia, Philippines and Singapore had obviously invested more in human capital and past the phase in which the TFP growth rate benefited from the initial development of human capital and where five other ASEAN countries were experiencing. Until 2002, the number of countries within the medium regime of human capital increased and the number of countries above 10.542 years of schooling remained zero. In 2014, Malaysia and Singapore's human capitals had enhanced their respective countries' TFP growth rates. Meanwhile, only Cambodia still has its human capital in the low regime.

Table 6: Countries in each regime at different observed period

Threshold Variable		**HC ≤ 4.336**	**4.336<HC≤10.542**	**HC > 10.542**
Human capital	1991	Cambodia, Indonesia, Laos, Thailand, Vietnam	Malaysia, Philippines, Singapore	-
	2002	Cambodia, Laos	Indonesia, Malaysia, Philippines, Singapore Thailand, Vietnam	-
	2014	Cambodia	Indonesia, Laos, Philippines, Thailand, Vietnam	Malaysia, Singapore

4.2.2 Thresholds in human capital for catch-up term

The catch-up term is an interaction between human capital and technology gap, denoting the absorptive capacity (or imitation term) of a nation. Given the distance of follower country to the technology frontier, searching for the threshold(s) within human capital will ascertain the number of regimes with respect to the catch-up term. As mentioned above, the technology gap denotes the selection set for follower countries. How much follower countries could learn or absorb from the selection set by means of all kinds of technology spillover depends upon the human capital level of the follower nation. In other words, the pace of catching up with the technology frontier may not be similar for the follower countries. Indeed, Table 7 shows that the test statistics F_1 is the only one with a bootstrap p-value of 0.005, whereas the test statistics F_1 and F_2 do not support the double and triple threshold model. Since the single threshold model is accepted, the plot of likelihood ratio of the threshold gives an estimate of the value of γ in which the corresponding likelihood ratio equal to zero.

Table 7: Tests for threshold effects

Test for single threshold	
F_1	12.037***
P-value	0.005
(1%, 5%, 10% critical values)	(9.529, 5.719, 4.060)
Test for double threshold	
F_2	6.630
P-value	0.139
(1%, 5%, 10% critical values)	(14.412, 10.792, 7.985)
Test for triple threshold	
F_3	7.257
P-value	0.078
(1%, 5%, 10% critical values)	(16.527, 8.585, 6.324)

Note: 1. 1000 bootstrap replications were used for each of the three bootstrap tests.

2. *** p<0.01, ** p<0.05, * p<0.1

Figure 2: Likelihood ratio of the threshold/thresholds

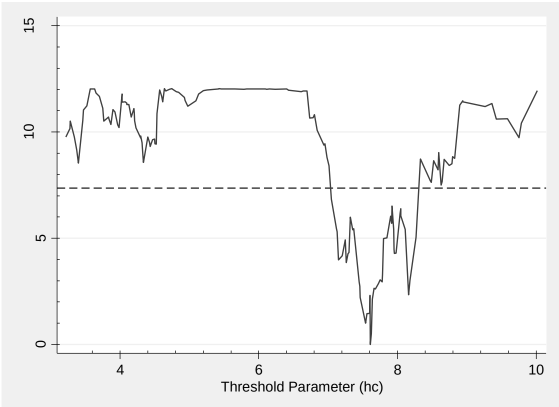


Table 8: Threshold estimates

	Estimate		95% confidence interval
$\hat{\gamma}^1$	7.608		[7.046 , 8.268]

Table 8 gives the threshold estimate with asymptotic 95% confidence interval. The single threshold found, splits the sample of the catch-up term into two groups. The sample of countries with no more than 7.608 years of schooling constructs the first regime named 'low catch-up'; while the sample above the threshold value is the 'high catch-up' regime. In Table 9, the nonlinearity of the catch-up term found for both 'low catch-up' and 'high catch-up' regimes positively affect TFP growth rate in varying magnitudes. More specifically, the 'low catch-up' regime increases TFP growth rate by 0.0181; and the 'high catch-up' regime, with the higher capacity to absorb those technology spillovers, increases TFP growth rate slightly more, i.e. by 0.0193. In addition, the effects of both 'low catch-up' and 'high catch-up' regimes are greater than that of their innovative capacity (HC).

Table 9: Threshold Panel regression (Threshold(s) in human capital)

VARIABLES	Threshold model (2)
HC	-0.0130**
	(0.005)
Catch-up(low)	0.0181***
	(0.004)
Catch-up(high)	0.0193***
	(0.004)
Government expenditure	0.164
	(0.146)
Openness	0.000940
	(0.008)
Urbanization	-0.0798
	(0.080)
FDI	0.0225***
	(0.008)
Constant	1.035***
	(0.028)
Country dummies	Yes
Year dummies	Yes
Observations	192
R-squared	0.557
Number of id	8
F	6.458

Note: 1. 1000 bootstrap replications were used for each of the three bootstrap tests. 2. *** p<0.01, ** p<0.05, * p<0.1

Both 'low catch-up' and 'high catch-up' regimes include different countries at each observed period. From Table 10, all ASEAN countries in this study had human capital below 7.608 years of schooling in 1991; and therefore are placed in the 'low catch-up' regime. After 12 years, Malaysia, Philippines and Singapore came out from the 'low catch-up' regime and benefited from a higher growth effect stemming from the catch-up term. Until 2014, only Cambodia and Laos were not in the 'high catch-up' regime.

Table 10: Countries in each regime at different observed period

Threshold Variable		HC ≤ 7.608	HC > 7.608
Catchup	1991	Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, Vietnam	-
	2002	Cambodia, Indonesia, Laos, Thailand, Vietnam	Malaysia, Philippines, Singapore
	2014	Cambodia, Laos	Indonesia, Malaysia, Philippines, Singapore Thailand, Vietnam

5. Conclusion

This study first gives the estimated series of TFP growth rate for ASEAN 8 countries by using a new method developed by Feenstra et al. (2013) and Inklaar and Timmer (2013) for further investigating cross-country productivity convergence. Based on the Nelson-Phelps model (Nelson and Phelps, 1966) and Benhabib and Spiegel (1994, 2005), human capital endogenously enters into the technology progress and is affecting in two ways; namely domestic innovation and the catch-up term from the technology frontier, both of which focus upon productivity convergence. Using two-way fixed-effect estimation, this study also considers the effects of innovation term, denoted by human capital, and catch-up term upon TFP growth rate. Human capital is found to be negatively associating with TFP growth rate; whereas the catch-up term has a positive effect and is greater than that of the former. This demonstrates that the development in domestic innovation is still insufficient and technology spillover from the frontier plays a crucial role in the entire ASEAN region. Furthermore, by taking human capital composition into account, primary, secondary and tertiary educations individually representing the proxies for the innovation term have different effects upon TFP growth rate. Secondary education dominates the negative effect, which may lead to the human capital being negatively associated with TFP growth rate. Correspondingly, catch-up terms also show different situations based on different absorptive capacity. Only secondary and tertiary education attainments multiplied with the technology gap will generate positive effects, while primary education is obviously inadequate in imitating external advanced technology; and therefore negatively affects TFP growth rate, proving that human capital has to reach a certain threshold value (Benhabib and Spiegel, 2005). Hence, the catch-up process would act as a booster for those following countries to approach the technology frontier.

According to the effects of innovation and the catch-up term upon TFP growth rate, when human capital composition is considered, negative relationship between TFP growth rate and human capital is probably attributable to nonlinearity. This study uses threshold-seeking procedures proposed by Hansen (1999) to examine existence of the number of thresholds in variables, namely innovation term and catch-up term. Innovation term is found to have two thresholds; and for the catch-up term, there is a single threshold in terms of human capital. Through the two-way fixed-effect threshold model, significant positive effects generated by human capital (low and high regimes) are found and less than the negative effect stemming from the human capital (medium regime) is found. In addition, Malaysia and Singapore are the only countries having entered into the regime of high human capital. Most of other ASEAN countries are still in the medium regime. For more than two decades, the progress of innovation in most ASEAN countries is quite obvious. After splitting the catch-up term into two regimes (low and high), higher human capital denoting higher absorptive capacity is, as expected, leveled up the influence of catch-up term on TFP growth. Besides, except for Cambodia and Laos, other ASEAN countries are the members of the regime of high catch-up term.

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