Nonlinear Effect of Human Capital on Economic Growth

Yan Su

China Center for Human Capital and Labor Market Research, Central University of Finance and Economics, Beijing, China

Email address:
suyan_fiona@163.com

Abstract: Under the "new normal", China's economic development mode has shifted from scale and speed to quality and efficiency, and the development driving force has shifted from mainly relying on factor inputs such as resources and low-cost labor to innovation driven. Therefore, it is particularly important to correctly understand the different promoting effects of human capital on economic growth in different stages of human capital development. Consequently, the panel smooth transition regression model was used to study the threshold characteristics and regional differences for human capital of mental quality and physical quality to the economic growth from 1982 to 2019 in China. The results shown that, the mental quality and physical quality of urban and rural have nonlinear effects on economic growth, in addition to the model of physical quality of urban has two system, the other three models are three system. Except the effect of mental quality of rural on the economic growth inhibited the transformation of restrain to promote, the effect of rest of the models always shows promotion performance, along with the promotion of mental quality and physical quality of urban and rural, the promoting effect of economic growth is gradually strengthened. The stimulating effect of mental quality and physical quality of human capital on economic growth exits regional difference, the role of human capital on economic growth is more obvious especially in the eastern coastal areas and relatively developed areas of economy.

Keywords: Human Capital, Economic Growth, Threshold Characteristics, PSTR

1. Introduction

1.1. Background

Since the structural problems of China's economy have been fully exposed, i.e., with the fading of many dividends in terms of population, trade and institutions, and the gradual fading of the latecomer advantage, China's long-standing reliance on investment and labor-driven crude economic growth has been weak. The accompanying factor mismatch, dual-track price system and widespread market monopoly have failed to create effective incentives for technological innovation and high-end human capital accumulation, leading to an imbalance between supply and demand, with both sides unable to respond effectively to the market. With the progressive impact of the global financial crisis on China's social economy in 2008, the deep-rooted contradictions in China's social and economic development have become concentrated. China's economy has now entered a new normal of development, and the accompanying problems are that the linkage between major economic indicators has diverged, economic growth continues to show a downward trend, and the

traditional way of relying on increased investment in factors of production, such as material and labor inputs, to drive economic growth is no longer applicable, and the sustainability of future economic growth is seriously challenged. Against this backdrop, accelerating the pace of transformation and structural adjustment has become an inevitable choice to maintain the long-term momentum of the social economy. The new approach to economic development, which aims to be intensive, endogenous and sustainable, places higher demands on technological innovation and the accumulation and release of human capital on which innovation depends.

1.2. Literature Review

Schultz is the first to construct a theory of human capital, systematically describing the role of individual human capital such as knowledge, technical ability and health [1]. Since then, the analysis of the economic growth effects of human capital has quickly become a hot topic of research within macroeconomics and its cross-cutting areas. For example, studies by Uzawa, Nelson et al., Lucas, and Aghion et al. have

shown that investment in human capital is a major factor in promoting economic growth. Theoretical and empirical approaches to human capital research are still expanding, and the focus of research has been more on the role of education on human capital and hence on economic growth [2-5]. Cohen & Soto use data from the OECD and UNESCO databases for 1960-2000 and find through cross country regression analysis that education has a significant effect [6]. Alfred & Peter find that sustainable economic growth is the result of human capital accumulation [7]. Fleisher et al. study the relationship between human capital and regional economic development inequality using provincial panel data in China and find that both direct and indirect effects human capital has a significant positive effect [8]. Ding & Knight use a systematic panel generalized moments estimation method to regress cross-provincial data in China, and the empirical results show that primary education has no significant effect on economic growth, but high school education and higher education have a positive contribution to economic growth. and the latter has a greater boost than the former [9]. Pelinescu finds the importance of human capital in economic development through a panel data study and argues that if there is underinvestment in human capital it can affect the sustainable development of the economy [10]. Chowdhury et al. and Affandi et al. analyzed the data of Bangladesh and Indonesia respectively and believed that high-quality education level and curriculum focusing on improving cognitive skills are the key to ensure sustained economic growth [11, 12]. Hanushek & Woessmann empirically shows that the overall cognitive ability and education level of labor force are closely related to long-term economic growth, and the role of skills and the quality of economic system complement each other [13].

Since the late 1990s, economists in China have also begun to study human capital theory. By comparing the role of human capital investment and fixed asset investment on economic growth, Guo et al. found that the former was more conducive to promoting economic growth than the latter [14]. In a study of capital deepening, human capital accumulation and sustained economic growth in China, Tang points out that China's rapidly rising human capital will lead to higher physical capital per capita due to its externalities, which, combined with an increase in the capital-output ratio and increasing marginal rewards of human capital, makes China's economic growth more sustainable [15]. Yang et al. measures the impact of education and health on economic growth by combining them into human capital and shows that the contribution of human capital accumulation to economic growth is significant [16]. Wei & Li used quantile regression to study the impact of human capital on China's economic growth, and the results showed that human capital has a significant contribution to economic growth and there are significant differences in this contribution in different positions of the conditional distribution [17]. The results of Feng et al. show that the marginal output effect of human capital investment in China is higher than that of physical capital investment, and the marginal output contribution of vocational education is higher than that of higher education [18]. Huang et al. found that at the current stage of socioeconomic structure, the role of primary education on economic growth in China is greater than that of

higher education, and the contribution of higher education to economic growth in the central and western regions is greater than that in the east [19]. Du et al. found that for the country, the direct effect of human capital on economic growth is not significant, and human capital mainly acts indirectly on economic growth through technological innovation and technological imitation [20]. Yang & Xing also believe that the improvement of human capital level is reflected in the increase of labor skills, which promotes the level of R & D and innovation, improves the productivity and output level of enterprises [21].

At the same time, human capital is a comprehensive concept that includes not only the level of education and years of education, but also health status and work experience, etc., and research on healthy human capital has gradually increased in recent years. Vogl focused on the relationship between education and health in developing countries, noting that improved health directly affects educational outcomes, while increased longevity motivates people to increase investment in human capital, which in turn affects a country's economic development [22]. Luo found that healthy human capital accelerates economic growth in the region and has a significant boost to the economies of neighboring regions with a higher degree of aggregation, and the more developed the economy, the more pronounced this boost is [23]. Huang selected six factors affecting healthy human capital to construct a health index and estimated the impact of healthy human capital on economic growth by using a panel data model with an instrumental variable estimation method. The results show that the contribution of healthy human capital to economic growth is significantly greater than that of physical capital in most provinces and cities in China, while the effect of healthy human capital on economic growth has regional variability [24]. Feng & Chai analyze the impact of two kinds of health investments on health accumulation and economic growth in an endogenous growth model that includes both government and private health investments. Their conclusion is that the effect of healthy human capital on economic growth varies at different stages, public and private health investments have to be kept in appropriate proportions for the economic growth rate to be optimal [25]. The regression results of Wang et al. show that both health expenditure and education expenditure have a significant positive impact on economic growth [26].

Throughout the literature, the positive contribution of human capital to economic growth is discussed, and human capital is mainly defined as the result of two factors: education level or health. Azariadis & Drazen find multiple steady-state equilibrium solutions for economic growth when human capital is introduced under the Diamond model: countries with initial human capital on either side of the human capital threshold may end up with very different growth effects, with growth showing dispersion [27]. That is, there may be a threshold for the effect of human capital on economic growth, and there are differences in the role of human capital in driving economic growth around that threshold. If there is indeed a threshold effect of human capital in economic growth, then the elasticity coefficient of human capital on economic growth obtained by using linear model regression is biased and the results obtained may underestimate or overestimate the contribution of human capital. The subsequent

structure of this paper is arranged as follows: the third part is the model and data description; the fourth part is the empirical analysis based on 33 years of panel data from 31 provinces and regions in China, and finally is the concluding section.

2. Description of the Model and Data

2.1. Model Set up

The usual approaches to panel data are fixed effects models, random effects models and mixed estimation models. These models assume homogeneity or time-point invariance of individual parameters in the cross-section, but ignore the case of relatively large individuals, and thus are insufficient to describe the asymptotic or nonlinear transformation characteristics of the variables when individuals are relatively large. To address this problem, Hansen proposed a panel threshold (PTR) model, which not only addresses the shortcomings of the model's insufficient sample size, but also provides better access to the heterogeneity characteristics of cross-sectional data than the traditional panel data model [28]. However, the model divides the observed threshold variables into different groups because of the introduction of the schematic function, and the borders between groups are very distinct and discrete jumps, which is not consistent with the real-world situation. Subsequently, González et al. (2005) usefully extended the PTR by proposing a panel smoothed transformed regression model (PSTR). This model is closer to economic reality by introducing a continuous transformation function thus making the coefficients of the model shift smoothly and nonlinearly with the change in the transformation variable, and thus the transformation of the institutions becomes a continuous and smooth process.

The basic panel smoothed transformation regression model is shown as below:

$$y_{it} = \mu_i + \beta_0 x_{it} + \beta_1 x_{it} g\left(q_{it}; \gamma, c\right) + \varepsilon_{it} \qquad (1)$$

where, y_{it} is the explained variable, is a scalar. x_{it} is the explanatory variable, is a k-dimensional column vector. μ_i is an individual fixed effect, ε_{it} denotes the error term. $i = 1, 2, \cdots N$; $t = 1, 2, \cdots, T$. $g\left(q_{it}; \gamma, c\right)$ is a transformation function, which is on the continuous variation of q_{it} between 0-1. The logistic function is set up in the form of

$$g\left(q_{it}; \gamma, c\right) = \left[1 + \exp\left(-\gamma \prod_{j=1}^{m}\left(q_{it} - c_j\right)\right)\right]^{-1} \qquad (2)$$

$$\gamma > 0, \ c_1 \le c_2 \le \cdots c_m$$

In equation (2), γ is the smoothing parameter, also known as the slope coefficient or smoothing factor, which determines the rate at which the transition between the two types of mechanisms occurs; c is the location parameter of the transition, also known as the threshold level, which determines where the transition between the mechanisms occurs; q_{it} is the transition function, which can be a component

of the explanatory variable, a function of a component, or an exogenous variable not included in the explanatory variable; and m indicates the number of location parameters contained in the transition function $g\left(q_{it}; \gamma, c\right)$, and usually takes the value of 1 or 2. When $m=1$, the conversion function contains one positional parameter.

$$g_1\left(q_{it}; \gamma, c\right) = \left\{1 + \exp\left[-\gamma\left(q_{it} - c\right)\right]\right\}^{-1} \qquad (3)$$

It is easy to know that $\lim_{q_{it} \to -\infty} g_1\left(q_{it}; \gamma, c\right) = 0$ and $\lim_{q_{it} \to +\infty} g_1\left(q_{it}; \gamma, c\right) = 1$. When $g_1\left(q_{it}; \gamma, c\right) = 0$, the corresponding model is called the low regime. When $g_1\left(q_{it}; \gamma, c\right) = 1$, it is called the high regime. When the transition function $0 < g_1\left(q_{it}; \gamma, c\right) < 1$, the corresponding model also transitions smoothly between the high and low regimes. When $m=2$, $g\left(q_{it}; \gamma, c\right)$ contains two positional parameters.

$$g_2\left(q_{it}; \gamma, c\right) = \left\{1 + \exp\left[-\gamma\left(q_{it} - c_1\right)\left(q_{it} - c_2\right)\right]\right\}^{-1} \qquad (4)$$

$g_2\left(\cdot\right)$ about $\left(c_1 + c_2\right)/2$ symmetry and reaches a minimum at that point, the corresponding mechanism is called the intermediate mechanism.

In particular, the PSTR model is transformed into a panel threshold regression (PTR) model if $\gamma \to +\infty$. If $q_{it} = c$ or $\gamma \to 0$, $g_1\left(q_{it}; \gamma, c\right) = 0.5$, PSTR model degenerates into a linear fixed effects model. Thus, both the PTR model and the linear fixed effects model are special forms of the PSTR model.

In the PSTR model equation (1), the marginal effects of the explanatory variables on the explanatory variables can be expressed as

$$e_{it} = \frac{\partial y_{it}}{\partial x_{it}} = \beta_0 + \beta_1 g\left(q_{it}; \gamma, c\right) \ ; \forall i, \forall t \qquad (5)$$

Because $0 \le g\left(q_{it}; \gamma, c\right) \le 1$, so e_{it} can be seen as the weighted average of β_0 and β_1. The value of β_1 greater than 0 means that the effect of the explanatory variable on the explained variable increases as the transformed variable increases. The value of β_1 less than 0 means that the effect of the explanatory variable on the explained variable decreases as the transformed variable increases.

2.2. Data Description

The time series of the study is set as 1982-2019, and a panel data of 38 years for 31 provinces across the country is constructed. Given the availability of relevant statistics, GDP per capita is used to measure the level of economic development. The level of human capital is measured comprehensively by brain quality and physical quality, where brain quality is measured by per capita investment in education fees; physical quality is measured by per capita expenditure on

medical care. In the empirical analysis of this paper, the explanatory and transformation variables are the same. To enhance the comparability and interpretability of the findings, the equations are built in two aspects, urban and rural.

Other control variables are: (1) total fixed capital investment, which controls the impact of fixed capital investment on economic growth in each province. This paper adopts the perpetual inventory method to account for the total fixed capital investment in each province in the growth level, which is calculated as $K_G = K'_G(1-D) + K_I$. K_G refers to the total fixed capital investment, K_I is the amount of new fixed capital investment, K'_G is the total fixed capital before depreciation at the end of the previous year, D is the depreciation rate, which is taken as 5% in this paper. (2) Technological progress, which is used to control the role of the level of technological progress in economic growth in each province, is measured by the R&D investment in R&D. (3) Working population as a share of total population, used to control

for the impact of the size of the labor force on economic growth in each province, this variable is measured as the ratio of the available working population to the total population.

Taking price changes into account, each nominal value was transformed into the corresponding real value by adjusting the price index with 1982 as the base period. The data are obtained from China Statistical Yearbook, China Demographic Statistical Yearbook, China Labor Statistical Yearbook, China Science and Technology Statistical Yearbook, Compilation of Statistical Information of New China in the Six Decades, Provincial and Municipal Statistical Yearbooks in the past years, WIND database and CEE database, etc. Some missing data are obtained by linear interpolation or extrapolation. In the empirical analysis, all data were logarithmically processed in order to overcome possible heteroskedasticity and ensure the smoothness of the series. The descriptive statistics of the data of the above variables are shown in Table 1.

***Table 1.** Descriptive statistics table.*

Variables	Definitions	No.	Mean	STD	Min	Max
Y	Per capita GDP	1178	7.491	0.952	5.634	9.835
UE	Urban per capita investment in education	1178	4.813	0.735	2.621	6.591
RE	Rural per capita investment in education	1178	3.345	1.072	-0.726	5.482
UH	Urban per capita medical expenditure	1178	3.586	1.484	-0.872	5.896
RH	Rural per capita medical expenditure	1178	2.783	1.279	-3.944	5.724
K	Total fixed capital investment	1178	6.369	1.962	1.383	10.362
A	Technology Progress	1178	0.732	2.351	6.531	5.687
L	Labor Force /Total population	1178	0.525	0.073	0.192	0.748

3. Empirical Analysis

3.1. Nonlinearity Test

It is also necessary to determine whether there are nonlinear effects in the model before estimating the PSTR model, i.e., to test whether the PSTR model is appropriate. The original hypothesis is $H_0 : \gamma = 0$ or $H_0 : \beta_1 = 0$, but since the model contains unidentified parameters γ and c, the model cannot be tested for nonlinearity directly. The common method is to approximate replace the $g(\cdot)$ in the original model with the first-order Taylor expansion with the help of $g(q_{it}; \gamma, c)$ when the $\gamma = 0$ to obtain an auxiliary regression model on the linearity of the parameters, as shown below.

$$y_{it} = \mu_i + \beta_0' x_{it} + \beta_1' x_{it} q_{it} + \cdots + \beta_m' x_{it} q_{it}^m + \zeta_{it}, \quad i = 1, 2, \cdots N, \ t = 1, 2, \cdots T \tag{6}$$

where the parameter vector of $\beta_1' \cdots \beta_m'$ is a multiple of γ. $\zeta_{it} = \varepsilon_{it} + A_m \beta_1 x_{it}$, A_m is the remainder of the Taylor expansion. Thereby, the original hypothesis can now be set to $H_0' : \beta_1' = \cdots = \beta_m' = 0$, which is equivalent to $H_0 : \gamma = 0$. The nonlinearity test can be performed by constructing asymptotically equivalent statistics of LM, LM_F and LRT, the specific form of the test can be written as:

$$LM = TN(SSR_0 - SSR_1) / SSR_0 \tag{7}$$

$$LM_F = \left[(SSR_0 - SSR_1) / mK\right] / \left[SSR_0 / TN - N - m(K+1)\right] \tag{8}$$

$$LRT = -2\left[\log(SSR_1) - \log(SSR_0)\right] \tag{9}$$

In the above equations, LM and LM_F are asymptotically obeyed to $\chi^2(mK)$, LRT asymptotically obeyed to

$F(mK, TN - N - m(K+1))$, SSR_0 and SSR_1 are the residual sums of squares under the original and alternative hypotheses, respectively, and K is the number of explanatory variables in the model. If the test rejects the original hypothesis $H_0 : \gamma = 0$, it means that the PSTR model can be used for analysis, while further residual nonlinearity tests are required to determine whether there is only one transformation function or at least two transformation functions, as shown in Table.

3.2. Determining the Number of Positional Parameters

After determining the number of transformation functions, it is necessary to determine the number of positional parameters. Drawing on the ideas of Teräsvirta, sequential inspection the null hypothesis of $H_{01:} \beta_1' = 0 | \beta_2' = \beta_3' = 0$, $H_{02:} \beta_2' = 0 | \beta_3' = 0$, $H_{03:} \beta_3' = 0$ and then the specific form of

the transformation function is determined based on the strongest rejection principle [29]. From the p-values corresponding to each model statistic in Table 3, in models A, B and D, the number of m is 2 and in model C, the number of m is 1.

Table 2. *The results of linearity test and non-linearity test.*

		Model A			Model B		
		LM	LM$_F$	LRT	LM	LM$_F$	LRT
linearity test	H$_0$: r=0 H$_1$: r=1	15.394 (0.000)	14.912 (0.000)	17.908 (0.000)	28.606 (0.000)	17.946 (0.000)	11.586 (0.000)
nonlinearity test	H$_0$: r=1 H$_1$: r=2	2.351 (0.156)	2.008 (0.172)	2.335 (0.152)	1.009 (0.892)	1.564 (0.756)	1.238 (0.853)

		Model C			Model D		
		LM	LM$_F$	LRT	LM	LM$_F$	LRT
linearity test	H$_0$: r=0 H$_1$: r=1	25.763 (0.000)	14.065 (0.000)	19.663 (0.000)	24.173 (0.000)	19.315 (0.000)	23.039 (0.000)
nonlinearity test	H$_0$: r=1 H$_1$: r=2	0.911 (0.340)	0.829 (0.368)	0.986 (0.358)	0.158 (0.716)	0.167 (0.521)	0.154 (0.712)

Note: The corresponding P values are in parentheses.

Table 3. *Selection of optimal position parameters.*

Models	A	B	C	D
H1	1.608 (0.014)	1.734 (0.025)	2.014 (0.049)	2.218 (0.034)
H2	1.546 (0.046)	1.612 (0.033)	0.665 (0.694)	1.628 (0.032)
H3	1.037 (0.263)	1.168 (0.352)	—	1.128 (0.962)

Note: The corresponding P values are in parentheses.

Based on the results of the above tests, the following four models were finalized for estimation:

$$Y_{it} = \mu_i + \beta_{00}UE_{it} + \beta_{10}K_{it} + \beta_{20}A_{it} + \beta_{30}L_{it} + \left(\beta_{01}UE_{it} + \beta_{11}K_{it} + \beta_{21}A_{it} + \beta_{31}L_{it}\right)g\left(UE_{it};\gamma,c\right)+\varepsilon_{it} \tag{10}$$

$$Y_{it} = \mu_i + \beta_{00}RE_{it} + \beta_{10}K_{it} + \beta_{20}A_{it} + \beta_{30}L_{it} + \left(\beta_{01}RE_{it} + \beta_{11}K_{it} + \beta_{21}A_{it} + \beta_{31}L_{it}\right)g\left(RE_{it};\gamma,c\right)+\varepsilon_{it} \tag{11}$$

$$Y_{it} = \mu_i + \beta_{00}UH_{it} + \beta_{10}K_{it} + \beta_{20}A_{it} + \beta_{30}L_{it} + \left(\beta_{01}UH_{it} + \beta_{11}K_{it} + \beta_{21}A_{it} + \beta_{31}L_{it}\right)g\left(UH_{it};\gamma,c\right)+\varepsilon_{it} \tag{12}$$

$$Y_{it} = \mu_i + \beta_{00}RH_{it} + \beta_{10}K_{it} + \beta_{20}A_{it} + \beta_{30}L_{it} + \left(\beta_{01}RH_{it} + \beta_{11}K_{it} + \beta_{21}A_{it} + \beta_{31}L_{it}\right)g\left(RH_{it};\gamma,c\right)+\varepsilon_{it} \tag{13}$$

3.3. Estimation Results

Table 4 shows the estimation results of equations (10), (11), (12) and (13) (obtained through MATLAB 7.0). From the table, it is clear that most of the variables are significantly pass the test.

Table 4. *Estimation results.*

	Coef.	Eq.(10)	Eq.(11)	Eq.(12)	Eq.(13)
	β_{00}	0.163** (0.106)	-0.001** (0.006)	0.178*** (0.048)	0.088*** (0.021)
linear part parameter estimation	β_{10}	0.205*** (0.028)	0.103*** (0.034)	-0.321*** (0.102)	-0.086 (0.355)
	β_{20}	0.018* (0.016)	0.008* (0.008)	0.067** (0.038)	0.039*** (0.012)
	β_{30}	0.371*** (0.077)	0.339*** (0.044)	0.584*** (0.087)	0.515*** (0.245)
Slope coefficient	γ	3.837	6.447	0.848	0.501
Location parameters	C$_1$ C$_2$	4.534 5.477	2.509 4.432	1.447 —	-2.014 4.642
	β_{01}	0.369*** (0.092)	0.453*** (0.052)	0.328*** (0.108)	0.371** (0.186)
nonlinear part parameter estimation	β_{11}	-0.048** (0.049)	-0.099** (0.041)	0.316*** (0.133)	0.164 (0.397)
	β_{21}	0.086*** (0.028)	0.043* (0.024)	-0.026 (0.068)	0.051 (0.071)
	β_{31}	-0.059*** (0.049)	-0.032*** (0.016)	-0.334*** (0.644)	-0.355*** (0.045)

Note: Corresponding standard errors are in parentheses, *, **, *** denote 10%, 5% and 1% significance levels, respectively.

3.3.1. Analysis of Brain Quality Threshold Characteristics

Equations (10) and (11) are three-regime models with urban and rural per capita education fee inputs as the transformation variables, and there is a double-threshold effect, and there are significant differences in their effects on economic growth at different levels of urban and rural per capita education fee inputs. Looking first at the urban per capita education fee input, when $UE_{it} < 4.534$ or $UE_{it} > 5.477$, it is in the out-of-model regime. When $4.534 < UE_{it} < 5.477$, the model is in the intermediate regime. The effect of per capita education fee input on economic growth always shows a boosting effect ($\beta_{00} > 0$, $\beta_{00} + \beta_{01} > 0$), i.e., an increase in per capita education fee input enhances economic development and the boosting effect on economic development becomes more significant after crossing the threshold, with the turning point occurring around 93.162 ($e^{4.534}$) and 239.156 ($e^{5.477}$) per capita education fee input. In addition, $\gamma = 3.8375$, indicating that the speed of model transformation is relatively moderates and the transformation function shows a smooth and gradual transformation trend (as shown in Figure 1). Then look at the impact of rural per capita education expenditure on economic growth. When $RE_{it} < 2.509$ or $RE_{it} > 4.432$, it is in the out-of model regime, when $2.509 < RE_{it} < 4.432$, the model is in the intermediate regime.
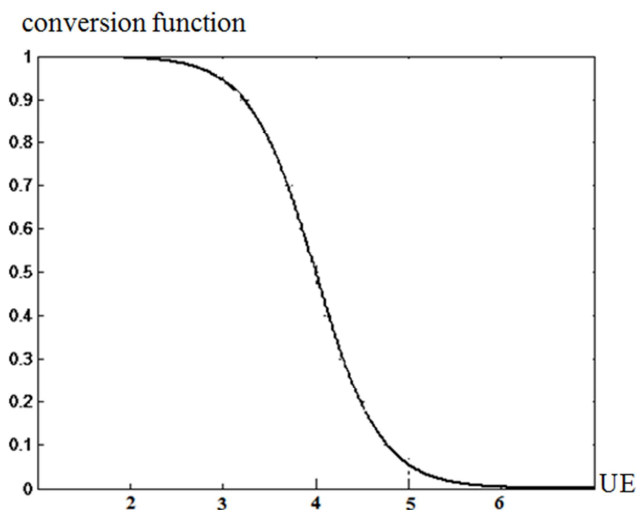

Figure 1. Conversion function of Eq. (10).

The relationship between rural per capita education expenditure and economic growth is first negative and then transforms into a positive contribution relationship ($\beta_{00} < 0$, $\beta_{00} + \beta_{01} > 0$), i.e., an increase in rural per capita education expenditure after crossing the threshold significantly contributes to economic growth, with the turning point occurring at around 12.302 and 84.186 in rural per capita education expenditure. $\gamma = 6.447$, the model transforms faster and the curve of the transition function is steeper (as shown in Figure 2). This shows that when per capita consumption input is used as the transformation variable, the elasticity values of 0.532 and 0.452 are obtained for urban and rural areas respectively when they are in the intermediate regime, and the elasticity gap between rural and urban areas

is smaller, and both have a significant driving effect on economic growth, indicating the need to continue to increase the construction of education infrastructure and other aspects of urban and rural areas, and even more so in rural areas.

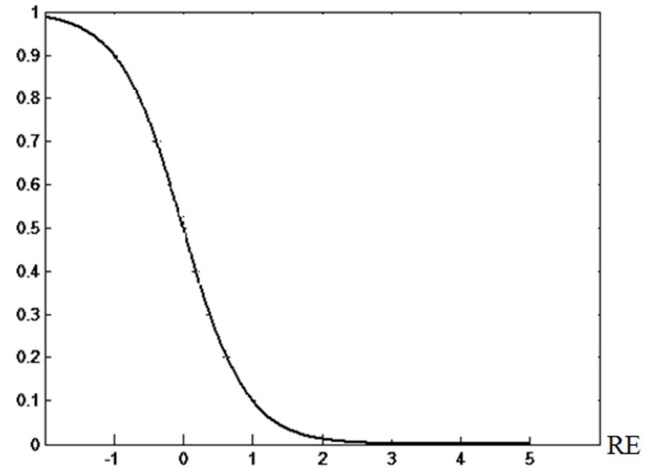*Figure 2. Conversion function of Eq. (11).*

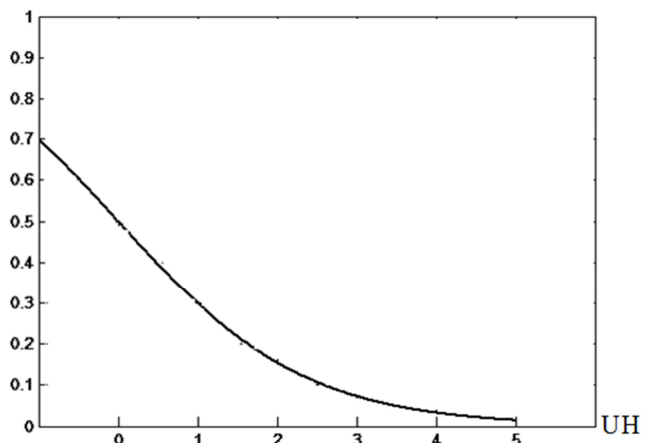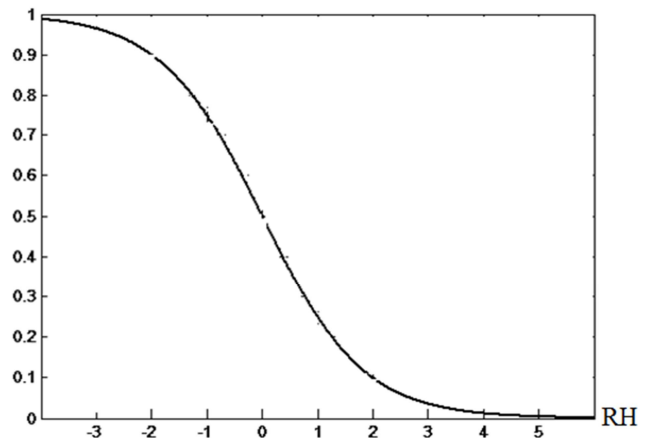*Figure 3. Conversion function of Eq. (12).*

Figure 4. Conversion function of Eq. (13).

3.3.2. Analysis of Physical Fitness Threshold Characteristics

Equations (12) and (13) are models with urban and rural per capita medical expenditure as the transformation variables, respectively, with the former being a single threshold and the latter a double threshold. The linear effect of urban per capita medical expenditure on economic growth is 0.179 when urban per capita medical expenditure is below 4.252, and after crossing the threshold of 4.252, the pulling effect of per capita medical expenditure in personal expenditure on economic growth begins to appear, which can significantly increase the level of economic growth ($\beta_{00} + \beta_{01}$=0.507), but the speed of conversion of this model is slower (as shown in Figure 3). The linear effect of rural per capita medical expenditure on economic growth is 0.088 when rural per capita medical expenditure is below 0.133, and after entering the threshold of 103.783, the pulling effect of per capita medical expenditure in personal expenditure on economic growth starts to appear, which can significantly increase the level of economic growth ($\beta_{00} + \beta_{01}$=0.459). In addition, the rate at which the model switches from one zone system to another is 0.501, indicating a slow switching rate and a flat, smooth and gradual trend in the switching function (as shown in Figure 4). In summary, it can be seen that when per capita health expenditure is used as the switching variable, the results obtained are similar to those obtained when per capita education input is used as the switching variable, with elasticity values of 0.507 and 0.459 for urban and rural areas, respectively, contributing significantly to economic growth.

3.3.3. Analysis of Threshold Characteristics of Control Variables

In terms of control variables, there is a significant linear and non-linear effect between gross fixed capital investment and per capita investment in education in urban and rural areas, with the linear part having elasticity values of 0.205 and 0.103, respectively, which are positively correlated, and the non-linear part having elasticity values of -0.048 and -0.099, i.e., negatively correlated with per capita investment in education after crossing the threshold. In general, gross fixed capital investment promotes economic development and this promotion diminishes as the amount of education fee investment per capita increases in urban and rural areas. There is a significant effect between gross fixed capital investment and urban per capita medical expenditure only, with the elasticity value changing from -0.321 to -0.004, indicating that as urban per capita medical expenditure increases, gross fixed capital investment has a dampening effect on economic growth. The value of the elasticity level between the level of technological progress and per capita education fee investment in urban and rural areas changes from 0.018 and 0.008 to 0.104 and 0.052, respectively, and is significant, i.e., it indicates that its role in promoting economic development increases with the increase in per capita education fee investment in urban and rural areas; the linear part of the results between the level of technological progress and per capita medical fee expenditure in urban and rural areas is significant, with elasticity values The linear part of the results between the level of technical progress and per capita medical

expenditure in urban and rural areas is significant, with elasticity values of 0.067 and 0.039 respectively, but the non-linear part is not significant, which indicates that the increase in per capita medical expenditure has a relatively weak effect on the role of technical progress in the economy. The results for the share of working population in total population and per capita education expenditure and per capita medical expenditure in urban and rural areas are significant, with positive coefficient values for the linear part and negative coefficient values for the non-linear part. Overall, the elasticity level values change from 0.371, 0.339, 0.584 and 0.515 to 0.311, 0.307, 0.249 and 0.160 respectively, i.e., the driving effect of the labor force share on economic development decreases with the increase of per capita investment in education and per capita expenditure on medical care, which indicates from the side that the improvement of the quality of the labor force is better than the increase of the quantity of the labor force. This shows that the quality of the working population is more important than the quantity of the working population, and the health of the working population should be taken into consideration.

According to the threshold back to the original data, it can be found that: between 1982 and 2018, each province and region has achieved the threshold in different years, and in terms of per capita education expenditure, they all follow the pattern of the developed eastern region being the first to cross, followed by the central region, and finally the western region; in terms of per capita health expenditure, especially in urban areas, the threshold crossing is more scattered and no longer follows the above pattern. One commonality is that the less developed regions in the west cross the second threshold later, near the end of the study time series. The results of the study show that the provinces that crossed the higher threshold and had larger logarithms are mostly located in the eastern coastal and economically developed regions, with the corresponding less developed regions having weaker levels of development and entering the higher regime later, which can further widen the economic development gap between provinces and regions.

4. Conclusion

This paper uses a panel smoothed transformed regression model (PSTR) to investigate the threshold characteristics and regional differences in the effect of human capital brain quality and physical quality on economic growth in China's provinces, and divides them by urban and rural areas, building four models in total. As the transformation variable changes, the economic growth effect of human capital corresponds to a smooth transformation between high and low regimes. With other control variables being the same, the effects of human capital brain quality and physical quality on economic growth were analyzed separately with urban and rural per capita education fee inputs and per capita medical fee pointed out as the transformation variables, and the following basic conclusions were obtained.

First, the non-linear relationship between brain quality and economic growth is both present. The test results for both

models are significant before and after the threshold values, with its effect on economic growth consistently showing a boost on the urban side, and on the rural side, its effect on economic growth shifts from inhibiting to promoting. After the threshold is crossed, the contribution of brain quality to economic growth gradually increases with the increase in per capita investment in education.

Second, the non-linear relationship between physical fitness and economic growth also holds. After the threshold is crossed, the contribution of physical fitness to economic growth increases gradually with the increase in per capita investment in health care.

Third, there are significant regional differences in the economic growth effects of human capital brain quality and physical quality. Except for urban per capita medical expenditure, the results of the other three models follow the pattern of developed eastern regions taking the lead in crossing, followed by central and finally western regions, that is, most of the provinces crossing higher thresholds and with larger logarithmic values are located in the eastern coastal and economically developed regions, and the development of less developed western regions has been at a disadvantage.

Fourth, in terms of the elasticity level after crossing the threshold, not only are the effects of the mental and physical quality of human capital on economic growth significant and not very different, but the difference between the coefficients of economic growth in urban and rural areas is also not as large as expected. This shows that while the quality of the workforce is improving, attention should also be paid to the health of workers, as only healthy human capital is a lasting source of economic growth.

Based on the conclusions, we have the following policy implications. In the future, the household registration system should be further deregulated to realize the flow and allocation of talents among different regions and maximize the effectiveness of resources; focus on social security investment in education and medical care in rural areas to fully release the huge development potential of rural areas, implement effective regulation and comprehensive support in industrial restructuring, patent protection and institutional construction based on local conditions and scientific planning, enhance In addition to improving the mental quality of human capital, we should also pay attention to the improvement of physical quality.

References

[1] Schultz T W. Education and Economic Growth. In N. B. Henry (Ed#), Social Forces Influencing American Education [M]. Chicago: University of Chicago Press. 1961: 85—90.

[2] Uzawa H. Optimum technical change in an aggregative model of economic growth [J]. International economic review, 1965, 6 (1): 18-31.

[3] Nelson, R. and E, Phelps. Investment in Humans, Technological Diffusion and Economic Growth [J]. American Economic Review, 1966 (56): 69-75.

[4] Lucas R E. On the mechanics of economic development [J]. Journal of monetary economics, 1988, 22 (1): 3-42.

[5] Aghion, P, Howitt P. A Model of Growth through Creative Destruction [J]. Econometrica, 1992, 60 (3): 323-351.

[6] Cohen D, Soto M. Growth and human capital: good data, good results [J]. Cepr Discussion Papers, 2007, 12 (1): 51-76.

[7] Greiner A, Flaschel P. Economic Policy in a Growth Model with Human Capital, Heterogenous Agents and Unemployment [J]. Computational Economics, 2009, 33 (2): 175-192.

[8] Fleisher B, Li H, Zhao M Q. Human capital, economic growth, and regional inequality in China [J]. Journal of Development Economics, 2010, 92 (2): 215-231.

[9] Ding S, Knight J. Why has China Grown So Fast? The Role of Physical and Human Capiital Formation [J]. Oxford Bulletin of Economics & Statistics, 2011, volume 73 (2): 141-174 (34).

[10] Elena Pelinescu. The Impact of Human Capital on Economic Growth [J]. Procedia Economics and Finance, 2015: 184–190.

[11] Chowdhury M N M, Uddin M J, Uddin N, et al. Human capital development and economic growth in Bangladesh [J]. Journal of World Economic Research, 2018, 7 (2): 52-63.

[12] Affandi Y, Anugrah D F, Bary P. Human capital and economic growth across regions: a case study in Indonesia [J]. Eurasian Economic Review, 2019, 9 (3): 331-347.

[13] Hanushek E A, Woessmann L. Education, knowledge capital, and economic growth [J]. The Economics of Education, 2020: 171-182.

[14] Guo Qingwang, Lv Bingyang, Zhang Deyong. Fiscal expenditure structure and economic growth [J]. Economic Theory and Economic Management, 2003, 11: 5-12.

[15] Yang, Jianfang, Gong, Liutang, Zhang, Qinghua. Human capital formation and its impact on economic growth-an endogenous growth model including education and health inputs and its test [J]. Management World, 2006, 05: 10-18+34+171.

[16] Wei, Ha-Hai, Li, Shu-Pei. Human capital, human capital structure and regional economic growth: An empirical study based on quantile regression method [J]. Finance and Trade Research, 2009, 05: 15-24.

[17] Feng Xiao, Zhu Yanyuan, Yang Xi. A study on the production function of Chinese national economy based on the variance of human capital distribution [J]. Economics (Quarterly), 2012, 02: 559-594.

[18] Huang Yanping, Liu Yu, Wu Yiqun. Regional economic growth differences in China: effects based on graded education [J]. Economic Research Journal, 2013: 94-105.

[19] Du Wei, Yang Zhijiang, Xia Guoping. Research on the mechanism of the role of human capital in driving economic growth [J]. China Soft Science, 2014, 08: 173-183.

[20] Li Chengyou, Sun Tao, Jiao Yong. Factor endowment, wage gap and human capital formation [J]. Economic Research Journal, 2018, 53 (10): 113-126.

[21] Yang Ziwei, Xing Chunbing. Education, unemployment and human capital investment [J]. Research on Labor Economy, 2019, 7 (02): 60-77.

[22] Vogl T S. Education and Health in Developing Economies [J]. Encyclopedia of Health Economics, 2014: 246-249.

[23] Luo Yongmin. Public health expenditure, health human capital and economic growth [J]. Southern Economics, 2011, 04: 3-15.

[24] Huang Xiaoping, Yan Lifang, Liu Shan. A study of regional differences in the impact of health human capital on economic growth [J]. Health Economics Research, 2013, 02: 22-27.

[25] Feng Yan, Chai Zhihong. The impact of healthy human capital on economic growth [J]. Economic and Management Research, 2016, 02: 21-27+123.

[26] Wang Dihai, Li Xiawei, Huang Liang. How health investment affects economic growth: a study from transnational panel data [J]. Economic Science, 2019 (01): 5-17.

[27] Azariadis C, Drazen A. Threshold externalities in economic development [J]. Quarterly Journal of Economics, 1990, 105 (2): 501-26.

[28] Hansen B E. Threshold effects in non-dynamic panels: Estimation, testing, and inference [J]. Journal of Econometrics, 1999, 93 (2): 345-368.

[29] Teräsvirta T. Specification, estimation, and evaluation of smooth transition autoregressive models [J]. Journal of the American Statistical Association, 1994, 89 (425): 208-218.