Journal of Economic Science Research
https://ojs.bilpublishing.com/index.php/jesr

ARTICLE

Calculation and Measurement of China's Human Capital after Comparing Human Capital with Technological Innovation

Kangping Wu Mengtao Wu*

School of Economics and Management, Tsinghua University, Beijing, 100084, China

Received: 4 October 2021; **Accepted:** 27 October 2021; **Published:** 1 December 2021

Citation: Wu KP, Wu MT. Calculation and Measurement of China's Human Capital after Comparing Human Capital with Technological Innovation. *Journal of Economic Science Research*, 2022, 5(1), 3796. https://doi.org/10.30564/jesr.v5i1.3796

Abstract: Human capital, as a synthesis of wisdom and physical fitness condensed in workers, is sometimes confused with technological innovation by existing literature. This paper makes comparisons between these two terminologies. Technological innovation is a short-term activity that attaches importance to economic benefits while human capital accumulation is a long-term strategic process with lifelong benefits, and human capital is the foundation of technological innovation. In empirical part, this paper adopts Solow Residual Method to calculate stock, elasticity and growth rate of human capital of 10 countries after eliminating physical capital, labor force and technological innovation. It is found that human capital stock in the United States is the largest and human capital growth in China is the fastest. Calculation is followed by measurement. We construct a comprehensive index of human capital by using Index Weight Assignment Method and Two-level & Three-factor CES Function to measure and predict human capital level in China. Both calculating and measuring results show that growth rate of China's human capital is around 5%. In the future, for high-quality economic development, China should give priority to human capital development and comprehensively improve human capital competitiveness.

Keywords: Solow residual method, Index weight assignment method, Two-level & Three-factor CES Function, Comprehensive index of human capital, High-quality economic development

1. Introduction

The study of human capital in economics began in the 17th century, but it was not until the late 1950s and early 1960s that the theory of human capital was gradually formed. In 1960, Schultz [1], the initiator of human capital theory, first put forward and discussed complete concept of human capital. Human capital refers to a synthesis of

*Corresponding Author:
Mengtao Wu,
School of Economics and Management, Tsinghua University, Beijing, 100084, China;
Email: wumt.18@sem.tsinghua.edu.cn

DOI: https://doi.org/10.30564/jesr.v5i1.3796

knowledge, ability and health condensed in workers that can realize value proliferation. Education is the main way to accumulate human capital. Subsequently, Becker [2] completed development process of human capital theory from concrete to abstract and established the human capital investment theory, marking the formal formation of modern human capital theory. In the late 1980s and early 1990s, New Growth Theory, founded by Romer and Lucas, pushed human capital research to another high spot. In Lucas' economic growth model [3], human capital and technological innovation (or knowledge) exist at the same time. Accumulation of human capital only depends on existing level of human capital and has nothing to do with technological innovation – that is, human capital and technological innovation are two independent elements.

In many existing papers, however, there is no clear boundary between human capital and technological innovation. These two notions are sometimes regarded as the same thing without being distinguished in form or content. Some researchers distinguish them in form, but human capital includes technological innovation in content, which is another common confusion – that is, form is separated but content is not really separated. Moreover, some papers distinguish them both in form and content, but in empirical study, human capital is presented by education and technological innovation is presented by R&D. Technically, that is education and R&D are distinguished rather human capital and technological innovation in this kind of literature. The questions, whether human capital and technological innovation are independent conceptually or practically, what are the differences and connections between them, and what is the definition and scope of human capital, need to be further studied, which is the starting point and innovative contribution of this paper. Human capital is a critical indicator reflecting a country's comprehensive national strength, and competition of national comprehensive strength is essentially competition of human capital. Therefore, it is crucial to correctly calculate human capital, scientifically measure human capital and understand its contribution to economic growth.

This paper, at first, makes comparisons between human capital and technological innovation in three angles – that are definition, essence and quantitative difficulty. Technological innovation is a short-term activity centered on economic benefits while human capital refers to a synthesis of wisdom and physical fitness condensed in workers. Human capital is cumulative, and human capital accumulation is a long-term strategic process with lifelong benefits. Secondly, on the basis of distinguishing two terminologies, physical capital, labor force and technological innovation are eliminated by Solow Residual Method in order to calculate stock, growth rate and elasticity of human capital of 10 representative countries, including China, the United States and Japan from 1996 to 2019. The results show that stock of human capital in the United States is the largest and growth of human capital in China is the fastest. This paper then adopts Index Weight Assignment Method and Two-level & Three-factor CES Function to construct a comprehensive index of human capital to measure human capital level in China from 1978 to 2019. It is found that the growth rate of human capital in China is around 5%. The calculating and measuring results are consistent, indicating scientific effectiveness of the comprehensive index of human capital. Subsequently, we predict China's human capital level in 10 years and point out the direction and destination of human capital development in the future.

The remaining sections are arranged as follows. The second section is literature review that discusses existing papers' confusion on human capital and technological innovation in three aspects. The third section analyzes differences and relationship between human capital and technological innovation. The fourth section uses Solow Residual Method to calculate stock, growth rate and elasticity of human capital. The fifth section adopts Index Weight Assignment Method and Two-level & Three-factor CES Function to construct a comprehensive index of human capital, and then calculates and predicts human capital level in China. The final section is conclusion.

2. Literature Review

The confusion between human capital and technological innovation in existing studies can be divided into three main categories. First of all, human capital and technological innovation are directly regarded as the same notion without being distinguished either in form or content. The feature of this kind of research is that only physical capital, labor force and technological innovation appear in growth model but human capital is ignored or contained in technological innovation. For example, based on the assumptions that physical capital and labor force bring about total output and remaining contribution factors belong to total factor productivity, Wu [4] and Tu and Xiao [5] used Stochastic Frontier Production Function Method to decompose total factor productivity into technological progress and technological efficiency. They found that since reform and opening-up, the main source of China's total factor productivity growth was technological progress. Similarly, Zheng and Hu [6], Yan and Wang [7] and Yu et al. [8] adopted Malmqusit Index Method to decompose total factor productivity into technological progress and technological efficiency, thus gained the same conclusion as Wu's [4]. Xu et al. [9] constructed an accounting framework of Aggregate Production Possibility Frontier (APPF) to explore driving force of China's economic growth. The empirical results showed that physical capital investment was the main driving force, and contribution of total factor productivity was also obvious. In these papers, total factor productivity is seen as a technological factor, which means except physical capital and labor force, human capital has no place. This may inevitably lead to overestimation of technological innovation's contribution, meanwhile, underestimation of human capital's contribution to economic growth. Some scholars, such as Chen and Li [10], pointed out that the impact of human capital on economic growth should not be ignored. Notwithstanding, only technological innovation appeared in their economic growth model instead of human capital. Zhao and Yang [11] argued that technological progress was not the only factor leading to total output other than capital and labor input. Therefore, total factor productivity was divided into technological progress and institutional change in their study and the latter had a significant impact on economic growth through capital and labor channels. However, Zhao and Yang did not further explore root cause of institutional change, which was actually the role of human capital. Mentioning the importance of human capital in economic growth, Fleisher, Li and Zhao [12] believed that except physical capital and labor force, if remaining economy-driving forces were all classified as total factor productivity without considering human capital, the contribution of technological innovation to economic growth would be overestimated. On the contrary, introduction of human capital into economic growth accounting would rationalize contribution of technological innovation.

Secondly, some researchers distinguish the two notions in form, but in content, human capital includes technological innovation. To be specific, technological innovation is regarded as a part of human capital, which is a kind of confusion that form is separated but content is not really separated. In the paper of Wang and Fan [13], for instance, the indicators measuring human capital stock included not only workers' education level but also R&D expenditure and technological achievement represented by the number of patent applications. Besides, many other scholars regard R&D expenditure as a part of human capital investment. Xu and Gong [14] defined human capital investment as the amount of financial expenditure on culture, education, science and health. Hou et al. [15] pointed out that the use of scientific research expenditure was actually a process of continuous improvement of scientific researcher's ability, hence scientific research expenditure belonged to human capital investment. Xu [16] also stated that R&D was a process of creating and applying knowledge, which consumed individual intelligence and physical strength and produced innovative outcomes. As a result, both education expenditure and scientific research expenditure should belong to human capital investment. In addition to scientific research expenditure, Song et al. [17] treated the number of scientific and technological personnel per 10000 urban employees as human capital. Sun and Yi [18] regarded the proportion of scientific researchers in total population as educational human capital. Lu and Zhou [19] considered the acceptance of patent applications and turnover of technology market as a part of human capital. Nevertheless, Qian [20] argued that the target of human capital investment was human while the target of R&D investment was object. If R&D expenditure can be seen as a part of human capital investment simply because it can improve ability of scientific researchers, then almost all productive expenditures will belong to human capital investment, which is obviously inconsistent with the reality. In summary, whether R&D expenditure belongs to human capital investment is controversial and the reason is that boundary between human capital and technological innovation is unclear.

Finally, some papers have distinguished human capital and technological innovation both in form and content, yet there are still problems of incompletion. To be specific, human capital is represented only by education-related indicators. As mentioned above, human capital, a combination of wisdom and physical fitness, is accumulated through education, basic research, on-the-job training and medical care. In other words, the distinction is made between technological innovation and education rather than human capital. In earlier studies, Romer [21] expressed human capital in terms of literacy rate in UNESCO database. Mankiw, Romer and Weil [22] adopted the proportion of workers with secondary education in total population as human capital. Romer [23] and Barro and Lee [24] took primary and secondary school enrollment rate in the initial year as the initial level of human capital. Wang and Yao [25] used average years of education of the population aged 14 to 65 to represent human capital stock, and then calculated total factor productivity in Solow Residual Method. It was revealed that physical capital was the main source of China's economic growth, and the contribution of total factor productivity was greater than that of human capital. Different from average years of education, Wang et al. [26] multiplied the total amount of labor force with a certain degree of education by years of education to measure human capital stock. They then measured technological innovation with scientific and technological capital stock accumulated by R&D expenditure. It was found that human capital and technological innovation contributed increasingly to China's economic growth. Bai and Zhang [27] adopted years of education to calculate simultaneously the stock and intensity of human capital. In their empirical study, human capital stock was estimated by total years of education, human capital intensity was approximated by average years of education, and R&D intensity was measured by the proportion of R&D expenditure in GDP. They claimed that human capital was a labor-quality other than labor-quantity input. Thus it must be taken into consideration when estimating total factor productivity. In addition to human capital stock, Whalley and Zhao [28] saw the number of graduates with different education levels as estimated value of human capital and then calculated the residual in growth accounting to obtain total factor productivity. The empirical results showed that the value of total factor productivity was very small and negative, indicating that China's economic growth was mainly driven by joint accumulation of physical capital and human capital. The conclusions of Whalley and Zhao are different from those of Wang et al. and Wang and Yao due to various measurement indicators of human capital.

By reviewing literature, we can find that human capital and technological innovation have not been well distinguished. Two opinions that technological innovation includes human capital and human capital includes technological innovation exist at the same time. In addition, the academic world has not reached an agreement on measurement indicators of human capital. Different measurement indicators may lead to different conclusions and contributions of human capital to economic growth. This paper subsequently will discuss differences and relationship between human capital and technological innovation, which is also helpful to calculation and measurement of human capital.

3. Differences and Relationship between Human Capital and Technological Innovation

Before defining the concept and scope of human capital, we need to clarify differences and relationship between human capital and technological innovation. The differences are mainly reflected in the following three aspects.

In the first aspect, technological innovation emphasizes behavior while human capital emphasizes connotation. Technological innovation, on the one hand, is generation of new ideas and invention of new technologies; on the other hand, it refers to transforming potential productivity into real productivity as well as transforming new knowledge or technology into specific innovation achievements (such as products or services), which then enter market and finally realize market value. To sum up, technological innovation is an innovative behavior of scientific researchers and emphasizes commercial application of new technology. Human capital, however, is a combination of wisdom and physical fitness condensed in workers. Wisdom includes quality, ability and experience, and physical fitness includes health, physical strength and action. The accumulation channels of human capital include education, "learning by doing", health care and sports activities. Human is the carrier of human capital – in other words, human capital cannot exist independently without the carrier. Intangible human capital is attached to individual and takes individual's physical ability as the premise. It is reflected through a certain labor and production process playing the role of value proliferation.

The second point is that technological innovation is a short-term business activity with real-time benefits while human capital accumulation is a long-term strategic process with lifelong benefits. Technological innovation is a discontinuous event whose beginning is generation of new knowledge or technology, and ending is successful realization of innovative achievements' commercial value. Moreover, technological innovation has periodicity, and each cycle includes four stages – formation, development, maturity and recession. If innovation achievement is no longer required by market, creating profits will become difficult. Then market will initiate elimination function and technology will initiate self-renewal function. In the end, existing technology will be replaced by another new technology. Third, market demand is the starting point and profit is the core driving force of technological innovation. To ensure market position and economic benefits, innovation subject needs to adapt to changeable market demand and carry out technological innovation activities quickly and frequently. The standard to test success of technological innovation activity is not completion of technology but realization of commercial value. Therefore, technological innovation is an economic activity pursuing short-term benefits. Contrary to short-term technological innovation, human capital means long-term accumulation, which is a process of continuous improvement of wisdom and physical fitness. The total amount of wisdom and physical fitness stored in individuals at a certain time is the result of human capital accumulation, whose main channel is education. Generally, the purpose of a country's education development is not to pursue profits but to improve national quality and provide potential sources for both social and economic development. Furthermore, the accumulating process of human capital is phased over several steps. Before taking part in work, individuals accumulate human capital in forms of quality and ability through education, aiming to be capable of thinking and understanding. During work, workers accumulate human capital in forms of skills and experience through practice and on-the-job training, aiming to have creativity and productivity. An old Chinese saying goes, "It takes ten years to grow a tree but one hundred years to cultivate a person". Human capital is of great strategic significance because it is real embodiment of a country's power and determines economic growth potential. If compared technological innovation to the sudden impulse of economic growth, then human capital is the sustainable driving force of economic growth.

Last but not least, technological innovation is easy to quantify while human capital is difficult to quantify. The indicators measuring technological innovation include the number of international patent applications of PCT (Patent Cooperation Treaty), intellectual property income, top 500 world-famous brands, etc. In addition, there are other indicators such as R&D expenditure, R&D personnel, scientific and technological papers and works, technological invention awards, etc. These indicators all have specific values, so technological innovation is much easier to quantify. On the contrary, human capital quantification is doomed to be difficult. As mentioned above, human capital refers to wisdom and physical ability which is not independent of individual, so it is impossible to observe it directly. Moreover, human capital accumulation is a continuous dynamic process that is much more complicated to measure than static activities. However, this does not mean that human capital cannot be measured. In next section, Solow Residual Method will be used in an effort to measure human capital.

Although there are several differences between human capital and technological innovation, there are still connections between them. On the one hand, technological innovation is an activity of applying new knowledge and technology and then transforming them into innovative achievement. New knowledge and technology come from human wisdom and quality, which means technological innovation is essentially a kind of human activity. On the other hand, perceiving changes of market demand, realizing commercial values of innovative achievement, imitating and surpassing new technology all need individual's ability, experience and physical fitness as the backing. Accordingly, technological innovation is inseparable from the role of human capital. The relationship between human capital and technological innovation is also reflected in that human capital can promote technological innovation, absorption and imitation. Benhabib and Spiegel [29], based on cross-section panel data of 78 countries from 1960 to 1985, found that level of human capital stock determined level of technological innovation, and technologically weak countries with more human capital stock could quickly catch up with technologically leading countries. Vandenbussche, Aghion and Meghir [30], based on panel data of 19 OECD countries from 1960 to 2000, claimed that skilled human capital contributed to technological innovation and unskilled human capital contributed to technological imitation. Fleisher, Li and Zhao [12] used provincial data of China from 1985 to 2003 to investigate impacts of human capital on total output and total factor productivity. Their study showed that human capital directly promoted economic growth by itself and indirectly promoted through technological innovation channel. Furthermore, impacts of human capital on total factor productivity can also be divided into direct impact and indirect impact. The direct impact is reflected in improvement of technological innovation and the indirect impact is reflected in improvement of technological absorption capacity.

These are the main differences and connections between human capital and technological innovation. In a word, technological innovation is a short-term activity that attaches importance to economic benefits while human capital accumulation is a long-term process that attaches importance to social benefits. Human capital is the foundation of technological innovation. Clarifying the differences between them will help to measure stock and growth rate of human capital and objectively understand the contribution of human capital to economic growth.

4. Calculating Stock and Growth Rate of Human Capital

4.1 Model Setting

We assume a Cobb-Douglas production function, and input factors include physical capital, human capital, labor force and technological innovation. Bai and Zhang [27] pointed out that when accounting for technological innovation or total factor productivity, physical capital, labor force and human capital are necessary elements. Thus, when we calculate human capital, production function should also include physical capital, labor force and technological innovation. Based on the assumption of Cobb-Douglas production function, to calculate stock and growth rate of human capital, this paper uses Solow Residual Method, which is proposed by American economist Robert M. Solow based on Cobb-Douglas production function to calculate the residual value after regression. As discussed in the third section, there are obvious differences between human capital and technological innovation. Therefore, when using Solow Residual Method to calculate human capital stock, we will further eliminate technological innovation after eliminating physical capital and labor force. Assuming Cobb-Douglas production function is constant returns to scale and technological progress is Harold neutral, the production function is:

$$Y_t = K_t^{\alpha} H_t^{\beta} (AL)_t^{1-\alpha-\beta} \quad (1)$$

In this function, Y_t is total output, K_t is physical capital, H_t is human capital, A_t is technological innovation, L_t is labor force, and $(AL)_t$ is effective labor force., α, β and $1\text{-}\alpha\text{-}\beta$ are output elasticity, i.e. share of factor income of physical capital, human capital and effective labor force respectively.

Take natural logarithm on both sides of Function 1 and obtain:

$$\ln Y_t = \alpha \ln K_t + \beta \ln H_t + (1-\alpha-\beta)\ln(AL)_t \quad (2)$$

Take derivation of t on both sides of Equation 2 and move items to get Solow residual value:

$$\beta\frac{\dot{H}_t}{H_t} = \frac{\dot{Y}_t}{Y_t} - \alpha\frac{\dot{K}_t}{K_t} - (1-\alpha-\beta)\left(\frac{\dot{A}_t}{A_t} + \frac{\dot{L}_t}{L_t}\right) \quad (3)$$

Accordingly, growth rate of human capital is:

$$g_H = [g_Y - \alpha g_K - (1-\alpha-\beta)(g_A + g_L)]/\beta \quad (4)$$

In Equation 4, g_H is growth rate of human capital, g_Y is growth rate of total output, i.e. economic growth rate, g_K is growth rate of physical capital, g_A is growth rate of technological innovation, and g_L is growth rate of labor force.

4.2 Variable Choices and Data Sources

This paper collects the time series data of 10 representative countries from 1996 to 2019 to calculate and compare human capital country by country. First, GDP growth rate is selected to represent economic growth. Economic growth refers to the continuous and stable increase of an economy's production over a period of time due to the increase of input factors [18]. And GDP refers to the final result of production activities of all permanent residents in a country (or region) within a certain period of time. Thus, GDP growth rate can be used to measure economic growth. Data are from Penn World Table 10.0 database [31], which provides two types of GDP – output-side real GDP and expenditure-side real GDP. The former one aims to measure living standard of people and the latter one aims to measure actual production capacity of an economy [32]. Since the input factors we select are all from production field, output-side real GDP is more suitable for our empirical study. Second, physical capital stock is calculated by using buildings and equipment inputs. As mentioned by Sun and Ren [33], in theory of growth accounting, when measuring physical capital, it is necessary to classify input factors, which are generally divided into buildings and equipment. Penn World Table 10.0 database provides the actual value of physical capital stock that is calculated by using constant prices of buildings and equipment. Next, referring to the practice of Zhao and Yang [11], the number of persons engaged is used to measure labor force, and data is also from Penn World Table 10.0 database. Finally, the proportion of R&D expenditure in GDP and the number of patent applications are selected to measure technological innovation. It is believed that intangible technological capital stock is accumulated by R&D investment. Therefore, when investigating the contribution of technological capital, Wang et al. used the proportion of R&D expenditure in GDP [26]. Deng [34] further claimed that patents and R&D activities were closely linked, and combination of the two could better measure technological innovation. Besides, we obtain data from WDI (World Development Indicators) database of the world bank, and then integrate labor force and technological innovation to obtain effective labor force.

4.3 Calculation and Comparison of Human Capital

Combining indicators and data, the econometric regression equation corresponding to equation 2 is:

$$\ln Y_t = \beta_0 + \beta_1 \ln K_t + \beta_2 \ln(AL)_t + \varepsilon_t \quad (5)$$

In this equation, residual term includes human capital in logarithmic form. Ordinary Least Square is used to estimate country by country, and basic regression results are shown in the odd columns of Table 1 and Table 2. It should be noted that there is a certain connection between human capital, physical capital and effective labor force, which implies that regression will inevitably have endogeneity problem. In the absence of instrumental variables, this paper solves endogeneity by using lagged values of physical capital and effective labor and Two-stage Least Square method. The regression results are shown in the even columns of Table 1 and Table 2.

In the above tables, the coefficient of ln(capstock) is output elasticity of physical capital, i.e. . The coefficient of ln(efflabor) is output elasticity of effective labor, i.e. . Subsequently, output elasticity of human capital, i.e. can be obtained, which is shown in the antepenultimate row of Table 1 and Table 2. After calculating growth rate of total

Table 1. Regression results of China, the United States, Japan, Germany, and the United Kingdom

	China		United States		Japan		Germany		United Kingdom	
Variables	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
ln(capstock)	0.472***		0.533***		0.209**		0.206**		0.491***	
	(-0.0768)		(-0.171)		(-0.0884)		(-0.0784)		(-0.055)	
ln(efflabor)	0.102***		0.203***		0.352***		0.583***		0.390*	
	(-0.0238)		(-0.0619)		(-0.0952)		(-0.101)		(-0.197)	
L.ln(capstock)		0.477***		0.524***		0.205**		0.208**		0.497***
		(-0.0776)		(-0.168)		(-0.0868)		(-0.0792)		(-0.0557)
L.ln(efflabor)		0.099***		0.200***		0.363***		0.557***		0.479*
		(-0.0231)		(-0.0609)		(-0.0983)		(-0.0968)		(-0.242)
Output Elasticity of Human Capital	0.426	0.424	0.264	0.276	0.439	0.432	0.211	0.235	0.119	0.024
Observations	24	24	24	24	24	24	24	24	24	24
R-squared	0.998	0.998	0.987	0.987	0.778	0.778	0.925	0.925	0.847	0.847

Table 2. Regression results of Australia, Canada, India, Brazil and Republic of Korea

	Australia		Canada		India		Brazil		Republic of Korea	
Variables	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
ln(capstock)	0.468***		0.470***		0.508***		0.335***		0.452***	
	(-0.105)		(-0.0318)		(-0.048)		(-0.0607)		(-0.039)	
ln(efflabor)	0.168***		0.316***		0.208***		0.193***		0.330***	
	(-0.031)		(-0.0318)		(-0.0403)		(-0.0348)		(-0.0657)	
L.ln(capstock)		0.464***		0.466***		0.518***		0.330***		0.440***
		(-0.105)		(-0.0315)		(-0.0489)		(-0.0598)		(-0.038)
L.ln(efflabor)		0.167***		0.255***		0.212***		0.197***		0.363***
		(-0.0309)		(-0.0257)		(-0.0411)		(-0.0356)		(-0.0721)
Output Elasticity of Human Capital	0.364	0.369	0.214	0.279	0.284	0.270	0.472	0.473	0.218	0.197
Observations	24	24	24	24	24	24	24	24	24	24
R-squared	0.948	0.948	0.952	0.952	0.998	0.998	0.990	0.990	0.967	0.967

output, physical capital stock, and effective labor force of each country, we then calculate growth rate of human capital by using factor output elasticity of 2-SLS and equation 4, and the results are shown in Table 3. Finally, the residual value of regression is derived – that is, human capital stock of each country from 1997 to 2019, as depicted in Figure 1 below.

As can be seen in Table 3 and Figure 1, the growth rate of human capital in developing countries is generally higher than that in developed countries. From 1996 to 2019, China has the highest growth rate of human capital (4.92%) and is more than twice as much as that of the United States. In terms of human capital growth rate, China is followed by India, whose GDP is close to Germany's GDP. Similarly, India's human capital growth rate is twice as much as that of Germany. The reason may be that India, as a developing country, has high growth rate of population and effective labor input, hence growth of human capital has an advantage of population scale.

A more noteworthy country is Japan. As shown in Table

Table 3. The growth rate of total output, physical capital, effective labor force and human capital of each country from 1996 to 2019

	Growth rate of total output	Growth rate of physical capital	Growth rate of effective labor force	Growth rate of human capital
China	6.60%	8.71%	3.57%	4.92%
The United States	2.46%	1.98%	3.59%	2.57%
Japan	0.36%	0.35%	0.95%	-0.12%
Germany	2.21%	2.11%	2.32%	2.05%
The United Kingdom	2.50%	3.92%	1.08%	1.53%
Australia	3.56%	2.84%	5.13%	3.77%
Canada	2.83%	2.81%	3.72%	2.05%
India	7.30%	9.77%	5.24%	4.17%
Brazil	3.65%	4.86%	2.15%	3.43%
Republic of Korea	3.06%	3.86%	2.27%	2.72%

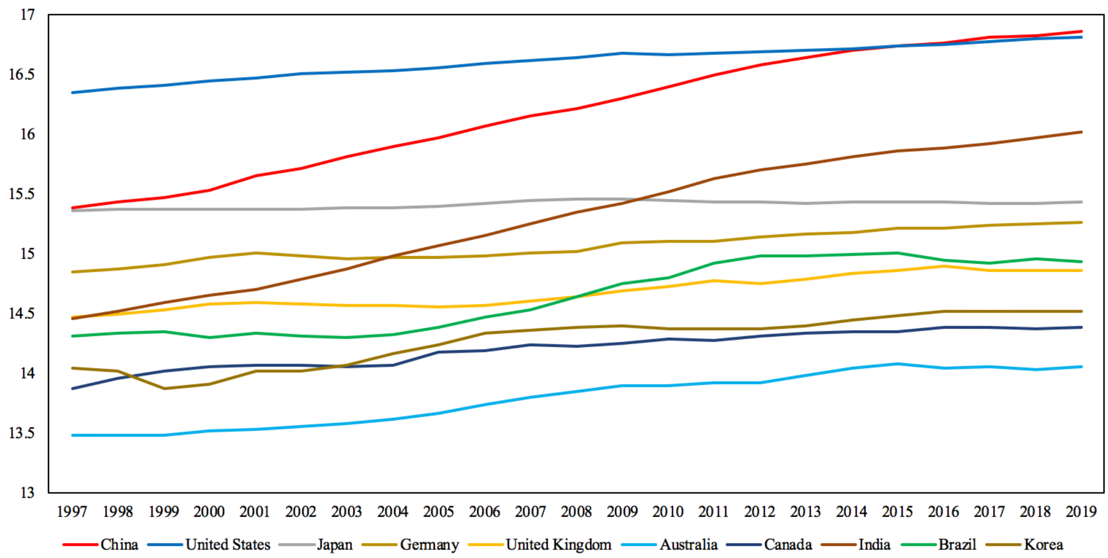

Figure 1. Human capital stock based on regression residual values of each country from 1996 to 2019

1, Japan has a large elasticity of human capital, which is credited with government's successive attention to education and two successful education reforms in history. The first education reform took place in Meiji Restoration period (1868-1912). Reform contents included learning actively from western advanced countries, forming a unified education network throughout the country and taking primary compulsory education as the central link of education reform [35]. In the early stage after World War II, Japan, as a defeated country, was devastated and depressed and its total output fell sharply. In 1947, Japan's government published the basic law on education, which proposed to establish a democratic and cultural country. To achieve this goal, Japan mainly depended on the power of education, thus second comprehensive education reform commenced. First step was increasing investment in education to ensure adequacy of education funds. From 1960 to 1970, growth rate of Japan's education expenditure firstly exceeded its GDP. At the same time, the proportion of government education expenditure in GDP continued to increase, which surpassed 4% (4.01%) in 1972, further surpassed 5% (5.06%) in 1979 and finally reached 5.60% in 1987, higher than other developed countries' in the same period. Second policy was reforming compulsory education and strengthening its popularization. In 1947, Japan's government changed the compulsory education from six-year to nine-year and continued to popularize it nationwide. In 1953, the popularization rate of compulsory education reached 99.9%, and in 1971, the enrollment rate of primary and secondary schools was over 100% (100.85%), ranking in the forefront among developed countries. The third point was attaching importance to senior high school and higher education to cultivate professional talents. Japan's senior high school enrollment rate was about 40% in 1950, running up to 93% in 1976. Higher education enrollment rate was about 20% in 1960, amounting to over 50% in 1976 [36], marking the beginning of higher education popularization. The popularization of senior high school education and higher education had further promoted accumulation of human capital and provided abundant professional talents for transformation of industrial structure, technology introduction and absorption in Japan. In addition, Japan strengthened science and engineering education of university to cultivate scientific and technological talents for R&D. Meanwhile, it revitalized vocational education to provide skilled talents for industrial development. Only after two or three decades, Japan's education had advanced tremendously and education level of the whole population had been greatly improved, which accumulated a large amount of human capital for economic growth. In 1972, Japan overtook Germany and became the world's second largest economy. In the meantime, Japan's technological innovation level gradually surpassed that of Germany, Britain and France. Takeo Fukuda, the 67th Prime Minister of Japan (served from 1976 to 1978), once pointed out that, "It is human capital that revitalizes the country, shoulders the national missions and realizes the national prosperity. Japan is not a well-resourced country, and the reason why it is able to become strong and powerful in a short time is popularization of education and improvement of national education level". However, after the 1990s, because of capital market collapse and real estate bubble, Japan's economy suddenly slowed down and growth rate of human capital, at the same time, had not improved for a while. According to the calculation results in Table 3, average growth rate of human capital in Japan from 1996 to 2019 is -0.12%, ranking poorly among many countries. Japan has a high elasticity of human capital, so as long as the human capital development strategy is properly changed, growth effect of human capital can be brought into play again.

In China, human capital stock had been continuously rising from 1996 to 2019, and even surpassed that of United States in 2015. Since the 1990s, with rapid economic growth, fast urbanization process, prominent demographic dividend and attention of the whole society and families to education, China had a great advantage of accumulating human capital. Demographic dividend was gradually changing into human capital dividend, and China was gradually moving from a country with large population to a country with powerful human capital. Education is the main way of human capital accumulation, and China holds the biggest educational work all over the world. After years of development and reform, China's education had made great achievements and overall education level of people had been greatly improved. As can be seen first from education investment, the total investment in education increased at an average annual rate of 16.30% from 1991 to 2019, from 73.150 billion yuan to 501.7812 billion yuan, and the proportion in GDP increased from 3.32% to 5.09% [37]. Secondly, from the perspective of education, the number of people without being educated of the total population in China had been decreasing from 39.00% to 7.33% from 1982 to 2019. Among the population aged 15 and over, people with junior high school education or above increased from 251 million to 932 million, and the proportion increased from 37.15% to 82.52%. The average schooling years of working-age population increased from 6.24 years in 1985 to 10.5 years in 2019 [38], higher than world average level 8.5 years [39]. Thirdly, from the perspective of education enrollment rate, the population coverage rate of nine-year compulsory education reached 85% in 2000, and the goal of "basically popularizing nine-year compulsory education and basically eliminating illiteracy among young and middle-aged people" was initially achieved. In 2002, the gross enrollment rate of higher education reached 15%, marking the beginning of higher education popularization. In 2010, the population coverage rate of "two basically" reached 100%, which meant that China had fully realized the goal of "two basically" and taken the lead in realizing education for all people among nine large-population developing countries (which are China, India, Indonesia, Bangladesh, Pakistan, Egypt, Nigeria, Mexico and Brazil). In 2015, the gross enrollment rate of senior high school education reached 87%, marking the realization of "basically popularizing senior high school education". By the end of 2018, the gross enrollment rate of pre-school education was 81.7%, the net enrollment rate of primary school-age children was 99.95%, the gross enrollment rate of junior middle school was 100.9%, the consolidation rate of nine-year compulsory education was 94.2%, the gross enrollment rate of senior high school was 88.8%, and the gross enrollment rate of higher education was 48.1% [40].

Since human capital stock is going up, the contribution of human capital to China's economic growth is also becoming increasingly prominent. Column 2 of Table 1 shows that elasticity of human capital is 0.424, close to that of physical capital 0.477, which means that China's economic growth is driven by accumulation of both physical capital and human capital. Large-scale physical capital investment can promote rapid improvement of economic growth in the short term. However, it is impossible for an economy to achieve sustainable growth only by physical capital investment without human capital accumulation. When there is too much physical capital and little human capital, advanced machinery and equipment cannot be fully utilized by workers, and production efficiency is greatly reduced, resulting in the decline of marginal income of physical capital, which will finally hinder economic development. On the contrary, when there is too much human capital and little physical capital, resources such as production materials and jobs will become tight because high-level human capital has to engage in simple work so that low-level human capital becomes unemployed. In brief, economic growth needs both physical capital and human capital. The coordination and matching of these two kinds of capital can ensure a rapid and sustainable economic growth. The matching of human capital and physical capital, in addition, is a sufficient and necessary condition for technological innovation. Technological innovation is a process of transforming new ideas and technologies into innovative achievements and then realizing commercial value. This process is inseparable from machinery, equipment, and wisdom and physical strength of technicians. Therefore, without either human capital or physical capital, technological innovation cannot take place.

Since the stock, output elasticity and growth rate of human capital are all calculated by using Solow Residual Method, this paper will next adopt Index Weight Assignment Method and Two-level & Three-factor CES Function to construct a comprehensive index so as to measure human capital stock of China from 1978 to 2019. We then compare the measuring results with the calculating results to test rationality of this comprehensive index, and finally predict China's human capital level in 10 years.

5. Measuring China's Human Capital Stock

5.1 Measuring Indicators

Referring to the concept of human capital and the differences between human capital and technological innovation in section 3, we define that human capital includes three factors – knowledge, quality and health. Knowledge comes from basic research, quality comes from education, and health comes from medical care and sports. Therefore, the comprehensive index of human capital is composed of three sub-indicators – basic research, education (academic and physical education) and health care. General research and experimental development (R&D) are divided into three types – basic research, applied research and experimental development. Basic research refers to experimental or theoretical research aiming to reveal essence of objective things and obtain new discoveries, theories and basic principles. It takes scientific theories and works as the main form, reflecting original innovation ability of knowledge. Unlike applied research and experimental development, the objective of basic research is not specific application or economic benefit. That's why we classify the basic research into human capital as the source of knowledge.

To unify dimension, we use the number of personnel in relevant fields for three sub-indicators. As mentioned above, human capital refers to knowledge, quality and physical ability attached to individuals. Therefore, it is reasonable using the number of personnel to represent human capital. First, basic research is presented by the number of researchers in basic research and experimental development, involving scientific R&D institutions, colleges and universities and industrial enterprises above designated scale. Second, mainly accumulated by education, human capital is embodied in quality and ability of school students, which will determine employment rate of graduates [41]. Thus, education index is seen as the number of graduates of all kinds of education at all levels, including general education, vocational education and adult education. Thirdly, employees in health and sports industries are necessary for people to obtain medical resources and participate sports activities, which can objectively reflect a part of human capital [18]. That's why we use the number of personnel in various health institutions and sports system to represent health care index. The personnel of health institutions include health technicians such as doctors, nurses and pharmacists, as well as non-health technicians such as managers and skilled workers, involving hospitals, grass-roots medical and health institutions, professional public health institutions, etc. The personnel of sports system include athletes, full-time coaches, full-time cultural teachers, involving sports administrative organs, training bases and stadiums, sports vocational colleges, sports middle schools and primary schools. The classification standard and data sources stem from China Statistical Yearbook and China Education Statistical Yearbook of the National Bureau of Statistics.

5.2 Measuring Equation

Cobb-Douglas function assumes that substitution elasticity between two factors is one, but practically, substitution elasticity between every two indicators of human capital comprehensive index is different. Under this situation, Two-level & Three-factor CES Function, which allows substitution elasticity varies among factors, is another choice. This paper uses Two-level & Three-factor CES Function to construct a comprehensive index of human capital, which is shown as:

$$H_t = [w_2\left(w_1 BR_t^{\rho_1} + (1-w_1)EDU_t^{\rho_1}\right)^{\frac{\rho_2}{\rho_1}} + (1-w_2)HS_t^{\rho_2}]^{\frac{1}{\rho_2}} \quad (6)$$

The first level is:

$$H_t^{'} = \left(w_1 BR_t^{\rho_1} + (1-w_1)EDU_t^{\rho_1}\right)^{\frac{1}{\rho_1}} \quad (7)$$

The second level is:

$$H_t = (w_2 H_t^{'\rho_2} + (1-w_2)HS_t^{\rho_2})^{\frac{1}{\rho_2}} \quad (8)$$

The first-level elements include the number of basic researchers, i.e. BR_t, and the number of education graduates, i.e. EDU_t. The substitution elasticity between BR_t and EDU_t is $\sigma_1 = 1/(1-\rho_1)$. At the second level, the combined element of BR_t and EDU_t, i.e. $H_t^{'}$ recombines with the number of health and sports personnel, i.e. HS_t to form an integrated CES function. The substitution elasticity between $H_t^{'}$ and HS_t is $\sigma_2 = 1/(1-\rho_2)$. w_1 and w_2 are weights, equal to relative ratio of expenses which are respectively R&D expenditure, total investment of national education and total cost of medical care. Calculating equation of substitution elasticity σ_1 is:

$$\sigma_1 = \frac{d(\frac{EDU_t}{BR_t})/(\frac{EDU_t}{BR_t})}{dMRS_1/MRS_1} \quad (9)$$

In Equation 9, is marginal rate of substitution between the number of basic researchers and the number of education graduates . And it is calculated as follows:

$$MRS_1 = -\frac{(1-w_1)d(EDU_t)}{w_1 d(BR_t)} \quad (10)$$

Similarly, calculating equation of substitution elasticity is:

$$\sigma_2 = \frac{d(\frac{HS_t}{H_t^{'}})/(\frac{HS_t}{H_t^{'}})}{dMRS_2/MRS_2} \quad (11)$$

In Equation 11, is marginal rate of substitution between the combined element and the number of health and sports personnel . And it is calculated as follows:

$$MRS_2 = -\frac{(1-w_2)d(HS_t)}{w_2 d(H_t^{'})} \quad (12)$$

5.3 Measuring Results

By using data of three sub-indicators and equation 7 to 12, substitution elasticities are calculated as and . Bringing them into equation 6, we can obtain the final measuring results of human capital. In line with the year span in section 4, Table 4 shows human capital from 1996 to 2019. Further calculation shows that growth rate of the measuring value of human capital is 5.02%, very close to that of the calculating value of human capital 4.92% in section 4. This indicates that the comprehensive index of human capital constructed above is scientific and effective. Moreover, growth rate of the number of basic researchers is 5.00%, growth rate of the number of school graduates is 0.39%, growth rate of the number of health and sports personnel is 1.22%, and growth rate of combined factor (of the number of basic researchers and school graduates) is 5.01%.

Table 4. Measuring results of China's human capital stock from 1996 to 2019

Year	Number of basic researchers	Number of graduates	Number of health and sports personnel	Human capital H'	Human capital H
1996	6.96	5050.02	688.35	7.10	7.35
1997	7.17	5341.28	698.80	7.30	7.57
1998	7.87	5575.14	701.65	8.02	8.31
1999	7.60	5845.38	704.67	7.74	8.01
2000	7.95	5968.62	706.40	8.09	8.36
2001	7.88	5967.40	702.81	8.02	8.27
2002	8.40	6073.28	667.68	8.55	8.81
2003	8.97	6210.26	636.27	9.12	9.40
2004	11.07	6304.25	647.67	11.25	11.58
2005	11.54	6433.14	658.90	11.72	12.06
2006	13.13	6426.20	682.61	13.33	13.71
2007	13.81	6561.03	711.23	14.02	14.40
2008	15.40	6612.67	740.24	15.63	16.07
2009	16.46	6554.90	793.48	16.69	17.17
2010	17.37	6525.76	836.30	17.61	18.10
2011	19.32	6447.99	877.33	19.59	20.13
2012	21.22	6377.95	927.55	21.51	22.10
2013	22.32	6183.63	994.28	22.61	23.24
2014	23.54	5877.79	1038.24	23.85	24.53
2015	25.32	5749.69	1084.30	25.65	26.41
2016	27.47	5768.17	1132.06	27.83	28.68
2017	29.01	5726.28	1189.60	29.38	30.30
2018	30.50	5710.15	1244.56	30.88	31.87
2019	39.20	5810.69	1307.65	39.69	40.97

Next, based on above five growth rates, we can project human capital and relevant indicators in 10 years. The predicting formulas are $BR_{t+1} = BR_t \times (1 + 5.00\%)$, $EDU_{t+1} = EDU_t \times (1 + 0.39\%)$, $HS_{t+1} = HS_t \times$

$(1+1.22\%)$, $H'_{t+1} = H'_t \times (1+5.01\%), H_{t+1} = H_t \times (1+5.02\%)$. In addition to three sub-indicators, we also predict the number of ordinary senior high school and college graduates by using growth rate of , and professional (or assistant) doctors per 1000 population by using growth rate of . Prediction results are shown in Table 5. In terms of research and experimental development, the number of people engaged in basic research in 2019 is 392,000, which, according to prediction, will double to 670,800 by 2030. Moreover, the proportion of basic research investment in total R&D investment in 2019 is 6.14%. This number, based on prediction by using growth rate of , will go up to 8.24% in 2025, which is consistent with the goal of China's 14th Five-year Plan. The 14th Five-year Plan proposes that for innovation-driven development, average annual growth rate of R&D investment should remain more than 7%, and proportion of basic research investment in total R&D investment should reach more than 8%. Secondly, when it comes to education, in 2019, China's population aged 15 to 64 is 986 million with ordinary senior high school graduates accounting for 0.80% and ordinary university graduates accounting for 0.77%. Besides, senior high school education gross enrollment rate is 89.5% and higher education gross enrollment rate is 51.6%. It is predicted by using growth rate of that senior high school gross enrollment rate will reach 93.39% in 2030 and that of higher education will reach 53.84%. Accordingly, policy implication is that China must accelerate popularization of senior high school education and higher education. At last, in health care, the 14th Five-year Plan has added the indicator "number of occupational (assistant) doctors per 1000 population" into the category of people's livelihood and well-being, which is the main indicator of economic and social development. In 2019, the number of occupational (assistant) doctors per 1000 population is 2.76 and it will reach 3.16 in 2030, predicted by using growth rate of .

6. Conclusions

Discussing differences between human capital and technological innovation, and defining the concept and scope of human capital are of great significance to correctly understand human capital and its contribution to economic growth. After pointing out confusions between human capital and technological innovation in the existing literature, this paper first distinguishes them in three aspects. First, technological innovation emphasizes human behavior and results, which is an economic activity that transforms new knowledge or new technology into innovative achievement and finally realizes market value. Human capital emphasizes human connotation and quality, which is a synthesis of wisdom and physical fitness condensed in workers. Second, technological innovation is a short-term business activity with real-time benefits while human capital accumulation is a long-term strategic process with lifelong benefits. Third, it is easy to quantify

Table 5. Ten-year prediction of China's human capital

Year	Number of basic researchers	Number of education graduates	Number of health and sports personnel	Human capital	Number of ordinary university graduates	Number of ordinary senior high school graduates	Number of licensed doctors/1000
2020	41.16	5833.20	1323.60	43.03	761.47	792.31	2.80
2021	43.22	5855.79	1339.75	45.19	764.42	795.38	2.83
2022	45.39	5878.48	1356.09	47.45	767.38	798.46	2.86
2023	47.66	5901.25	1372.64	49.83	770.35	801.55	2.90
2024	50.04	5924.11	1389.38	52.33	773.34	804.65	2.93
2025	52.55	5947.05	1406.33	54.96	776.33	807.77	2.97
2026	55.18	5970.09	1423.49	57.72	779.34	810.90	3.01
2027	57.94	5993.22	1440.85	60.61	782.36	814.04	3.04
2028	60.84	6016.43	1458.43	63.65	785.39	817.19	3.08
2029	63.88	6039.74	1476.22	66.85	788.43	820.36	3.12
2030	67.08	6063.13	1494.23	70.20	791.48	823.54	3.16

technological innovation but difficult to quantify human capital, but this does not mean that human capital cannot be calculated or measured. That's what we do in section 4 and 5. In section 4, Solow Residual Method is used to calculate stock, growth rate and output elasticity of human capital in 10 representative countries from 1996 to 2019. The calculation results show that the United States has the largest stock of human capital while China has the fastest growth of human capital (4.92%, more than twice as much as that of the United States). In section 5, we adopt Index Weight Assignment Method and Two-level & Three-factor CES Function to construct a comprehensive index of human capital which includes three sub-indicators – the number of basic researchers, the number of graduates and the number of health and sports personnel. Subsequently, the comprehensive index plays an important role in calculating China's human capital from 1978 to 2019 and predicting human capital level in the next 10 years. Comparing the calculating and measuring results, we find that the comprehensive index of human capital is scientific and effective, and growth rate of human capital in China is around 5%. In line with the final prediction results, China should continue to increase proportion of basic research investment in total R&D investment, accelerate popularization of senior high school education and higher education, and expand supply of medical and health resources. Nowadays, the strategic orientation of China's economic development is paying attention to technological innovation, sustainable development and modern economic system construction. Human capital is the foundation of technological innovation as well as the long-term driving force of economic growth. National rejuvenation and high-quality economic development all depend on it. Therefore, China must give top priority to the development of human capital and comprehensively improve the level of human capital through education, basic research, medical care and sports activities.

References

[1] Schultz, T. W., 1960. The Formation of Human Capital by Education[J]. Journal of Political Economy. 68(6), 571-583.

[2] Becker, G. S., 1964. Human capital: A Theoretical and Empirical Analysis with Special Reference to Education[M]. New York: Columbia University Press.

[3] Lucas, R. E., 1988. On the Mechanics of Economic Development[J]. Journal of Monetary Economics. 22, 3-42.

[4] Wu, Y.R., 2002, Is China's Economic Growth Sustainable? A Productivity Analysis[J]. China Economic Review. 11(3), 278-296.

[5] Tu, Z.G., Xiao, G., 2005. China's Industrial Productivity Revolution—A Stochastic Frontier Production Function Analysis of TFP Growth in China's Large and Medium Industrial Enterprises[J]. Economic Research Journal. 3, 4-15.

[6] Zheng, J.H., Hu, A.G, 2004. An Empirical Analysis of Provincial Productivity in China (1979-2001)[R]. Working Paper No.127, University of Gothenburg, Department of Economics.

[7] Yan, P.F., Wang, B., 2004. Technical Efficiency, Technical Progress and Productivity Growth: An Empirical Analysis Based on DEA[J]. Economic Research Journal. 12, 55-65.

[8] Yu, J., Liu, R.S, Cao, Y., Pang, J.G., 2009. An Empirical Analysis of the Contribution Rate of Scientific and Technological Progress in China: 1979~2004—Based on DEA-Malmquist Index[J]. Soft Science. 23(2), 1-6.

[9] Xu, X.C, Zhang, Z.W., Chang, Z.H., Lei, Z.K., 2020. Industrial Productivity and Economic Growth Drivers in China[J]. The Journal of World Economy. 43(02), 27-50.

[10] Chen, Y., Li, Q., 2006. Measuring the S&T Progress to Economic Development: Limitation of Solow Residual and the Modification of Production Function[J]. Studies in Science of Science. 24(S2), 414-420.

[11] Zhao, Z.Y., Yang, C.F., 2011. Estimation and Explanation of China's Total Factor Productivity: 1979-2009[J]. Research on Financial and Economic Issues. 9, 3-12.

[12] Fleisher, B., Li, H., Zhao, M. Q., 2010. Human Capital, Economic Growth, and Regional Inequality in China[J]. Journal of Development Economics. 92(2), 215-231.

[13] Wang, X.L., Fan, G., 2004. Analysis on the Regional Disparity in China and the Influential Factors[J]. Economic Research Journal. 1, 33-44.

[14] Xu, X.F., Gong, D.E., 2003. An Empirical Analysis and Comparative Study of Human Capital in China's Eastern, Central and Western Regions[J]. Enterprise Economy. 10, 70-72.

[15] Hou, F.Y., Fan, Y.B., Sun, G.L., 2005. Assessment of Human Capital Reserve in China[J]. Nanjing Business Review, 3, 27-54.

[16] Xu, X.M., 2009. Human Capital Investment Compensation of Scientific Research in Universities: Based on the Regulation of Expenditures in Scientific Research Funds[J]. China Soft Science. 12, 37-43.

[17] Song, S.F., Chu, G. S. F., Cao, R.Q., 2002. Intercity

Regional Disparity in China[J]. China Economic Review. 11(3), 246-261.

[18] Sun, D.S., Yi, J.B., 2013. An Empirical Study on the Relationship between Human Capital Stock and Economic Growth—Based on International Comparative Perspectives[J]. Commercial Research. 9, 7-15.

[19] Lu, J., Zhou, H.M., 2013. Empirical Analysis of Coupling Relationship Human Capital and Economic Growth in Chinese Provinces[J]. The Journal of Quantitative and Technical Economics. 9:3-19.

[20] Qian, X.Y., 2011. The Level of Human Capital: Methodology and Empirical Study[M]. Beijing: The Commercial Press.

[21] Romer, P. M., 1989. Human Capital and Growth: Theory and Evidence[R]. Carnegie Rochester Conference. 32(1), 251-286.

[22] Mankiw, N. G., Romer, D. and Weil, D. N., 1992. A Contribution to the Empirics of Economic Growth[J]. The Quarterly Journal of Economics. 107(2), 407-437.

[23] Romer, P. M., 1993. Idea Gaps and Object Gaps in Economic Development[J]. Journal of Monetary Economics. 32, 543-573.

[24] Barro, R. J., Lee, J.W., 2001. International Data on Education Attainment: Updates and Implications[R]. Oxford Economic Papers. 53(3):541-563.

[25] Wang, Y., Yao, Y.D., 2003. Sources of China's Economic Growth, 1952-99: Incorporating Human Capital Accumulation[J]. China Economic Review. 14(1), 32-52.

[26] Wang, X.L., Fan, G., Liu, P., 2009. Transformation of Growth Pattern and Growth Sustainability in China[J]. Economic Research Journal. 1, 4-16.

[27] Bai, C.G., Zhang, Q., 2015. Estimation of China's Productivity and Decomposition of Volatility[J]. The Journal of World Economy. 38(12), 3-28.

[28] Whalley, J., Zhao, X., 2013. The Contribution of Human Capital to China's Economic Growth[J]. China Economic Policy Review. 2(1), 1350001.1-1350001.22.

[29] Benhabib, J., Spiegel, M. M., 1994. The Role of Human Capital in Economic Development Evidence from Aggregate Cross-country Data[J]. Journal of Monetary Economics. 34(2), 143-173.

[30] Vandenbussche, J., Aghion, P., Meghir, A. C.,2006. Distance to Frontier, Growth, and the Composition of Human Capital[J]. Journal of Economic Growth. 11(2), 97-127.

[31] Feenstra, R. C., Inklaar, R., Timmer, M. P., 2015. The Next Generation of the Penn World Table[J]. American Economic Review. 105(10), 3150-3182.

[32] Feenstra, R. C., Heston, A., Timmer, M. P., Deng, H.Y., 2009. Estimating Real Production and Expenditures Across Countries: A Proposal for Improving the Penn World Tables[J]. Review of Economics and Statistics. 91(1), 201-12.

[33] Sun, L.L., Ren, R.E., 2005. Estimation of Capital Investment and Total Factor Productivity in China[J]. The Journal of World Economy. 12, 3-13.

[34] Deng, Y.H., Wu G.S., 2002. A Summary of Several Measurement Methods of Technological Innovation[J]. Science & Technology Progress and Policy. 7, 66-67.

[35] Wang, G., 1987. History of Japan's Education[M]. Changchun: Jilin Education Press.

[36] Liang, Z.Y., 1981. Japan's Education and Economic Development after the Second World War[M]. Beijing: People's Education Press.

[37] Finance Department of the Ministry of Education, Statistics Department of Social Science, Technology and Cultural Industry of the National Bureau of Statistics[R]. China Educational Finance Statistical Yearbook. Beijing: China Statistics Press, 2020.

[38] China Center for Human Capital and Labor Market Research. China Human Capital Index Report[R]. Beijing: Central University of Finance and Economics, 2021.

[39] United Nations Development Programme. Human Development Report[R]. New York, 2020.

[40] Ministry of Education of the People's Republic of China. National Statistical Bulletin on the Development of Education[R]. Beijing, 2020.

[41] Kong, Z., 2008. The Influence of Education on Human Capital and Employment[J]. Education & Economy. 1, 12-16.