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The role of human capital in China's economic development: Review and new evidence ☆

Wei CHI *

E-51 School of Economics and Management, Tsinghua University, Beijing, 100084 China

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Abstract

We carefully utilize empirical methods and measurement, and find that the effect of human capital on China's economic growth may be indirect through physical capital investment. This result is different than that found for OECD countries and has not been suggested by previous studies. In addition, in determining physical capital investment, workers with college education play a more significant role than those with primary and secondary education, suggesting the possibility of capital-skill complementarity. This finding has implications for China's future regional growth inequality: the inequality may increase rather than decrease, because physical capital investment continues to accumulate faster in the eastern area where the human capital stock is larger and thus leads to greater economic growth in the east.

JEL classification code: J24
Keywords: Education; Human capital; Economic growth; Skill-capital complementarity

1. Introduction

Close-to-double-digit growth in the last several decades has gained China the praise of growth miracle. Amid the acclaim, there have been some concerns. One concern is that China's economic growth is largely labor intensive, featuring high fixed capital investment and energy consumption (Arayama & Miyoshi, 2004; Chow, 1993; International Energy Agency, 2005; Yusuf, 1994).[1] This growth pattern faces a limit. Alternatively, growth driven by human capital has potential to be substantial and sustainable due to the increase in productivity, technological innovation and diffusion (Aghion & Howitt, 1998; Lucas, 1988; Nelson & Phelps, 1966; Romer, 1990).

Another concern is, although China achieved fast economic development, the growth rates of different regions vary notably, so that the regional development gap has not been reduced but even enlarged. The large differences across regions may be caused by different regional natural conditions, government policies, and fixed capital investment including

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* Tel.: +86 10 62795072; fax: +86 10 62772021.
E-mail address: chiw@sem.tsinghua.edu.cn.

[1] According to the IEA's estimate, to produce the same dollar amount of GDP, China uses 3 times more energy than the world's average level.

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foreign direct investment. Different human capital levels across regions may also be an important contributor to regional development inequality.

Our study pertains to the two aforementioned concerns. Using provincial data from 1996 to 2004, our initial findings show an insignificant effect of human capital and a sizeable and significant effect of fixed capital investment on economic development. We also find evidence of convergence in growth rates across regions conditional on the inclusion of human capital and physical capital. These findings are consistent with empirical evidence found by previous research which suggests that China's economic growth is mostly driven by fixed capital investment and that regional development inequality is attributable to different physical capital investment amounts across regions.

However, our further analysis shows that fixed assets investment is endogenous as 84% of variation in the fixed assets investment across provinces may be explained by the provincial initial human capital stock and wealth level. Moreover, college or above level education is a more important determinant of physical capital investment decisions than primary or secondary education. After correcting for endogeneity using the two-stage least square method, we find that the effect of fixed capital investment on the growth rate is no longer significant.

These new findings have two potentially important implications: 1) human capital has already played a significant role in China's economic development in recent years, and the role of human capital may be indirect by impacting physical capital investment. 2) China's regional growth inequality may increase rather than decrease in the future. This is because eastern areas traditionally have a large stock of college-educated workers and college-educated workforce is more likely to attract physical capital investment than primary and secondary education. Thus, rather than flow to the west voluntarily, physical capital investment will continue to build up in the eastern area where the human capital stock is larger and cause the eastern area to grow faster than the central and western areas.

The rest of paper is organized as follows: in Section 2 we review previous empirical evidence regarding the role of human capital in China's economic development. Section 3 describes data and variables. Sections 4–6 presents sequentially the estimates of growth models; the impact of human capital on fixed assets investment; the 2SLS estimates; and the contribution of government and social education expenditure to workers' educational attainment. A summary and conclusion is contained in Section 8.

2. Literature review

China's rapid economic growth has stimulated a wide research interest and heated debate. The research and debate focus on whether China's economic growth is mainly driven by productivity growth or by capital and labor factor accumulation. Some researchers are more optimistic, showing evidence of a clear improvement of total factor productivity (TFP) in the post-reform period of China, and also finding that the increase in TFP has made a substantial contribution to economic growth. Specifically, the increase in TFP contributes 40% to GDP growth, roughly the same as that contributed by fixed assets investment (Borensztein & Ostry, 1996; Hu & Khan, 1997; Jefferson, Rawski, & Zheng, 1992; Yusuf, 1994). Other researchers conclude more pessimistically that economic growth in China is still mostly driven by capital investment (Chow & Lin, 2002; Woo, 1998; Wu, 2003). For example, Chow and Lin (2002) showed that the increase in TFP contributed 29% to GDP growth during 1978 to 1998, compared to a 62% contribution by capital.

Compared to capital investment and TFP, the increase in labor has generally been found as a less important growth factor. Recent research shows that 10–20% of GDP growth may be attributable to the growth of labor force (Chow & Lin, 2002; Hu & Khan, 1997; Woo, 1998; Wu, 2003). Despite the importance of the question, whether and how human capital contributes to fast economic growth in China has not been examined thoroughly. Relatively few empirical studies have included human capital as a growth factor in addition to labor. Among the few exceptions are Wang and Yao (2003) who constructed a measure of the stock of human capital and incorporated it in the growth accounting. They found that capital, labor, human capital, and TFP each accounted for 48, 16, 11, and 25% of GDP growth during the period 1978–1999. Fleisher and Chen (1997) examined the impact of human capital on TFP with human capital measured by the percentage of university graduates in the population, and found that human capital had a significant effect on TFP. Other than Wang and Yao (2003) and Fleisher and Chen (1997), several studies have included human capital in the regressions to explain regional growth disparity in China. However, since these studies focus on assessing whether the growth rates of different regions converged or not, they have not investigated the role of human capital thoroughly. Table 1 shows the list of these studies.

Table 1
Summary of previous studies

Studies	Time period of data	Dependent variable	Human capital measure	Major findings on the effect of human capital
Chen and Fleisher (1996)	1978–1993 Provincial data	Mean log difference of GDP per capita from 1993 to 1978	Secondary school enrollment/ total population in 1986	Positive but insignificant
Song, Chu, and Cao (2000)	1991 City level data	GDP per capita 1991	Number of science and technology workers per 10,000 urban workers, and per capita spending on education and science	Positive and significant
Wei et al. (2001)	1986–1995 Provincial data	Ln(per capital GDP) growth from year $t-1$ to t, $t=1987,\ldots, 1995$	Change of secondary school enrollment/ total population from year $t-1$ to t.	Positive but insignificant
Yao and Zhang (2001)	1978–1995 Provincial data	Ln(per capita GDP) growth over a four-year time span, 1978–83, 1983–87, 1987–91, and 1991–95	Average expenditure on education, science, health care, and culture activities per work-age person over the four-year time span	Positive and significant
Arayama and Miyoshi (2004)	1978–1998 Provincial data	Growth in GDP	Annual growth rate of the share of workers with secondary educational attainment	Human capital contributes 15 percent to growth. It contributes more to economic growth of central and western areas than that of the east.
Kawakami (2004)	1978–1990, 1991–1998 Provincial data	Ln(per capital GDP) growth from year $t-1$ to t, $t=1978–90, 1990–95$	The number of full-time teachers/the number of students enrolled in high schools in year t	Positive and significant

Outside China, there is a growing empirical labor literature that examines the role of human capital in economic development using cross-country data. These empirical studies include Barro (1991), Benhabib and Spiegel (1994), Barro and Sala-i-Martin (1995), Barro (2001), Gemmell (1996), and Bils and Klenow (2000). Most of these studies use Summers–Heston cross-country data (1991), which became available since the early 1990s. Krueger and Lindahl (2001) reviewed this literature and pointed out several empirical methodological issues that require attention, such as the measurement of human capital, differences between the stock and accumulation of human capital,[2] endogeneity of physical capital investment, and the indirect effect of human capital.

Those empirical studies using cross-country data have generally found that the initial stock of human capital has a larger impact on the growth rate than the increase in human capital. The exception is Gemmell (1996) who found that both the stock and accumulation of human capital were significant determinants of growth. In addition, Gemmell (1996) found that human capital had both a direct effect on growth and an indirect effect through physical capital investment.

Previous Chinese studies have not paid special attention to the differences between the stock and accumulation of human capital. Neither did they address other empirical methodological issues that Krueger and Lindahl (2001) pointed out. As can be seen in Table 1, these studies use different measures of human capital such as secondary school enrollment, the student–teacher ratio, spending on education and science, and the number of science and technology workers. Some found a significant positive effect of human capital, while others found an insignificant effect.

Our study resembles Chen and Fleisher (1996) most. They use data from 25 provinces during the period 1978–1993, and estimate the impact of human capital on the growth rate of real GDP per capita, controlling for physical

[2] There is some theoretical underpinning to why empirical growth studies need to distinguish the effect of the stock and accumulation of human capital. In the neoclassic growth literature, human capital is not considered to have a special role in production (Solow, 1956). Later theoretical studies incorporate human capital in the growth models. In one category, Mankiw, Romer, and Weil (1992) and Lucas (1988) believe that economic growth is driven by the *accumulation* of human capital. In the other category, Nelson and Phelps (1966) and Romer (1990), believe that the *stock* of human capital generates innovation and facilitates technology diffusion and adaptation, which, in turn, leads to technological progress and sustained economic growth. Also in their opinion, workers' secondary and college educational attainment rather than primary education are associated with technology innovation and diffusion, and economic growth.

assets accumulation, employment growth, foreign investment, and the coastal dummy variable. The secondary school enrollment rate in 1986 is used as a proxy for the human capital level. They found that human capital had a positive but statistically insignificant effect on the per capita GDP growth rate. Our study uses similar regression models as Chen and Fleisher (1996). With the availability of more human capital data, we follow suggestions given by Krueger and Lindahl (2001), distinguishing the stock and accumulation of human capital and investigating the potential endogeneity of physical asset investment.

3. Data and variables

Data used in our study are compiled from China Statistics Yearbooks and China Labor Statistical Yearbooks, two major sources of public data in China, from year 1996 to 2004. Provincial GDP, population, labor force, education, fixed assets investment, government revenue and expenditure, government expenditure on education, and total social education expenditure, are selected. The reason that we choose 1996 as the beginning year of the sample is because the key variable, workers' educational attainment, is reported in labor statistics yearbooks only since 1996. Another reason is that from 1997, Chongqin became the fourth municipal city directly under the central government following Beijing, Tianjin, and Shanghai, and reported data separately from Sichuan province. A statistics yearbook reports the data of the previous year. Therefore, separate data for Chongqin and Sichuan became available from 1996. Thus, our data consist of a 9-year panel of the total 31 provinces and municipal cities directly under the central government.

One of the major methodological issues in the empirical research of human capital and economic growth is the measurement of human capital. We use workers' educational attainment to measure human capital because it is

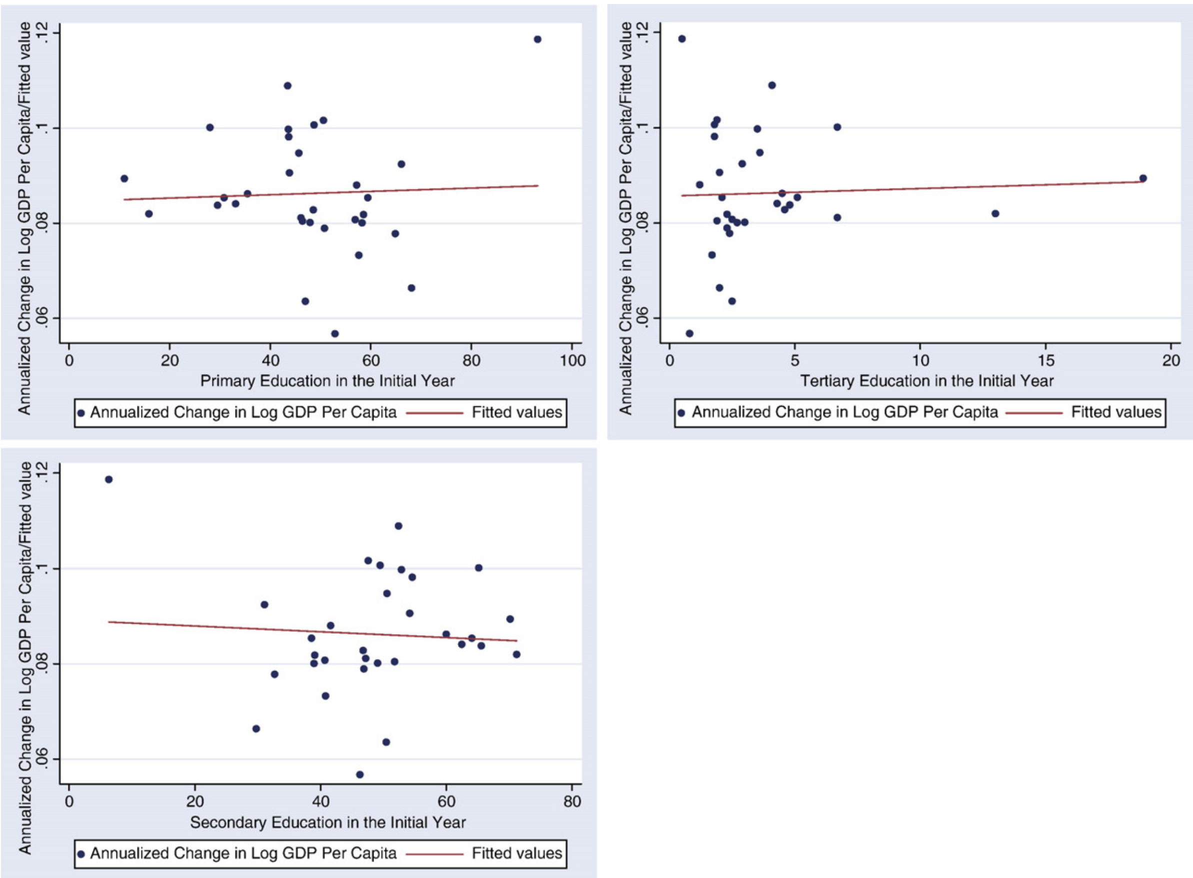

Fig. 1. Human capital stock and economic growth.

generally considered a better measure than the school enrollment rate or student–teacher ratio[3] which was frequently used in the past studies (Temple, 1999; Krueger & Lindahl, 2001). Workers' educational attainment is not often available whereas school enrollment data are. To remedy this problem, some researchers predicted workers' educational attainment and used it in the growth regression.[4] The predicted workers' educational attainment is undoubtedly an advance over the school enrollment rate, but is also subject to a greater measurement error.

We are in a better position to deal with the measurement issue. Our data is rich in information about education. In addition to school enrollment and the number of full-time teachers and staff in schools, our dataset also has educational attainment of labor force, specifically, the percentage of workers having primary, secondary, or tertiary education in a province. Unlike Barro and Lee (1993), and Benhabib and Spiegel (1994), our data are not estimated but based on surveys, and therefore are less erroneous.[5]

Variable definition and summary statistics can be found in Appendix Table. To give a descriptive presentation of the relationship between the stock and accumulation of human capital and economic growth, we plot provincial per capita GDP growth against the percentage of workers with primary, secondary, and tertiary education in 1996, and also against the change in workers' primary, secondary, and tertiary educational attainment from 1996 to 2004. In Figs. 1 and 2, the line among the scattered points represents the fitted value based on the simple single-variable regression. None of the slope estimates in the figures are significantly different from zero, suggesting that human capital has an insignificant effect on growth.

In addition, we also plot GDP growth against average fixed assets investment and the initial year's GDP level. The results are documented in Fig. 3. Fixed assets investment is positively associated with economic growth, and the slope estimate is significantly positive. The initial GDP level is also positively related to GDP growth, suggesting that rich provinces may get richer while the poor gets poorer (i.e., growth divergence), yet this estimate is not significant.

4. Estimates of growth models

Following Chen and Fleisher (1996), we estimate both cross-sectional and panel provincial growth equations. Different from them, we include two human capital variables, the initial level of human capital and the increase in human capital. Our cross-sectional growth equation is specified the same as that in Barro (1991), Benhabib and Spiegel (1994), Barro and Sala-i-Martin (1995), and Gemmell (1996).

The two models are as follows:

$$\Delta\,\mathrm{Log}\ (\mathrm{GDP})_{t-n,t} = \beta_1 + \beta_2 \Delta \mathrm{HC}_{t-n,t} + \beta_3 \mathrm{HC}_{t-n} + \beta_4 \Delta\,\mathrm{Log}\, K_{t-n,t} + \beta_5\, \mathrm{Log\ GDP}_{t-n} + \psi' \Delta X_{t-n,t} + \varepsilon \tag{1}$$

$$\Delta\,\mathrm{Log}\ (\mathrm{GDP})_{t-1,t} = \beta_1 + \beta_2 \Delta \mathrm{HC}_{t-1,t} + \beta_3 \mathrm{HC}_{t-1} + \beta_4 \Delta\,\mathrm{Log}\, K_{t-1,t} + \beta_5\, \mathrm{Log\ GDP}_{t-1} + \psi' \Delta X_{t-1,t} + \varepsilon \tag{2}$$

$\Delta\mathrm{Log}\ (\mathrm{GDP})_{t-n,t}$: The average annual increase of a province's log GDP per capita from year $t-n$ to t; GDP is deflated to the 1996 value using the provincial consumer price index;

$\Delta\mathrm{Log}\ (\mathrm{GDP})_{t-1,t}$: The increase of a province's log GDP per capita from year $t-1$ to t;

[3] Because of labor migration, student enrollment rates would not be an appropriate measure of provincial workers' human capital, as some students may work in other provinces after graduation or the local labor force may contain workers who were educated in other provinces. Labor migration across countries is relatively infrequent, thus this problem may not be serious. In the pre-reform period of China when labor migration across provinces was highly restricted, this problem might not be serious either. However, after economic reform, in recent years, although "Hukou" system has not been officially eliminated, labor migration across provinces has become much easier. Therefore, workers' educational attainment is a better and more direct measure of workforce human capital than school enrollment rates. Moreover, the student–teacher ratio may measure the quality of school, but does not necessarily measure the human capital level of workers.

[4] Barro and Lee (1993) and Benhabib and Spiegel (1994) use country-level data and regress workers' educational attainment on student enrollment rates for the countries where both data are available, and then predict average years of schooling for the countries that educational attainment data are missing.

[5] We have run the same regressions using the school enrollment rate and the student–teacher ratio as the measure of human capital. The results are not significantly different from those reported in the paper. They are available upon request.

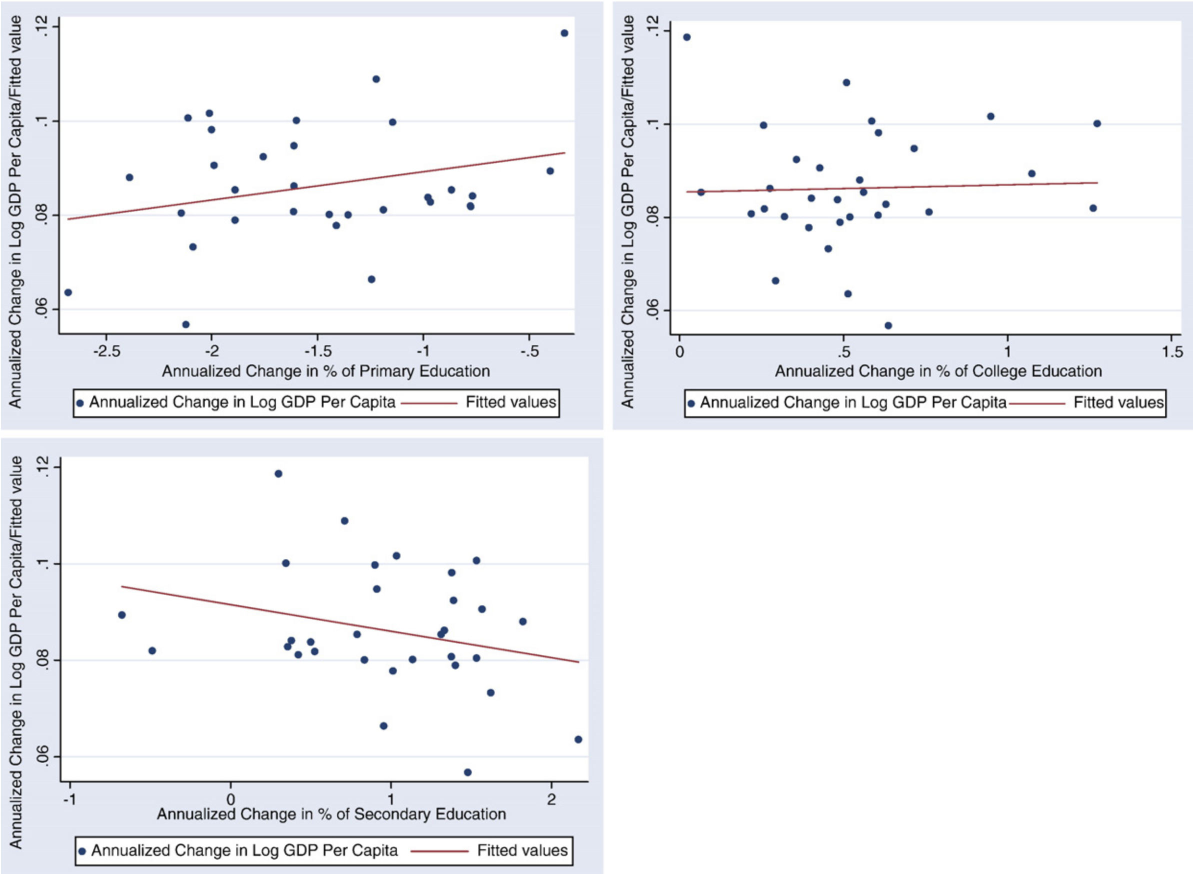

Fig. 2. Accumulation of human capital and economic growth.

$\Delta HC_{t-n,t}$: The average annual increase of the provincial human capital level from year $t-n$ to t; Human capital is measured by the percentage of workers with primary, secondary, or tertiary educational attainment.

$\Delta HC_{t-1,t}$: The increase of provincial human capital from year $t-1$ to t;

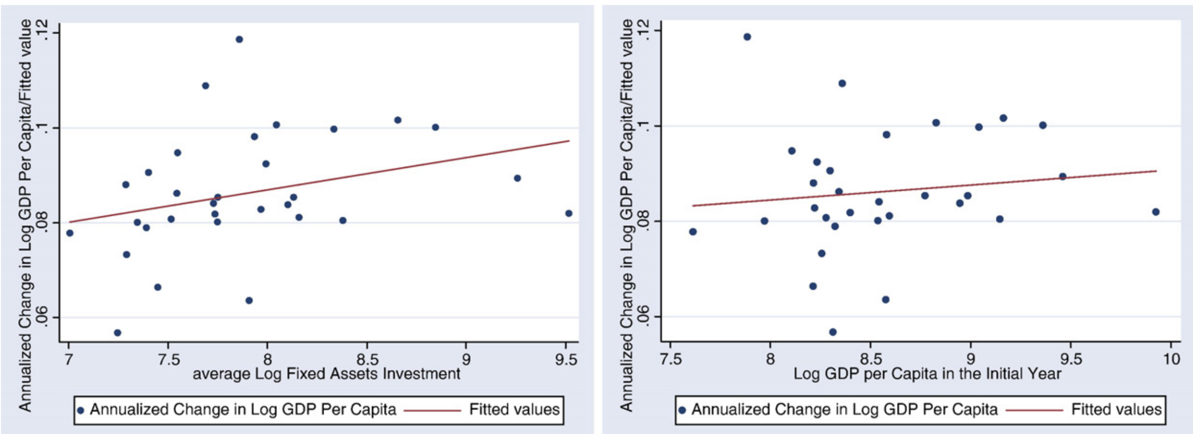

Fig. 3. Fixed capital investment, initial GDP level, and economic growth.

HC_{t-n}: Provincial human capital in the initial year $t-n$;
HC_{t-1}: Provincial human capital in the previous year $t-1$;
$\Delta LogK_{t-n,t}$: The average annual per capita fixed assets investment of a province from year $t-n$ to t;
$\Delta LogK_{t-1,t}$: Fixed assets investment per capita of a province from year $t-1$ to t;
$LogGDP_{t-n}$: A province's log GDP per capita in the initial year $t-n$;
$LogGDP_{t-1}$: A province's log GDP per capita in the previous year $t-1$;
$\Delta X_{t-n,t}$ and $\Delta X_{t-1,t}$ represent the average annual change of X variables from year $t-n$ to t, and the change of X from year $t-1$ to t, respectively.

Columns (1) through (10) of Table 2 report the estimates of cross-sectional growth equations.[6] As the first step, we only include GDP per capita in the initial year to test absolute convergence. The result is reported in column (1). Economic growth of different provinces did not show absolute convergence during the period 1996–2004. However, neither did it significantly diverge.

In the second step, we add human capital variables into the model. The results are documented in columns (2) through (4). As can be seen, neither the initial level nor the increase of workers' educational attainment explains the growth rate. Overall, these specifications have a small adjusted R^2.

As the third step, we include provincial fixed assets investment as an explanatory variable. The results can be found in columns (5) to (7). The adjusted R^2 improved considerably. Provincial fixed assets investment is significantly associated with the growth rate. Moreover, GDP per capita in the initial year starts to show a negative sign, suggesting that provinces with a high initial GDP grew slower than those with a low GDP. This result suggests that provincial economic growth shows conditional convergence with the inclusion of fixed assets investment and human capital stock and accumulation. In this stage, human capital variables, regardless of primary, secondary, or tertiary education, remain insignificant.

In the last step, we include the growth of labor force, provincial foreign direct investment, and the dummy indicator of whether a province is located in the coastal region as additional control variables. As fixed assets investment already includes foreign direct investment (FDI), FDI has little additional effect. The growth rate is negatively related to the rate of labor force growth.[7] Moreover, coastal provinces have a higher growth rate with all else controlled for. The higher growth rate of coastal provinces may be due to better natural conditions and preferential policies given to these areas since the beginning of economic reform.

The panel growth estimates are documented in columns (11) through (13).[8] These results resemble the cross-sectional growth estimates. Neither the stock nor the accumulation of human capital appears to have a significant impact on per capita GDP growth. So far, our results are consistent with previous research, which finds that economic growth in China is mostly driven by fixed assets accumulation, and that the growth rates of different provinces show conditional convergence after including fixed assets investment, and finally that human capital has an insignificant effect on provincial economic growth.[9]

In another variation, we utilize panel data and estimate panel growth models incorporating provincial fixed effects. The fixed effect panel growth model is specified as follows:

$$\Delta \mathrm{Log}\ (\mathrm{GDP})_{it} = \beta_1 + \beta_2 \Delta \mathrm{HC}_{it} + \beta_3 \mathrm{HC}_{it-1} + \beta_4 \Delta \mathrm{Log}\ K_{it} + \beta_5 \mathrm{Log\ GDP}_{it-1} + \psi' \Delta X_{it} + v_i + \varepsilon_{it} \tag{3}$$

where subscript i denotes a province and t a year. Provincial fixed effects are represented by v_i. Other than the regressors (X) included in the equation, there are other province-specific variables that affect provincial economic growth, such as local infrastructure and economic policies. The omission of these variables could lead to biased estimates. The panel growth model with fixed effects can alleviate this problem, as the omitted province-specific variables are captured by the provincial fixed effect. We also estimate dynamic panel growth models with the lagged

[6] The cross-sectional growth equation estimates are tested for heteroskedasticity. Breusch–Pagan/Cook–Weisberg test for heteroskedasticity cannot reject the null hypothesis of constant variance.
[7] The negative effect of employment growth on economic growth has also been found by Chen and Fleisher (1996) and Gemmell (1996).
[8] Foreign direct investment is missing for some provinces in some years. Therefore, this variable is not included in the panel growth estimation.
[9] Chen and Fleisher (1996), Wei, Liu, Song, and Romilly (2001), Arayama and Miyoshi (2004).

Table 2
The effect of workers' educational attainment on economic growth

Dependent variable: Annualized change in log GDP per capita, 1996–2004

	Cross-sectional growth models									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Log (GDP per capita)$_{96}$	0.003	0.008	0.005	0.004	−0.015	−0.021	−0.022**	−0.030*	−0.032*	−0.030*
	(0.514)	(0.007)	(0.007)	(0.006)	(0.014)	(0.015)	(0.010)	(0.017)	(0.017)	(0.015)
ΔPrimary		0.006			0.002			0.001		
		(0.004)			(0.004)			(0.004)		
Primary$_{96}$		0.0003			0.0001			0.0002		
		(0.0002)			(0.0002)			(0.0002)		
ΔSecondary			−0.006			0.001			0.002	
			(0.004)			(0.005)			(0.005)	
Secondary$_{96}$			−0.0003			−0.0002			0.0001	
			(0.0002)			(0.0003)			(0.0002)	
ΔTertiary				−0.003			−0.001			−0.0003
				(0.011)			(0.001)			(0.001)
Tertiary$_{96}$				−0.0001			−0.009			−0.010
				(0.001)			(0.010)			(0.009)
Log (Fixed assets investment per capita)					0.020*	0.025*	0.033***	0.025**	0.029**	0.030***
					(0.011)	(0.013)	(0.010)	(0.011)	(0.012)	(0.010)
ΔLabor force								−0.488**	−0.503**	−0.460**
								(0.215)	(0.215)	(0.209)
Log (Foreign direct investment per capita)								0.003	0.004	0.003
								(0.003)	(0.003)	(0.003)
Coastal								0.020**	0.020**	0.019**
								(0.008)	(0.008)	(0.008)
Constant	0.059	0.011	0.059	0.048	0.052	0.077	0.024	0.176*	0.168**	0.143*
	(0.041)	(0.064)	(0.052)	(0.056)	(0.065)	(0.051)	(0.048)	(0.087)	(0.076)	(0.076)
Adj. R^2	−0.02	0.04	0.02	−0.09	0.12	0.11	0.22	0.32	0.33	0.36

Dependent variable: Change in log GDP per capita from year $t-1$ to t, $t=1997,\ldots, 2004$

	Panel growth models		
	(11)	(12)	(13)
Log (GDP per capita)$_{t-1}$	−0.018*	−0.019*	−0.017*
	(0.009)	(0.009)	(0.008)
ΔPrimary	0.001		
	(0.004)		
Primary$_{t-1}$	0.0004		
	(0.0003)		
ΔSecondary		0.002	
		(0.001)	
Secondary$_{t-1}$		0.0002	
		(0.0002)	
ΔTertiary			0.001
			(0.002)
Tertiary$_{t-1}$			0.0003
			(0.001)
Log (Fixed assets investment per capita)	0.028***	0.028***	0.029***
	(0.009)	(0.010)	(0.010)
ΔLabor force	−0.123	−0.124	−0.141
	(0.084)	(0.086)	(0.085)
Coastal	0.018**	0.018**	0.015*
	(0.008)	(0.008)	(0.008)
Constant	0.156*	0.147**	0.139*
	(0.079)	(0.066)	(0.066)
Adj. R^2	0.44	0.44	0.43

Table 3
Fixed effects and dynamic panel growth estimates

Dependent variable: Change in log GDP per capita from year $t-1$ to t, t=1997,..., 2004						
	Fixed effects panel growth models			Dynamic panel growth models		
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log (GDP per capita)$_{t-1}$	–	–	–	0.169*	0.160*	0.266**
				(0.096)	(0.093)	(0.102)
Log (GDP per capita)$_{t-1}$	−0.137***	−0.119***	−0.184***	−0.503***	−0.515***	−0.529***
	(0.039)	(0.037)	(0.039)	(0.102)	(0.098)	(0.115)
ΔPrimary	−0.001			−0.003***		
	(0.001)			(0.001)		
Primary$_{t-1}$	−0.001			−0.004***		
	(0.001)			(0.001)		
ΔSecondary		0.001			0.003***	
		(0.001)			(0.001)	
Secondary$_{t-1}$		−0.001			0.004*	
		(0.001)			(0.002)	
ΔTertiary			0.004*			−0.0003
			(0.002)			(0.002)
Tertiary$_{t-1}$			0.009***			0.005
			(0.003)			(0.003)
Log (Fixed assets investment per capita)	0.141***	0.144***	0.145***	0.227***	0.224***	0.224***
	(0.020)	(0.020)	(0.019)	(0.031)	(0.030)	(0.033)
ΔLabor Force	0.163*	0.156*	0.119	−0.088	−0.096	−0.109
	(0.092)	(0.093)	(0.088)	(0.070)	(0.065)	(0.093)
Constant	0.225	0.042	0.516**	0.027***	0.033***	0.031***
	(0.279)	(0.185)	(0.226)	(0.009)	(0.009)	(0.010)

Data source: China Statistics Year Book, China Labor Statistics Yearbook, 1996–2004.
Note: *, **, and *** indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. Foreign direct investment is missing for some provinces in some years. Therefore, this variable is not included in the model.

dependent variable, using Generalized Moment Method (GMM) as suggested by Arellano and Bond (1991). The model is specified as follows:

$$\Delta \mathrm{Log}\ (\mathrm{GDP})_{it} = \beta_0 + \beta_1 \Delta \mathrm{Log}\ (\mathrm{GDP})_{it-1} + \beta_2 \Delta \mathrm{HC}_{it} + \beta_3 \mathrm{HC}_{it-1} + \beta_4 \Delta \mathrm{Log}\ K_{it} + \beta_5 \mathrm{Log\ GDP}_{it-1} + \psi' \Delta X_{it} + v_i + \varepsilon_{it} \tag{4}$$

where ΔLog (GDP)$_{it-1}$ denotes the one-year lagged dependent variable. The same as the fixed effect panel growth model, the dynamic panel growth model can also mitigate the omitted variable problem because it includes v_i. In addition, the model allows dynamics of adjustment by including the lagged variable and hence gives more robust estimates.

The fixed effects and dynamic panel growth estimates are documented in Table 3. As can be seen, the effect of fixed assets investment on GDP growth remains sizeable and significant. In some specifications, the impact of human capital becomes significant. In general, tertiary education has a positive and larger impact on GDP growth than primary and secondary education. The results also imply conditional convergence of GDP growth as well as a positive correlation between growth rates in two consecutive years. So far, our analysis limits to the direct effect of human capital on growth. In the subsequent sections, we further investigate the possibility of the indirect effect of human capital on growth.

Notes to Table 2
Data source: China Statistics Year Book, China Labor Statistics Yearbook, 1996–2004.
Note: *, **, and *** indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. Foreign direct investment is missing for some provinces in some years. Therefore, this variable is not included in the panel growth regression.

5. Impact of human capital stock on fixed assets investment

Standard growth theory typically assumes a two-factor (capital, K and labor, L) production function, i.e., $y=f(K,L,t)$ where y denotes growth and t denotes time. In some studies, the growth accounting has been extended to include human capital as an additional input. In this framework, technology change is represented by the improvement in TFP over time, which is the increase in the total output with respect to the inputs where the marginal rate of transformation of given inputs remains constant, and hence technology change is essentially factor-neutral (Hornstein, Krusell, & Violante, 2005; Violante, 2007). However, some key facts observed in recent decades have cast doubts on the "factor-neutral" technology change. For example, the wage of better-educated skilled workers has increased much more rapidly than that of less-educated low-skilled workers in many developed countries, despite the major increase in the relative supply of skilled workers. To explain these new phenomena, the standard growth theory has been extended to include skill-biased technology change (SBTC). Skill-biased production technology favors skilled labor over unskilled labor by increasing skilled labor's productivity more than that of the unskilled (Hornstein et al., 2005; Violante, 2007). To incorporate SBTC, the growth function adopts the three-factor form which distinguishes skilled (S) and unskilled labor (U), i.e., $y=f(K,S,U,t)$. The elasticity of output with respect to an input changes over time, and technology change is skill-biased if $\frac{\partial^2 \ln y}{\partial S \partial t} > \frac{\partial^2 \ln y}{\partial U \partial t}$ (Berman, Somanathan, & Tan, 2005).

Assuming capital to be quasi-fixed, the share of skilled labor in the total wage bill or employment can be derived from the translog cost function dual to the three-factor production function, and it has been shown that under SBTC, a large K is associated with a greater share of skilled workers, which is referred to as skill-capital complementarity (Berman, Bound, & Griliches, 1994; Berman et al., 2005; Griliches, 1969). With the same theoretical underpinning, we focus on the impact of existing human capital stock on the later physical capital investment. In China, there remain large differences in workers' human capital levels across provinces due to historical circumstances.[10] This variation is potentially exogenous, as it is determined before the later physical capital investment decisions are made. Under the SBTC hypothesis, provinces with a large stock of highly-educated skilled workers are more likely to attract the inflow of physical capital. Specifically, we regress average fixed assets accumulation during the period 1996–2004 on provincial workers' education levels in the initial year 1996. In estimating the impact of the *initial* human capital stock on the *later* physical capital accumulation, the time order helps to identify the causal relationship to some degree.[11] The results are reported in columns (1) through (9) in Table 4.

Since China is a transition country, we need to explain institutional background regarding provincial capital investment. Chinese provincial fixed assets investment comes from four sources: state budgetary appropriation, domestic loans, foreign investment, and fund-raising and others.[12] Under the centrally planned system, state budgetary appropriation accounted for a large percentage of fixed assets investment.[13] Under this category, government had authority to determine where to allocate new fixed asset investment through budgetary appropriation. The second category, domestic loans, was issued by banks. Before the reform, all the banks were entirely owned by the state. State banks were often used by government as a vehicle to achieve policy goals rather than make profits. Before the reform, foreign investment and self-raised funds were very limited if not none at all. Therefore, fixed assets investment decisions were mostly made by government in the centralized and authoritative way before economic reform. The objective of government was not to maximize the return to the investment but rather to achieve certain societal or military goals such as well-known "three-line construction" projects. When government made such fixed asset investments, provincial human capital and capital-skill complementarity were hardly given any consideration.[14] After the reform, China has started to transform into a market economy. A characteristic of a market economy is that physical

[10] In 1996, 17 years after the economic reform, Beijing had the largest human capital stock: 19% of workers had college or above educational attainment, which was 5 times higher than the country's average, and almost 40 times higher than Tibet where only half percent of workers had college or above educational levels.

[11] The rigorous test of the causal relationship would require a well-designed experiment.

[12] The explanation for the different categories of fixed assets investment can be found in China Statistics Yearbooks.

[13] In 1981, state budgetary appropriation accounted for 28.1% of the total fixed assets investment. It dropped to the lowest level of 2.7% in 1996. Since 1996, in response to the increased regional development disparity, government increased budgetary appropriation to support the development of central and western regions. In 2004, state budgetary appropriation was 5.7%. Data source: China Statistics Yearbook 2005.

[14] Government-directed investment suffered low economic efficiency. Yet, it did achieve the goals of redistributing wealth across regions and reducing regional development inequality. For example, with "three-line construction" projects, both financial capital and human capital were "forced" or "persuaded" to move to the inland, otherwise they would stay in the eastern region.

Table 4
The impact of human capital and initial wealth on fixed assets investment

Dependent variable: Average annual log fixed assets investment per capita, 1996–2004

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$Primary_{96}$	−0.021***			0.005			0.005		
	(0.005)			(0.004)			(0.004)		
$Secondary_{96}$		0.022***			0.010**			0.010**	
		(0.007)			(0.004)			(0.005)	
$Tertiary_{96}$			0.113***			0.040**			0.048***
			(0.021)			(0.015)			(0.015)
Log (GDP per capita)$_{96}$				1.157***	1.226***	0.861***	1.133***	1.236***	0.633***
				(0.132)	(0.120)	(0.106)	(0.219)	(0.195)	(0.175)
Coastal							0.025	−0.011	0.251
							(0.179)	(0.167)	(0.155)
Constant	8.910***	6.854***	7.465***	−2.251*	−2.119***	0.371	−2.045	−2.196	2.212
	(0.277)	(0.349)	(0.108)	(1.287)	(0.892)	(0.877)	(1.983)	(1.496)	(1.423)
Adj. R^2	0.32	0.22	0.49	0.81	0.83	0.84	0.82	0.80	0.85

Dependent variable: Average annual log fixed assets investment per capita, 1996–2004

	(10)	(11)	(12)
Enrollment_Primary1981	−0.002***		
	(0.0003)		
Enrollment_Secondary1981		0.001	
		(0.001)	
Enrollment_Tertiary 1981			0.020***
			(0.003)
Constant	10.951***	7.466***	7.527***
	(0.955)	(0.424)	(0.099)
Adj. R^2	0.54	0.04	0.62

Data source: China Statistics Year Book, China Labor Statistics Yearbook, 1996–2004.
Note: *, **, and *** indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses.

capital investment decisions are decentralized and made by individual firms to maximize the return. China has made remarkable progress on this perspective: government budgetary fixed assets investment has reduced considerably; state banks have been reformed to operate independently and take responsibilities for their own profit and loss; foreign investment and private fund-raising have increased dramatically. When an individual firm decides where to invest, it will consider the local human capital stock and capital-skill complementarity to increase efficiency. The time period under study is 1996–2004, which was 17 years after the launch of the reform. Government's influence on fixed asset investment still exists but the scope of the influence has been much reduced.

Columns (1) to (3) in Table 4 show that the higher percentage of workers with secondary and tertiary education in 1996 leads to greater fixed assets accumulation between 1996 and 2004. Moreover, as both secondary and tertiary education have a positive impact on physical capital investment, tertiary education has a greater effect. These results lend some support to the capital-skill complementarity hypothesis. Although China has been known for labor-intensive production, these results suggest that in recent years (1996–2004), production technology may have shown some degree of skill-biased progress.

Moreover, some researchers suggest that a country or region's initial wealth in terms of GDP per capita may cause larger physical capital investment in the future years (Blomstrom, Lipsey, & Zejan, 1996). For this reason, we add the initial GDP into the model as another variable to predict the later fixed capital investment. The results are documented in columns (4) through (6) in Table 4. The provincial GDP level in 1996 does have a significant impact on physical capital investment between 1996 and 2004. Based on column (6), which gives the most conservative estimate, if the initial GDP per capita increases by 10%, the average annual physical capital investment per capita would increase by 9%, indicating a 0.9 elasticity.

One may argue that in wealthy provinces people tend to also have better education and higher human capital. That is, a province's GDP level is very likely to be correlated with the workforce human capital level. Due to multicollinearity, once GDP per capita is included in the model, the effect of human capital may significantly drop. Our results show that the effect of tertiary and secondary education remains statistically significant after the inclusion of the initial GDP, although the size of the effect decreases somewhat. This suggests that the *stock* of human capital and the initial wealth of a province are both important determinants of the later physical capital investment. Jointly, they predict 84% of variation in the provincial physical capital investment amounts.

Other than the initial wealth and better-educated workforce, coastal regions may also attract physical capital investment because of better natural conditions and preferential economic policies. In columns (7) through (9) of Table 4, we include the dummy indicator of coastal region to control for this additional effect. The coefficient estimate of coastal region is insignificant. This suggests that the differences between the coastal and inland provinces in physical capital accumulation may be mostly due to their differences in the initial GDP and human capital stock.

To further ensure causality in the time order, we use the human capital stock in 1981 to predict the average fixed assets accumulation during the period 1996–2004. Due to the lack of workforce human capital data in 1981, we use the ratio of primary, secondary, and tertiary school enrollment per 10,000 population to proxy human capital in 1981. These results are reported in columns (10) through (12) in Table 4. As can be seen, the tertiary human capital stock in 1981 has a large, positive, and significant impact on the later fixed assets accumulation during 1996–2004, while primary education in 1981 has a negative and significant impact. This result further suggests that the initial human capital stock affects the later physical assets investment.

6. Estimates of growth models correcting for endogenous fixed assets investment

As can be seen from Table 4, a province's initial stock of human capital has a sizeable and significant impact on the later physical capital investment. This result suggests that physical capital investment (ΔK) may be endogenous. The lack of control for endogeneity could result in biased estimates of growth equations, e.g., the large positive effect of capital investment on growth may be due to bias. To correct for endogeneity, an instrumental variable may be used. A valid instrument (Z) has to satisfy two conditions: (1) it is exogenous and uncorrelated with the error term, i.e., $\text{cov}(\varepsilon, Z)=0$; (2) it is highly correlated with the endogenous explanatory variable, but not directly correlated with the dependent variable. In our context, the instrument has to be correlated with physical capital investment but not directly correlated with growth rates.

In general, identifying an absolutely valid instrumental variable is difficult in empirical macro models, and our study is no exception. Nevertheless, we made attempts to locate a somewhat valid instrumental variable to identify the model. Our choice of the instrumental variable is the initial stock of tertiary human capital. As we have explained in the previous section, the initial human capital stock is presumably exogenous. A province's human capital stock in the initial year (1996) was already formed before the later (1996–2004) physical capital investment decisions were made. In China, there remains a large variation across provinces in the stock of tertiary human capital, which is mostly due to historical factors. For example, Beijing had the largest stock of tertiary human capital in 1996, as 19% of workers had college or above educational attainment, compared to the country's average of 3.8% (please also see Appendix Table). This cross-province variation was given when a firm decides in which provinces to invest, and thus was considered exogenous.

As can be seen from Table 4, a province's initial human capital stock positively affects the later physical capital investment. Moreover, the growth equation estimates documented in Table 2 show that the human capital stock, in general, has a small and insignificant effect on per capita GDP growth. These results are empirical evidence suggesting a direct relationship between the human capital stock and physical capital investment but no direct relationship between human capital and growth. From the theoretical perspective, growth accounting implies that the *increase* of human capital (ΔHC), rather than the *stock* of human capital, along with the increase in physical capital and TFP, directly contributes to economic growth. Endogenous growth theory also suggests that the stock of human capital affects economic growth by impacting technology innovation and diffusion (Nelson & Phelps, 1966; Romer, 1990). Thus, from both empirical and theoretical perspectives, we find that the initial human capital stock may be a somewhat valid instrumental variable, as it is directly related to technology and capital investment and indirectly related to growth.

We estimate two-stage least square models. In the first stage, fixed assets investment is regressed on the initial tertiary educational attainment and all the exogenous variables used in the second stage. In the second stage, the regressors include the predicted fixed assets investment from the first stage and exogenous variables including the initial GDP per capita and/or coastal region dummy variable. The initial tertiary educational attainment is excluded

Table 5
The instrumental variable regression of economic growth: endogenous fixed assets investment

Dependent variable: Annualized change in log GDP per capita, 1996–2004	OLS	IV(2SLS)	OLS	IV(2SLS)
	(1)	(2)	(3)	(4)
Log (GDP per capita)$_{96}$	−0.021**	0.008	−0.032**	−0.019
	(0.010)	(0.022)	(0.010)	(0.017)
Log (Fixed assets investment per capita)	0.023**	−0.004	0.022**	0.008
	(0.009)	(0.022)	(0.008)	(0.016)
Coastal			0.016**	0.017**
			(0.007)	(0.008)
Constant	0.084**	0.055	0.180***	0.173***
	(0.038)	(0.048)	(0.057)	(0.060)
Adj. R^2	0.17	0.16	0.26	0.19

Data source: China Statistics Year Book, China Labor Statistics Yearbook, 1996–2004.
Note: IV(2SLS) uses the percentage of workers having college or above education in the initial year1996 as the instrumental variable; *, **, and *** indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses.

from the second stage to identify the model. The results of 2SLS models are compared to OLS estimates, and the Hausman tests are conducted to test endogeneity of fixed assets investment. Table 5 reports the estimates of OLS and the second stage of 2SLS models, as the first stage estimates of 2SLS are already reported in Table 4. As can be seen in columns (1) and (2) of Table 5, fixed assets investment and the initial GDP per capita are no longer significant in the 2SLS model. The Hausman test result shows that physical capital investment is endogenous.[15] In columns (3) and (4), we report the OLS and 2SLS estimates that include the dummy variable, coastal region. The coefficient estimate of coastal region is similar in the OLS and 2SLS models, being sizeable and significant. This result suggests that there are still some unexplained coastal–inland differences in growth rates.

7. Education Expenditure and Educational attainment

Since education, especially tertiary education, plays a significant role in economic growth, it is worth investigating how a province could increase the workforce educational attainment. We examine the impact of provincial government and social education expenditure on workers' educational attainment.

Government education expenditure is measured by the ratio of government expenditure on education to the total government expenditure. It shows how much emphasis a provincial government places on education. On average, provinces spent 15% of the total government expenditure on education, such as funding schools and paying teachers salary. The province with the least government expenditure on education spent 10% and the highest spent 19%. Social education expenditure includes funds of social organizations and citizens for running schools, donations and fund-raising for running schools, tuition and miscellaneous fee, and other education funds, in addition to government expenditure on education.[16] Provincial social education expenditure ranges from 2.8% of provincial GDP to 7.8%.[17]

We regress the average annual increase of the percentage of workers with primary, secondary, and tertiary educational attainment during the period 1996–2004 on the average annual education expenditure during this period. In some specifications, we also control for the province's initial GDP level. The results are reported in Table 6. As can be seen, greater government education expenditure increases the percentage of workers attaining secondary education and reduces the percentage with only primary education. Social education expenditure mainly contributes to the increase in the percentage of workers with primary education. Although both government and social education expenditure enhance primary and secondary educational attainment, neither significantly increases the percentage of

[15] Hausman test statistics, c^2 (1)=2.90; p-value=0.08.
[16] The definition of social education expenditure is given in China Statistics Yearbooks, various issues.
[17] These summary statistics can be found in Appendix Table.

Table 6
The effect of government and social education expenditure on workforce educational attainment

Dependent variable: Annualized change in the percentage of workers having primary, secondary, and tertiary education, 1996–2004

Dependent variable		Government education expenditure	Social education expenditure	Log (GDP per capita)$_{96}$	Constant	Adj. R^2
ΔPrimary	(1)	−0.140***			0.645	0.28
		(0.039)			(0.601)	
	(2)	−0.144***		0.191	−0.936	0.29
		(0.039)		(0.181)	(1.617)	
	(3)		0.271***		−2.708***	0.28
			(0.076)		(0.354)	
	(4)		0.306***	0.323*	−5.634***	0.33
			(0.076)	(0.182)	(1.682)	
ΔSecondary	(5)	0.123**			−0.911	0.18
		(0.045)			(0.696)	
	(6)	0.133***		−0.570***	3.810**	0.36
		(0.040)		(0.184)	(1.649)	
	(7)		−0.282***		2.226***	0.26
			(0.084)		(0.386)	
	(8)		−0.364***	−0.743***	8.950***	0.58
			(0.065)	(0.156)	(1.441)	
ΔTertiary	(9)	0.017			0.276	−0.02
		(0.023)			(0.363)	
	(10)	0.010		0.380***	−2.871***	0.38
		(0.008)		(0.085)	(0.762)	
	(11)		0.013		0.474**	−0.03
			(0.046)		(0.214)	
	(12)		0.059	0.421***	−3.335***	0.43
			(0.036)	(0.085)	(0.782)	

Data source: China Statistics Year Book, China Labor Statistics Yearbook, 1996–2004.
Note: *, **, and *** indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses.

workers with college or above education. Yet, as shown in previous tables, tertiary education has a greater impact on physical capital investment than primary and secondary education.

8. Summary and conclusion

China's rapid economic growth in the last several decades has drawn great research interests from all over the world. Researchers have examined the pattern and sources of China's economic growth, and generally found that physical capital investment was the main engine of growth and that growth rates of different regions converged after taking into consideration of different physical capital investment amounts. However, the question remains whether economic growth in China is sustainable. Believing human capital is the key to the long-run economic growth, we focus on finding empirical evidence of the role of human capital in China's economic development in recent years, so that our findings may have implications for future development policies.

We do not find strong evidence that workers' human capital in a province directly contributes to provincial economic growth. However, a province's initial stock of human capital has a large and significant impact on the later fixed assets accumulation. In particular, provincial workforce tertiary educational attainment is a more dominant factor of physical capital investment than primary or secondary education. After correcting for endogeneity, fixed assets investment is no longer significant in the growth equation.

These results suggest that production in the advanced eastern area of China might have shown some degree of capital-skill complementarity in recent years, as higher education appears to be a more important determinant of fixed assets investment than primary and secondary education. On the other hand, this finding raises the concern that inland provinces may not be able to catch up with eastern provinces quickly and easily. If labor and capital are substitutes, as classical production theories assumed, the marginal return to capital would decrease in the eastern region as economy advances and capital accumulates. Subsequently, capital will flow to the inland where labor is cheaper and the return to capital is higher, and will boost economic growth of inland provinces. By the working of this market mechanism, the gap between eastern and western areas would reduce, which requires no intervention from government to direct investment or redistribute wealth. However, with capital and skill complementary, physical capital investment will continue to accumulate in the eastern region because of the higher human capital of workforce and the greater initial wealth. This will, in turn, accelerate economic growth in the eastern region and widen the gap between eastern and western provinces.

Based on our findings about the role of human capital, inland provinces may enhance workers' educational attainment to attract physical capital investment and boost economic growth. We investigate the effect of provincial government and social education expenditure on workers' educational attainment. We find that education expenditure could increase the percentage of workers with primary and secondary education but does not significantly raise the percentage of workers with college or above educational attainment. More effective policies need to be considered to enhance workers' tertiary educational attainment.

Appendix Table: Variable definition and summary statistics

Variables	Definition	Mean	Std. Dev.	Min.	Max.
ΔLog (GDP per capita)	Annualized change in log per capita GDP, 1996–2004	0.086	0.013	0.057	0.119
Log (GDP per capita)$_{96}$	Log per capita GDP in the initial year, 1996	8.580	0.501	7.613	9.926
ΔPrimary (%)	Annualized change in the percentage of workers with primary education, 1996–2004	−1.496	0.588	−2.678	−0.333
Primary$_{96}$ (%)	The percentage of workers having primary education in the initial year 1996	47.852	15.924	11	93.2
ΔSecondary (%)	Annualized change in the percentage of workers with secondary education, 1996–2004	0.963	0.634	0.678	2.167
Secondary$_{96}$ (%)	The percentage of workers with secondary education in the initial year 1996	48.352	13.408	6.3	71.2
ΔTertiary (%)	Annualized change in the percentage of workers with tertiary education, 1996–2004	0.531	0.297	0.022	1.274
Tertiary$_{96}$ (%)	The percentage of workers with tertiary education in the initial year 1996	3.810	3.660	0.5	18.9
Enrollment_Primary1981	Primary school enrollment per 10,000 population in year 1981	1385.921	216.050	723.990	1609.564
Enrollment_Secondary 1981	Secondary school enrollment per 10,000 population in year 1981	506.876	39.852	102.151	773.644
Enrollment_ Tertiary 1981	Tertiary school enrollment per 10,000 population in year 1981	18.594	22.233	6.367	108.648
Log (Fixed assets investment per capita)	Log fixed assets investment per capita, 1996–2004	7.895	0.580	7.005	9.516
Log (Foreign direct investment per capita)	Log foreign direct investment per capita, 1996–2004	11.839	1.567	9.198	14.764
ΔLabor force	Annualized change in log labor force, 1996–2004	7.283	0.959	4.767	8.482
Government education expenditure (%)	Government education expenditure/total government expenditure *100%	15.291	2.334	10.328	19.421
Social education expenditure (%)	Total social education expenditure/GDP*100%	4.475	1.194	2.799	7.830
Coastal	=1 for provinces in the coastal area including Beijing, Tianjin, Hebei, Liaoning, Shanghai, Shandong, Jiangsu, Zhejiang, Fujian, and Guangdong, and =0 for other provinces.	0.323			

Data source: China Statistics Year Book, China Labor Statistics Yearbook, 1996–2004.

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