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Belton Fleisher
Haizheng Li
Min Qiang Zhao

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Forschungsinstitut
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Institute for the Study
of Labor

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Belton Fleisher
Ohio State University
and IZA

Haizheng Li
Georgia Institute of Technology

Min Qiang Zhao
Ohio State University

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IZA

P.O. Box 7240
53072 Bonn
Germany

Phone: +49-228-3894-0
Fax: +49-228-3894-180
E-mail: iza@iza.org

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ABSTRACT

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We study the dispersion in rates of provincial economic- and TFP growth in China. Our results show that regional growth patterns can be understood as a function of several interrelated factors, which include investment in physical capital, human capital, and infrastructure capital; the infusion of new technology and its regional spread; and market reforms, with a major step forward occurring following Deng Xiaoping's "South Trip" in 1992. We find that FDI had much larger effect on TFP growth before 1994 than after, and we attribute this to emergence of other channels of technology transfer when marketization accelerated. We find that human capital positively affects output per worker and productivity growth. In particular, in terms of its direct contribution to production, educated labor has a much higher marginal product. Moreover, we estimate a positive, direct effect of human capital on TFP growth. This direct effect is hypothesized to come from domestic innovation activities. The estimated spillover effect of human capital on TFP growth is positive and statistically significant, which is very robust to model specifications and estimation methods. The spillover effect appears to be much stronger before 1994. We conduct cost-benefit analysis and a policy "experiment," in which we project the impact increases in human capital and infrastructure capital on regional inequality. We conclude that investing in human capital will be an effective policy to reduce regional gaps in China as well as an efficient means to promote economic growth.

JEL Classification: O15, O18, O47, O53

Keywords: regional inequality, TFP growth, FDI, human capital, technology spillovers

Corresponding author:

Belton M. Fleisher
Department of Economics
The Ohio State University
1945 North High Street
Columbus, OH 43210
USA
E-mail: fleisher.1@osu.edu

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1. Introduction

Although it is generally believed that human capital plays an important role in economic growth, studies about the effect of education on growth based on cross-country data have produced surprisingly mixed results (Krueger 1995, Pritchett 2001, Temple 2001, Islam 1995, Benhabib and Spiegel 1994, Mankiw et. al. 1992, and Barro 1991). One reason for this uncertainty is that the impact of education has varied widely across countries because of very different institutions, labor markets and education quality (Temple 1999, Pritchett 2001), making it hard to identify an average effect. This paper reports research on the role of human capital, infrastructure capital, and foreign investment on economic growth in China. We investigate the role of educated workers in the production process itself, as well as on total factor productivity (TFP) growth. We believe the results have important implications for an understanding of economic growth in general as well as for factors contributing to China's rapidly rising regional inequality.

China's dramatic economic growth since the beginning of economic reform in 1978, along with wide regional disparities in growth rates, provides a very important and useful episode to analyze for the effects of human capital on growth. By the year 2000, China found itself with one of the highest degrees of income inequality in the world (Yang, 2002). Regional economic inequality is a relatively new phenomenon in China's last half century. From the beginning of the Mao era through early 1990's, inequality (as measured by the coefficient of variation among four regions' per-capita nominal gross domestic product) across major regions trended downward. However, this measure of inequality rose sharply in the decade of the 1990s (Figure 1).[1]

Figure 2 illustrates the trends in regional inequality in China using the ratio of per capita GDP between the three non-coastal regions and the coastal region. The industrial northeast, where per capita gross domestic product substantially exceeded that in the

[1] The four regions defined in this study are: coastal (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, and Guangdong-Hainan); northeast (Heilongjiang, Jilin, Liaoning), interior (Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi, Sichuan-Chongqing, Guizhou, Yunnan, and Shaanxi) and far west (Gansu, Qinghai, Ningxia, and Xinjiang). We have excluded Xizang (Tibet) and Inner Mongolia provinces due to lack of data, combined Chongqing with Sichuan and Hainan with Guangdong. The division of the four regions is based on the results of past research and our own judgment regarding the major economic and geographical clusters that characterize distinct "clubs" of economic growth and development in China.

coastal region at the end of the Mao era experienced a sharp reversal so that by 2003, its standing relative to the coast had fallen to 30 percent less than the coast. The coast's advantage over the interior and far west had grown to a ratio of approximately 2.4 by 2003. By comparison, among the major regions of the United States in 2004, the ratio of the highest to lowest regional per-capita GDP was only 1.32 (United States Bureau of Economic Analysis, current web site). In China in the year 2003, the ratio of real per-capita GDP between the wealthiest province and the poorest was 8.65, while in India for 2002, the comparable ratio (in nominal terms) was only 4.6 (Networkindia).[2]

A body of research has shown that total factor productivity (TFP) growth has played an important role in post-reform growth in China (Chow 1993, Borensztein & Ostry 1996, Young 2003, Wang and Yao 2003, and Islam et all 2006), but they do not explicitly model the role of human capital in the production function or its role in explaining TFP growth. It is widely hypothesized that human capital has a direct role in production through the generation of worker skills and also an indirect role through the facilitation of technology spillovers. However, such effects and especially their impacts on regional inequality in China have not been fully analyzed. In published papers, Chen and Fleisher (1996), Fleisher and Chen (1997) and Démurger (2001) provide evidence that education at the secondary or college level helps to explain differences in provincial growth rates. Liu (2007b, 2007c) demonstrates important external effects of human capital on productivity in rural and urban China. This paper provides a framework and evidence expanding our understanding the role of human capital in production and in TFP growth in China.

It is important to note that, as Fleisher (2005) and Heckman (2005) have noted, China's investment in human capital at the level of education beyond the secondary level until very recently has been very small in comparison with nations at similar levels of per capita income and economic development, and its geographical dispersion has been large. In 2004, the government expenditures on education were 2.79% of GDP and had been below 3% in most years since 1992, much lower than the average of 5.1% in developed countries. As shown in Table 1, the proportion of college graduates in the population

[2] http://networkindia.iesingapore.com/inn/news/index.cfm?fuseaction=viewContent&Cat=10&ID=804&viewmonth=6-2005 [Access Date: Dec. 20, 2005].

was 0.4% in 1982 and had risen to only 1.7% by 1992. Starting in 1999, the Chinese government increased education expenditures sharply, and the enrollment of college students accelerated from 7.4% in 1997-98 to 21.3% in 1998-98. The annual growth rate between 1999 and 2003 was 26.6% (State Statistical Bureau, Various Years)[3]. However, by 2003, the proportion of college graduates in the national population was still very low, at 5.2%. The proportion of college graduates in the coastal, far west, and northeast regions exceeded 6% in 2003, while in the interior (with nearly 52% of the national population) it was only 4.2%. For high-school graduates and above, the proportion in the population was approximately 43% in the coastal region, 53% in the northeast and only about 38% in the far west and interior regions.

China's economic marketization, both internally and with respect to the outside world, has been protracted, with alternating periods of gradualism, stagnation, and sharp jumps.[4] Marketization has required and been reinforced by transformation (still incomplete) of the structure of business and commercial law. The associated introduction of foreign ownership through foreign direct investment (FDI) is one of the most likely contributors to economic growth in China. The role of FDI has received much attention because of its potential for bringing in new technology, with its attendant spillovers, both technical and managerial (Liu, 2007a. See Cheung and Lin, 2003 for a thorough analysis and references to earlier literature.). FDI has facilitated emergence of the non-state-owned sector as foreign investors have become partners in formerly state-owned enterprises. The direction of FDI is obviously encouraged by exogenous geographical and political factors such as proximity to major ports, decisions to create special economic zones and free trade areas, and new ownership forms. In addition, the profitability of FDI is expected to depend on local taxation policies, local expenditures on infrastructure, schools, etc, and by labor-market conditions. There is likely to be a degree of endogeneity in these relationships (Li and Liu, 2005). One of the major features of our research is to incorporate the endogeneity of FDI in a model explaining China's increased regional economic disparity.

[3] The enrollment data exclude Inner Mongolia and Tibet in order to be consistent with the sample of provinces that we use in this paper.
[4] The slow pace of China's transformation has distinguished it from most other formerly planned economies, especially those of Central and Eastern Europe and the much of the former Soviet Union (Fleisher, Sabirianova, and Wang, 2005).

Still another major source of growth has been investment in infrastructure capital. At the beginning of reform, transportation and communications infrastructure were poor, but governments at various levels have invested heavily in the construction of highways, expansion of rail systems, and development of electronic communications facilities. Neglect of the marketization process, opening to the outside world, and investment in infrastructure capital would lead to an incomplete, and probably biased, understanding of the role of human capital, because local human capital stock is likely to be correlated with those factors.[5]

Another aspect of China's transformation that cannot be neglected is its uneven pace. It is generally agreed that a sharp acceleration in China's gradual "growth out of the plan" (Naughton, 1995) followed Deng Xiaoping's famous 1992 "South Trip. Although urban economic reform began in the period 1983-85, the Chinese economy was still largely a command economy under the old planning system, with the share of state-owned enterprises (SOEs) accounting for more than half of gross industrial output. After Deng's visit to south China, the country moved much more quickly towards an open, market economy. In the period 1992 to 1994, the share of SOEs in industrial output dropped 14 percentage points (from 48.1% to 34.1%), an annual rate over three times as rapid as during the period 1978 to 1992. The SOE share in industrial output fell to 13% by 2003.

The year 1994 marked the beginning of withdrawal of government subsidies for loss-incurring SOE's, and this hardening of budget constraints became much more earnest in 1997 (Appleton et al., 2002). There was also a shift toward fiscal federalism after 1994 that, through separating central and local government taxation and relaxing ties between provincial and sub-provincial treasuries and the center, reinforced imposition of hard budget constraints on SOEs (Ma and Norregaard, 1998; Su and Zhao, 2004; Qian and Weingast, 1997). By making the direct costs of subsidizing provincial- and sub-provincial-owned state enterprises much more direct drains on local government treasuries, the fiscal reform provided strong incentives for the local governments to shift their expenditures from wasteful support of losing enterprises to expenditures on projects

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[5] Fleisher and Chen (1997) and Démurger (2001), among others, provide evidence of the importance of infrastructure investment for productivity and economic growth in China.

that would attract FDI, particularly infrastructure projects (Cao, Qian, and Weingast, 1999). Despite the potential contribution of these reforms to improved economic conditions, implementation was by no means perfect (Ma and Norregaard, 1998). We account for the structural break in the course of market reforms in China in the specification of our empirical models.

The remainder of this paper proceeds as follows. In section 2 we lay out our methodology. Section 3 describes our data. Section 4 reports our empirical results for aggregate production functions and TFP-growth models. In section 5, we conduct cost-benefit analysis by computing the rates of return to investment in human capital and telephone infrastructure. In addition, we perform a hypothetical experiment by evaluating alternative investment strategies in reducing regional inequality. Section 6 concludes and provides policy recommendations. The appendixes describe the construction of critical data series and provide details of mathematical derivations.

2. Methodology

In order to explore the importance of human capital, we specify and estimate provincial aggregate production functions in which inputs are specified to include physical capital and two categories of labor: (i) workers who have attended up to some high school without graduating and (ii) workers who have acquired at least a high-school diploma. The estimated output elasticities of the three inputs are used to calculate factor marginal products and also TFP. This strategy permits us to investigate two possible channels through which human capital may influence output. One channel is a direct effect, in that workers who have acquired at least a high-school diploma should have a higher marginal product than workers who have not achieved this level of schooling. The second channel is indirect, through TFP growth. We hypothesize that provinces with a relatively large proportion of highly educated workers benefit from being able to use new production techniques and to benefit from technology spillovers from the provinces with the highest technology levels.

The incorporation of a measure of human capital “inside” the production function is based on the micro-level evidence that workers with different educational attainment have different marginal products. For example, in analysis of firm data for China, Fleisher and Wang (2001, 2004) and Fleisher, Hu, and Li (2006) find evidence that highly educated workers have significantly higher marginal products than workers with lower levels of schooling. Our inclusion of human capital measures inside the production function is not unique. For example, Mankiw et al. (1992) have done so using aggregate data. However, other researchers, such as Nelson and Phelps (1966), Islam (1995), Benhabib and Spiegel (1994) for example, suggest that human capital mainly operates through total factor productivity (TFP), because it facilitates the development and adaptation of new technology. We adopt a mixture of these approaches to estimating the impact of investment in human capital on output and growth.

The production function including two types of labor is:[6]

$$Y_{it} = A_{it} K_{it}^{\beta_k} L_{eit}^{\beta_e} L_{nit}^{\beta_n} e^{u_{it}} \qquad (1)$$

where Y is output, K is capital, L_e is the number of workers with secondary education or above, L_n is the number of workers who have not graduated from high school, and u is a disturbance term, for province i= 1, 2, …, n from year t=1, 2, …, T.[7] The parameters β_k, β_e, and β_n are the output elasticities of the corresponding inputs.

In addition to its direct effect on output, human capital is believed to facilitate development and adoption of new technology, which is reflected in TFP. Thus, we investigate those effects of education in a TFP growth model along with other factors generally hypothesized to impact TFP, including FDI and local infrastructure capital. We first address the role of human capital. Following Nelson and Phelps (1966), we postulate that the diffusion of technology is positively related to human capital. Nelson and Phelps specify the growth rate of technology as

$$\frac{\dot{TFP}_t}{TFP_t} = \Phi(h)\left[\frac{TFP_t^* - TFP_t}{TFP_t}\right], \qquad (2)$$

$$\Phi(0) = 0, \qquad \Phi'(h) > 0$$

[6] Jones (2005) shows that the Cobb-Douglas form is a valid approximation in the aggregate for a variety of underlying micro firm production functions.

[7] An alternative measure of human capital is the number of workers with college education or above. Although we aggregate workers with at least high school diplomas in our estimation of the production function, we specify our TFP-growth equation to include only college graduates. Our rationale for this is that TFP growth is a function, in part, of technology spillovers, and we postulate that college graduates have a more significant role to play in this regard than do those with lower levels of schooling.

so that the growth rate of TFP is dependent on human capital (*h*) and the gap between its actual level and a hypothetical maximum level of TFP (TFP_t^*). The expression $\frac{TFP_t^* - TFP_t}{TFP_t}$ represents the technology gap, and $\Phi(h)$ represents the ability to adopt and adapt the technology, which is an increasing function of human capital (*h*). Thus, the new technology developed by an advanced region can have spillover effects to the benefit of poorer regions. Equation (2) describes the process of technological diffusion in what might be characterized as a learning-by-watching process.

Benhabib and Spiegel (1994) extend Nelson and Phelps' (1966) framework to include domestic innovation. They specify TFP growth as a function of human capital, and human capital is modeled to have both a direct effect (innovation) and as well as an indirect spillover effect working through technological diffusion. The indirect effect is captured by the interaction of human capital and the output gap:

$$[\log TFP_{iT}(h_{it}) - \log TFP_0(h_{it})] = c + gh_i + mh_i[\frac{Y_{\max} - Y_i}{Y_i}] \tag{3}$$

where $Y_{\max}$ is the highest level of provincial output in the regions studied (e.g., provinces in China), TFP_0 is total factor productivity in the initial year, *c* denotes the exogenous progress of technology, gh_i represents domestic innovation, and $mh_i[(Y_{\max} - Y_i)/Y_i]$ denotes technology diffusion. Benhabib and Spiegel (1994) measure human capital (h_i) by the average years of schooling. *g* and *m* are parameters.

Our full model represents provincial TFP growth as a function of human capital, infrastructure capital, physical-capital vintage effects, foreign direct investment, and regional technology spillovers. To capture the impact of a break in the reform process following Deng Xiao Ping's "South Trip," we impose a structural break in 1994 as follows:

$$\begin{aligned}[\log TFP_{i,t} - \log TFP_{i,t-1}] = {} & \eta_{1,i} + \eta_{2,t} + \varphi_1 RFDI_{i,t-2} + \varphi_2 RFDI\_YB_{i,t-2} + \phi_1^h h_{i,t-1} + \\ & \phi_1^s h_{i,t-1}[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t-1} - y_{i,t-1}}{y_{i,t-1}})] + \phi_2^s h_{i,t-1}[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t-1} - y_{i,t-1}}{y_{i,t-1}})]\_YB + \\ & \phi_1^v \Delta_t^2 K_i + \beta_1^r Road_{i,t-1} + \beta_2^r Road\_YB_{i,t-1} + \beta_1^t Tel_{i,t-1} + \mu_{i,t}\end{aligned} \tag{4}$$

YB is a year dummy which is set to be 1 if before 1994. As discussed previously, we measure human capital h_i in the TFP-growth equation as the percentage of the population with at least college degrees. The variable y_i denotes output per capita.

We assume that the technology-spillover process is limited by frictions and costs positively associated with distance. A region that is closer to the most advanced region is assumed to have better access to new technology than more distant regions. To capture this effect, the output gap is discounted by the railway distance between the capital city of each province and the capital city in the province with the highest output per capita (which is typically Shanghai). This distance variable is specified as $d_{\max\_i}$. Thus, we define "Human-capital spillover variable" as: $h_{it}[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t} - y_{it}}{y_{it}})]$.

We include a variable representing foreign direct investment, $RFDI_i$, the ratio of real foreign direct investment to the total work force, which is assumed to represent the embodiment of foreign technology. Finally, following Wolff (1991) and Nelson (1964) we include as an independent variable, the second difference in the ratio of physical capital, ($\Delta_t^2 K_i$), to reflect the assumption that new capital embodies the most recent technology. The dummy variables $\eta_{1,i}$ and $\eta_{2,t}$ represent provincial and annual fixed effects, respectively.

A concern about $RFDI_i$ is endogeneity of foreign direct investment (Li and Liu, 2005), because locations with higher TFP may offer higher investment returns.[8] Our use of two-period lagged *RFDI* in the regression equations should mitigate this effect, but if the error terms of the TFP growth model are serially correlated, it is still possible to have correlation between lagged *RFDI* and the contemporaneous errors in the model. We thus use instrumental variable estimation to correct for this possibility.

3. Data

Our data are from various years of the China Statistical Yearbook, Population Census (1983, 1993, and 2001), Annual Population Change Survey (State Statistical

[8] It is possible that the construction of the human capital spillover variable creates an endogeneity problem. This issues are discussed in footnote 20.

Bureau, 1996, 1998, 1999, 2002 and 2003), Hsueh, Li, and Liu (1993), Sylvie Démurger (personal communication), and Fu (2004). One important feature of this study is that our data are not only deflated over time but also by an index that accounts for living-cost differences across provinces. Therefore, our data are comparable across provinces where living costs are quite different. GDP and capital-stock deflators are based on official price indexes (China Statistical Yearbook) linked to the 1990 national values of a typical living expenditure basket reported in Brandt and Holz (2006), specifying Beijing as the base province and 1990 as the base year.[9]

To estimate the capital stock for each province, we adopt Holz's (2006) cumulative investment approach. Holz's method adjusts official data so that investment- and capital-stock figures more closely approximate appropriate theoretical concepts of productive capital. The equation for constructing capital stock follows Equation 7' in Holz (2006):[10]

$$ROFA_t = ROFA_0 + \sum_{i=1}^{t} \frac{investment_i}{P_i} - \frac{scrap\_rate_i * OFA_{i-1}}{P_{i-k}}, \quad k = 16,$$

where $ROFA_t$ is "the real original value of fixed assets", and k is "the average number of years between purchase and decommissioning of fixed assets" (Holz, 2006).[11] The variable $investment_i$ is effective investment, defined as the product of the transfer rate and gross fixed capital formation. Holz defines the transfer rate as the ratio of official effective investment to official total investment expenditures.[12] The variable $scrap\_rate_i$ is set to be 1% in the initial year, and it is moved linearly up to 2.5% in 2003.[13] The variable P_i denotes the price index for investment. Due to the lack of investment price

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[9] The capital-stock deflator is constructed as follows. The first step is to construct the implicit deflator of gross fixed capital formation for the period 1966-1990. The second step is to combine the implicit deflator series with the official price indices of investment in fixed assets (available since 1991 from China Statistical Yearbook). The third step is to construct the comparable provincial capital-stock deflator, assuming 50% of components in the original deflator series are comparable across provinces and the remaining provincial differences in the deflator series can be accounted by Brandt and Holz's (2006) 1990 national values of a typical living expenditure basket.

[10] An alternative approach to construct physical capital is the NIA method also discussed in Holz (2006). Fleisher, Li and Zhao (2006) use the NIA approach. In this study, we apply the cumulative investment approach, because based on Holz (2006), this approach works better in panel data and in controlling for the problem caused by the official revaluations of the original values of fixed assets in 1993.

[11] Holz (2006) suggests that k = 16 or above is preferred.

[12] Due to the lack of data, we use Holz's (2006) the estimated national transfer rates to approximate provincial transfer rates.

[13] This imputation was kindly suggested by Carsten Holz.

data prior to 1991, we construct an implicit deflator for capital formation for the years 1966 through 1990 from State Statistical Bureau (1997).[14] The initial value of fixed assets (OFA_0) is assumed to be the nominal depreciation value over the depreciation rate, which is set at 0.05. For a discussion of assumed depreciation rates see Wang and Yao (2003).

The numbers of college graduates are estimated based on the annual flow of college graduates anchored to periodic population census data. Details are contained in Fleisher, Li and Zhao (2006). The numbers of high school graduates along with the infrastructural data are provided by Sylvie Demurger for the years 1978 through 1998 and from State Statistical Bureau for the years 1999 through 2003. Foreign direct investment data from 1985 to 1996 are obtained from China Statistics Press (1999). Data after 1995 are from State Statistical Bureau (various years). The original data are deflated using the U.S. GDP deflator with 1990 as the base year. Summary statistics are reported in Tables 2a, 2b and 2c.

As can be seen in Tables 2a, 2b and 2c, on average, the ratio of the workforce with secondary school or above to those with less education averaged about 33% in 1985; this ratio rose to 45% in 1994 and reached 68% in 2003. The ratio of individuals with at least a college education in the population was about 1.3% in 1985; it roughly doubled to 2.5% in 1994, and it reached 6.2% in 2003. There is considerable variation in this ratio across provinces. The distribution of FDI per worker also varies widely across provinces. Between 1985 and 1994, FDI shot up from $5.27/worker to $62.34/worker; subsequently, the rate of increase was slower, and the ratio reached $78/worker in 2003. The acceleration of capital formation is distributed very unequally across provinces, and it exhibits a downward trend. The telephone infrastructure intensity increased dramatically and accelerated over the entire period, while road intensity increased at a much slower speed, also accelerating in the second decade. Market-economy development as measured by the ratio of total employment in non-state sectors increased 13-fold between 1985 and 1994 and 2.8 times between 1994 and 2003. However, the ratio is still quite

[14] We first collect nominal values and real growth rates of gross fixed capital formation. Then, we construct the implicit deflator as follows: $[(\text{nomial value})_t / (\text{nomial value})_{t-1}] / (\text{real growth rate})_t = [(\text{Price}_t \times \text{Quantity}_t) / (\text{Price}_{t-1} \times \text{Quantity}_{t-1})] / (\text{Quantity}_t / \text{Quantity}_{t-1}) = \text{Price}_t / \text{Price}_{t-1}$.

low in absolute terms and in comparison to other transition economies (Fleisher, Sabirianova, and Wang, 2005), less than 6% in 2003.

4. Empirical Results

Table 3 reports estimation results for a provincial-level production function with two types of labor categorized according to educational attainment. There are three columns. The first column reports simple ordinary least squares (OLS) results as a bench mark; columns 2 and 3 are estimated with a 2-way fixed effects (FE) procedure (including dummy variables for each year and province); column 2 is unrestricted with respect to returns to scale and column 3 imposes constant returns to scale (CRS).

In column 1, there is strong evidence for the significance of the structural break, in that the elasticities of capital and of two categories of labor differ significantly between the two periods. The FE estimates are designed to control for the well-known problem of omitted variables in estimating production functions, which leads to inconsistent estimates of the inputs elasticities. As expected, the F-test strongly rejects the null of no fixed effects. The biggest difference between the FE and OLS estimates, though, is in the elasticity of less-educated labor. In the OLS estimation, the elasticity of less-educated labor is positive after 1994 but is almost zero in the first time period. In the FE estimation without imposing CRS, the elasticity of less-educated labor is also more negative before 1994. One possible explanation is that workers with less than a high school diploma are so abundant that their marginal contribution to provincial production is negligible. The evidence from our estimates is that this “surplus” diminished after 1994; this is consistent with the hypothesis that Deng’s “South Trip” did mark and acceleration in China’s transformation from a planned economy to a market economy. In column 2, we see that the estimated capital elasticity is smaller before 1994 than afterward; while the elasticity of educated labor is not only much larger than that of less-educated labor, but also larger during the early period than in the later period.

When the FE estimates are not constrained to CRS, the sum of the input elasticities is much smaller than 1 for both time periods.[15] Given our prior that the

[15] Such diseconomies of scale in an aggregate production function seem implausible and, we suspect are inherent in application of FE estimation, which would increase the share of variation in the regressors that is due to measurement error and leads to attenuation bias.

aggregate production function for Chinese provinces is plausibly CRS, we follow much literature and impose this restriction. The elasticity of capital is higher under the CRS constraint, as is that of educated labor. The sum of the input elasticities of capital and educated labor is close to unity, implying that the (residual) elasticity of less educated labor is negligible, which is consistent with the results without imposition of CRS.[16] When the CRS constraint is imposed, there is no clear evidence of a structural break in the estimated input elasticities separating the period before 1994 from that afterward.

4.1 Provincial marginal products

One way to view regional productivity disparities is to use the estimated production function to calculate provincial marginal products for labor (MPL) and capital (MPK). Figures 3 and 4 show that MPL for educated labor and MPK follow different trends: while the series for MPL for educated labor have grown and diverged, those for MPK initially declined, but trended upward after about 1990 and tended to converge, at least among three regions. It is notable that MPK, which is an approximation of the rate of return to physical capital, has remained relatively high, despite economy-wide growth in ratios of physical capital to labor. In the northeast, coastal and interior regions, MPK reached a level above 30% after 1994, while the far west region, MPK has been relatively stable, falling behind other regions after 1996. The northeast region has experienced fastest growth in MPK since 1991.

The MPL of workers with at least a high school education rose everywhere; there was an approximately 3-fold increase in the coastal and northeast region. The coastal region experienced the fastest growth, and its advantage over other regions has been rising over time. Consistent with its negligible estimated production elasticity, the pattern of MPL for workers with below secondary education is very much lower than that of educated workers, and the disparity between the two categories of labor has been rising rapidly. The increasing gap between the MPL of educated workers and those who have not graduated from secondary school suggests that there is a high rate of return to schooling beyond the primary level.

[16] We also estimated models with CRS imposed only after 1994, based on the assumption that it is more likely to reach CRS as economic growth continues. The results are close to the model with CRS for both periods.

The regional distribution of factor marginal products and their trends raises concerns for the future course of regional inequality. The much higher marginal productivity of educated labor in the coastal region area compared to the far west and interior regions is likely to induce a drain brain from the disadvantaged to more developed areas. Similarly, the relatively low marginal product of capital in the far west region discourages investment there. Thus the future growth is likely to continue to be slower in the low-income areas of China than in the high-income, rapidly growing areas. In order to develop policy recommendations, we need to calculate internal rates of return that take into account both marginal benefits and costs for alternative policy instruments. Moreover, the policy benefits should consider not only their impacts on factor marginal products, but also their effects on TFP growth.

4.2 Total Factor Productivity Growth

TFP growth has important implications for regional disparity in China's economic development. Figure 5 shows the TFP growth pattern for each region. The growth increased from 1989 to 1994 in every region and then slowed down except for the northeast. The slower pace of TFP growth in the later stage of economic reform in China has been observed in other studies, for example Islam et al. (2006). Since 1999, regional TFP annual growth rates have been mostly in the rage of 1-5% with northeast region on the top.

In order to understand the determinants of TFP growth, as discussed in the methodology section, we model TFP growth as a function of FDI, physical capital vintage, and human capital, with human capital operating through two channels, both a direct effect on TFP growth and an indirect effect through technology spillovers.[17] Given the probable lag between investment and placing new capital into production, we lag FDI one year relative to the TFP growth series. This lag also mitigates the endogeneity problem, insofar as TFP growth increases the profitability of investment projects. We also include interaction terms between the 1994 dummy and other regressors to capture the possibility of a structural break following Deng's "South Trip."

[17] While there is little doubt that the shift of workers from low-productivity agricultural work to higher productivity work elsewhere has been a major force in China's economic growth (Young, 2003), we do not explicitly model geographical and intersectoral migration in this paper.

TFP growth regression results are presented in Tables 4 and 5. In Table 5, variables representing infrastructure capital are included as regressors. Each table reports the results of four specifications, all of them estimated with two-way fixed effects: (1) TFP derived from production function estimated with no scale constraint; (2) TFP derived from production function constrained to constant; (3) and (4), same as (1) and (2), but estimated by Instrumental Variable (IV) procedure.[18]

As can be seen in Table 4, columns (1) and (2), although the production function estimates are quite different when we impose CRS, the TFP-growth regressions are not very sensitive to the imposition of the CRS constraint. In both cases, most explanatory variables have similar sign and significance, the principal exception being the coefficient of FDI after 1994, which is positive in both columns, but statistically insignificant in column (1). Additionally, the direct effect of human capital is larger without CRS (0.54), compared to that with CRS (0.40).[19]

With or without constrained returns to scale, the estimated impact of FDI is much larger and more significant before 1994. In column (1), the magnitude of the coefficient implies that if FDI were to increase by $50/worker (the provincial sample mean is $78/worker in 2003), the expected TFP growth rate would be 0.037 (3.7 percentage points) more per year before 1994. For the period 1994 and later, the economic impact is negligible by comparison.

The estimated direct and spillover effects of human capital are positive and significant under both specifications of the production function. For example, the coefficient of the college-graduates variables in column (1) implies that, if the ratio of college graduates to population increases by 0.01, TFP growth increases by 0.54 percentage points per year. An indirect effect of human capital operating through technology spillover is modeled in the spillover variable, and it is much larger before 1994. As hypothesized, the vintage of capital measured by the acceleration of new investment has a positive and significant effect on TFP growth, consistent with the hypothesis that new capital embodies technological change.

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[18] In all models, the F-test on fixed effects strongly rejects the null of no fixed effects.

[19] The capital vintage effect and the direct effect of human capital on new innovation should not be affected by the stage of economic reform, and thus we do not include a structural change for them.

We discussed above that FDI may be endogenous because it is likely to earn a higher return in places where TFP growth is higher. Thus FDI and TFP growth are likely to be simultaneously determined. To address this econometric problem, we apply IV estimation.[20] We use as an instrument for FDI the lagged value of the degree of marketization in the local economy, which we measure by proportion of urban labor employed in non-state owned firms. This group of firms includes share holding units, joint ownership units, limited liability corporations, share-holding corporations, and units funded from abroad, Hong Kong, Macao and Taiwan. Presumably, the previous value of the proportion of workers in the non-state owned sector is correlated with local FDI, but not correlated with the current TFP growth.[21] As Table 2c shows, approximately 6% of urban workers were employed in the non-state owned sector nationally in 2003, and the variation across provinces is extremely high.

The 2SLS estimation results are reported in columns (3) and (4). As expected, the degree of marketization has a positive and significant effect on FDI in the first stage (not reported).[22] A Hausman test on the endogeneity of FDI rejects the null that FDI is exogenous, regardless of whether the CRS constraint is imposed on the underlying production function.[23] The 2SLS FE estimation results are generally similar to the FE estimates in columns (1) and (2). The major difference as that the estimated impact of FDI on TFP growth is larger both before and after 1994, and it is statistically significant in all cases. The estimated direct effect of human capital (college graduates) is also higher.

The estimated impact of local infrastructure capital on TFP growth is reported in Table 5. Not only is better infrastructure likely to promote the growth of total factor

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[20] The most serious potential endogeneity problem for the human capital spillover variable is due to the potential simultaneity between TFP and the output level, which is used to construct the degree of spillover. However, the extent and the direction of such correlation is unclear. In order to test the sensitivity our estimates to this problem, we have estimated our models with one- and two-period lags of spillover variable, assuming that previous spillover does not depend on the current TFP growth. The results are quite robust.

[21] Hale and Long (2007) used port availability and access to domestic market of the province as an instrument for FDI.

[22] It is arguable that the degree of marketization should be included in the TFP model instead of using it as an instrument. We tested this possibility by including the market system as a regressor in a number of alternative specifications, but it is insignificant.

[23] The Hausman test is conducted using a regression based approach by appending the residuals from the first stage regression of endogenous variables.

productivity, omission of this variable may lead to biased estimates because FDI and human capital measures are likely to be positively correlated with local infrastructure, i.e., a place with better infrastructure usually has more educated people and can attract more FDI. So omission of infrastructure variables will cause over-estimation of the effects of FDI and human capital. We represent local infrastructure capital with two variables, telephone ownership and length of roads and highways relative to surface area of a province. Telephone intensity can be viewed as a proxy of telecommunication infrastructure, while road intensity represents transportation infrastructure.

As can be seen in Table 5, the telephone ownership rate has a positive estimated effect on TFP growth, but road intensity has a positive and significant coefficient only before 1994.[24] Inclusion of the infrastructure measures in the FE estimation (columns 1 and 2) leads to a much smaller and less significant estimated coefficient of FDI, both before and after 1994. The estimated direct effect of human capital also becomes much smaller and is statistically insignificant. Both results indicate possible over-estimation when infrastructure variables are omitted. The spillover effect of human capital does not change much between tables 4 and 5.

In columns (3) and (4) of tables 4 and 5, we see that the 2SLS estimation is more robust to the addition of the infrastructure variables than is the FE estimation. The biggest change is that the coefficient of FDI becomes insignificant both in statistical sense and economic sense in the period following 1994. For the pre-1994 period, the estimated coefficient of FDI is nearly the same in magnitude and significance in the 2SLS estimates shown in both tables 4 and 5. In both specifications, the 2SLS estimated coefficient of FDI is much larger than the FE estimate, more consistently so before 1994 than after. Although the direct effect of human capital is smaller, it remains marginally significant in the 2SLS estimation when CRS is not imposed on the underlying production function. As expected again, compared to Table 5, in 2SLS estimation when infrastructure is controlled for, the estimated effects of FDI and human capital become

[24] We believe that the effect of telecommunication infrastructure should not change with economic structure, and thus do not interact it with year 1994 dummy. Inclusion of the interaction terms makes it insignificant in both periods. The effect of transportation, however, may change with the economic structure. For example, transportation infrastructure may be used more intensively as market economy develops and as transportation services and construction can be run by non-state owned sectors.

smaller. In general, the effects of infrastructure on TFP in the IV estimation become smaller relative to the FE estimates, both in magnitude and in statistical significance.[25]

To summarize the estimation results of alternative specifications and estimation procedures for the TFP growth equation, we draw the following conclusions. First, FDI has a much larger effect on TFP growth before 1994. After 1994, its effect is much smaller or statistically insignificant. Second, the direct effect of human capital measured by the proportion of college graduates is positive and highly significant in the models without infrastructure. It remains positive, although statistically insignificant in some estimation, when infrastructure variables are included in the model. Third, the spillover effect of human capital on TFP growth is positive and statistically significant, which is very robust to model specifications and estimation methods. The spillover effect appears to be much stronger before 1994, approximately double the effect after 1994. Fourth, capital vintage always has positive and statistically significant effect on TFP growth. Finally, telecommunication infrastructure as measured by telephone intensity generally has had a positive effect on TFP growth. The estimated coefficients for road intensity, on the other hand, are negligible in 2SLS estimates.

Taken together, these results suggest either that disembodied technology transmission as an engine of growth became less important as the reforms inspired by Deng's "South Trip" took hold or that distance from Shanghai became a smaller barrier to the transmission of technology spillovers. To test this conjecture, we estimated the regression equation reported in column (4) without "discounting" the human-capital spillover variable with distance from Shanghai. The estimation results are very similar

[25] We conducted unit root tests on the variables in the TFP regressions, namely, the TFP growth rate, FDI per capita, and the measures of human capital, spillovers, infrastructure, and physical-capital vintage. Two types of unit root tests were carried out: Dickey-Fuller GLS test (Elliott, Rothenberg, and Stock, 1996) and the KPSS test (Kwiatkowski, Phillips, Schmidt, and Shin, 1992). The DF-GLS test is based on the null of unit root while the KPSS test is based on the null of stationarity. The results of these tests indicate that most of the variables seem to contain a unit root in a number of provinces. However, it is well documented in the literature that most unit root tests are not powerful enough to distinguish a unit root process with a highly persistent stationary process based on a short period of data, such as used in this study. Moreover, the confirmatory results based on unit root tests (e.g., DF-GLS) and stationary tests (e.g., KPSS) are not always correct. In their review of Monte Carlo simulation studies from the literature, Maddala and Kim (1998) conclude that the proportion of correct confirmations is low if the true model is stationary. Therefore, we choose to run panel regressions without taking into account possible unit root processes. If some of the variables are indeed not stationary, we run the risk of spurious regressions, but our regression results do not seem to display serious symptoms of spurious regressions, such as, high R-square and t-values. Test statistics are available from the authors on request.

for all variables except the interaction term between the pre-1994 dummy and the spillover variable. The coefficient of this variable becomes negative and statistically significant, implying that without the distance correction, the spillover effect is unobservable before 1994. That is, the effect of distance as a barrier to technology transmission declined.

5. Policy Implications

In order to understand the economic importance of our estimation results, we calculate the impacts of possible policy interventions through human capital and infrastructure investments. An output-maximizing policy maker would rely on rates of return in designing an optimal investment policy. Therefore, we estimate the internal rates of return to investment in education and telecommunication infrastructure with telephones as a proxy. The internal rate of return is calculated by equalizing the estimated cost to the present value of estimated future benefits as reflected in the contribution to TFP growth or directly to production (as in the case of secondary or higher schooling).[26]

5.1 Internal Rates of Return

The returns to higher education and infrastructure are assumed to emanate from their impacts on TFP growth, while the return to secondary education is postulated to arise from its direct impact as a factor of production.[27] We develop simple approaches to estimate the costs of these investments. We assume that the inevitable errors in estimating costs do not vary substantially across provinces, but rather are more serious for comparison of alternative investment strategies. We therefore must be much more cautious in comparing returns to different types of investment than in deriving the implications of each policy individually for regional or provincial inequality.

[26] We do not compute the internal rates of return to road construction because the coefficient estimate of road construction is mostly insignificant.
[27] In computing the rates of return to education, we separate the impacts of education into two parts: a direct effect and an indirect effect. The direct effect of education operates through the production function by sending less educated workers to acquire high school education. The indirect effect of education operates through the TFP growth equation by sending workers with high school diplomas to receive college education. The lengths of high school and college education are assumed to be 3 and 4 years, respectively. The rates of return to schooling are based on the assumption of a 40-year working life.

In estimating the return to investing in secondary education, we assume that less educated labor is sent to high school or college and then becomes highly-educated labor with a higher marginal product. In estimating the return to education based its impact on TFP growth, we assume that high school students are sent to college and thus contribute to higher TFP growth after entering the workforce. Costs of education consist of two components: foregone production while a worker is taken out of production and sent to school and the direct costs of teachers, administrators, "bricks and mortar," and other direct expenses of schooling. Details of estimating the internal rates of return to human capital are given in Appendix A and B.

The calculated internal rates of return to education are reported in Table 6, columns 1 and 2. Column 1 contains the estimated rates of return to secondary education, which occurs directly in the production process. The national average rate of return is approximately 50%, and is almost the same magnitude in each of the four regions. It is interesting to compare the estimated rates of return in Table 6 with the marginal product of educated labor shown in Figure 3. It is clear that the marginal product of educated labor is much higher in the coastal region than elsewhere, but therefore so is the opportunity cost of sending a coastal worker to high school. Thus, when the opportunity cost is included in the calculation of policy benefits, the northeast and interior regions have higher returns than the coastal region (particularly than in Beijing, which has a particularly high concentration of educated workers). Therefore, one might argue that it is justifiable for the government to invest more resources to secondary education in less developed areas for both the political reason to reduce inequality and the economic reason to generate comparable returns.

The calculated national average rate of return per year of additional schooling to investment in higher education is reported in column 2 of Table 6. It is based on the 2SLS estimates reported in column (4) of Table 5.[28] The national average rate of return is approximately 33%. The interior region has the highest return of 38%, much higher than in other regions. There is more regional variation in the rate of return to college than

[28] The estimated internal rate of return to college is a very conservative estimate as we used the results from column (4) in Table 5 and treat the direct effect of college education as zero. If we use the results from column (3) without imposing CRS, where the direct effect of college education is almost significant at the 10% level, the estimated rate would be much higher.

in the rate of return to secondary school. As can be seen from Table 1, the proportion of college graduates is 4.15% in the interior region in 2003, the lowest among the four regions, while the national average is 5.17%. It is clear that the low density of college graduates in the population and the relatively high productivity generates the highest returns for investing in college education in the interior region. In Figure 2, we see that the interior region has very low per capita GDP relative to the coast (less than half as high). The investment in human capital to increase the number of college graduates in this region should have an important impact in reducing its income gap relative to the coast and northeast.

Column (3) in Table 6 contains the calculated rates of return for telephone infrastructure, based on its contribution to TFP growth. Since the impact of telephone ownership is likely to reflect all telecommunications infrastructure, we estimate the cost based on total telecommunication investment accordingly. The assumptions and methods used are detailed in Appendix C. We assume zero maintenance costs and thus may overestimate the rates of return. The national average rate of return to investment in telecommunication infrastructure is nearly 52%.[29] Regional variation is high, ranging from nearly 68% in the coastal region to approximately 41% in the far west and interior regions. Unlike the return of human capital investment, the investment in telecommunication infrastructure appears to be positively correlated with local development. The rates of return are much higher for relatively developed areas. For example, the return is 92% in Shanghai and 70% in Beijing; while only 35% in Gansu and 28% in Guizhou. We conjecture that this regional pattern is attributable to scale effects, and it implies that efficient infrastructure investments, while productive, are not likely to reduce regional inequality. Rather they are likely to increase regional disparities.

It is known that policies that improve efficiency may also increase inequality. Our results show that this is not the case for investment in human capital in China, particularly investment in higher education, where the return is highest in China's very large and economically disadvantaged interior region. Based on the internal rates of

[29] Given the difficulty in estimating the cost of infrastructure and education, we do not compare the rates of return between them.

return, we find that investing in human capital, both in secondary education and higher education, generates comparable or higher returns in less developed areas relative than in the more developed coastal region. Thus it should be effective in achieving both efficiency and equality goals.

5.2 Hypothetical Policy Experiments

Given that the starting point of this paper was the observation that regional inequality in China has soared, it is interesting to perform a hypothetical policy experiment. Suppose, for example, that the central government were to invest in human capital or telecommunication infrastructure in the northeast, far west and interior regions in order to reduce the regional per-capita output gaps. The total amount of investment is assumed to be 10% of central government total revenue, every year for 5 years. The first investment would yield returns starting in 2004, and the last investment would yield returns in 2008. The fund from the central government would be distributed to the provinces in those non-coastal regions annually, weighted by the size of each province's population.

We analyze three scenarios: allocation to increase the number of college graduates, to increase the number of secondary-school graduates, or to investment in telecommunications infrastructure. Assume the burden of the tax is on consumption expenditure in the year it is imposed. We use the regression results underlying the rate of return estimates reported in Table 6 to discuss these policy alternatives in terms of their ability to reduce regional inequality over a 10-year horizon through 2013. Details of the derivations and calculations are reported in appendix D. Table 7 shows the impacts of these alternative projects.

The first line of each cell in Table 7 is the predicted ratio of per-capita GDP in one of the other three regions to the coastal region if one of the three policy actions is undertaken.[30] The last row shows the predicted regional GDP ratio if no policy is undertaken, and the second line of each cell is the difference between the no-policy ratio and the ratio under a given policy. Finally, the third line in each cell shows the

[30] The policy actions are applied only to the non-coastal regions. The 2013 per-capita GDP in the coastal region is predicted without any policy intervention.

percentage decline in the provincial GDP ratio under each policy. For example, the number 0.4999 in the first line of the last column indicates that a policy of increasing secondary education in the interior region, with no change in the coastal region, would increase the interior/coast inequality ratio from 0.4006 to 0.4999, or by approximately 24.79% of the 2003 ratio by the year 2013. In the first row, we see that the impact of a policy focused on secondary education would have about the same impact on reducing regional inequality in the far west as in the interior. The same policy applied to the northeast region would reduce the income gap by about 15%.

In the second row of Table 7, we see that investment in college education would reduce the inequality ratio between the interior/coastal gap by approximately 15%, double that for the far west region and much higher than for northeast region. This is regional difference probably attributable to the much lower proportion of college graduates in the interior region than elsewhere. The impact of investment in telecommunication infrastructure would reduce the income gap by about a third across all three non-coastal regions.

6. Conclusion and Recommendations

China's spectacular economic growth has benefited its provinces and regions quite unequally. China now has one of the highest degrees of regional income in inequality in the world. We investigate the determinants of the dispersion in rates of economic growth and TFP growth. We hypothesize that the regional pattern of these growth rates can be understood as a function of several interrelated factors, which include investment in physical capital, human capital, and infrastructure capital; the infusion of new technology and its regional spread; and market reforms, with a major step forward occurring following Deng Xiaoping's "South Trip" in 1992.

The following empirical results are robust to alternative model specifications and estimation methods. First, FDI had much larger effect on TFP growth before 1994. After 1994, its effect becomes much smaller or statistically insignificant. The declining effect of FDI in the later stage of economic transition is consistent with the hypothesis that the acceleration of market reforms reduced the impact of FDI on technology transmission, not because technological advance became less important, but because the channels of its dissemination became more diffuse. We find that telecommunication infrastructure, which we measure by telephone intensity, generally has a positive effect on TFP growth, but that transportation infrastructure, which we measure by road intensity, has no significant impact after 1994. We also find a robust relationship between capital vintage and TFP growth. This is consistent with the hypothesis that investment in new capital stock is an effective means of technology transmission.

We find that human capital positively affects output in three ways. First, educated labor makes a direct contribution to production. Workers with a secondary-school diploma or higher education have a much higher marginal product than labor with less than a secondary-school diploma. Second, we estimate a positive, direct effect of human capital (measured by the proportion of college graduates) on TFP growth. This direct effect is hypothesized to come from domestic innovation activities. Third, we present evidence of an indirect spillover effect of human capital on TFP growth which is positive and statistically significant and which is very robust to model specifications and estimation methods. The spillover effect appears to be much stronger before 1994, approximately half again as large as after 1994. This evidence of regime shift after 1994 is consistent with that for the impact of FDI, and is also consistent with the impact of accelerating market reform.

We derive cost-benefit analysis of possible policies to raise GDP using an internal rate of return metric and obtain the following results from a policy "experiment" in which we project the impact of one time increases in human capital and infrastructure capital on regional inequality. (1) The interior region would gain substantially relative to the coast from increasing the proportion of workers with a high-school diploma, as would the far west; the northeast region would also gain significantly. (2) Investment in college graduates would generate a relative gain for the interior that is much larger than that for the far west and the northeast. (3) All three non-coastal regions would experience a large increase in their per-capita incomes relative to the coast from investment in telecommunications infrastructure. It is important to note that rates of return to investment in both levels of human capital are negatively related to the current relative income standing of the four regions. However the return to telecommunications investment is highest in the coast. Thus efficiency and equality considerations coincide for the human-capital investments, but are opposed for infrastructure investment.

We find evidence that China's transition toward a market economy accelerated after 1994. A beneficial aspect of this marketization has been the decline of regional barriers to the spread of technology and to the movement of labor and capital. As a result, regional discrepancies in the impact of FDI, infrastructure and human capital have declined. A worrisome implication, though, is that regional income and productivity gaps appear to have widened significantly as physical and human capital have moved toward destinations where their productivity and pay are higher. Thus, Chinese policy makers face a dilemma, because continued economic transformation toward a market system may aggravate the problem of regional inequality, with attendant political implications. The government may face choices between policies that increase the efficiency of resource allocation and those that benefit economically disadvantaged regions relative to the coast. Certainly this appears to be true for investing in telecommunication infrastructure in China's less developed areas. However, the choice is not so difficult when it comes to investment in human capital. Hence, increasing the number of high-school and college graduates in less developed areas in China serves both efficiency goal and equality goal. We conclude that investing in human capital will be an effective policy to reduce regional gaps in China as well as an efficient means for increasing the overall level of GDP and economic growth.

There is a direct implication of our research findings for China's on-going Go-West, formally known as the "Grand Western Development" Project, which was launched in 2000. It encompasses eleven provinces including the entire far west region as defined in this paper and five provinces in our interior region. The largest part of expenditure mandating from this project is focused on investment in infrastructure. Between 2000 and 2005, the cumulative investment in infrastructure was about 1 trillion Yuan (about US$125 billion).[31] The results of our research imply that, it is important to put human capital investment ahead of infrastructure in this project, both for reasons of economic efficiency and for reducing inequality.

[31] http://cppcc.people.com.cn/GB/34961/70385/70386/4783169.html [Access Date: January 23, 2007].

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Table 1
High School and College Graduates (%)

	High school graduates / Population					College graduates / Population				
	Coastal	Northeast	Far West	Interior	National	Coastal	Northeast	Far West	Interior	National
1982	26.66	34.55	21.19	22.12	24.80	0.54	0.63	0.47	0.33	0.44
1983	26.20	34.11	21.46	21.73	24.41	1.02	1.36	0.91	0.63	0.84
1984	25.77	33.70	21.69	21.34	24.03	1.05	1.39	0.92	0.64	0.86
1985	26.52	34.85	22.83	22.03	24.79	1.07	1.42	0.94	0.66	0.88
1986	27.26	35.95	23.91	22.73	25.55	1.10	1.46	0.95	0.68	0.91
1987	28.02	36.96	25.12	23.45	26.33	1.15	1.52	0.98	0.71	0.94
1988	28.79	38.03	26.44	24.13	27.10	1.19	1.58	1.01	0.73	0.98
1989	29.51	38.90	27.63	24.80	27.82	1.24	1.63	1.04	0.76	1.02
1990	29.50	39.67	28.16	25.28	28.16	1.66	2.33	1.42	1.03	1.38
1991	30.17	40.62	29.13	25.96	28.86	1.84	2.74	2.09	1.26	1.63
1992	30.90	41.59	30.04	26.65	29.59	1.89	2.80	2.11	1.29	1.67
1993	31.68	42.51	30.89	27.36	30.35	1.93	2.85	2.12	1.32	1.70
1994	32.49	43.47	31.44	28.01	31.08	1.98	2.91	2.13	1.35	1.74
1995	33.25	44.39	31.88	28.74	31.82	2.04	2.98	2.14	1.39	1.79
1996	34.04	44.92	32.50	29.34	32.48	2.22	3.37	2.77	1.61	2.03
1997	35.13	45.95	33.17	30.25	33.45	2.69	3.81	2.97	1.73	2.30
1998	36.46	47.14	33.94	31.23	34.56	3.15	4.24	3.17	1.84	2.57
1999	37.79	48.25	34.82	32.21	35.67	3.52	4.54	3.98	2.04	2.86
2000	37.08	49.34	34.87	34.04	36.50	4.09	5.30	3.55	2.74	3.49
2001	39.75	50.48	36.43	34.56	37.84	4.90	5.27	4.41	3.02	3.94
2002	41.29	51.82	37.57	35.98	39.28	5.59	5.28	5.21	3.38	4.40
2003	42.88	53.32	38.95	37.58	40.86	6.20	6.58	6.00	4.15	5.17

Note: Tibet and Inner Mongolia are excluded for lack of continuous data.

Table 2a
Summary Statistics - 1985
Mean (Standard Deviation)

Variable	1985 Coastal	Northeast	Far West	Interior	National
GDP	622.75	547.48	116.05	484.21	482.88
(100,000,000 yuan)	(284.34)	(241.10)	(73.06)	(236.48)	(281.83)
Capital	1081.91	1386.15	216.78	953.90	935.39
(100,000,000 yuan)	(546.06)	(600.75)	(102.67)	(671.64)	(636.15)
Labor secondary and higher	529.33	466.48	112.40	498.09	447.85
(10,000 workers)	(272.43)	(184.45)	(87.83)	(270.78)	(274.34)
Labor below secondary	1430.69	862.95	389.27	1772.49	1352.58
(10,000 workers)	(974.98)	(239.00)	(344.55)	(927.25)	(942.55)
FDI / total workforce	14.95	0.52	0.22	0.48	5.27
(1 US dollars per worker)	(25.19)	(0.45)	(0.13)	(0.48)	(15.62)
College graduates / population	20.34	14.11	10.07	6.82	12.62
(1 person / 1000 persons)	(21.00)	(1.77)	(1.91)	(1.99)	(13.19)
Human-capital spillover variable	0.024	0.011	0.011	0.019	0.018
	(0.023)	(0.003)	(0.004)	(0.008)	(0.015)
Second difference of log capital	0.009	0.010	0.015	0.004	0.008
	(0.013)	(0.009)	(0.022)	(0.009)	(0.013)
Telephones / population	13.94	9.65	5.03	3.39	7.84
(1 unit/ 1000 person)	(13.37)	(1.95)	(3.03)	(1.37)	(8.94)
Roads / area	0.30	0.15	0.05	0.19	0.20
(km length per km^2)	(0.09)	(0.07)	(0.04)	(0.04)	(0.10)
Urban non-state workforce / total workforce	20.76	23.05	2.28	2.03	10.65
(1 person / 10000 persons)	(13.77)	(36.33)	(1.24)	(1.96)	(16.03)

Notes:
1. All the monetary values were deflated with the base of Beijing 1990. The means are the provincial average, and the Standard deviations are in the parentheses.
2. Tibet and Inner Mongolia are excluded for lack of continuous data.
3. "Human-capital spillover variable": $h_{it}[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t}-y_{it}}{y_{it}})]$. $h_{i,t}$ is measured as the proportion of people who have at least college degrees, $y_{i,t}$ is GDP per capita (10,000 yuan per person), and d_{max_i} is the rail road distance between province i and the province with the highest GDP per capita in units of 1,000 kilometers. If $y_{max\_i} = y_{i,t}$, spillover term = 0.
4. "Urban non-state workforce" are employed in share holding units, joint ownership units, limited liability corporations, share-holding corporations, and units funded from abroad, Hong Kong, Macao and Taiwan.

Table 2b
Summary Statistics - 1994
Mean (Standard Deviation)

Variable	1994				
	Coastal	Northeast	Far West	Interior	National
GDP	1790.38	1140.95	263.73	1054.25	1192.15
(100,000,000 yuan)	(984.07)	(522.66)	(195.26)	(516.82)	(831.24)
Capital	2924.61	2522.14	562.89	1871.91	2101.13
(100,000,000 yuan)	(1385.08)	(1043.59)	(352.57)	(1062.23)	(1328.09)
Labor secondary and higher	771.86	693.80	196.23	788.35	684.62
(10,000 workers)	(432.69)	(198.62)	(152.94)	(408.41)	(413.99)
Labor below secondary	1585.79	897.70	445.61	2047.08	1528.35
(10,000 workers)	(1089.38)	(188.93)	(420.02)	(1051.42)	(1074.56)
FDI / total workforce	157.27	35.83	7.12	11.98	62.34
(1 US dollars per worker)	(115.54)	(24.48)	(8.30)	(8.25)	(94.50)
College graduates / population	38.06	28.77	21.59	14.02	24.80
(1 person / 1000 persons)	(41.44)	(2.57)	(7.15)	(5.37)	(25.68)
Human-capital spillover variable	0.030	0.023	0.028	0.041	0.033
	(0.029)	(0.005)	(0.010)	(0.018)	(0.021)
Second difference of log capital	0.010	-0.001	-0.002	0.003	0.005
	(0.016)	(0.008)	(0.010)	(0.010)	(0.012)
Telephones / population	80.16	39.84	19.82	15.48	40.39
(1 unit/ 1000 person)	(56.22)	(5.32)	(7.67)	(4.30)	(43.17)
Roads / area	0.40	0.18	0.06	0.21	0.25
(km length per km^2)	(0.15)	(0.10)	(0.05)	(0.04)	(0.15)
Urban non-state workforce / total workforce	333.35	171.18	32.80	44.09	152.96
(1 person / 10000 persons)	(221.90)	(82.77)	(28.92)	(27.30)	(186.01)

See note in Table 2a

Table 2c
Summary Statistics - 2003
Mean (Standard Deviation)

Variable	2003 Coastal	Northeast	Far West	Interior	National
GDP	4782.02	2526.56	581.63	2470.28	2967.32
(100,000,000 yuan)	(2632.27)	(1081.19)	(406.25)	(1249.03)	(2232.36)
Capital	7899.16	4163.88	1208.88	3952.38	4885.03
(100,000,000 yuan)	(3708.76)	(1525.63)	(796.81)	(2313.54)	(3492.15)
Labor secondary and higher	1098.67	805.43	246.79	1140.44	956.90
(10,000 workers)	(690.43)	(239.34)	(173.02)	(587.09)	(623.32)
Labor below secondary	1467.12	704.00	395.76	1908.34	1403.36
(10,000 workers)	(999.34)	(182.36)	(321.28)	(971.78)	(1003.44)
FDI / total workforce	194.58	48.70	3.82	18.03	78.19
(1 US dollars per worker)	(152.02)	(58.97)	(2.94)	(19.51)	(121.23)
College graduates / population	85.96	64.66	57.42	43.81	62.19
(1 person / 1000 persons)	(56.61)	(19.67)	(23.10)	(12.75)	(38.51)
Human-capital spillover variable	0.067	0.048	0.072	0.124	0.089
	(0.055)	(0.009)	(0.014)	(0.067)	(0.060)
Second difference of log capital	0.001	0.001	0.000	0.003	0.002
	(0.010)	(0.010)	(0.014)	(0.015)	(0.012)
Telephones / population	327.18	250.94	170.66	144.38	221.05
(1 unit/ 1000 person)	(87.66)	(45.95)	(30.84)	(31.38)	(99.48)
Roads / area	0.65	0.24	0.09	0.36	0.40
(km length per km^2)	(0.25)	(0.10)	(0.07)	(0.10)	(0.25)
Urban non-state workforce / total workforce	1047.35	627.04	409.52	264.52	587.22
(1 person / 10000 persons)	(754.26)	(89.05)	(266.61)	(105.26)	(557.23)

See note in Table 2a

Table 3
Production Function Estimates 1985-2003

		2-way FE, 2 periods,	
Dependent variable: $\log(GDP_t)$	(1) OLS, 2 periods	(2) Scale Unconstrained	(3) Scale Constrained to CRS
Intercept	-1.68***	4.44***	0.42***
	(-13.38)	(9.42)	(7.70)
log(Capital $_t$)	0.95***	0.48***	0.54***
	(29.54)	(19.81)	(18.95)
log(Labor Secondary and Higher $_t$)	0.015	0.20***	0.43***
	(0.26)	(3.55)	(6.85)
log(Labor Below Secondary $_t$)	0.20***	-0.18***	
	(5.47)	(-2.82)	
log(Capital $_t$)*Year 1994	-0.45***	-0.18***	-0.03
	(-8.17)	(-7.52)	(-0.94)
log(Labor Secondary and Higher $_t$) * Year 1994	0.49***	0.16***	-0.03
	(5.59)	(4.37)	(-0.69)
log(Labor Below Secondary $_t$) * Year 1994	-0.18***	-0.092***	
	(-3.79)	(-4.29)	
Year 1994	1.28***		
	(7.08)		
N	513	513	513
R square	0.97	0.996	0.99
Adjusted R square	0.97	0.996	0.99
F-statistics	2060.29	2357.90	1003.07
F Test for No Fixed Effects: F Value (Pr > F)		89.54 (<.0001)	62.87 (<.0001)

Notes:
1. Hainan is included in Guangdong; and Chongqing is included in Sichuan. Tibet and Inner Mongolia are excluded for lack of continuous data.
2. t-values are in the parentheses. The stars *, ** and *** indicate the significance level at 10%, 5%, and 1%, respectively.
3. YB = 1 if year < 1994; 0 otherwise.
4. Units of measurement. “GDP”: 100,000,000 yuan. “Capital”: 100,000,000 yuan. “Labor Secondary and Higher”: 10,000 workers. “Labor Below Secondary”: 10,000 workers. All the monetary values were deflated with the base of Beijing 1990.

Table 4
TFP growth regression, 1987-2003

	Two-Way FE		Two-way FE + 2SLS	
Dependent variable: $\log(TFP_t) - \log(TFP_{t-1})$	(1) Scale Unconstrained	(2) Scale Constrained to CRS	(3) Scale Unconstrained	(4) Scale Constrained to CRS
Intercept	0.014	-0.0095	-0.033	-0.045**
	(0.87)	(-0.64)	(-1.36)	(-1.99)
FDI_{t-2}	0.037	0.076**	0.14**	0.13**
	(1.15)	(2.50)	(2.30)	(2.36)
FDI_{t-2} * Year 1994	0.74***	0.70***	1.94***	1.74***
	(3.28)	(3.33)	(4.04)	(3.92)
College graduates $_{t-1}$	0.54***	0.40**	0.79***	0.70***
	(2.89)	(2.30)	(3.60)	(3.41)
Human capital spillover $_{t-1}$	0.26*	0.38***	0.33**	0.39***
	(1.92)	(2.99)	(2.17)	(2.75)
Human capital spillover $_{t-1}$ * Year 1994	0.37**	0.29**	0.50***	0.41***
	(2.33)	(1.98)	(2.94)	(2.60)
Capital Vintage $_t$	0.47***	0.39***	0.49***	0.39***
	(3.93)	(3.48)	(3.95)	(3.40)
N	459	459	459	459
R square	0.98	0.60		
F-statistics	532.24	12.82	495.25	12.14
F Test for No Fixed Effects: F Value (Pr > F)	572.87 (<.0001)	12.16 (<.0001)	530.93 (0.0001)	11.67 (0.0001)
Hausman Test for Endogeneity: F Value (Pr > F)			4.58 (0.0108)	5.29 (0.0054)

Notes:
1. All the regressions include a dummy variable for each year and for each province.
2. Year 1994 = 1 if year < 1994; 0 otherwise.
3. t-values are in the parentheses. The stars *, ** and *** indicate significance levels at 10%, 5%, and 1%, respectively.
4. "FDI": 1,000 US dollars per worker. "College graduates": the proportion of population who have college degrees or above. "Capital Vintage": double difference of log Capital. "Human capital spillover" variable is defined in the text. All the monetary values were deflated with the base of Beijing 1990.
5. In the 2SLS, the market economy variable and its interaction term with "Year 1994" are used as instrumental variables.

Table 5
TFP growth regression, 1987-2003

	Two-Way FE		Two-Way FE + 2SLS	
Dependent variable: log(TFP_t) – log(TFP_{t-1})	(1) Scale Unconstrained	(2) Scale Constrained to CRS	(3) Scale Unconstrained	(4) Scale Constrained to CRS
Intercept	-0.025 (-1.02)	-0.037 (-1.65)	-0.042 (-1.52)	-0.060** (-2.36)
FDI_{t-2}	-0.021 (-0.41)	0.042 (0.89)	0.059 (0.38)	0.0045 (0.03)
FDI_{t-2} * Year 1994	0.51** (1.99)	0.38 (1.59)	1.92*** (2.95)	1.69*** (2.82)
College graduates $_{t-1}$	0.18 (0.79)	0.077 (0.37)	0.55 (1.64)	0.28 (0.91)
Human capital spillover $_{t-1}$	0.32** (2.34)	0.43*** (3.38)	0.33** (2.07)	0.38*** (2.64)
Human capital spillover $_{t-1}$ * Year 1994	0.40** (2.36)	0.28* (1.79)	0.57*** (2.66)	0.52*** (2.64)
Capital Vintage $_t$	0.49*** (4.13)	0.42*** (3.82)	0.49*** (3.84)	0.39*** (3.33)
Telephones $_{t-1}$	0.24*** (2.93)	0.25*** (3.24)	0.17 (0.98)	0.30* (1.85)
Roads $_{t-1}$	0.018 (0.57)	-0.015 (-0.50)	-0.0035 (-0.08)	-0.011 (-0.26)
Roads $_{t-1}$ * Year 1994	0.093*** (2.64)	0.12*** (3.57)	0.012 (0.22)	0.028 (0.58)
N	459	459	459	459
R square	0.98	0.62		
F-statistics	513.21	13.02	474.67	12.22
F Test for No Fixed Effects: F Value (Pr > F)	521.93 (<.0001)	13.03 (<.0001)	482.33 (0.0001)	12.19 (0.0001)
Hausman Test for Endogeneity: F Value (Pr > F)			3.08 (0.0472)	3.55 (0.0297)

Notes:
1. All the regressions include a dummy variable for each year and for each province.
2. Year 1994 = 1 if year < 1994; 0 otherwise.
3. t-values are in the parentheses. The stars *, ** and *** indicate significance levels at 10%, 5%, and 1%, respectively.
4. “FDI”: 1,000 US dollars per worker. “College graduates”: the proportion of population who have college degrees or above. “Capital Vintage”: double difference of log Capital. “Telephone”: number of units per person. “Road”: km per km^2. “Human capital spillover” variable is defined in the text. All the monetary values were deflated with the base of Beijing 1990.
5. In the 2SLS, the market economy variable and its interaction term with “Year 1994” are used as instrumental variables.

Table 6
Internal Rates of Return to Investment in Education and Telephone Infrastructure

Province	(1) Direct contribution to production though secondary education	(2) Indirect contribution to production though higher education	(3) Telephone
Beijing	0.2384	0.1403	0.6988
Tianjin	0.4700	0.2217	0.7843
Hebei	0.5510	0.3744	0.5295
Shanxi	0.5054	0.4173	0.4719
Liaoning	0.4811	0.2786	0.6360
Jilin	0.4942	0.3325	0.5419
Heilongjiang	0.5786	0.3151	0.5351
Shanghai	0.4289		0.9241
Jiangsu	0.5547	0.4434	0.6576
Zhejiang	0.4647	0.4259	0.6698
Anhui	0.4682	0.4677	0.4200
Fujian	0.6142	0.2679	0.5947
Jiangxi	0.5178	0.4638	0.4226
Shandong	0.5668	0.3324	0.6332
Henan	0.5726	0.4580	0.4089
Hubei	0.5162	0.3262	0.4762
Hunan	0.4684	0.4111	0.4355
Guangxi	0.4882	0.3140	0.4181
Sichuan	0.5094	0.2974	0.4200
Guizhou	0.4087	0.3417	0.2769
Yunnan	0.5849	0.2516	0.3492
Shaanxi	0.4326	0.3818	0.3810
Gansu	0.4632	0.3111	0.3536
Qinghai	0.5137	0.2786	0.4134
Ningxia	0.4706	0.3087	0.4033
Xinjiang	0.4944	0.2467	0.4504
Guangdong	0.5503	0.2307	0.6099
Coastal	0.4932	0.3046	0.6780
Northeast	0.5180	0.3087	0.5710
Far West	0.4855	0.2863	0.4052
Interior	0.4975	0.3755	0.4073
National	0.4966	0.3323	0.5154

Note:
1. Production function: 2-way FE, 2 periods, CRS.
2. The computation of rates of return (ρ_i^s) are discussed in Appendix A-C.
3. Regional calculations are arithmetic means of the constituent provinces.

Table 7
Impact on Regional Ratios of Per-Capita GDP under Alternative Hypothetical Policy Scenarios in 2013

	NE/Coastal	FW/Coastal	Interior /Coastal
Secondary Education (Direct Contribution)	1.0147	0.4521	0.4999
Increase compared to No Policy	0.1343	0.0903	0.0993
% of Increase in the Ratios	15.25%	24.96%	24.79%
College Education (Indirect Contribution)	0.9061	0.3872	0.4626
Increase compared to No Policy	0.0257	0.0254	0.0620
% of Increase in the Ratios	2.92%	7.02%	15.48%
Telephones	1.1737	0.4823	0.5341
Increase compared to No Policy	0.2933	0.1205	0.1335
% of Increase in the Ratios	33.31%	33.31%	33.33%
Predicted ratios without any policy imposed	0.8804	0.3618	0.4006

Note: The details about the alternative hypothetical policy are provided in Appendix D.

Figure 1 Coefficient of Variation Nominal GDP per Capita (4 regions)

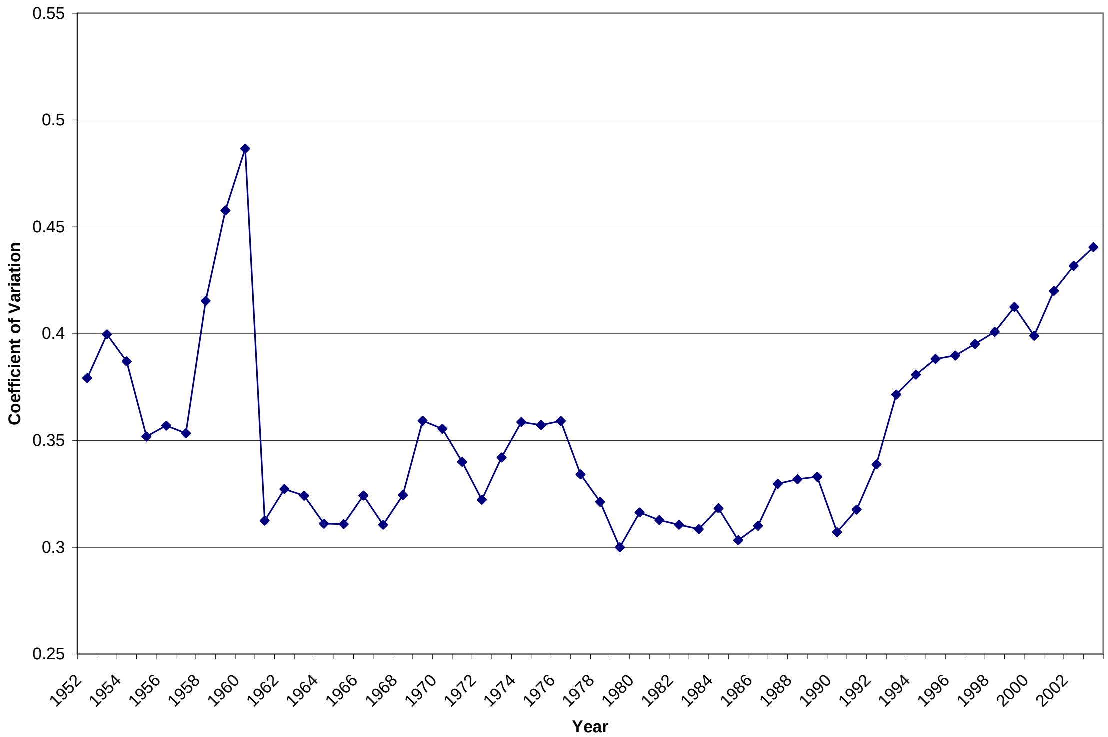


Figure 2 Real Per Capita GDP Ratios

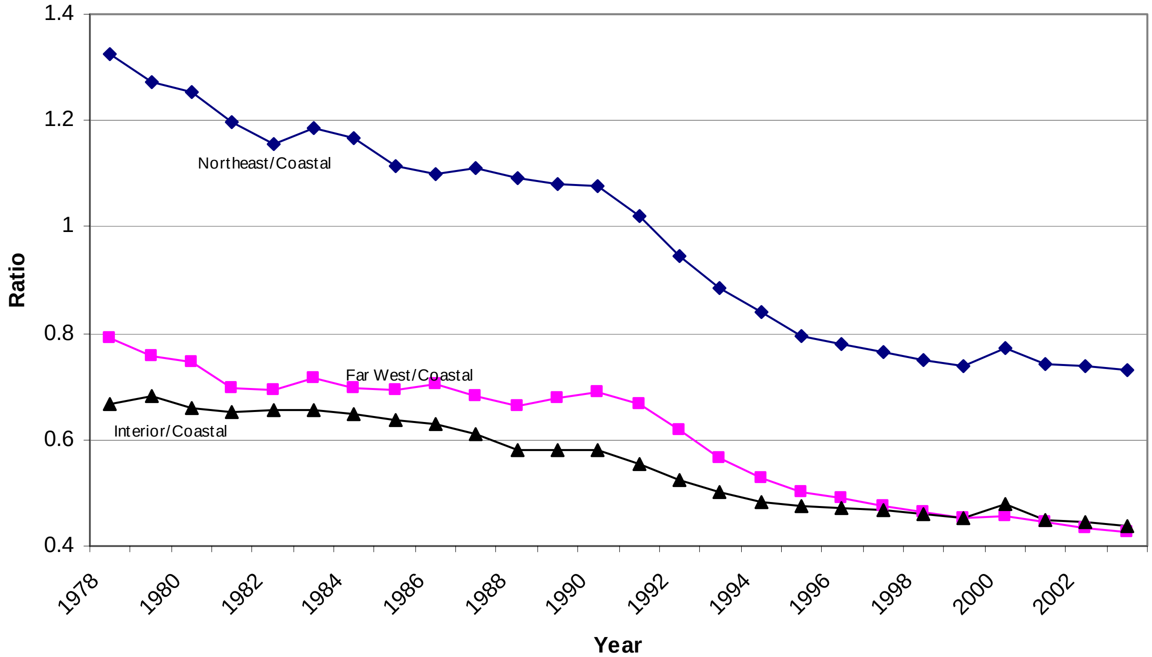


Figure 3 Marginal Product of Labor

(Two Categories of Labor, 2-Way FE with CRS)

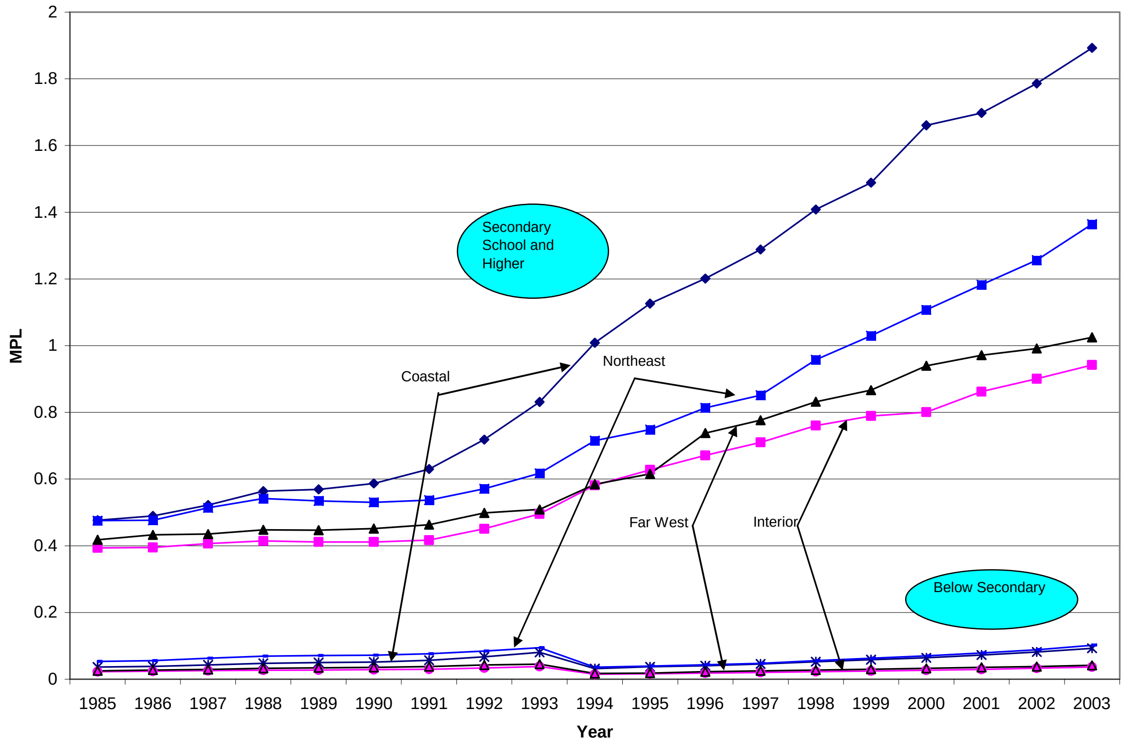


Figure 4 Marginal Product of Capital
(Two categories of Labor, 2-Way FE with CRS)

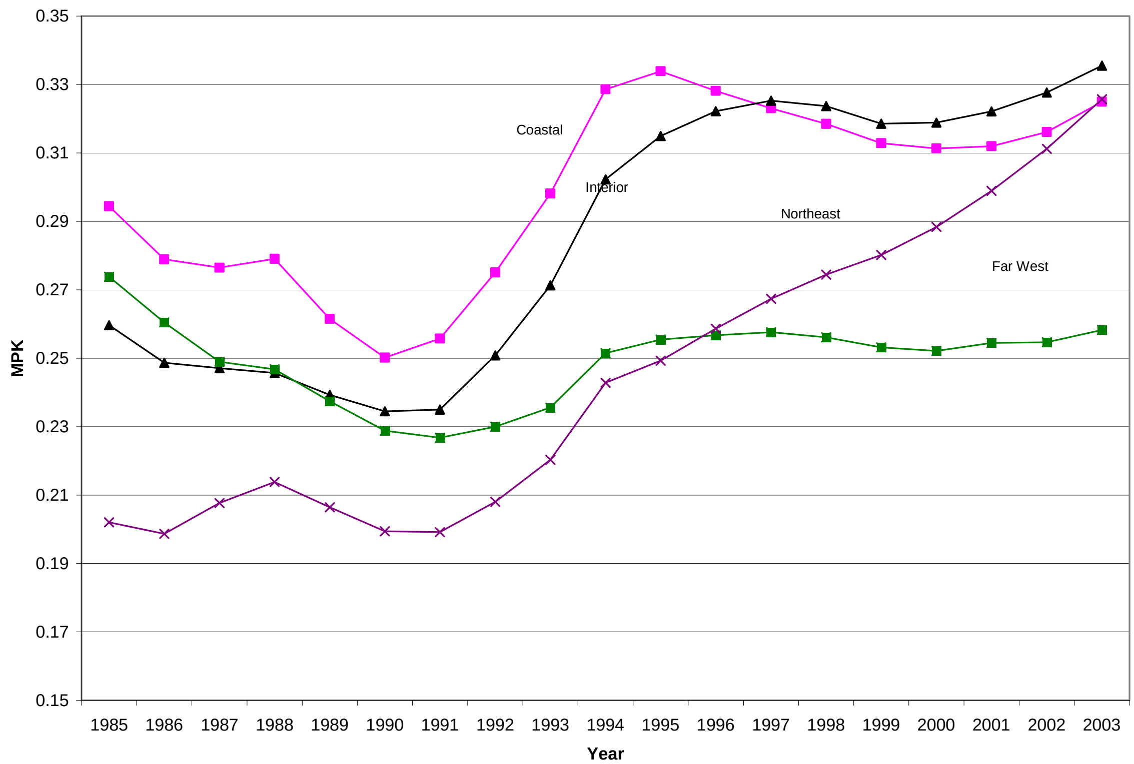
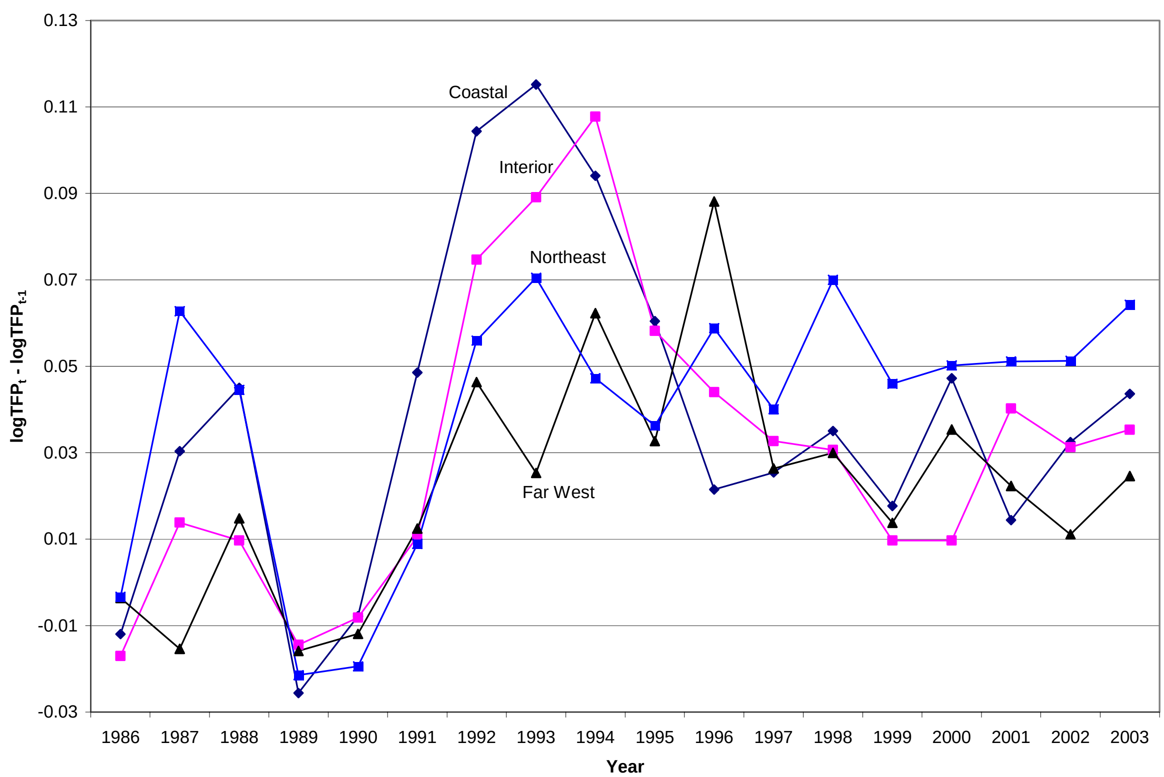


Figure 5 Total Factor Productivity Growth
(Two categories of Labor, 2-Way FE, with CRS)



Appendix

Production Function:

$$\log Y_{i,t} = \log TFP_{i,t} + \beta_k \log K_{i,t} + \beta_k^{YB}(\log K_{i,t} \cdot YB) + \beta_e \log L_{ei,t} + \beta_e^{YB}(\log L_{ei,t} \cdot YB)$$
$$+ \beta_n \log L_{ni,t} + \beta_n^{YB}(\log L_{ni,t} \cdot YB) + u_{i,t}$$

TFP Growth Equation:

$$[\log TFP_{i,t} - \log TFP_{i,t-1}] = \eta_{1,i} + \eta_{2,t} + \varphi_1 RFDI_{i,t-2} + \varphi_2 RFDI\_YB_{i,t-2} + \phi_1^h h_{i,t-1} +$$
$$\phi_1^s h_{i,t-1}[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t-1} - y_{i,t-1}}{y_{i,t-1}})] + \phi_2^s h_{i,t-1}[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t-1} - y_{i,t-1}}{y_{i,t-1}})]\_YB +$$
$$\phi_1^v \Delta_t^2 K_i + \beta_1^r Road_{i,t-1} + \beta_2^r Road\_YB_{i,t-1} + \beta_1^t Tel_{i,t-1} + \mu_{i,t}$$

A. The Rate of Return to Education Based on Its Direct Effect

Basic Assumptions:

- Policy scenario: each provincial government is going to invest in education by sending less-educated workers to receive high school education. In order to maintain the same ratio of college graduates to high-school graduates in the population, some of the workers will continue their studies at college. The lengths of the high school education and the college education are assumed to be three years and four years, respectively. After the graduation, the workers will be sent to work for N_2 years (starting at time t+1).

  $$dL_i = dL_{ei,t+1} = dL_{ei,t+2} = \ldots$$
  $$= -dL_{ni,t+1} = -dL_{ni,t+2} = \ldots$$

  Let x_i be the proportion of workers who have college degrees in province *i* in 2003. Under this policy, there will be $x_i \cdot dL_i$ number of workers to receive both high school and college education, and $(1 - x_i) \cdot dL_i$ number of workers to receive only high school education.
- Before imposing the policy, assume all the variables stay constant in projecting the future output, which is growing at the annual rate of w_i.

  $$w_i = \log TFP_{i,2003} - \log TFP_{i,2002}$$

  Other variables: $L_{ei} = L_{ei,t+1} = L_{ei,t+2} = \ldots$

  $$L_{ni} = L_{ni,t+1} = L_{ni,t+2} = \ldots$$
- The current time t = 2003, and *YB* = 0 after time t.

Return to Education Based on Its Direct Effect:

$$\log Y_{i,t+j} - \log Y_{i,t+j-1} = w_i, \quad j \geq 1$$
$$\log Y_{i,t+j} = \log Y_{i,t} + j \cdot w_i = \log Y_{i,t} + j \cdot w_i = \log Y_{i,t} + j \cdot w_i$$

Let $\Upsilon_{j,i} = j \cdot w_i$

Then, $Y_{i,t+j} = Y_{i,t} e^{\Upsilon_{j,i}}$

Return to education at time t+j:

$$\frac{\partial Y_{i,t+j}}{\partial L_{ei,t+j}} = \frac{Y_{i,t+j}}{L_{ei,t+j}} \beta_e = \frac{Y_{i,t} e^{\Upsilon_{j,i}}}{L_{ei}} \beta_e , \quad \frac{\partial Y_{i,t+j}}{\partial L_{ni,t+j}} = \frac{Y_{i,t+j}}{L_{ni,t+j}} \beta_n = \frac{Y_{i,t} e^{\Upsilon_{j,i}}}{L_{ni}} \beta_n$$

$$dY_{i,t+j} = \frac{Y_{i,t} e^{\Upsilon_{j,i}}}{L_{ei}} \beta_e dL_{ei,t+j} + \frac{Y_{i,t} e^{\Upsilon_{j,i}}}{L_{ni}} \beta_n dL_{ni,t+j} = \frac{Y_{i,t} e^{\Upsilon_{j,i}}}{L_{ei}} \beta_e dL_i - \frac{Y_{i,t} e^{\Upsilon_{j,i}}}{L_{ni}} \beta_n dL_i$$

Total return to education (from year t+1 to year t+N_2):

$$\text{Return} = (\frac{Y_{i,t}}{L_{ei}} \beta_e - \frac{Y_{i,t}}{L_{ni}} \beta_n) dL_i \cdot \sum_{j=1}^{N_2} \frac{e^{\Upsilon_{j,i}}}{(1+\rho_i^s)^j}$$

Investment Cost:

The cost of investment per year:

Direct cost: D_i

Indirection cost: $\frac{\partial Y_{i,t}}{\partial L_{ni,t}} = \frac{Y_{i,t}}{L_{ni,t}} \beta_n$

Total cost: $dL_i \cdot (D_i + \frac{Y_{i,t}}{L_{ni}} \beta_n)$

Assume the unit costs of high school education and college education are $dL_i \cdot (D_i^h + \frac{Y_{i,t}}{L_{ni}} \beta_n)$ and $dL_i \cdot (D_i^c + \frac{Y_{i,t}}{L_{ni}} \beta_n)$, respectively. The length of high school education is N_{1h} -year, and the length of college education is N_{1c} -year.

$$(1-x_i) \cdot dL_i \cdot (D_i^h + \frac{Y_{i,t}}{L_{ni}} \beta_n) \cdot [1 + ... + (\frac{1}{1+\rho_i^s})^{-N_{1h}+1}] + x_i \cdot dL_i \cdot (D_i^c + \frac{Y_{i,t}}{L_{ni}} \beta_n) \cdot [1 + ... + (\frac{1}{1+\rho_i^s})^{-N_{1c}+1}]$$

$$+ x_i \cdot dL_i \cdot (D_i^h + \frac{Y_{i,t}}{L_{ni}} \beta_n) \cdot [(\frac{1}{1+\rho_i^s})^{-N_{1c}} + ... + (\frac{1}{1+\rho_i^s})^{-N_{1h}-N_{1c}+1}]$$

$$= dL_i \cdot (D_i^h + \frac{Y_{i,t}}{L_{ni}} \beta_n) \cdot [(1-x_i) + x_i \cdot (1+\rho_i^s)^{N_{1c}}] \cdot \frac{(1+\rho_i^s)^{N_{1h}} - 1}{\rho_i^s} + dL_i \cdot (D_i^c + \frac{Y_{i,t}}{L_{ni}} \beta_n) \cdot [x_i \cdot \frac{(1+\rho_i^s)^{N_{1c}} - 1}{\rho_i^s}]$$

The Rate of Return (ρ_i^s) to Education Based on Its Direct Effect:

$$(\frac{Y_{i,t}}{L_{ei}}\beta_e - \frac{Y_{i,t}}{L_{ni}}\beta_n)\sum_{j=1}^{N_2}\frac{e^{\Upsilon_{j,i}}}{(1+\rho_i^s)^j} = (D_i^h + \frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(1-x_i) + x_i\cdot(1+\rho_i^s)^{N_{1c}}]\cdot\frac{(1+\rho_i^s)^{N_{1h}}-1}{\rho_i^s}$$
$$+(D_i^c + \frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[x_i\cdot\frac{(1+\rho_i^s)^{N_{1c}}-1}{\rho_i^s}]$$

B. The Rate of Return to Education Based on Its Indirect Effect

Basic Assumptions:

- Policy scenario: each provincial government is going to invest in education by sending workers with high school diplomas to receive college education. The length of the college education is assumed to N_1 (=4) years. After the graduation, the workers will be sent to work for N_2 years (starting at time t+1, with constant population Pop_i).

  $$dh_i = dh_{i,t+1} = dh_{i,t+2} = ...$$
- Before imposing the policy, assume all the variables stay constant in projecting the future output, which is growing at the annual rate of w_i.

  $$w_i = \log TFP_{i,2003} - \log TFP_{i,2002}$$

  Other variables: $L_{ei} = L_{ei,t+1} = L_{ei,t+2} = ...$

  $L_{ni} = L_{ni,t+1} = L_{ni,t+2} = ...$

  $Pop_i = Pop_{i,t+1} = Pop_{i,t+2} = ...$
- Let *E* be the proportion of workers with college degrees. Due to the lack of data, we assume that the proportion of workers with college degrees (E_i) is equal to the proportion of people with college degrees (h_i) before the policy imposed.

  Since $dE_i = dh_i$ and $dE_i = dE_{i,t+1} = dE_{i,t+2} = ...$,

  $$dh_i = dh_{i,t+1} = dh_{i,t+2} = ...$$
- The current time t = 2003, and *YB* = 0 after time t.

Return to Education Based on Its Indirect Effect:

Based on the TFP Growth Equation,

$$\log TFP_{i,t+2} = \log TFP_{i,t+1} + h_{i,t+1}\cdot\{\phi_1^h + \phi_1^s[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t+1}-y_{i,t+1}}{y_{i,t+1}})]\} + \ other\ \ variables$$
$$= \log TFP_{i,t+1} + h_{i,t+1}\cdot\{\phi_1^h + \phi_1^s[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t}-y_{i,t}}{y_{i,t}})]\} + \ other\ \ variables$$

Let $\vartheta_i = \phi_1^h + \phi_1^s[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t}-y_{i,t}}{y_{i,t}})]$

Then, $\log TFP_{i,t+2} = \log TFP_{i,t+1} + h_{i,t+1}\cdot\vartheta_i + \ other\ \ variables$

Note: Other variables are not the functions of *h*. Although *h* is increased at time t+1, there are no impacts on $TFP_{i,t+1}$ due to the assumption of the lagged impact of *h*.

Return to education at time t+2:

$$\frac{dY_{i,t+2}}{dh_{i,t+1}} = \frac{dY_{i,t+2}}{d\log Y_{i,t+2}} \frac{d\log Y_{i,t+2}}{d\log TFP_{i,t+2}} \frac{d\log TFP_{i,t+2}}{dh_{i,t+1}} = Y_{i,t+2} \frac{d\log TFP_{i,t+2}}{dh_{i,t+1}} = Y_{i,t} e^{\Upsilon_{2,i}} \cdot \vartheta_i$$

$$dY_{i,t+2} = Y_{i,t} e^{\Upsilon_{2,i}} \cdot \vartheta_i \cdot dh_{i,t+1} = Y_{i,t} e^{\Upsilon_{2,i}} \cdot \vartheta_i \cdot dh_i$$

Return to education at time t+3:

$$dY_{i,t+3} = 2Y_{i,t} e^{\Upsilon_{3,i}} \cdot \vartheta_i \cdot dh_i$$

Return to education at time t+j ($j \geq 2$):

$$dY_{i,t+j} = (j-1) \cdot Y_{i,t} e^{\Upsilon_{j,i}} \cdot \vartheta_i \cdot dh_i$$

Total return to education (from year t+1 to year t+N_2):

$$\text{Return} = Y_{i,t} \cdot \vartheta_i \cdot dh_i \cdot \sum_{j=2}^{N_2} \frac{(j-1) \cdot e^{\Upsilon_{j,i}}}{(1+\rho_i^s)^j}$$

Investment Cost:

The cost of investment per year:

Direct cost: D_i

Indirection cost $\frac{dY_{i,t}}{dL_{ei,t}} = \frac{Y_{i,t}}{L_{ei,t}} \beta_e$

Total cost: $dE_i \cdot Workforce_i \cdot (\frac{Y_{i,t}}{L_{ei}} \beta_e + D_i)$

Assume the government pays $dE_i \cdot Workforce_i \cdot (\frac{Y_{i,t}}{L_{ei}} \beta_e + D_i^c)$ each year until the workers finish their N_1-year college education at time t.

$$dE_i \cdot Workforce_i \cdot (\frac{Y_{i,t}}{L_{ei}} \beta_e + D_i^c) \cdot [1 + (\frac{1}{1+\rho_i^s})^{-1} + \ldots + (\frac{1}{1+\rho_i^s})^{-N_1+1}]$$

$$= dE_i \cdot Workforce_i \cdot (\frac{Y_{i,t}}{L_{ei}} \beta_e + D_i^c) \cdot \frac{(1+\rho_i^s)^{N_1-1} - 1}{\rho_i^s}$$

The Rate of Return (ρ_i^s) to Education Based on Its Indirect Effect:

$$Y_{i,t} \cdot \vartheta_i \cdot \sum_{j=2}^{N_2} \frac{(j-1) \cdot e^{\Upsilon_{j,i}}}{(1+\rho_i^s)^j} = Workforce_i \cdot (\frac{Y_{i,t}}{L_{ei}} \beta_e + D_i^c) \cdot \frac{(1+\rho_i^s)^{N_1-1} - 1}{\rho_i^s}$$

The estimates of D (Direct Cost)

Direct cost = total expenditures/ total number of students

Unit: 100,000,000 yuan / 10,000 persons

Table I

Year: 2002	Higher Education	High School
Beijing	2.8116	0.5149
Tianjin	1.2546	0.3945
Hebei	0.5967	0.1593
Shanxi	0.6901	0.1753
Liaoning	0.9439	0.2324
Jilin	0.9738	0.2197
Heilongjiang	0.8082	0.1367
Shanghai	1.7431	0.4931
Jiangsu	1.0842	0.3081
Zhejiang	1.1719	0.3765
Anhui	0.8645	0.1936
Fujian	1.0761	0.2074
Jiangxi	0.6734	0.1435
Shandong	0.8363	0.2148
Henan	0.5285	0.1157
Hubei	1.0849	0.1880
Hunan	0.8072	0.1850
Guangxi	0.8064	0.1804
Sichuan	1.0213	0.1776
Guizhou	0.6730	0.1278
Yunnan	0.7701	0.1881
Shaanxi	0.9156	0.0936
Gansu	0.8995	0.1421
Qinghai	0.8827	0.1608
Ningxia	0.8478	0.1394
Xinjiang	0.6211	0.1664
Guangdong	1.2340	0.2946

Notes:
1. All the data were collected from the 2003 Education Statistical Yearbook.
2. The total expenditure data are deflated using GDP deflator (base = Beijing, 1990).
3. Hainan is included in Guangdong; Chongqing is included in Sichuan.

C. The Rate of Return to Infrastructure Measures

Basic Assumptions:

- Policy scenario: each provincial government is going to invest *C* dollars on infrastructure at time t. The newly increased infrastructure will be available at the beginning of time t+1. The rate of return is computed based on the service provided by the newly increased infrastructure during the time between t+1 and t+N_2.

$$dTel_{i,t+j} = (1-R)^{j-1} dTel_i, \quad j \geq 2$$

$$dRoad_{i,t+j} = (1-R)^{j-1} dRoad_i, \quad j \geq 2$$

- Before imposing the policy, assume all the variables stay constant in projecting the future output, which is growing at the annual rate of w_i

$$w_i = \log TFP_{i,2003} - \log TFP_{i,2002}$$

- Depreciation ratio, R = 0.06. The initial stock of infrastructure (at time t) is assumed to be maintained at the same level throughout the years. The depreciation is only applied to the newly increased infrastructure (starting at t+2).
- The current time t = 2003, and YB = 0 after time t.

Telephone Infrastructure

Based on the TFP Growth Equation,

$$\log TFP_{i,t+2} = \log TFP_{i,t+1} + \beta_1^t Tel_{i,t+1} + \ other \ \ variables$$

Note: Other variables are not the functions of *Tel*. Although *Tel* is increased at time t+1, there are no impacts on $TFP_{i,t+1}$ due to the assumption of the lagged impact of *Tel*.

Return to telephone infrastructure at time t+2:

$$dY_{i,t+2} = Y_{i,t} e^{\Upsilon_{2,i}} \cdot \beta_1^t \cdot dTel_{i,t+1} = Y_{i,t} e^{\Upsilon_{2,i}} \cdot \beta_1^t \cdot dTel_i$$

Return to telephone infrastructure at time t+3:

$$dY_{i,t+3} = Y_{i,t} e^{\Upsilon_{3,i}} \cdot \beta_1^t \cdot [1 + (1-R)] \cdot dTel_i$$

Return to Road Construction at time t+j ($j \geq 2$):

$$dY_{i,t+j} = Y_{i,t} e^{\Upsilon_{j,i}} \cdot \beta_1^t \cdot \frac{1-(1-R)^{j-1}}{R} \cdot dTel_i$$

Total return to road (from year t+1 to year t+N_2):

$$\text{Return} = Y_{i,t} \cdot \beta_1^t \cdot dTel_i \cdot \sum_{j=2}^{N_2} \frac{e^{\Upsilon_{j,i}}}{(1+\rho_i^s)^j} \cdot \frac{1-(1-R)^{j-1}}{R}$$

Investment Cost:

Let C_i^t be the unit cost of telephone in Province *i*.

Then, the investment cost is: $dTel_i \cdot Pop_i \cdot C_i^t$

The Rate of Return (ρ_i^s) to Telephone Infrastructure:

$$Y_{i,t} \cdot \beta_1^t \cdot \sum_{j=2}^{N_2} \frac{e^{\Upsilon_{j,i}}}{(1+\rho_i^s)^j} \cdot \frac{1-(1-R)^{j-1}}{R} = Pop_i \cdot C_i^t$$

Cost estimates for the telephone

The CSY reports the aggregate investment cost for "Transportation, Storage, Postal and Telecommunication Services," and there is no simple way to separate telecommunication investment from transportation. In order to estimate the cost of telecommunication, we run a simple regression model with the dependent variable defined as average annual investment on transportation, storage, postal and telecommunication services between 2001 and 2002 (per 100 million yuan). The independent variables are (the data on storage facility are not available):

avg_road_01_02: average annual road construction between 2001 and 2002 (per 1,000 km).

avg_telephone_01_02: average annual number of telephones increased between 2001 and 2002 (per 10,000 unit).

In this case, we can estimate the marginal cost of telecommunication infrastructure, while telephone ownership is used as a proxy for such infrastructure. We assume that the average cost is constant and thus equals marginal cost. The regression results are reported in Table II below. All the monetary values were deflated using the price index of investment (Base = Beijing, 1990)

Table II

Regressor	Coefficient	Std Error	t-statistc	p-value
Intercept	9.67	15.84	0.61	0.55
avg_road_01_02	0.39	1.12	0.35	0.73
avg_telephone_01_02	0.81	0.11	7.15	<.0001
R-square: 0.6827				

Notes:
1. Hainan is included in Guangdong; and Chongqing is included in Sichuan. Tibet and Inner Mongolia are excluded for lack of continuous data.
2. We would like to use more recent data to estimate the costs for road construction and telephone. However, the telecommunication services are no longer grouped with transportation, storage and postal since 2003.

D. Impact on Regional Ratios of Per-Capita GDP under Alternative Hypothetical Policy Scenarios in 2013

Basic Assumptions:

- Policy scenario: the central government is going to invest in human capital or telecommunication infrastructure in the northeast, far west and interior regions, in order to reduce the regional per-capita output gaps. The total amount of investment is assumed to be 10% of the central government total revenue every year for 5 years. The fund is distributed to the provinces in those non-coastal regions, weighed by population size of the province.[32]
- The first investment project is assumed to be completed at the beginning of 2004, and the last investment project is assumed to be completed at the beginning of 2008. For simplicity, the increases in the levels of human capital and infrastructure from each investment project are assumed to be the same. The impacts of those investment projects on regional inequality are evaluated at the end of the 10th year (2013).
- There are two channels through which human capital can influence output: the direct contribution to production and the indirect contribution through the TFP growth on production. For the direct contribution, each non-coastal provincial government sends workers to receive high school education (some of them will continue their education at college in order to maintain the same ratios of college graduates to high-school graduates as in 2003). For the indirect contribution, each non-coastal provincial government sends workers with high school education to receive college education. The lengths of high school and college education are assumed to be 3-year and 4-year, respectively.
- The infrastructure construction is assumed to be completed in 1 year. Depreciation ratio, R = 0.06. The initial stock of infrastructure (in 2003) is assumed to be maintained at the same level throughout the years. The depreciation is only applied to the newly increased infrastructure (starting in 2005).
- We assume $\log Y_{i,t+1} - \log Y_{i,t} = \log TFP_{i,t+1} - \log TFP_{i,t} = w_i$ before imposing the policy. w_i is a provincial constant, which is set to be $\log TFP_{i,2003} - \log TFP_{i,2002}$. For simplicity, we assume $\frac{y_{\max} - y_i}{y_i}$ stays constant after the policy imposed.

Direct Contribution of Human Capital:

Let g_i be the increase in the number of workers with at least secondary high school degrees from each investment project.

t = 2004: $L_{ei} \rightarrow L_{ei} + g_i \qquad L_{ni} \rightarrow L_{ni} - 5 \cdot g_i$

⋮

t ≥ 2008: $L_{ei} \rightarrow L_{ei} + 5 \cdot g_i \qquad L_{ni} \rightarrow L_{ni} - 5 \cdot g_i$

[32] The total government revenue is 2171.525 billion yuan in 2003. We assume that the total cost of each investment project is the same and equal to 2171.525 billion yuan.

$$\log Y_{i,2004}^{New} - \log Y_{i,2003} = w_i + \beta_e \cdot \log(\frac{L_{ei}+g_i}{L_{ei}}) + \beta_n \cdot \log(\frac{L_{ni}-5\cdot g_i}{L_{ni}})$$

$\vdots$

$$\log Y_{i,2008}^{New} - \log Y_{i,2007}^{New} = w_i + \beta_e \cdot \log(\frac{L_{ei}+5\cdot g_i}{L_{ei}+4\cdot g_i})$$

$$\log Y_{i,2009}^{New} - \log Y_{i,2008}^{New} = w_i$$

$\vdots$

$$\log Y_{i,2013}^{New} - \log Y_{i,2003} = 10\cdot w_i + \beta_e \cdot \sum_{t=1}^{5} \log(\frac{L_{ei}+t\cdot g_i}{L_{ei}+(t-1)\cdot g_i}) + \beta_n \cdot \log(\frac{L_{ni}-5\cdot g_i}{L_{ni}})$$

$$\Rightarrow Y_{i,2013}^{New} = Y_{i,2003} \cdot \exp\left(10\cdot w_i + \beta_e \cdot \log(\frac{L_{ei}+5\cdot g_i}{L_{ei}}) + \beta_n \cdot \log(\frac{L_{ni}-5\cdot g_i}{L_{ni}})\right)$$

Indirect Contribution of Human Capital:

Let g_i be the increase in the number of workers with college degrees from each investment project. The first investment project is completed at the beginning of 2004, but the growth rate of *TFP* will not be affected until in 2005 due to the assumption of the lagged impact. Due to the lack of data, we assume that the proportion of workers with college degrees is equal to the proportion of people with college degrees before the policy imposed. Let L_{ci} denote the original number of workers with college degrees.

t = 2004: $L_{ei} \rightarrow L_{ei} - 4\cdot g_i$ $\quad L_{ci} \rightarrow L_{ci} + g_i$

t = 2005: $L_{ei} \rightarrow L_{ei} - 3\cdot g_i$ $\quad L_{ci} \rightarrow L_{ci} + 2\cdot g_i$

$\vdots$

t $\geq$ 2008: $L_{ei} \rightarrow L_{ei}$ $\quad L_{ci} \rightarrow L_{ci} + 5\cdot g_i$

$$\log Y_{i,2004}^{New} - \log Y_{i,2003} = w_i + \beta_e \cdot \log(\frac{L_{ei}-4\cdot g_i}{L_{ei}})$$

$\vdots$

$$\log Y_{i,2008}^{New} - \log Y_{i,2007}^{New} = w_i + \beta_e \cdot \log(\frac{L_{ei}}{L_{ei}-g_i}) + \left(\phi_1^h + \phi_1^s[\frac{1}{d_{\max\_i}}(\frac{y_{\max}-y_i}{y_i})]\right)\cdot\frac{4\cdot g_i}{pop_i}$$

$$\log Y_{i,2009}^{New} - \log Y_{i,2008}^{New} = w_i + \left(\phi_1^h + \phi_1^s[\frac{1}{d_{\max\_i}}(\frac{y_{\max}-y_i}{y_i})]\right)\cdot\frac{5\cdot g_i}{pop_i}$$

$\vdots$

$$\log Y_{i,2013}^{New} - \log Y_{i,2003} = 10\cdot w_i + \left(\phi_1^h + \phi_1^s[\frac{1}{d_{\max\_i}}(\frac{y_{\max}-y_i}{y_i})]\right)\cdot\left(\frac{35\cdot g_i}{pop_i}\right)$$

$$\log Y_{i,2013}^{New} = Y_{i,2003} \cdot \exp\left(10\cdot w_i + \left(\phi_1^h + \phi_1^s[\frac{1}{d_{\max\_i}}(\frac{y_{\max}-y_i}{y_i})]\right)\cdot\left(\frac{35\cdot g_i}{pop_i}\right)\right)$$

Telephones:

Let g_i be the increase in the number of telephones from each investment project. The first investment project is completed at the beginning of 2004, but the growth rate of *TFP* will not be affected until in 2005 due to the assumption of the lagged impact.

t = 2004: $Tel_i \rightarrow Tel_i + g_i$

t = 2005: $Tel_i \rightarrow Tel_i + 2 \cdot g_i$

⋮

t ≥ 2008: $Tel_i \rightarrow Tel_i + 5 \cdot g_i$

$$\log Y_{i,2005}^{New} - \log Y_{i,2004} = w_i + \beta_1^t \frac{g_i}{Pop_i}$$

⋮

$$\log Y_{i,2009}^{New} - \log Y_{i,2008}^{New} = w_i + \beta_1^t \frac{g_i + g_i \cdot (1-R) + g_i \cdot (1-R)^2 + g_i \cdot (1-R)^3 + g_i \cdot (1-R)^4}{Pop_i}$$

$$\log Y_{i,2010}^{New} - \log Y_{i,2009}^{New} = w_i + \beta_1^t \frac{g_i + g_i \cdot (1-R) + g_i \cdot (1-R)^2 + g_i \cdot (1-R)^3 + g_i \cdot (1-R)^4}{Pop_i} \cdot (1-R)$$

⋮

Let $q = 1 + (1-R) + (1-R)^2 + (1-R)^3 + (1-R)^4 = \frac{1-(1-R)^5}{R}$

Denote z as follows:

$$z = 5 + 4(1-R) + 3(1-R)^2 + 2(1-R)^3 + (1-R)^4 + q(1-R) + q(1-R)^2 + q(1-R)^3 + q(1-R)^4$$

$$Y_{i,2013}^{New} = Y_{i,2004} \exp\left(\frac{\beta_1^t}{Pop_i} g_i \cdot z + 9 \cdot w_i \right) = Y_{i,2003} \exp\left(\frac{\beta_1^t}{Pop_i} g \cdot z + 10 \cdot w_i \right)$$