DISCUSSION PAPER SERIES

IZA DP No. 3576

# Human Capital, Economic Growth, and Regional Inequality in China

Belton Fleisher
Haizheng Li
Min Qiang Zhao

June 2008

Forschungsinstitut
zur Zukunft der Arbeit
Institute for the Study
of Labor

# Human Capital, Economic Growth, and Regional Inequality in China

**Belton Fleisher**
*Ohio State University and IZA*

**Haizheng Li**
*Georgia Institute of Technology*

**Min Qiang Zhao**
*Ohio State University*

Discussion Paper No. 3576
June 2008

IZA

P.O. Box 7240
53072 Bonn
Germany

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

IZA Discussion Paper No. 3576
June 2008

# ABSTRACT

## Human Capital, Economic Growth, and Regional Inequality in China*

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 of 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: China, TFP growth, economic growth, human capital, infrastructure

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

* We are grateful to Xian Fu, Li Liang, Yang Peng, Zhimin Xin and Luping Yang for their able and enthusiastic help in compiling data for this research. Carsten Holz was generous in helping us with conceptual issues and data problems. Sylvie Demurger generously provided her data on infrastructure and the population with schooling at the secondary level and higher. We thank Josef Brada Stephen Cosslett, Isaac Ehrlich, Paul Evans, Joe Kaboski, Cheryl Long, Zhiqiang Liu, Masao Ogaki, Pok-sang Lam, David Romer, Yong Yin, and Shujie Yao for their helpful comments. The paper has benefited from participants in seminars at the University at Buffalo Economics Department, at the Conference on the Chinese Economy, sponsored by CERDI/IDREC, University of the Auvergne, France, and at the ASSA Meetings.

## 1. Introduction

. This paper reports research on the role of human capital, infrastructure capital, and foreign direct investment (FDI) on regional inequality economic growth in China. China's dramatic economic growth since the beginning of economic reform in 1978 and its wide regional disparities in growth rates are worth studying not only to understand their causes, but also to derive implications for policies to harness the causes of growth to reduce inequality in other countries. We model two roles for human capital: (i) workers with higher education embody human capital that contributes directly to output in the production process itself; (ii) human capital, particularly that represented by higher education, plays an important role in total factor productivity (TFP) growth. Infrastructure capital is hypothesized to affect GDP through TFP growth, as is FDI. We derive three sets of hypothetical policy implications from our empirical results. (1) We use our estimated production function parameters we calculate marginal products of labor and capital and then project the reallocation of labor or physical capital that would bring about equality of marginal products across major regions. (2) We project results of another reallocation scenario—the impact on the time path of regional GDP ratios of a transfer of resources from investment in physical capital to investment in human capital and infrastructure capital. (3) We calculate rates of return to policies that would reallocate resources from physical capital investment to investment in infrastructure and human capital. We believe the results have important implications for an understanding of economic growth in general, for factors contributing to China's rapidly rising regional inequality, and for the design of policies that would lead to a more equitable distribution of the benefits of .growth within the world's most rapidly expanding economy.

## 2. Background

By the year 2000, China found itself with not only one of the highest rates of economic growth but also 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 across major regions (as measured by the coefficient of variation of per-capita nominal gross domestic product) trended downward, but it 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 coastal region at the end of the Mao fell to a position 30 percent less than the coast by 2003. The coast's early advantage over the interior and far west soared 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 1.3 (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]

### 2.a *Human Capital and Growth*

China's investment in human capital at the level of education beyond the secondary level 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 (Fleisher, 2005; Heckman, 2005). However, public and private expenditures on schooling, especially at the college level, have accelerated rapidly in recent years. 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 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

[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.

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

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.

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 al. 2006), but these papers do not explicitly model the role of human capital in the production function or its role in explaining TFP growth. Although it has long been believed that human capital plays is fundamental to economic growth, studies based on cross-country data have produced surprisingly mixed results (Barro, 1991, Mankiw et. al. 1992, Benhabib and Spiegel 1994, Islam 1995, Krueger 1995, Pritchett 2001, Temple 2001). 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

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. Using a less technical approach than many studies, but one that is highly informative and suggestive, Sonobe et al (2004) show that subtle and important changes in quality control, efficient production organzition and marketing

[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.

of manufactured goods among emerging private enterprises have been more likely to occur in firms where managers have acquired relatively high levels of education. This paper provides a framework and evidence expanding our understanding the role of human capital in production and in TFP growth in China.

We are looking for *causal* relationships between human capital and both production and TFP growth. Therefore we must be concerned with the possibility that the proportion of educated persons in a province's population is the result of high income or high return to schooling, rather than the reverse. Bils and Klenow (2000) argue that the cross-country correlation between schooling levels and TFP growth could be partly due to omitted variables positively related to both variables, such as property-rights enforcement and openness as well as an endogenous response of schooling choices to expected return to investment in human capital. Our use of data across provinces within a single country reduces the impact of legal-institutional differences, such as property rights definition and enforcement on TFP growth. Moreover, in our estimation, we hold constant the impact of other variables on output and TFP growth, including physical capital, capital vintage, FDI, infrastructure capital, and institutional factors associated with development of the private economy. The provinces vary immensely in both the amounts spent on education per capita and in the proportion of provincial GDP spent on education. Over the period 1999-2003, the maximum-minimum ratio of per-pupil expenditure across provinces exceeded a factor of 10, the ratio for proportion of GDP spent on education exceeded 3.5 (Heckman, 2005). We control for the possible biasing impact of this correlation by using two-way fixed effect estimation and holding constant physical capital in the production function estimation.

Another problem in obtaining unbiased estimates of the impact of human capital on output and growth would be "brain drain" of persons with higher levels of schooling from the places where they obtained their schooling to locations where their productivity is higher and growing faster. This possible source of bias, while present, is attenuated in China by interregional and interprovincial migration restrictions due to residency-permit, or *hukou* requirements (Liu, 2005). However, *hukou* barriers to migration are lower for workers with more schooling and lowest for college graduates (Liu, 2005). A college degree has long been the surest way to be assured of obtaining an urban *hukou* (Zhao, 1997), and attainment of a high-school diploma one necessary condition for enrollment in a university; universities are located in in large urban areas and provincial capitals, and their locations have been determined by historical factors, and political considerations, defense goals, and the like. It is consistent with the impact of schooling on growth that it is equally or more likely that universities tend to generate “Silicon-Valley”-like impacts on growth than that their locations have been the result of growth. The factors discussed above imply that there is likely to be an endogenous relationship between college-level schooling, urban location, and growth, but this is not the same as an endogenous relationship between schooling and *provincial* growth. Given that our education breaks are above junior high school and above elementary school, endogeneity bias is likely to be less than if our schooling break were for college and above.[4] Moreover, as Zhao (1999) shows, rural citizens tend to prefer off-farm work in rural locations and small towns to migration to distant urban locations. The impact of more schooling on productivity in local industry is one of the main channels that human capital is likely promote higher output and TFP growth in our framework.

### ***2.b*** **Foreign Direct Investment and Growth**

China’s path toward a market economy has been much more gradual than that of most other formerly planned economies, in particular those of the former Soviet Union and Central and Eastern Europe (Fleisher, Sabirianova, and Wang, 2005), but it has not been a smooth path, periods of gradualism alternating with, stagnation, and sharp jumps. A significant force pushing the economy toward marketization has been the spontaneous growth of local private enterprises, some originating from township and village enterprises (TVEs). Another major force has been the introduction of (partial) foreign ownership through foreign direct investment (FDI). The role of FDI has received much attention because of its potential for bringing in new production and managerial technologies, with their attendant spillovers (Liu, 2007a). (See Cheung and Lin, 2003 for

---

[4] In an attempt to assess the direction and amount of interprovincial migration flows workers with education above elementary school, we have added the flows of flows of junior high-school graduates between 1990 and 2000 to the 1990 provincial stocks of these workers. We then compared the sums to the actual stocks in 2000. Assuming zero mortality, if there were no net interprovincial migration of these workers, the difference between these two variables would be equal. They are not equal, but the implied direction of migration is inward, not toward the coast.

a thorough analysis and references to earlier literature on FDI in China.). FDI has facilitated the transformation of the state-owned and the collective sectors. 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 legal authorization for 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..

**2.c *Infrastructure and Growth***

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]

**2.d *Marketization, the Profit Motive, and Hardened Budget Constraints.***

Another important aspect of China's transformation 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 spring, 1992 "South Trip" in which he reaffirmed his belief in policies that not only allowed, but encouraged, Chinese citizens to follow the profit motive in the quest of personal wealth.. Although urban economic reform began in the period 1983-85, the Chinese economy was still largely operating 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.

[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.

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 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 intensification in the impact of market reforms after 1997 in the specification of our empirical models.

The remainder of this paper proceeds as follows. In section 3 we lay out our methodology. Section 4 describes our data. Section 5 reports our empirical results for aggregate production functions and TFP-growth models. In section 6, 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

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. Other researchers, such as Nelson and Phelps (1966), Islam (1995), and Benhabib and Spiegel (1994), 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.

Another issue that must be addressed in specifying the aggregate production function is the intensification of the exposure of Chinese firms, in particular SOEs, to market competition and government decisions to accelerate the hardening of budget constraints for SOEs after 1997 (Appleton, et al, 2002). It seems likely that not only did SOEs increase their productivity in response to market competition reinforced by administrative tightening of their ability to borrow funds to offset losses, but also that some SOEs, at least, proved to be more formidable competitors for firms in the private and quasi-private sectors. Striking (although somewhat casual) evidence of the impact of the acceleration of market reforms is illustrated in figure 3. The real GDP series and capital stock series are in striking contrast to the labor series. While GDP and capital stock increase at steady annual rates of about 10% and 9% per year, respectively, throughout the period 1985-2003, employment *declines* abruptly between 1997 and 1998 and grows very slowly through 2003. Detailed analysis of individual provinces reveals considerable variation in employment and output growth, with employment in Shanghai, for example lower in 2003 than in 1993 although GDP more than tripled over the same period; in contrast in western and much poorer Shanxi, employment did decline in the late 1990s, but by 2003 was somewhat higher than in 1996, and GDP increased far less dramatically than in Shanghai.

The productivity shock resulting in the discontinuity in 1997 illustrated in figure 3 creates a problem for estimating the aggregate production function. In order to avoid bias resulting from omitting this variable, which is correlated with both output and employment, we have incorporated alternative proxies for the productivity shock in specification of the aggregate production function. Inspection of the data imply, as discussed above, that the productivity shock did not affect all provinces equally. A simple approach is to include a dummy variable with a value equal to 1 in 1999 and later, equal to 0 prior to 1999, interacted with dummy variables representing each province.[6] Another approach is to interact annual time dummy variables with each of the four regions defined in this paper.

In order to find a less mechanical proxy for the 1997 productivity shock we have searched for evidence of the hardened-budget-constraint and competitive-markets impacts apart from the contrasting time series shown in figure 2. Data on the number of workers laid-off (*xiagang*) by SOEs is a likely starting point. Data on the number of *xiagang* workers are reported by enterprises starting in the year 1997—consistent with the hypothesis that the serious impact of hardened budget constraints began to be felt only after 1997 (Appleton et al., 2002). The *xiagang* series is shown in figure 3. The *xiagang* series is only a starting point, though, because although the data document the beginning of the hardened budget constraint impact, they do not match its continued and likely *cumulative* impact. An additional complication is that the impact of increased market competition is unlikely to have been confined only to state enterprises. Insofar as

[6] We choose 1999 as the break point in order to roughly approximate the hypothesized lagged impact of hardened budget constraints on productivity.

state enterprises and the financial institutions that supported their losses were thrown into the sea of increased competition, other ownership forms probably had to sharpen their management skills in order to meet the increased competitive pressure. As figure 3 illustrates, the the reported number of *xiagang* workers peaked in 1999. The decline after 1999 occurred because laid-off workes may retire, become re-employed by their former enterprises or other enterprises, or, after three years, be dropped from the *xiagang* roles. It is unlikely that the impact of the productivity shock that started in 1997-98 peaked in 1999 and then declined afterward parallel the number of *xiagang* workers. Rather, it is more likely that firms' adjustment to the new economic environment accumulated over time. A suitable representation would be a monotonically increasing function (albeit at a declining rate). An approximation to such a function would be simply to cumulate the number of *xiagang* workers, treating the annual data as a first-difference of the desired function or of its logarithm.. Specifically, we can define

$$E_t(1) = R_t \cdot R_{t-1} \cdot R_{t-2} \cdot ....,$$

$$E_t(2) = 1 + (R_t - 1) + (R_{t-1} - 1) + (R_{t-2} - 1) + .... \text{ or}$$

where $R_t = (SOE_t + Xiagang_t) / SOE_t$, $SOE_t$ is total SOE employment in year t and $Xiagang_t$ is the total number of *xiagang* workers reported in year t. The series for both E(1) and E(2) are very closely approximated by a second degree of polynomial which increases at a decreasing rate..

. The production function including two types of labor is:[7]

$$Y_{it} = (A_{it} E_{it}^{\delta_i}) K_{it}^{\alpha} L_{eit}^{\beta} L_{nit}^{\gamma} e^{u_{it}} \qquad (1)$$

where *Y* is output, *K* is capital, $L_e$ is the number of workers with schooling above elementary school education or above, $L_n$ is the number of workers who have not graduated from elementary school, *E* is a proxy for the impact of hardened budget constraints as discussed above, and *u* is a disturbance term, for province i= 1, 2, …, n from year t=1, 2, …, T.[8] The parameters $\alpha$, $\beta$, and $\gamma$ are the output elasticities of the corresponding inputs. The parameters $\delta_i$ are assumed to be provincial-specific.

---

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

[8] 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

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

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

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

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 $mh_i[(Y_{\max} - Y_i)/Y_i]$

---

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.

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 Xiaoping's "South Trip," we impose a structural break in 1994 as follows:

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

$YB$ is a year dummy which is set to be 1 if before 1994. We measure human capital $h_i$ in the TFP-growth equation as the percentage of the population with schooling either (i) above upper middle school (senior high school) or (ii) above lower middle school (junior high school). 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.[9] Our use of two-period lagged *RFDI* in the regression equations should mitigate this effect, but if investors are forward looking, foreign investment may be correlated with future shocks. Moreover, 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 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.[10]

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):[11]

[9] It is possible that the construction of the human capital spillover variable creates an endogeneity problem. This issue is discussed in footnotes 17 and 21.

[10] 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.

[11] 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

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

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).[12] 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.[13] 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.[14] The variable $P_i$ denotes the price index for investment. Due to the lack of investment price data prior to 1991, we construct an implicit deflator for capital formation for the years 1966 through 1990 from State Statistical Bureau (1997).[15] 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;

---

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.

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

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

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

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

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 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 six columns. The first column reports the results for an ordinary least squares (OLS) which does not use either year- or provincial fixed effects. regression that includes the variable *E2* as defined above interacted with provincial dummy variables. This regression serves as a benchmark for those reported in columns (2) through (6), which are OLS regressions estimated with a 2-way fixed effects (FE) procedure that incorporate dummy variables for each year and province. Only the regression in column (2), does not include a variable to represent the hardened budget constraints and increased competitive-market pressure that began in 1997; the regressions in columns (3) through (6) each include such a variable as does the regression in column (1).

The most notable difference between the regression in column (1) and the FE regressions is that the estimated elasticity of capital is much higher, both absolutely and relative to the labor inputs in the no-FE estimate. To illustrate, the ratio of the capital elasticity to that of labor above elementary school is over 3 in column (1), but no higher than 1.4 in any of the other specifications. In columns (3) through (6), where the 1997 productivity shock is controlled for, the ratio of the capital elasticity to that of labor above elementary school varies from 0.56 to 1.4. Another notable difference among the production function estimates is that in the specification that does not control for the 1997 productivity shock, the estimated elasticity of labor with only elementary-school education or less is negative and significant. A third notable feature of the estimation results is that only in column (3) is the estimated capital elasticity smaller than that of labor with more than elementary school education. Moreover, the estimated elasticity of labor with elementary schooling or less is statistically indistinguishable from zero. This specification does include a time dummy variable to capture the impact of the 1997 productivity shock, but the dummy is interacted with the regions, not with individual provinces. The specifications in columns (4), (5), and (6) all account for provincial differences in the impact of the 1997 productivity shock. In the three regressions, the ratio of the estimated capital elasticity to the estimated elasticity of labor above elementary school ranges between 1.14 and 1.26. The ratio of the elasticity of labor with higher education to that of labor with elementary-school education nor less ranges between 4.46 in column (6) up to 6.7 in column (4). The sum of the input elasticities (estimated returns to scale) in the regressions shown in columns (4) through (6) is 0.94, 1.08, and 0.999, respectively. We have no reason to suspect that our estimates of the aggregate production function should not reflect constant returns to scale , and the robustness of our estimates to this assumption in all three FE specifications that yield a significantly positive estimated elasticity for workers with elementary schooling or less is reassuring.

To summarize, all of the regressions specified to reflect province-specific adjustments to the 1997 productivity shock yield quite similar estimates of the inputs elasticities. The estimates are even more consistent among the three FE specifications within this group. This robustness is important not only because it increases our confidence in the estimated parameters themselves, but also because the relationship among the elasticities, in particular the elasticities of the two labor categories, are used to derive important policy implications. In addition, our TFP growth estimation results (discussed in section 4.2) are quite robust to alternative production-function specifications.

### 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 5? and 6? show that MPL for educated labor and MPK follow different trends: while the series for MPL for educated labor have grown steadily and at least doubled in all four regions , MPK initially declined, but trended upward after about 1990, except in the far western region. The regional MPL series have also tended to converge, at least among three regions, with the ratio of MPL in 2003 to that in 1985 equalling 3.7 in the coastal region, and lower in all the others, with a value of 2.1 in the far west.. 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% by 2003, 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.

Consistent with its relatively small estimated production elasticity, the MPL for workers with below elementary education is generally much lower than that of educated workers, but the disparity between the two categories of labor has fallen. The ratio of MPL for less-educated workers in 2003 to that in 1985 is much higher in all four regions than the comparable ratio for more-educated workers. But interregional disparity in the MPL of this group has widened: for example, the 2003/1985 ratio of MPL in the coastal region is nearly 11, while that in the far west, it is 5.5. By 2003, the marginal product of less-educated workers in the coastal and northeast regions had surpassed that of more-educated workers in the populous interior region. The regional distribution of labor marginal products and their trends raises concerns for the future course of inequality. The relative marginal products of the comparatively much poorer interior and far west regions will not encourage physical capital investment to flow in ther directions, , and this suggests that future per-capita income growth is likely to continue to be slower in the low-income areas of China than in the high-income, rapidly growing areas.

An interesting question would be to ask what would happen if labor were reallocated among provinces to equalize marginal products. It is a simple matter to calculate the impact of this hypothetical policy on MPL of either labor category. For example, for workers with schooling above elementary level, the reallocation (holding physical capital and the other labor catetory constant) would raise the MPL of this group in Sichuan by approximately 114%, in Hunan by about 65%, and approximately 400% in Guizhou. However, MPL would fall in high-productivity areas such as Shanghai and Guangdong by about 95% and 39%, respectively. The corresponding change in the workforce of this category would be -57%, -43%, and -83% in Sichuan, Hunan, and Guizhou, respectively and 23-fold and a 72% respective increases in Shanghai and Guangdong. The social and political implication of such drastic policies would be immense.. Moreover, total China GDP would be raised by a one-time increase of only about 3% (not factoring in future impacts of a one-time labor reallocation on productivity growth). Reallocation of the workers with elementary schooling or more (holding constant the other two inputs) would result in a one-time increase in per-capita GDP of about 5.3%. It seems that policies to promote growth are likely to have higher payoff and to be met with greater acceptance by Chinese citizens. In the next sections we developrecommendations for cost-effective policies to promote growth. Two types of policies are considered: (i) policies to raise the productivity of labor by providing more schooling, and (ii) policies that increase TFP growth.

### 4.2 Total Factor Productivity Growth

TFP growth has important implications for regional disparity in China's economic development. Figure 7 illustrates this point. It shows that although TFP in the interior region was about 90% that of the coastal region in 1985, it has fallen rather steadily over the period through 2003 to less than 70% that of the coastal region.. A similar picture holds for the far western region compared to the coastal region and for both the interior and far west relative to the northeast. Clearly, targeting regional TFP growth should be an important aim of economic policy in China.

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.[16] 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."

TFP growth regression results are presented in Tables 4 and 5. In Table 5, variables representing infrastructure capital are included as regressors, and we report the results of including the lagged dependent variable as a regressor. Table 4 reports the results of five specifications, all of them estimated with two-way FE, and four of them using 2SLS.: 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.[17] 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.[18] As Table 2c shows, approximately 6% of

[16] 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.

[17] The 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.

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

urban workers were employed in the non-state owned sector nationally in 2003, and the variation across provinces is extremely high.

In columns (1), (4), and (5) of table 4, the regressions are based on the production function reported in table 3, column (6), while the regressions in columns (3) and (4) are based on the production functions reported in table 3, columns (3) and (4), respectively.[19] Columns (1) and (5) permit is to see the impact using 2SLS; columns (4) and (5) permit us to compare the results of two different definitions of schooling categories, above upper middle school (high school) and above lower middle school (junior high school). All three of these regressions are based on the production using the productivity-shock variable *E2*, while columns (2) and (3) are based on production functions time-dummy/regional interactions to capture the productivity-shock effect.

TFP growth regressions are quite robust to these alternative specifications. 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. 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.[20] [21] 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.[22] As Table 2c shows, approximately 6% of

[19] In all models, the F-test on fixed effects strongly rejects the null of no fixed effects.
[20] The Hausman test is conducted using a regression based approach by appending the residuals from the first stage regression of endogenous variables.
[21] The 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.
[22] Hale and Long (2007) used port availability and access to domestic market of the province as an instrument for FDI.

urban workers were employed in the non-state owned sector nationally in 2003, and the variation across provinces is extremely high.

The 2SLS regressions offer no big surprises compared to the FE-only regression. The estimated coefficients in the 2SLS regressions tend, if anything, to be somewhat larger and no less significant than those estimated by OLS. It is noteworthy that the 2SLS regressions based on the production function reported in table 3, column (3), which does not include a productivity-shock variable, yields results that are quite similar to the other 2SLS regressions. Given this robustness, we will devote our discussion of the estimation results to those shown in columns (4) and (5), both based on the production function that includes the productivity-shock variable, *E2*, but which include different education-category variables to reflect the direct influence of human capital on productivity growth.

The estimated impact of FDI is significant, but much larger and more significant before 1994. In column (4), 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 0.028 (2.8 percentage points) more per year before 1994. For the period 1994 and later, the estimated economic impact of the same FDI shock is about 0.00058 (.58 percentage points).We do not offer a deep explanation of the the drop in the impact of FDI after 1994, but we may speculate that prior to the inspiration to the growth of non-government enterprises offered by Deng Xiaoping's "South Trip," FDI-led growth nurtured by the coastal Special Economic Zones was relatively much more important than in the years following. More recently, private and "red-cap" enterprises and the evolution of TVEs from collectives to de facto private enterprises (notably in Zhejiang province Jiangsu provinces) have become relatively more important spearheads of growth.

The estimated direct effect of human capital is positive, but significant by conventional standards only in column (5) where the schooling category is workers who have achieved lower middle school education or more. In both columns, , the coefficient of the schooling variable implies that if the ratio of the respective schooling group to population increases by 0.01, which is approximately 10% of the sample mean value for this variable, TFP growth increases by between 0.32 and 0.39 percentage points per year, which is approximately 10% of the sample mean value for TFP growth) The indirect effect of human capital operating through technology spillover is modeled in the spillover variable, and the estimated effect is positive and significant, but much more significant (although somewhat smaller in magnitude) for the schooling category of workes who have achieved lower middle school education or more (column (5)). The estimated impact prior to 1994 is not significantly different than after 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. Theestimated coefficient of the proportion of the workforce in none-state enterprises, a proxy for the private sector, is uniformly insignificant across all specifications.

Table 5 differs in 4 ways from table 4: (i) two measures of infrastructure capital are included in all regressions; (ii) we include an additional lagged variable for the direct effect of the schooling variable; (iii) the lagged value of the dependent variable is included in one regression to test the effect of ignoring possible convergence effects; (iv) only the schooling group that has achieved at least lower middle school education is included. The basic thrust of the regressions reported in table 4 are quite robust to these modifications, so we limit our discussion to the additional variables included in the table. The second-lagged schooling variable has a somewhat larger and more significant effect on TFP growth than does the single-lagged variable. This suggests that the impact of innovation on TFP growth takes longer than one period. 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. The telephone ownership rate has a positive estimated effect on TFP growth, but road intensity does not. It is unfortunate that available data do not permit us to obtain accurate measures of the actual amount invested specifically in either type of infrastructure, and this opacity in the data may well affect the somewhat surprising results for road infrastructure. An anecdote illustrates this point. One of the authors journed by car from Hangzhou to Wenzhou last summer, and one of his traveling companions noted that the approximately 4-hour travel time had until recently been about twice as long.

This improvement would not be reflected in our highway length variable, as the improvement resulted mainly from converting the traditional highway to motorway status. The regression reported in column (4) includes the lagged dependent variable. The estimated coefficient is highly insignificant. There is no evidence of conditional convergence of TFP growth.[23]

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, and we attribute this to the growing role of locally produced growth engines in China's economic progress. . Second, the direct effect of human capital measured by the proportion of workers with greater than lower middle school education is positive and . 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 does not appear to be stronger before 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..

## 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

---

[23] 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.

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).[24]

**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.[25] 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.

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.

---

[24] We do not compute the internal rates of return to road construction because the coefficient estimate of road construction is mostly insignificant.

[25] 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.

The calculated internal rates of return to education are reported for each region in Table 6, columns 1 and 2. Column 1 contains the estimated rates of return to providing schooling above the elementary level, which occurs directly in the production process. (We assume that the proportional distribution of education outcomes above elementary matches the current distribution. That is, the likelihood that a student taken from the elementary group will complete lower middle school, upper middle school, or college matches the current distribution of these schooling levels in the population.) The national average rate of return is approximately 14.5%, and it is much higher in the far west and interior regions (about 17.5%) than in the coastal and northeast regions (about 12.7% and 10.2%, respectively). All of these estimates are much higher than the 7% return to education in production assumed by Bosworth and Collins (2008) in their work comparing TFP growth in China and India through 2004. It is instructive to compare the estimated rates of return in Table 6 with the marginal products of educated labor shown in Figure 5. It is clear that the marginal product of educated labor is much higher in the coastal region and northeast regions than elsewhere, but so is the marginal product of workers with elementary schooling or less.. Hence the opportunity cost of sending a coastal or northeast worker to school longer is higher than it is in the interior or far west regions. Moreover, the marginal product of the less-schooled group in the coastal and northeast regions has accelerated relative to that in the west and far west since the mid- to late 1990s.

The calculated [illegible] of return per year of additional schooling to investment in education above lower middle school based on its contribution to TFP growth is reported in column 2a of Table 6. It is based on the 2SLS estimates reported in column [illegible] of Table 5. The national average rate of return is approximately 24.5%. The interior region has the highest return of 26.5%, somewhat higher than in the other regions. A more accurate estimate of the return to investment in schooling is obtained if we combine the direct and indirect effects. Obviously, a simple addition of columns 1 and 2a is inappropriate. For example, suppose that a random individual is selected from among elementary school graduates to acquire further schooling. This individual may acquire education through lower middle school, upper middle school, or perhaps graduate from college. Each of these possible outcomes has attendant costs in terms of foregone production, foregone TFP growth, and attendant returns. The sign of the net outcome on the return to schooling is ambiguous, and this ambiguity is demonstrated in column 2b, where the combined direct and indirect impacts decrease for the economically advanced regions and increase for the interior and far west regions. The combined effect is highest in the far west, followed in decreasing order by the interior, coastal, and northeast regions.[26]

Column (3) in Table 6 contains the calculated rates of return for telecommunications infrastructure based on its contribution to TFP growth. 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 45%.[27] Regional variation in the returns to infrastructure is higher than for the returns to either type of schooling, ranging from nearly 51% in the northeast region to approximately 37% in the far west. Unlike the return of human capital investment in production, the investment in telecommunication infrastructure appears to be positively correlated with local development, being higher in the relatively developed regions. 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 suggest that this is not the case for investment in human capital in China, particularly investment in schooling above the elementary level, where the return in production is much higher in China's very large and economically disadvantaged interior and western regions than it is in the industrialized coastal and northeast regions. Investing in education of lower middle school, through its TFP-growth impact, is highest in the interior region, although somewhat surprisingly, lowest in the far west..

[26] It might be argued that the rates of return calculated from our data are not good estimates of the treatment effect of providing more schooling to the regional populations, because of selection and sorting biases (Heckman and Li, 2004). However, such biases should be mitigated in this study insofar as the distributions of individual comparative advantages within provinces are similar across provinces. Moreover, there is evidence that finance constraints are important in determining the level of schooling attainment in China (Heckman, 2005; Wang, Fleisher, Li, and Li, 2008).

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

### 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 two scenarios: allocation to increase the number of students advancing beyond primary school, distributed over higher levels of schooling in proportion to the current distribution of schooling in the workforce within each region, 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.[28] 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 percentage decline in the provincial GDP ratio under each policy. For example, the number 0.51 in the first line of the last column indicates that a policy of increasing schooling above the primary level in the interior region, with no change in the coastal

[28] 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.

region, would increase the interior/coast inequality ratio from 0.407 to 0.51, or by approximately 27.7%% of the 2003 ratio by the year 2013. In the first row, we see that the impact of a policy focused on raising schooling levels education would have a substantially smaller impact on reducing regional inequality in the far west than in the interior. The same policy applied to the northeast region would reduce the income gap by only about 6%. In the second row of Table 7, we see that investment in telecommunication infrastructure would reduce the income gap by about 28% 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 steps forward occurring following Deng Xiaoping's "South Trip" in 1992 and following the serious budget-constraint hardening that occurred in 1997 and subsequent years.

Our 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 negligible. The diminished impact 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[29]. We also

[29] A possible reason for this rather surprising result is that paved highway length is no longer an adequate measure of highway capacity. Unfortunately we do not have data on highway capacity, average speed of travel, etc.

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 more than primary-school education have a much higher marginal product than labor with no higher than primary schooling. Second, we estimate a positive, direct effect of human capital (measured by the proportion of workers with more than a lower middle school education) 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.

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. The robustness of our estimation results to alternative specifications makes us confident that our estimated returns to investment, particular in human capital, can serve as a reasonable guide for policy makers. However, measuring the relevant quantity and costs of infrastructure capital is problematic, given existing data, so a comparison of rates of return and policy impacts of investing in alternative forms of infrastructure capital or in infrastructure capital compared to human capital is an uncertain business. We nevertheless report the estimated rates of return on both human and infrastructure capital and the impacts of hypothetical policy experiments, because we believe that such a framework is the appropriate guide for correct economic policy. We find the following. (1) The interior region would gain substantially relative to the coast from increasing both the stock of human and infrastructure (telecommunications). (2) The far west would also experience a significant gain in relative GPP per capita, but more so from infrastructure investment than from human-capital investment. (3) The northeast would gain from infrastructure investment, but less so from increased human-capital investment. . One caveat to these policy implications is in order, though. To the extent that China's *hukou* policy places fewer restrictions on the rural-urban migration of highly educated workers than others, the beneficial impact on regional disparity of increasing investment in human capital could be attenuated by brain-drain from interior and far-western provinces to the coast. This negative influence would be greatest for those with college degrees and much less so for workers who advance only through high-school or lower levels of schooling attainment. It will be attenuated to the extent that investment in infrastructure enhances the amenities available to those who live in the interior and far western provinces.

We find evidence that China's transition toward a market economy accelerated after 1994. But Chinese policy makers face a dilemma, because continued economic transformation has not been equally beneficial across China's major regions. The interior region (near west) and far western regions lag far behind the coastal and northeast regions in economic progress.There is an important 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).[30] The results of our research imply that, it is important to put human capital investment on an equal footing in this project, both for reasons of economic efficiency and for reducing inequality

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

## References


Appleton, Simon, Knight, John, Song, Lina, Xia, Qingjie, 2002. Labor Retrenchment in China: Determinants and Consequences. China Economic Review 13, 252-275.

Barro, Robert, 1991. Economic Growth in a Cross Section of Countries. Quarterly Journal of Economics 106, 407-443.

Benhabib, Jess, Spiegel, Mark, 1994. The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data. Journal of Monetary Economics 34, 143-173.

Bils, Mark, Klenow, Peter J., 2000. Does Schooling Cause Growth? American Economic Review 90, 1160-1183.

Borensztein, E., Ostry, D. J. 1996. Accounting for China's Growth Performance. American Economic Review 86(2), 224– 228.

Bosworth, Barry, Collins, Susan M., 2008. Accounting for Growth: Comparing China and India. Journal of Economic Perspectives 28, 45-66.

Brandt, Loren, Holz, Carsten, 2006. Spatial Price Differences in China: Estimates and Implications. Economic Development and Cultural Change 55, 43-86.

Cao, Yuanzheng, Qian, Yingyi, Weingast, Barry, 1999. From Federalism, Chinese Style to Privatization, Chinese Style. Economics of Transition 7, 103-131.

Chen, Jian, Fleisher, Belton, 1996. Regional Income Inequality and Economic Growth in China. Journal of Comparative Economics 22, 141-164.

Cheung, Kui-yin, Lin, Ping, 2003. Spillover Effects of FDI on Innovation in China: Evidence from the Provincial Data. China Economic Review 15, 25-44.

China Statistics Press, 1999. Comprehensive Statistical Data and Materials on 50 Years of New China. Compiled by Department of Comprehensive Statistics of the National Bureau of Statistics. Beijing.

Chow, G. 1993. Capital Formation and Economic Growth in China. Quarterly Journal of Economics, 108(3), 809– 842.

Démurger, Sylvie, 2001. Infrastructure Development and Economic Growth: An Explanation for Regional Disparities in China? Journal of Comparative Economics 19, 95-117.

Elliott, Graham, Rothenberg, Thomas, and Stock, James, 1996. Efficient Tests for an Autoregressive Unit Root. Econometrica 64, 813-836.

Fleisher, B., 2005. Higher Education in China: A Growth Paradox? in Yum K. Kwan and Eden S. H. Yu eds., Critical Issues in China's Growth and Development. Ashgate Publishers, Aldershot UK and Burlington VT., 3-21.

Fleisher, B., Chen, Jian, 1997. The Coast-Noncoast Income Gap, Productivity and Regional Economic Policy in China, Journal of Comparative Economics 252: 220-236.

Fleisher, B., Hu, Yifan, Li, Haizheng, 2006. Higher Education and Worker Productivity in China: Educational Policy, Growth, and Inequality. Working paper, Department of Economics, Ohio State University.

Fleisher, B. Li, Haizheng, Zhao, Minqiang, 2006. Regional Disparity of Industrial Development and Productivity in China, Report to the World Bank.

Fleisher, B., Sabirianova, Klara, Wang, Xiaojun, 2005. Returns to Schooling during Early Transition: Evidence from Central and Eastern Europe, China, and Russia. Journal of Comparative Economics 33, 351-370.

Fleisher, B., Wang, Xiaojun, 2001. Efficiency Wages and Work Incentives in Urban and Rural China. Journal of Comparative Economics 29, 645-662.

Fleisher, B., Wang, Xiaojun, 2004. Skill Differentials, Return to Schooling, and Market Segmentation in a Transition Economic: The Case of Mainland China. Journal of Development Economics 73, 715-728.

Fu, Xiaolan, 2004. Limited Linkages from Growth Engines and Regional Disparities in China. Journal of Comparative Economics 32, 148-164.

Heckman, James J., 2005. China's Human Capital Investment. China Economic Review 16, 50-70.

Heckman, James J., and Xuesong Li, 2004. "Selection Bias, Comparative Advantage, and Heterogeneous Returns to Education: Evidence from China in 2000," Pacific Economic Review 9155-171.

Hale, Galina and Cheryl Long, 2007, Is There Evidence of FDI Spillover on Chinese Firms' Productivity and Innovation? Manuscript.

Holz, Carsten, 2006. New Capital Estimates for China. China Economic Review 17, 142-185.

Hsueh, Tien-tung, Li, Qiang, Liu, Shucheng 1993. China's Provincial Statistics, 1949-1989. Colorado: Westview Press.

Islam, Nasrul, 1995. Growth Empirics: A Panel Data Approach. Quarterly Journal of Economics 110, 1127-1170.

Islam, Nazrul, Dai, Erbiao, Sakamoto, Hiroshi, 2006. Role of TFP in China's Growth. Asian Economic Journal, Vol. 20, Issue 2, 127-159.

Jones, Charles I., 2005. The Shape of the Production Function and the Direction of Technical Change. Quarterly Journal of Economics 120, 517-550.

Krueger, Anne O., 1995. East Asian Experience and Endogenous Growth Theory, in Takatoshi Ito and Anne O. Krueger (eds.) Growth Theories in Light of the East Asian Experience. National Bureau of Economic Research-East Asia Seminar on Economics. Chicago: University of Chicago Press.

Kwiatkowski, Denis, Phillips, Peter, Schmidt, Peter and Shin, Yongcheol, 1992. Testing the Null Hypothesis of Stationary against the Alternative of a Unit Root. Journal of Econometrics 54, 159-178.

Li, Xiaoying, Liu, Xiaming, 2005. Foreign Direct Investment and Economic Growth: An Increasingly Endogenous Relationship. World Development 33, 393-407.

Liu, Zhiqiang, 2005. Institution and Inequality: the *Hukou* System in China. Journal of Comparative Economics 33, 133-157.

Liu, Zhiqiang, 2007a. Foreign Direct Investment and Technology Spillovers: Theory and Evidence. Journal of Development Economics in press.

Liu, Zhiqiang, 2007b. The External Returns to Education: Evidence from Chinese Cities. Journal of Urban Economics in press.

Liu, Zhiqiang, 2007c. Human Capital Externalities and Rural-Urban Migration: Evidence from Rural China. China Economic Review, in press.

Ma, Jun, Norregaard, John, 1998. China's Fiscal Decentralization. International Monetary Fund. http://www.imf.org/external/pubs/ft/seminar/2000/idn/china.pdf [Access Date: January 23, 2007].

Maddala, G.S. and Kim, In-Moo, 1998, Unit Roots, Cointegration, and Structural Change. Cambridge: Cambridge University Press.

Mankiw, N. Gregory, Romer, David, Weil, David N. 1992. A Contribution to the Empirics of Economic Growth. Quarterly Journal of Economics 1072, 407-457.

Naughton, Barry, 1995. Growing out of the Plan: Chinese Economic Reform 1978-1993. Cambridge, UK. Cambridge University Press.

Nelson, Richard, 1964. Aggregate Production Functions and Medium-Range Growth Projections. American Economic Review 54, 575-605.

Nelson, Richard, Phelps, Edmund, 1966. Investment in Humans, Technological Diffusion, and Economic Growth. American Economic Review Papers and Proceedings 56, 69-75.

Population Census Office, 1983. Zhongguo 1982 Nian Ren Kou Pu Cha 10% Chou Yang Zi Liao. Zhongguo Tong Ji Chu Ban She, Beijing.

Population Census Office, 1993. Zhongguo 1990 Nian Ren Kou Pu Cha Zi Liao. Zhongguo Tong Ji Chu Ban She, Beijing.

Population Census Office, 2001. 2000 Nian Di Wu Ci Quan Guo Ren Kou Pu Cha Zhu Yao Shu Ju. Zhongguo Tong Ji Chu Ban She, Beijing.

Pritchett, Lant (2001). Where Has All the Education Gone? World Bank Economic Review 15(3), 367-91.

Qian, Yingyi, Weingast, Barry, 1997. Federalism as a Commitment to Preserving Market Incentives. Journal of Economic Perspectives 11, 83-92.

Sonobe, Tetsushi, Hu, Dinghuan, Otsuka, Keijiro, 2004. From Inferior to Superior Products: An Inquiry into the Wenzhou Model of Industrial Development in China. Journal of Comparative Economics 32, 542-563.

State Statistical Bureau, 1996. China Regional Economy: A Profile of 17 Years of Reform and Opening Up. China Statistical Press, Beijing.

State Statistical Bureau, 1997. The Gross Domestic Product of China, 1952-1995, in Chinese, (Zhongguo Guonei Shengchan Zongzhi Hesuan Lishi Ziliao). Dongbei University of Finance and Economics Press, Danian, China.

State Statistical Bureau, 1996, 1998, 1999, 2002 and 2003. Annual Population Change Survey. Beijing, China.

State Statistical Bureau, Various Years. China Statistical Yearbook. China Statistical

Publishing House, China Statistical Information and Consultancy Center, Beijing.

Su, Ming, Zhao, Quanhou, 2004. China's Fiscal Decentralization Reform. China Ministry of Finance, Research Institute for Fiscal Science. http://www.econ.hit-u.ac.jp/~kokyo/APPPsympo04/PDF-papers-nov/Zhao-China.pdf [Access Date: January 23, 2007].

Temple, Jonathan, 1999. A Positive Effect of Human Capital on Growth. Economics Letters 65(1), 131-134.

Temple, Jonathan, 2001. Generalizations that aren't? Evidence on Education and Growth. European Economic Review 45(4-6), 905-918.

Wang, Xiaojun, Fleisher, Belton, Li, Haizehng, Li, Shi, 2008. Sorting, Selection and Transformation of the Return to College Education in China," (with Haizheng Li, Shi Li, and Xiaojun Wang). IZA Discussion Paper No. 1446. fttp://ftp.iza.org/dps/dp1446.pdf.

Wang, Yan, Yao, Yudong 2003. Sources of China's Economic Growth 1952-1999: Incorporating Human Capital Accumulation. China Economic Review 14, 32-52.

Wolff, Edward N., 1991. Capital Formation and Productivity Convergence over the Long Term. American Economic Review, vol. 81(3), 565–579.

Yang, Dennis Tao, 2002. What Has Caused Regional Inequality in China? China Economic Review 13, 331-334.

Yang, Hong, 2001. A Comparative Analysis of China's Permanent and Temporary Migration During the Reform Period. International Journal of Social economics 27, 173-193.

Young, Alwyn, 2003. Gold into Base Metals: Productivity Growth in the People's Republic of China during the Reform Period. Journal of Political Economy 111, 1220-1261.

Zhao, Yaohui, 1997. Labor Migration and Returns to Rural Education in China. American Journal of Agricultural Economics 79, 1278-1287.

Zhao, Yaohui, 1999. Labor Migration and Earnings Differences: The Case of Rural China. Economic Development and Cultural Change 47, 767-782

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 | 464.61 | 474.53 |
| (100,000,000 yuan) | (284.34) | (241.10) | (73.06) | (235.48) | (280.07) |
| Capital | 1081.91 | 1386.15 | 216.78 | 914.22 | 919.05 |
| (100,000,000 yuan) | (546.06) | (600.75) | (102.67) | (654.97) | (630.22) |
| Labor, elementary or below | 1107.22 | 596.67 | 317.17 | 1405.07 | 1067.31 |
| (10,000 workers) | (816.84) | (136.38) | (291.05) | (835.83) | (807.66) |
| Labor, above elementary | 854.54 | 732.96 | 184.66 | 747.65 | 700.00 |
| (10,000 workers) | (446.34) | (286.95) | (147.08) | (394.38) | (423.48) |
| FDI / total workforce | 14.70 | 0.52 | 0.21 | 0.45 | 5.01 |
| (1 US dollars per worker) | (24.48) | (0.45) | (0.15) | (0.47) | (14.96) |
| Above junior high / population | 12.90 | 12.25 | 7.89 | 6.97 | 9.57 |
| (1 person / 100 persons) | (7.98) | (0.78) | (0.89) | (2.11) | (5.36) |
| Human-capital spillover variable | 0.22 | 0.10 | 0.09 | 0.18 | 0.17 |
| | (0.23) | (0.04) | (0.05) | (0.09) | (0.14) |
| Second difference of log capital | 0.0092 | 0.0103 | 0.0147 | 0.0036 | 0.0077 |
| | (0.01) | (0.01) | (0.02) | (0.01) | (0.01) |
| Urban telephone subscribers / population | 5.70 | 3.75 | 2.69 | 1.54 | 3.28 |
| (1 subscriber/ 1000 person) | (5.66) | (0.66) | (0.80) | (0.71) | (3.63) |
| Roads / area | 0.30 | 0.15 | 0.05 | 0.18 | 0.20 |
| (km length per km$^2$) | (0.09) | (0.07) | (0.04) | (0.06) | (0.11) |
| Urban non-state workforce / total workforce | 20.67 | 23.05 | 2.27 | 1.96 | 10.28 |
| (1 person / 10000 persons) | (13.71) | (36.33) | (1.24) | (1.89) | (15.79) |

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 is 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 | 1008.58 | 1167.65 |
| (100,000,000 yuan) | (984.07) | (522.66) | (195.26) | (517.53) | (825.93) |
| Capital | 2924.61 | 2522.14 | 562.89 | 1807.05 | 2065.15 |
| (100,000,000 yuan) | (1385.08) | (1043.59) | (352.57) | (1037.42) | (1317.10) |
| Labor, elementary or below | 1152.09 | 534.92 | 321.34 | 1515.77 | 1123.15 |
| (10,000 workers) | (882.96) | (102.36) | (262.93) | (863.82) | (863.67) |
| Labor, above elementary | 1258.13 | 1059.64 | 243.44 | 1202.64 | 1068.12 |
| (10,000 workers) | (715.30) | (282.32) | (182.17) | (673.56) | (683.27) |
| FDI / total workforce | 157.67 | 35.79 | 7.21 | 11.71 | 60.56 |
| (1 US dollars per worker) | (118.34) | (24.52) | (8.09) | (7.81) | (94.45) |
| Above junior high / population | 14.93 | 14.16 | 9.87 | 8.10 | 11.20 |
| (1 person / 100 persons) | (11.22) | (1.93) | (1.67) | (2.44) | (7.10) |
| Human-capital spillover variable | 0.16 | 0.12 | 0.14 | 0.22 | 0.18 |
| | (0.16) | (0.05) | (0.06) | (0.10) | (0.12) |
| Second difference of log capital | 0.0105 | -0.0008 | -0.0016 | 0.0025 | 0.0041 |
| | (0.02) | (0.01) | (0.01) | (0.01) | (0.01) |
| Urban telephone subscribers / population | 46.32 | 30.35 | 14.31 | 11.21 | 24.99 |
| (1 subscriber/ 1000 person) | (37.47) | (3.48) | (3.59) | (3.54) | (26.07) |
| Roads / area | 0.40 | 0.18 | 0.06 | 0.20 | 0.24 |
| (km length per $km^2$) | (0.15) | (0.10) | (0.05) | (0.07) | (0.16) |
| Urban non-state workforce / total workforce | 334.34 | 170.94 | 33.69 | 47.32 | 150.88 |
| (1 person / 10000 persons) | (228.57) | (83.00) | (27.82) | (28.68) | (185.68) |

See note in Table 2a

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

| Variable | 2003 Coastal | Northeast | Far West | Interior | National |
|---|---|---|---|---|---|
| GDP | 4807.25 | 2525.77 | 586.49 | 2381.41 | 2920.19 |
| (100,000,000 yuan) | (2648.19) | (1082.18) | (412.06) | (1224.35) | (2221.34) |
| Capital | 7899.16 | 4163.88 | 1208.88 | 3836.44 | 4802.03 |
| (100,000,000 yuan) | (3708.76) | (1525.63) | (796.81) | (2242.13) | (3454.90) |
| Labor, elementary or below | 781.39 | 363.99 | 288.59 | 1149.39 | 823.98 |
| (10,000 workers) | (590.34) | (71.72) | (240.15) | (666.37) | (636.08) |
| Labor, above elementary | 1784.39 | 1145.45 | 353.96 | 1729.08 | 1487.88 |
| (10,000 workers) | (1101.59) | (356.09) | (258.45) | (1012.58) | (1026.04) |
| FDI / total workforce | 193.84 | 48.51 | 3.80 | 17.03 | 75.35 |
| (1 US dollars per worker) | (151.44) | (58.74) | (2.93) | (18.81) | (119.27) |
| Above junior high / population | 25.52 | 21.37 | 16.94 | 15.93 | 19.74 |
| (1 person / 100 persons) | (11.72) | (2.91) | (2.50) | (4.19) | (8.26) |
| Human-capital spillover variable | 0.23 | 0.17 | 0.23 | 0.43 | 0.31 |
| | (0.19) | (0.04) | (0.09) | (0.23) | (0.21) |
| Second difference of log capital | 0.0011 | 0.0008 | 0.0003 | 0.0069 | 0.0034 |
| | (0.01) | (0.01) | (0.01) | (0.02) | (0.01) |
| Urban telephone subscribers / population | 243.07 | 180.78 | 128.75 | 96.97 | 157.45 |
| (1 subscriber/ 1000 person) | (124.35) | (31.45) | (22.32) | (26.16) | (96.13) |
| Roads / area | 0.65 | 0.24 | 0.09 | 0.34 | 0.39 |
| (km length per $km^2$) | (0.25) | (0.10) | (0.07) | (0.13) | (0.26) |
| Urban non-state workforce / total workforce | 1047.43 | 627.03 | 409.52 | 291.14 | 587.13 |
| (1 person / 10000 persons) | (754.43) | (89.06) | (266.58) | (136.30) | (546.91) |

See note in Table 2a

**Table 3**
**Production Function Estimates 1985-2003**

| Dependent variable: log($GDP_t$) | (1) No FE With *E2**province | (2) 2-way FE Time and provincial. dummies only | (3) (2) plus Region*annual time dummy | (4) (2) plus Province* time dummy = 1 after 1998 | (5) (2) plus province*2nd degree Polytrend=0 before 1998 | (6) (2) plus province**E2* |
|---|---|---|---|---|---|---|
| log($Capital_t$) | 0.771*** (23.96) | 0.403*** (16.12) | 0.183*** (6.54) | 0.489*** (15.81) | 0.523*** (15.70) | 0.508*** (15.11) |
| log(Labor,>$Elem_t$) | 0.248*** (6.12) | 0.282*** (8.91) | 0.326*** (11.53) | 0.388*** (9.79) | 0.458*** (10.0) | 0.401*** (9.46) |
| log(Labor, ≤$Elem_{t\,t}$) | 0.060*** (3.56) | -0.103*** -(3.59) | 0.0391 (1.53) | 0.0584** (2.05) | 0.0907*** (3.10) | 0.090*** (3.3) |
| N | 532 | 532 | 532 | 532 | 532 | 532 |
| Adjusted R square | 0.964 | 0.995 | 0.997 | 0.996 | 0.997 | 0.997 |
| F Test for No Fixed Effects: F Value (Pr > F) | | 93.81 (<0.0001) | 104.91 (<.0001) | 106.70 (<.0001) | 107.88 (<.0001) | 111.06 (<.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. Units of measurement. "GDP": 100,000,000 yuan. "Capital": 100,000,000 yuan. "Labor, Greater than Elementary": 10,000 workers. "Labor, Elementary or Less": 10,000 workers. All the monetary values were deflated with the base of Beijing 1990.
4. (1) and (6) include the interaction terms between log(E2) and provincial dummies; (2)-(6) are 2-way FE; (3) includes the interaction terms between regional dummies and annual time dummies; (4) includes the interaction terms between a time dummy (= 1 after 1998) and four regional dummy variables ; (5) includes the provincial specific time trend and time trend squared (time trend = 0 if year <= 1997; = year – 1997 if year > 1997). .

**Table 4**
**TFP growth regressions without infrastructure variables, 1988-2003**

| Dependent variable: $\log(TFP_t) - \log(TFP_{t-1})$ | Two-Way FE | Two-way FE + 2SLS | | | |
|---|---|---|---|---|---|
| | (1) PF Table 3(6) | (2) PF Table 3(3) | (3) PF Table 3(4) | (4) PF Table 3(6) | (5) PF Table 3(6) |
| $FDI_{t-2}$ | 0.062 (1.38) | 0.0816 (1.32) | 0.108 (1.58) | 0.116* (1.66) | 0.130** (1.97) |
| $FDI_{t-2}$ * Year 1994 | 0.717*** (2.28) | 1.556*** (3.62) | 1.774*** (3.75) | 1.885*** (3.89) | 2.02*** (4.19) |
| Above Upper Middle School $_{t-1}$ | 0.198 (0.68) | 0.0152 (0.54) | 0.437 (1.40) | 0.388 (1.22) | |
| Above Lower Middle School$_{t-1}$ | | | | | 0.321** (2.16) |
| Human capital spillover $_{t-1}$ | 0.259* (1.77) | 0.252* (1.88) | 0.266* (1.80) | 0.261* (1.73) | 0.174*** (3.34) |
| Human capital spillover $_{t-1}$ * Year 1994 | 0.144 (0.77) | 0.224 (1.28) | 0.264 (1.36) | 0.290 (1.46) | 0.029 (1.11) |
| Capital Vintage $_t$ | 0.320** (2.52) | 0.557*** (4.71) | 0.385*** (2.95) | 0.346*** (2.60) | 0.286** (2.18) |
| Non-state Workforce$_{t-1}$ | 0.055 (0.32) | 0.180 (1.01) | 0.091 (0.47) | 0.104 (0.52) | 0.143 (0.91) |
| N | 448 | 448 | 448 | 448 | 448 |
| Adjusted R square | 0.483 | 0.525 | 0.480 | 0.473 | 0.490 |
| F Test for No Fixed Effects: F Value (Pr > F) | 9.59 (<.0001) | 10.03 (0.0001) | 9.49 (0.0001) | 9.27 (0.0001) | 9.92 (0.0001) |
| Test for Overidentifying Restrictions: F Values (Pr > F) | | 1.94 (0.1229) | 1.59 (0.1917) | 1.37 (0.2525) | 1.81 (0.1439) |
| Hausman Test for Endogeneity: F Value (Pr > F) | | 7.38 (0.0007) | 6.94 (0.0011) | 7.03 (0.0010) | 8.26 (0.0003) |

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. “Above Upper Middle School”: the proportion of population with education that are beyond the upper middle school. “Above Lower Middle School”: the proportion of population with education that are beyond the lower middle school. “Capital Vintage”: double difference of log Capital. “Human capital spillover” variable is defined in the text. “Non-state Workforce” is the proportion of urban labor employed in non-state owned firms. All the monetary values were deflated with the base of Beijing 1990.

6. In the 2SLS, “$FDI_{t-3}$”, “$FDI_{t-3}$ * Year 1994”, “Degree of Economic Zone $2_{t-3}$”, “Degree of Economic Zone $3_{t-3}$”, and “Degree of Economic Zone $4_{t-3}$” are used as instrumental variables.

**Table 5**
**TFP growth regressions with infrastructure variables 1988-2003**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Dependent variable: $\log(TFP_t) - \log(TFP_{t-1})$ | 2-way FE<br>PF Table 3(6) | 2-way FE + 2SLS<br>PF Table 3(6) | | |
| $FDI_{t-2}$ | 0.0737*<br>(1.67) | 0.0727<br>(1.11) | 0.107<br>(1.59) | 0.0732<br>(1.12) |
| $FDI_{t-2}$ * Year 1994 | 0.818***<br>(3.32) | 1.963***<br>(4.12) | 2.15***<br>(4.40) | 1.97***<br>(4.11) |
| Above Lower Middle School $_{t-1}$ | 0.192<br>(1.39) | 0.299**<br>(2.02) | 0.120<br>(0.71) | 0.297**<br>(1.99) |
| Above Lower Middle School $_{t-2}$ | | | 0.389**<br>(2.20) | |
| Human capital spillover $_{t-1}$ | 0.189***<br>(3.79) | 0.175***<br>(3.36) | 0.175***<br>(3.36) | 0.174***<br>(3.36) |
| Human capital spillover $_{t-1}$ * Year 1994 | -0.004<br>-(0.18) | 0.0217<br>(0.85) | 0.027<br>(1.05) | 0.021<br>(0.83) |
| Capital vintage $_t$ | 0.289**<br>(2.32) | 0.292**<br>(2.25) | 0.293**<br>(2.25) | 0.301**<br>(2.18) |
| Telephones $_{t-2}$ | 0.333**<br>(2.56) | 0.403***<br>(2.98) | 0.322**<br>(2.30) | 0.406***<br>(2.97) |
| Roads $_{t-2}$ | -0.008<br>-(0.23) | 0.0146<br>(0.38) | 0.0086<br>(0.22) | 0.0145<br>(0.37) |
| Non-state workforce$_{t-1}$ | -0.324<br>-(1.50) | -0.301<br>-(1.33) | -0.302<br>-(1.33) | -0.301<br>(-(1.33) |
| $\log(TFP_{t-1}) - \log(TFP_{t-2})$ | | | | -0.0104<br>-(0.20)) |
| N | 448 | 448 | 448 | 448 |
| Adjusted R square | 0.509 | 0.498 | 0.498 | 0.496 |
| F Test for No Fixed Effects: F Value (Pr > F) | 10.58<br>(<0.0001) | 10.22 (0.0001) | 10.10<br>(0.0001) | 8.32<br>(0.0001) |
| Test for Overidentifying Restrictions:<br>F Values (Pr > F) | | 1.45 (0.2279) | 1.49 (0.2163) | 1.45<br>(0.2269) |
| Hausman Test for Endogeneity of FDI: F Value (Pr > F) | | 10.22<br>(<0.0001) | 10.42<br>(<.0001) | 10.18<br>(<0.0001) |

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. "Above Lower Middle School": the proportion of population with education that are beyond the lower middle school. "Capital Vintage": double difference of log Capital. "Telephone": the proportion of urban telephone subscribers. "Road": km per $km^2$. "Non-state Workforce" is the proportion of urban labor employed in non-state owned firms. "Human capital spillover" variable is defined in the text. All the monetary values were deflated with the base of Beijing 1990.
5. The TFP growth is computed from the production function (2) in Table 3.
6. In the 2SLS, "$FDI_{t-3}$", "$FDI_{t-3}$ * Year 1994", "Degree of Economic Zone $2_{t-3}$", "Degree of Economic Zone $3_{t-3}$", and "Degree of Economic Zone $4_{t-3}$" are used as instrumental variables.

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

| Region | (1) Direct contribution to production via Education Greater than Elementary | (2) Education above Lower Middle School | | (3) Indirect Contribution to Production through TFP Growth via Telecommunication Infrastructure |
|---|---|---|---|---|
| | | (a) Indirect Contribution to Production through TFP Growth | (b) Combined Direct and Indirect Contributions | |
| Coastal | 0.133 | 0.252 | 0.239 | 0.531 |
| Northeast | 0.107 | 0.251 | 0.222 | 0.491 |
| Far West | 0.185 | 0.210 | 0.240 | 0.354 |
| Interior | 0.181 | 0.265 | 0.269 | 0.361 |
| National | 0.152 | 0.245 | 0.243 | 0.435 |

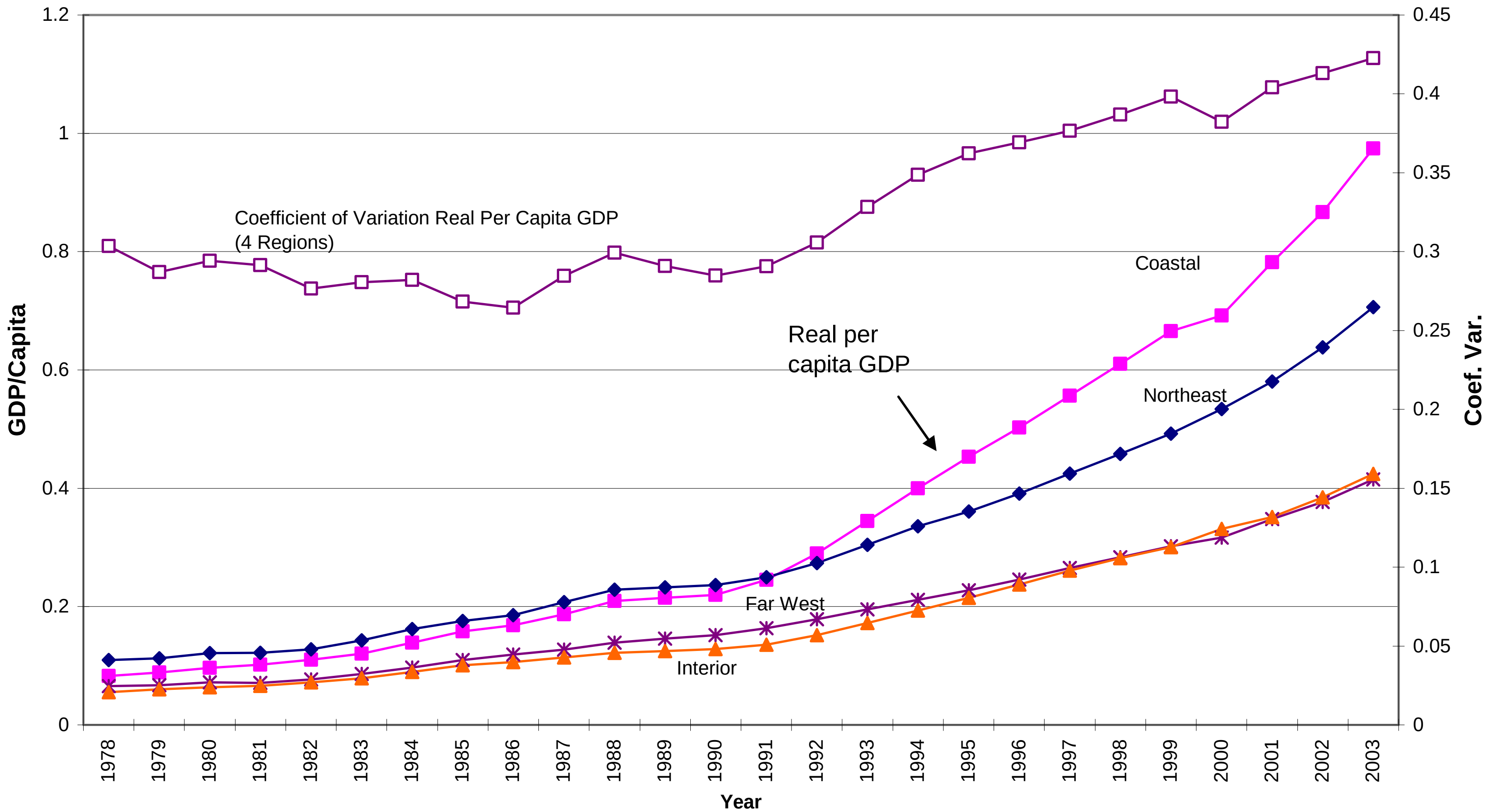
.
Note:
1. Production function: 2-way FE.
2. The computation of rates of return ( $\rho_i^s$ ) are discussed in Appendix A-D.
3. National calculations are arithmetic means of the constituent regions.

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

| | NE/Coastal | FW/Coastal | Interior /Coastal |
|---|---|---|---|
| Human Capital (Direct + Indirect Contribution) | 0.92 | 0.45 | 0.51 |
| Increase compared to No Policy | 0.054 | 0.072 | 0.11 |
| % of Increase in the Ratios | 6.2% | 19.2% | 26.2% |
| Telecommunication | 1.11 | 0.48 | 0.52 |
| Increase compared to No Policy | 0.24 | 0.10 | 0.11 |
| % of Increase in the Ratios | 27.67% | 27.67% | 27.67% |
| | | | |
| Predicted ratios without any policy imposed | 0.870 | 0.377 | 0.407 |

1. The details about the alternative hypothetical policy are provided in Appendix E.
2. The formula for computing "% of Increase in the Ratios" for Telecommunication is $\exp(\beta^t \cdot z \cdot g_i / Population_i) - 1$. $\beta^t$ (from the TFP growth equation) and $z$ (function of depreciation) are constants. The variable $g_i$ is the increase in the telecommunication infrastructure in each phase of the investment project. Since the investment funding received by each region is distributed according to its population size and the unit cost of telecommunication is set to be the same across regions, $g_i/Population_i$ will be identical across regions. Therefore, the percentages of increase in the ratios are identical across regions, as shown in the table.

# Figure 1 Real GDP per Capita (4 regions)



## Figure 2 Real Per Capita GDP Regional Ratios to Coast

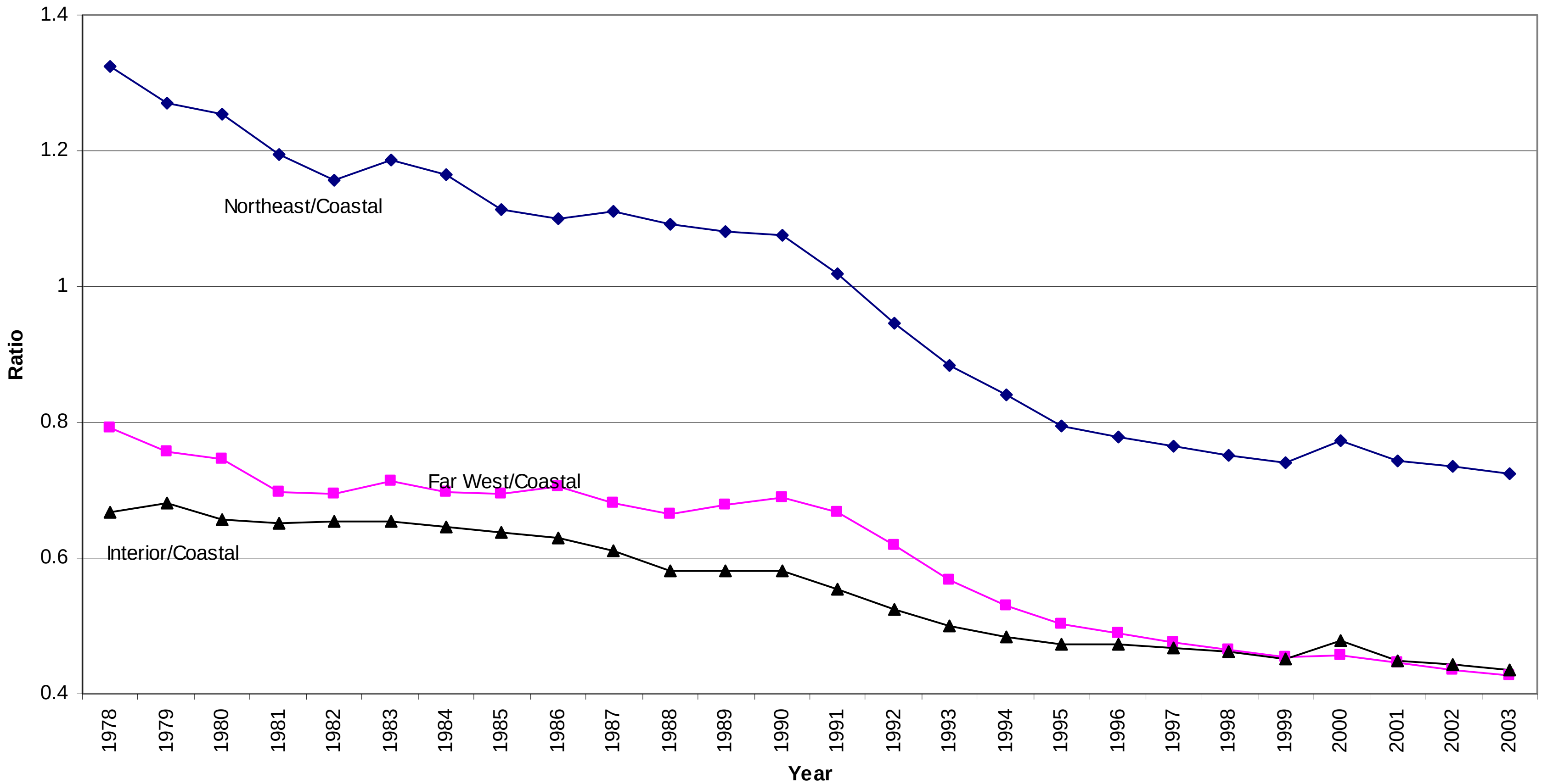


**Figure 3 Labor, Capital and Real GDP**

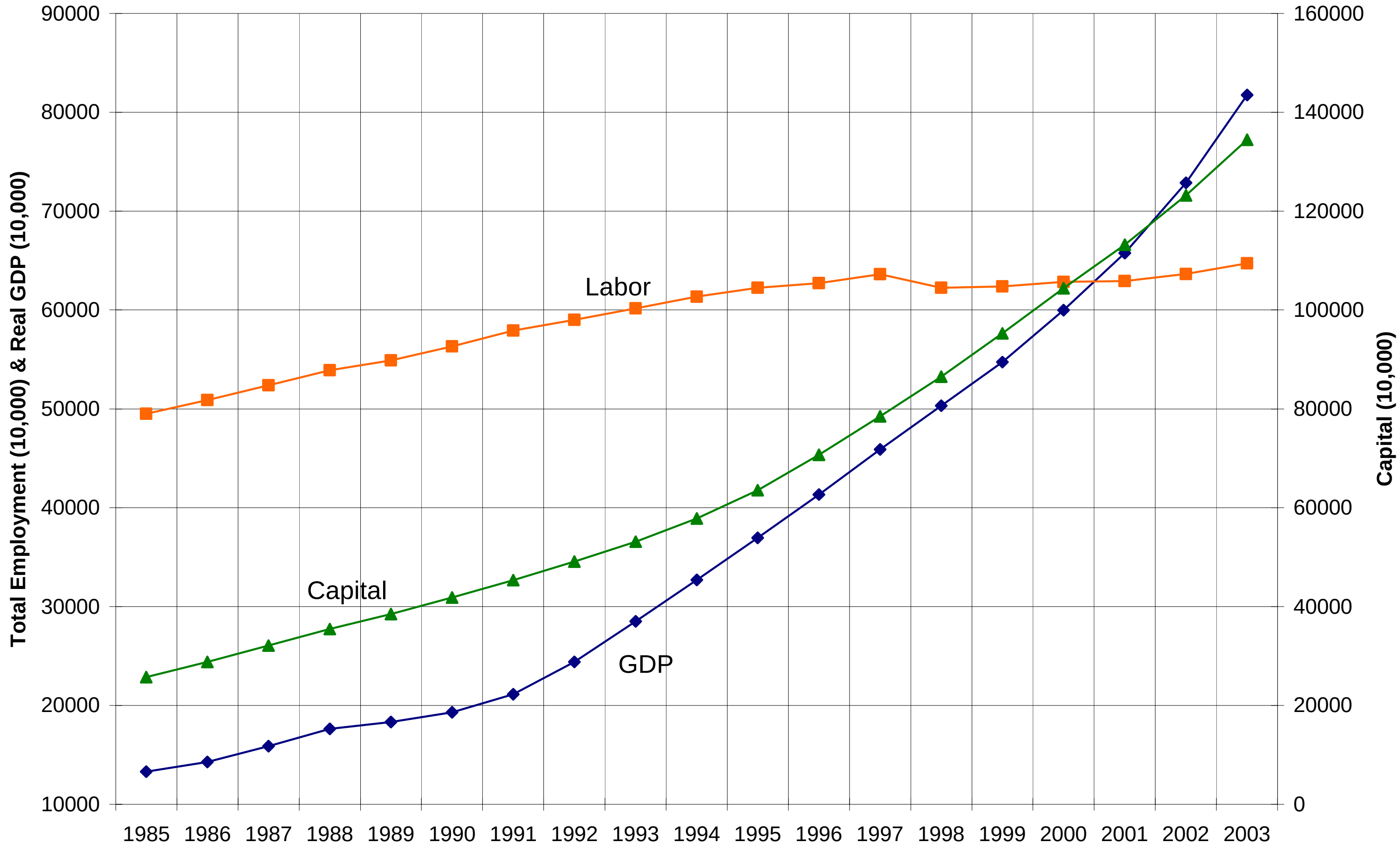


**Figure 4 Number of Reported Xiagang Workers**

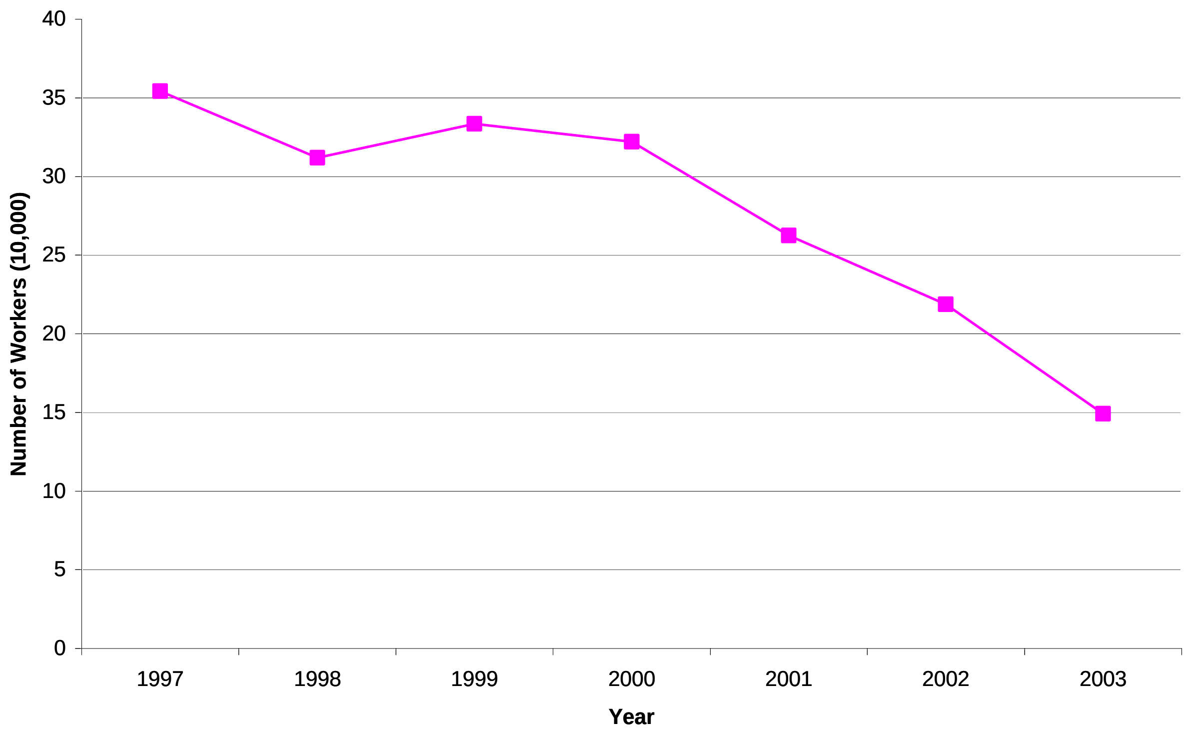
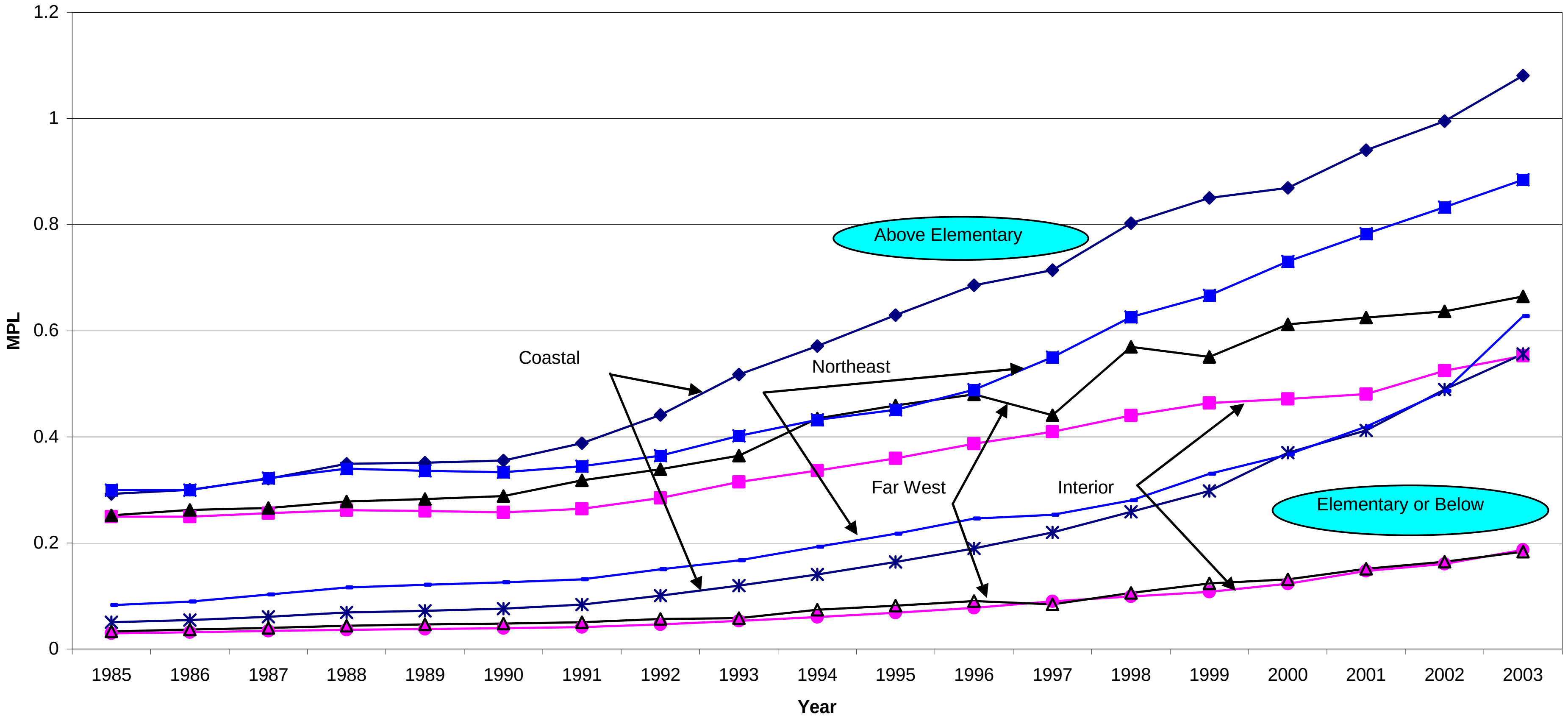
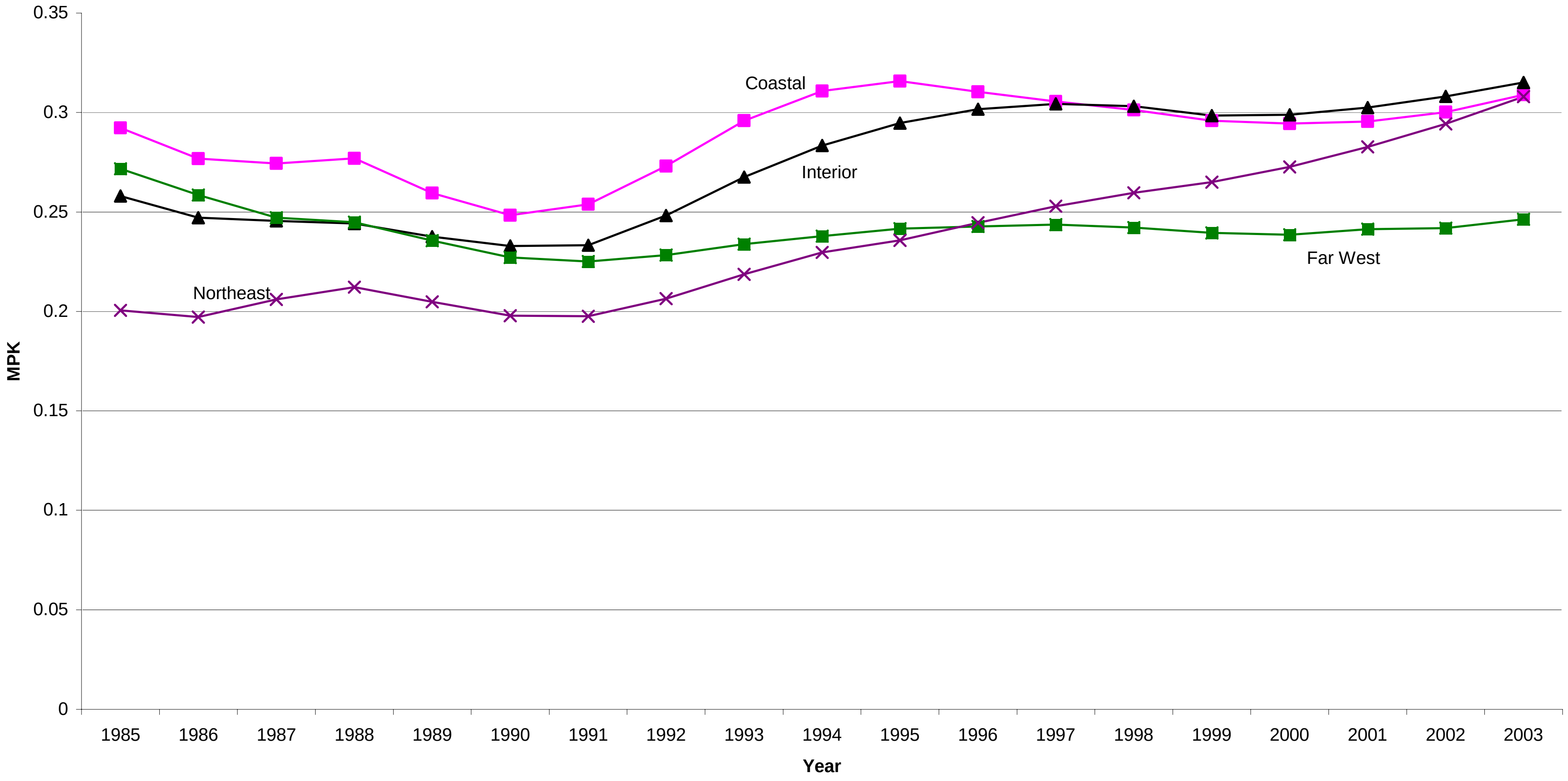


**Figure 5 Marginal Product of Labor (Two Categories of Labor, 2-Way FE with CRS)**



## Figure 6 Marginal Product of Capital
## (Two categories of Labor, 2-Way FE, E-based PF)



## Figure 7 TFP Interior Region/TFP Coastal Region (Two categories of Labor, 2-Way FE, E-based PF)

| | | | | |
|---|---|---|---|---|
| 1996 | 1.040782 | 0.752165 | 0.743252 | 0.823422 |
| 1997 | 1.063763 | 0.783285 | 0.715016 | 0.880443 |
| 1998 | 1.123308 | 0.812071 | 0.806538 | 0.948197 |
| 1999 | 1.153962 | 0.829041 | 0.802352 | 0.997696 |
| 2000 | 1.184302 | 0.84506 | 0.839911 | 1.060276 |
| 2001 | 1.236568 | 0.870723 | 0.863115 | 1.123619 |
| 2002 | 1.295097 | 0.917875 | 0.877405 | 1.191664 |
| 2003 | 1.374526 | 0.961042 | 0.909941 | 1.278386 |
| | | Int-Coast | | |
| 1985 | | | 0.839331 | |
| 1986 | | | 0.834113 | |
| 1987 | | | 0.819621 | |
| 1988 | | | 0.789331 | |
| 1989 | | | 0.799329 | |
| 1990 | | | 0.801341 | |
| 1991 | | | 0.769979 | |
| 1992 | | | 0.745393 | |
| 1993 | | | 0.723524 | |
| 1994 | | | 0.714658 | |
| 1995 | | | 0.712202 | |
| 1996 | | | 0.722692 | |
| 1997 | | | 0.736334 | |
| 1998 | | | 0.722928 | |
| 1999 | | | 0.71843 | |
| 2000 | | | 0.713551 | |

# Appendix

Production Function:

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

TFP Growth Equation:

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

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

**Basic Assumptions:**

- Policy scenario: each provincial government is going to launch an adult education program to move some of the workers from the low schooling ($L_n$) group to the high schooling ($L_e$) group. The goal of this exercise is to measure the rate of return to education based on its direct contribution on the production process.
- The future output in the absence of the adult education program is projected assuming all the variables stay constant (i.e., $L_{ei} = L_{ei,t+1} = L_{ei,t+2} = \ldots$ and $L_{ni} = L_{ni,t+1} = L_{ni,t+2} = \ldots$), so the annual growth of the future output is fixed to be $w_i$ (t is set to be 2003).

$$w_i = \sum_{y=2000}^{2003} \log TFP_{i,y} - \log TFP_{i,y-1}$$

- After the completion of the adult education program, the workers would be sent to work for $N_2$ years (starting at time t+1).

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

**Return to Education Based on Its Direct Contribution:**

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

$$\log Y_{i,t+j} = \log Y_{i,t} + j \cdot w_i$$

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+$N_2$):

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

$\rho_i^s$ is the rate of return.

**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: $dL_i \cdot \left(D_i + \frac{Y_{i,t}}{L_{ni}} \beta_n\right)$

Since $L_e$ is defined as "above elementary school," we should maintain the same composition of the three education groups (namely lower middle school, upper middle school, and college) for computing the cost of the adult education program. The lengths of the lower middle school, the upper middle school, and the college educations are assumed to be three years, three years, and four years, respectively.

Let $x_i$, $y_i$, and $z_i$ be the proportions of workers who have received lower middle school, upper middle school and college education in province $i$ in 2003, respectively (note: $x_i$ includes $y_i$, and $y_i$ includes $z_i$). If there are $dL_i$ number of workers who participate in the adult education program, then there will be $(y_i / x_i) \cdot dL_i$ number of the workers who will continue to upper middle school education, and $(z_i / x_i) \cdot dL_i$ number of the workers who will continue to college education in order to maintain the same composition of the three education groups.

Assume the costs of lower middle school, and upper middle school and college educations are $dL_i \cdot (D_i^l + \frac{Y_{i,t}}{L_{ni}} \beta_n)$, $dL_i \cdot (D_i^u + \frac{Y_{i,t}}{L_{ni}} \beta_n)$ and $dL_i \cdot (D_i^c + \frac{Y_{i,t}}{L_{ni}} \beta_n)$, respectively. The length of lower middle school education is $N_l$ –year; the length of upper middle school education is $N_u$ –year; the length of college education is $N_c$ -year.

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

$$(\frac{y_i}{x_i}-\frac{z_i}{x_i})dL_i\cdot\{(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[1+...+(\frac{1}{1+\rho_i^s})^{-N_u+1}]+\cdot(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_u}+...+(\frac{1}{1+\rho_i^s})^{-N_u-N_l+1}]\}+$$

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

$$(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_c-N_u}+...+(\frac{1}{1+\rho_i^s})^{-N_c-N_u-N_l+1}]\}$$

$$=(1-\frac{y_i}{x_i})\cdot dL_i\cdot(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_l}-1}{\rho_i^s}+$$

$$(\frac{y_i}{x_i}-\frac{z_i}{x_i})dL_i\cdot\{(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s}+(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u+N_l}-(1+\rho_i^s)^{N_u}}{\rho_i^s}\}+$$

$$\frac{z_i}{x_i}dL_i\cdot\{(D_i^c+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s}+(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}+(1+\rho_i^s)^{N_c}}{\rho_i^s}+$$

$$(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u+N_l}-(1+\rho_i^s)^{N_c+N_u}}{\rho_i^s}\}$$

**The Rate of Return ($\rho_i^s$) to Education Based on Its Direct Contribution:**

$$(\frac{Y_{i,t}}{L_{ei}}\beta_e - \frac{Y_{i,t}}{L_{ni}}\beta_n)\sum_{j=1}^{N_2}\frac{e^{\Upsilon_{j,i}}}{(1+\rho_i^s)^j} = (1-\frac{y_i}{x_i})\cdot(D_i^l + \frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_l}-1}{\rho_i^s} +$$

$$(\frac{y_i}{x_i} - \frac{z_i}{x_i})\{(D_i^u + \frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s} + (D_i^l + \frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u+N_l}-(1+\rho_i^s)^{N_u}}{\rho_i^s}\} +$$

$$\frac{z_i}{x_i}\{(D_i^c + \frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s} + (D_i^u + \frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s} +$$

$$(D_i^l + \frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u+N_l}-(1+\rho_i^s)^{N_c+N_u}}{\rho_i^s}\}$$

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

**Basic Assumptions:**

- Policy scenario: each provincial government is going to launch an adult education program to raise the level of schooling achieved beyond the nine-year compulsory education requirement. To do this, some of the workers who are in the high schooling group ($L_e$) and haven't received beyond lower middle school education are randomly selected to obtain higher levels. The goal of this exercise is to measure the rate of return to education based on its indirect contribution through TFP growth on the production process.
- The future output in the absence of the adult education program is projected assuming all the variables stay constant (i.e., $L_{ei} = L_{ei,t+1} = L_{ei,t+2} = \dots$; $L_{ni} = L_{ni,t+1} = L_{ni,t+2} = \dots$; $Population_i = Population_{i,t+1} = Population_{i,t+2} = \dots$), so the annual growth of the future output is fixed to be $w_i$ (t is set to be 2003).

$$w_i = \sum_{y=2000}^{2003}\log TFP_{i,y} - \log TFP_{i,y-1}$$

- After the completion of the adult education program, the workers would be sent to work for $N_2$ years (starting at time t+1, with constant population $Population_i$).
- Let $h_i$ and $E_i$ denote the proportions of people and workers who have received education that is beyond the level of the nine-year compulsory education in province $i$, respectively.

$$Workforce_i \cdot dE_i = Population_i \cdot dh_i \quad \text{(True under our policy scenario)}$$
$$dE_i = dE_{i,t+1} = dE_{i,t+2} = \ldots,$$
$$dh_i = dh_{i,t+1} = dh_{i,t+2} = \ldots$$

**Return to Education Based on Its Indirect Contribution:**

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*.

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

Since $h_i$ is defined as the proportion of the people who have received education that is beyond the level the nine-year compulsory education, we should maintain the same composition of the two education groups (namely upper middle school and college) for computing the cost of the adult education program. The lengths of the upper middle school and the college educations are assumed to be three years and four years, respectively.

Let $y_i$, and $z_i$ be the proportions of workers who have received upper middle school and college education in province *i* in 2003, respectively (note: $y_i$ includes $z_i$). If there are $dL_i$ number of workers who participate in the adult education program, then there will be $(z_i / y_i)\cdot dL_i$ number of workers who will continue to college education in order to maintain the same composition of the two education groups.

Assume the costs of upper middle school and college educations are $dE_i \cdot Workforce_i \cdot (D_i^u + \frac{Y_{i,t}}{L_{ei}} \beta_e)$ and $dE_i \cdot Workforce_i \cdot (D_i^c + \frac{Y_{i,t}}{L_{ei}} \beta_e)$, respectively. The length of upper middle school education is $N_u$ –year, and the length of college education is $N_c$ -year.

$$(1-\frac{z_i}{y_i})dE_i \cdot Workforce_i \cdot (\frac{Y_{i,t}}{L_{ei}}\beta_e + D_i^u)\cdot[1+(\frac{1}{1+\rho_i^s})^{-1}+...+(\frac{1}{1+\rho_i^s})^{-N_u+1}]+$$

$$\frac{z_i}{y_i}dE_i \cdot Workforce_i \cdot \{(D_i^c+\frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot[1+...+(\frac{1}{1+\rho_i^s})^{-N_c+1}]+(D_i^u+\frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot[(\frac{1}{1+\rho_i^s})^{-N_c}+...+(\frac{1}{1+\rho_i^s})^{-N_c-N_u+1}]\}$$

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

$$\frac{z_i}{y_i}dE_i \cdot Workforce_i \cdot \{(D_i^c+\frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s}+(D_i^u+\frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s}\}$$

**The Rate of Return ($\rho_i^s$) to Education Based on Its Indirect Contribution:**

$$\frac{Y_{i,t}\cdot\vartheta_i}{Population_i}\cdot\sum_{j=2}^{N_2}\frac{(j-1)\cdot e^{\Upsilon_{j,i}}}{(1+\rho_i^s)^j}=(1-\frac{z_i}{y_i})(\frac{Y_{i,t}}{L_{ei}}\beta_e+D_i^u)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s}+$$

$$\frac{z_i}{y_i}\{(D_i^c+\frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s}+(D_i^u+\frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s}\}$$

## C. The Rate of Return to Education Based on Its Direct and Indirect Contribution

**Basic Assumptions:**

- Policy scenario: each provincial government is going to launch an adult education program to raise the level of schooling achieved beyond the nine-year compulsory education requirement. To do this, some of the workers who are in the low schooling group ($L_n$) are randomly selected to obtain higher levels. The goal of this exercise is to measure the rate of return to education based on both its direct and indirect contribution on the production process.
- The future output in the absence of the adult education program is projected assuming all the variables stay constant (i.e., $L_{ei}=L_{ei,t+1}=L_{ei,t+2}=...$; $L_{ni}=L_{ni,t+1}=L_{ni,t+2}=...$; $Population_i=Population_{i,t+1}=Population_{i,t+2}=...$), so the annual growth of the future output is fixed to be $w_i$ (t is set to be 2003).

$$w_i=\sum_{y=2000}^{2003}\log TFP_{i,y}-\log TFP_{i,y-1}$$

- After the completion of the adult education program, the workers would be sent to work for $N_2$ years (starting at time t+1, with constant population $Population_i$ ).

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

- Let $h_i$ and $E_i$ denote the proportions of people and workers who have received education that is beyond the level of the nine-year compulsory education in province *i*, respectively.

$$dh_i = dL_i / Population_i \quad \text{(True under our policy scenario)}$$
$$dE_i = dE_{i,t+1} = dE_{i,t+2} = \ldots,$$
$$dh_i = dh_{i,t+1} = dh_{i,t+2} = \ldots$$

**Return to Education Based on Its Direct Contribution:**

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

**Return to Education Based on Its Indirect Contribution:**

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

**Investment Cost:**

The cost of investment per year:

Direct cost: $D_i$

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

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

Since $h_i$ is defined as the proportion of the people who have received education that is beyond the nine-year compulsory education level, we should maintain the same composition of the two education groups (namely upper middle school and college) for computing the cost of the adult education program. The lengths of the lower middle school, the upper middle school, and the college educations are assumed to be three years, three years, and four years, respectively.

Let $y_i$, and $z_i$ be the proportions of workers who have received upper middle school and college education in province $i$ in 2003, respectively (note: $y_i$ includes $z_i$). If there are $dL_i$ number of workers who participate in the adult education program, then there will be $(z_i / y_i) \cdot dL_i$ number of workers who will continue to college education in order to maintain the same composition of the two education groups.

Assume the costs of lower middle school, and upper middle school and college educations are $dL_i \cdot (D_i^l + \frac{Y_{i,t}}{L_{ni}} \beta_n)$, $dL_i \cdot (D_i^u + \frac{Y_{i,t}}{L_{ni}} \beta_n)$ and $dL_i \cdot (D_i^c + \frac{Y_{i,t}}{L_{ni}} \beta_n)$, respectively. The length of lower middle school education is $N_l$ –year; the length of upper middle school education is $N_u$ –year; the length of college education is $N_c$ -year.

$$(1-\frac{z_i}{y_i})dL_i\cdot\{(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[1+...+(\frac{1}{1+\rho_i^s})^{-N_u+1}]+\cdot(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_u}+...+(\frac{1}{1+\rho_i^s})^{-N_u-N_l+1}]\}+$$

$$\frac{z_i}{y_i}dL_i\cdot\{(D_i^c+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[1+...+(\frac{1}{1+\rho_i^s})^{-N_c+1}]+(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_c}+...+(\frac{1}{1+\rho_i^s})^{-N_c-N_u+1}]+$$

$$(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_c-N_u}+...+(\frac{1}{1+\rho_i^s})^{-N_c-N_u-N_l+1}]\}$$

$$=(1-\frac{z_i}{y_i})dL_i\cdot\{(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s}+(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u+N_l}-(1+\rho_i^s)^{N_u}}{\rho_i^s}\}+$$

$$\frac{z_i}{y_i}dL_i\cdot\{(D_i^c+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s}+(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s}+$$

$$(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u+N_l}-(1+\rho_i^s)^{N_c+N_u}}{\rho_i^s}\}$$

**The Rate of Return ( $\rho_i^s$ ) to Education Based on Both Its Direct Indirect Contribution:**

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

$$=(1-\frac{z_i}{y_i})\cdot\{(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s}+(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u+N_l}-(1+\rho_i^s)^{N_u}}{\rho_i^s}\}+$$

$$\frac{z_i}{y_i}\cdot\{(D_i^c+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s}+(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s}+$$

$$(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u+N_l}-(1+\rho_i^s)^{N_c+N_u}}{\rho_i^s}\}$$

**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 | Upper Middle School | Lower Middle 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.

## D. The Rate of Return to Infrastructure Investment

**Basic Assumptions:**

- Policy scenario: each provincial government is going to invest *C* dollars on infrastructure at time t. The goal of this exercise is to measure the rate of return to infrastructure investment.
- The newly increased infrastructure would 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 period between t+1 and t+$N_2$.
- The future output in the absence of the adult education program is projected assuming all the variables stay constant, so the annual growth of the future output is fixed to be $w_i$ (t is set to be 2003).

$$w_i = \sum_{y=2000}^{2003} \log TFP_{i,y} - \log TFP_{i,y-1}$$

- The depreciation rate ($R$) is set to 0.06. The initial stock of infrastructure (at time t) is assumed to be fixed at the same level throughout the years. The depreciation is applied only to the newly increased infrastructure (starting at t+2).

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

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

Telephone Infrastructure

Based on the TFP Growth Equation,

$$\log TFP_{i,t+3} = \log TFP_{i,t+2} + \beta^t Tel_{i,t+1} + \ other \ \ variables$$

Note: Other variables are not the functions of *Tel*.

Return to telephone infrastructure at time t+3:

$$dY_{i,t+3} = Y_{i,t} e^{\Upsilon_{3,i}} \cdot \beta^t \cdot dTel_{i,t+1} = Y_{i,t} e^{\Upsilon_{3,i}} \cdot \beta^t \cdot dTel_i$$

Return to telephone infrastructure at time t+4:

$$dY_{i,t+4} = Y_{i,t} e^{\Upsilon_{4,i}} \cdot \beta^t \cdot [1+(1-R)] \cdot dTel_i$$

Return to Road Construction at time t+j ( $j \geq 3$ ):

$$dY_{i,t+j} = Y_{i,t} e^{\Upsilon_{j,i}} \cdot \beta^t \cdot \frac{1-(1-R)^{j-2}}{R} \cdot dTel_i$$

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

$$\text{Return} = Y_{i,t} \cdot \beta^t \cdot dTel_i \cdot \sum_{j=3}^{N_2} \frac{e^{\Upsilon_{j,i}}}{(1+\rho_i^s)^j} \cdot \frac{1-(1-R)^{j-2}}{R}$$

**Investment Cost:**

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

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

**The Rate of Return ($\rho_i^s$) to Telephone Infrastructure:**

$$Y_{i,t} \cdot \beta_1^t \cdot \sum_{j=3}^{N_2} \frac{e^{\Upsilon_{j,i}}}{(1+\rho_i^s)^j} \cdot \frac{1-(1-R)^{j-2}}{R} = Population_i \cdot C_i^t$$

**Cost estimates for the telephone**

The China Statistical Yearbook reports the aggregate investment in "Transportation, Storage, Postal and Telecommunication Services." There is no simple way to separate telecommunication investment from transportation investment. In order to estimate the cost of telecommunication, we run a simple regression model with the dependent variable defined as the average annual investment in 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) as follows:

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

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

In this exercise, we estimate the marginal cost of telecommunication infrastructure, using telephone ownership as a proxy for such infrastructure. We assume that the average cost is constant and thus equals to the 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 | 21.24 | 13.04 | 1.63 | 0.12 |
| avg_road_01_02 | 0.27 | 1.02 | 0.26 | 0.79 |
| avg_telephone_01_02 | 1.10 | 0.14 | 8.02 | <.0001 |
| | | | | |
| Adjusted R-square: 0.7003 | | | | |

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.

## E. 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.
- There are five phases in this investment project. In each phase, the central government would distribute 10% of their annual revenue to the non-coastal provinces (weighed by their population size) to carry out the investment project.[31]
- The first phase of the investment project would be completed at the beginning of 2004, and the last phase investment project would be completed at the beginning of 2008. 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 impact on output: the direct contribution to the production process and the indirect contribution through the TFP growth on the production process. For the direct contribution, each non-coastal provincial government would launch an adult education program to move some of the workers from the low-skilled ($L_n$) group to the high-skilled ($L_e$) group. For the indirect contribution, each non-coastal provincial government would launch an adult education program to provide education service, which is beyond the level of the nine-year compulsory education, to some of the workers. The lengths of the lower middle school, upper middle school and college education are assumed to be 3-year, 3-year and 4-year, respectively.
- The depreciation rate of the telecommunication infrastructure ($R$) is assumed to be 0.06. The initial stock of the infrastructure (in 2003) is assumed to be fixed at the same level throughout the years. The depreciation is applied only to the newly increased infrastructure (starting at the beginning of 2005).

---

[31] The total government revenue is 2171.525 billion yuan in 2003. We assume that the central government would spend 217.1525 billion yuan in each phase of the investment project. For simplicity, we also assume that the unit costs of human capital and telecommunication infrastructure stay the same throughout the investment project, and the calculations of the unit costs are provided in Appendix A-C.

- We assume $\log Y_{i,t+1} - \log Y_{i,t} = \log TFP_{i,t+1} - \log TFP_{i,t} = w_i$ in projecting the "future" output and TFP in the absence of the investment project. $w_i$ is a provincial-specific constant ( $w_i = \sum_{y=2000}^{2003} \log TFP_{i,y} - \log TFP_{i,y-1}$ ). For simplicity, we assume $\frac{y_{\max} - y_i}{y_i}$ stays constant throughout the years.

**Direct Contribution of Human Capital:**

Let $g_i$ be the increase in the number of high-skilled workers ($L_e$) in each phase of the investment project.

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

⋮

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

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

⋮

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

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

⋮

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

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

**Indirect Contribution of Human Capital:**

Let $g_i$ be the number of workers who are involved in the adult education program in each phase of the investment project. The first phase of the investment project is completed at the beginning of 2004, but the growth rate of *TFP* would not be affected until in 2005 due to the assumption of the lagged impact. Let $L_{ci}$ denote the original number of workers who have received education that is beyond the level of the nine-year compulsory education.

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

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

⋮

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

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

⋮

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

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

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

$$\log Y_{i,2010}^{New} - \log Y_{i,2009}^{New} = w_i + \left( \phi_1^h + \phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \frac{5 \cdot g_i}{population_i}$$

⋮

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

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

**Both Direct and Indirect Contributions of Human Capital:**

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

t = 2005: $L_{ni} \rightarrow L_{ni} - 5 \cdot g_i \quad L_{ei} \rightarrow L_{ei} + 2 \cdot g_i \quad L_{ci} \rightarrow L_{ci} + 2 \cdot g_i$

$\vdots$

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

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

$$\log Y_{i,2005}^{New} - \log Y_{i,2004}^{New} = w_i + \beta_e \cdot \log(\frac{L_{ei} + 2 \cdot g_i}{L_{ei} + g_i}) + \left( \phi_1^h + \phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \frac{g_i}{populaton_i}$$

$\vdots$

$$\log Y_{i,2008}^{New} - \log Y_{i,2007}^{New} = w_i + \beta_e \cdot \log(\frac{L_{ei} + 5 \cdot g_i}{L_{ei} + 4 \cdot g_i}) + \left( \phi_1^h + \phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \frac{4 \cdot g_i}{populaton_i}$$

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

$$\log Y_{i,2013}^{New} - \log Y_{i,2003} = 10 \cdot w_i + \beta_e \cdot \log(\frac{L_{ei} + 5 \cdot g_i}{L_{ei}}) + \beta_n \cdot \log(\frac{L_{ni} - 5 \cdot g_i}{L_{ni}}) + \left( \phi_1^h + \phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \left( \frac{35 \cdot g_i}{population_i} \right)$$

$$\log Y_{i,2013}^{New} = Y_{i,2003} \cdot \exp\left( \begin{array}{c} 10 \cdot w_i + \beta_e \cdot \log(\frac{L_{ei} + 5 \cdot g_i}{L_{ei}}) + \beta_n \cdot \log(\frac{L_{ni} - 5 \cdot g_i}{L_{ni}}) + \\ \left( \phi_1^h + \phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \left( \frac{35 \cdot g_i}{population_i} \right) \end{array} \right)$$

**Telecommunication Infrastructure:**

Let $g_i$ be the increase in the telecommunication infrastructure in each phase of the investment project. The first phase of the investment project is completed at the beginning of 2004, but the growth rate of *TFP* will not be affected until in 2006 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: $Tel_i \rightarrow Tel_i + 5 \cdot g_i$

$$\log Y_{i,2006}^{New} - \log Y_{i,2005} = w_i + \beta^t \frac{g_i}{Population_i}$$

⋮

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

$$\log Y_{i,2011}^{New} - \log Y_{i,2010}^{New} = w_i + \beta^t \frac{g_i + g_i \cdot (1-R) + g_i \cdot (1-R)^2 + g_i \cdot (1-R)^3 + g_i \cdot (1-R)^4}{Population_i} \cdot (1-R)$$

⋮

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

Denote $z$ as follows:

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

$$Y_{i,2013}^{New} = Y_{i,2003} \exp\left( \frac{\beta^t}{Population_i} g_i \cdot z + 10 \cdot w_i \right)$$