Universität der Bundeswehr München

Fachgruppe für Volkswirtschaftslehre
Economic Research Group

VOLKSWIRTSCHAFTLICHE DISKUSSIONSBEITRÄGE

WORKING PAPERS IN ECONOMICS

Yanyuan Zhu and Xiao Feng

China's National Production Function Since 1997: A Reinvestigation

26. Jg. (2014), Nr. 2

Autoren/Authors

Xiao Feng
Institute of Economics and Education, Chinesisch-Deutsche Hochschule (CDH) der Tongji-Universität
Jishi Building 256, Cao-An Highway 4800
201804 Shanghai
China
fengxiao@tongji.edu.cn

Yanyuan Zhu
(yyz@tongji.edu.cn)

Herausgeber/Editors

Bis zum Jahr 2008 (20. Jg.) erschien diese Reihe unter dem Titel:
Until 2008 published as:
„Diskussionsbeiträge des Instituts für Volkswirtschaftslehre der Universität der Bundeswehr München".

Dieser Diskussionsbeitrag ist auch als elektronische Version verfügbar unter:
An electronic version of this paper may be downloaded from:
http://www.unibw.de/makro/forschung/diskussion

China's National Production Function Since 1997: A Reinvestigation

Yanyuan Zhu and Xiao Feng*

Feburary 2014

Abstract

We build China's national production function based on national accounting data since 1997, when China primarily transformed from the Planned economy to Market. By proxying and measuring stocks of human capital(HC), physical capital and the efficiency units, as well as government expenditure reflecting total factor productivity(TFP), we analyze CES production functions' explanation effects by numerical simulation, and then according to the findings, choose Cobb-Douglas form for further research. Our results include, first, Cobb-Douglas production function in the form of capital coefficients - capital relative density, appropriately reflects Chinaâs recent input-output relationship. Second, taking factor-augmenting technical progress into consideration, the proxy settings for two capitals are empirically plausible for future research on Chinaâs endogenous growth model. Third, expansionary government expenditure negatively affects Chinaâs TFP and output.

Keywords: national production function, factor-augmenting technical progress, physical capital efficiency units

JEL Classification: C52, E01, O47, O53

* Institute of Economics and Education, Tongji University, Shanghai, P.R.China. Corresponding author: Yanyuan Zhu, E-mail: yyz@tongji.edu.cn.

1 Introduction

1.1 Types of NPF: selection and comparisons

The national production function (henceforth NPF) is one of the keys to studies on national expansion path of production, and furthermore, the endogenous growth model. So far, a series of studies have focused on China's NPF(Zhang, 2005; Gao, 2009). In general they can be catogorized into three groups. The first category assumes NPF to be Cobb-Douglas type, e.g. Guo (2006); Cao (2007); Xu and Lin (2011); Feng et al. (2012). In a more general sense, the second category assumes CES type, e.g. Chen and Lian (2012). The third category assumes NPF parameters to be time varying, e.g. Zhang and Xu (2009); Zhang et al. (2011); Zhang (2011); Wang and Ge (2012). As to the third category, input factor's output elasticity is assumed to be composed of both a constant, and a time varying variable. Based on the assumption, regression results usually show higher goodness of fit, however the assumption implies that the production possibility frontier fluctuates as well(Fernández-Villaverde, 2010; Koop et al., 2013). The implication is open for duscission. In our opinion, it is the production circumstances, other than technical shocks, that change stochastically. Changes of production circumstances do affect actual output, but do not alter the potential production possibility frontier. Besides, even if NPF is set to be time varying, the implicit technical characteristics are not revealed out though. As to inquiries on the potentials of China's long-run growth, overcomplicated settings on production function types, tend to make the future work – the endogenous growth modelling – difficult to be empirically tested.

As to the other two categories, a series of China's growth studies priorly assume Cobb-Douglas or CES as the production function type, respectively. While so far, no much attentions focus on testing the prior assumption itself: whether we should use Cobb-Douglas or its more general form, the CES type function, to explain China's growth[1]?

The main aim of this article is, to formulate an NPF which accurately describes China's input-output relation since 1997. To achieve this aim, we divide our research into three sub-goals. The first sub-goal, we need to empirically compare effects of different NPF types including Cobb-Douglas and CES, and find out which one fits more in explaining China's past output.

1.2 Human capital stock: proxies and measurements

From the perspective of macroeconomics, NPF is a simplification of producing process, describing how inputs turn into output, under specific production circumstances. Input factors include labor, human capital, physical capital and so on. In order to empirically analyze the process, we need to find appropriate proxy for each input factors, and propose plausible means to measure it.

In the earlier studies on NPF and economic growth, pure labor is often considered as a direct input factor(Solow, 1956, 1957). In the past 30 years, the endogenous growth models based on neo-classical growth theories, also consider the mechanisms and effects of human capital (henceforth HC) accumulation(Lucas, 1988; Mankiw et al., 1992; Funke and Strulik, 2000; Ben-Gad, 2012).

Considering labor as an independent input, the argument is open for discussion. First in real scenario, the HR manager responsible for recruiting in companies, interviews candidates who represent homogeneous HC stock, which reflects each individual's education backgrounds and working experiences. Such characteristics are crucial to whether or not

[1] Take cross-country studies as example, Duffy and Papageorgiou (2000) run panel data based on 82 countries dataï$\frac{1}{4}$to compare the explaining effects of different production functions types, on input-output relationship. While so far, few focus on China's past decade as a case study, to test which type fits more.

the candidate will be hired. In Macroeconomic analysis, the treatment of counting pure labor input as direct, independent input factor, seems lack of microfoundation. Second, a series of studies on China find that pure labor's output elasticity is negative on national level(Zhu, 2011), negative or insignificantly positive on industry level(Yang, 2013). It is probably due to the labor surplus in production sectors(Knight et al., 2011; Golley and Meng, 2011; Feng et al., 2012). Thus it might be inappropriate to explain China's national output by pure labor input[2].

HC is difficult to be directly observed or measured. If we want to take HC as input factor into NPF analysis, the problem is how to choose appropriate indices as proxy(Woessmann, 2003; Folloni and Vittadini, 2010). Generally speaking, now there are two methods to proxy HC, learning-by-doing (LBD) and learning-by-education (LBE). The lack of persistent, macro-level data support, makes it difficult to conduct HC measurement via LBD. As to LBE, two approaches are conducted. First is to measure the efficiency unit of labor input, by implementing Mincerian wage equation(Mincer, 1974; Carstensen et al., 2009; Wang and Yue, 2009; Li et al., 2010). Second is to consider education as a HC production sector, analyze the sectoral input-output, and find proper proxies.

In the previous studies Feng et al. (2012) on one hand calculate China's "efficient" labor units by Mincerian equation, and on the other hand, analyze HC sector's production process, and proxy HC stock by dispersion of employment with different education attainment. The results confirm the plausibility of method, which proxies China's HC stock by employment's average schooling years, as well as the dispersions[3]. However, if we use dispersion index as HC proxy to construct endogenous growth model, then multiple HC sectors have to be included, and the cross-sectoral relationships not only among different

[2] Moreover, a cross-country study based on ASEAN countries including China, Lao PDR, Vietnam and Thailand, analyzes the production effects of education/vocational education, and finds that the output elasticities of pure labor in such countries are not always significantly positively, sometimes even negative, see Feng et al. (2013).

[3] Such plausibility is also confirmed by a series of cross-country studies, e.g. Park (2006); Feng et al. (2013).

educational levels, but also between HC and other sectors, will have to be taken into consideration. This will inevitably raise the complexity and difficulty for model development. Thus, the second sub-goal of this article is, to find appropriate proxy for measuring HC stock's proxy.

1.3 Physical capital stock and capital-augmenting technical progress

Physical capital is another important input factor. So far there is no officially released data on China's physical capital stock. The fact has been calling for approximations among economists. Apparently for China's NPF analysis we need to measure physical capital stock based on previous studies(Zhang et al., 2004; Shan, 2008; Hui, 2009; Ye, 2010; Li, 2011; Fang, 2012).

Generally speaking, their measurements rely on perpetual inventory method with homogenous assumption, implying that investment share the same productivity, regardless of the periods they are invested. While according to vintage capital theory, there exists a mutual relationship between physical capital accumulation and (capital augmenting) technical progress. On one side, emerging technological advances increase the productivity of fixed capital investment of current time period, in comparison to that of previous periods. On the other side, along with capital accumulation, the productivity increase due to technology advances, stimulate increasing investment too(Greenwood and Jovanovic, 2001; Jovanovic and Yatsenko, 2012). Physical capital accumulation in different periods, might be heterogeneous in nature: newer investment is more productive due to technology advances.

In the previous studies, Feng et al. (2012) measure physical capital stock by efficiency units, which is adjusted via fixed capital price index and gross price index. However, if we use Feng et al. (2012)'s approach of measurement, to proceed into further stage of studies, the China's endogenous growth model, then we need to on one hand distinguish investment production sector from the final good production sector, and on the other hand, to also consider both domestic and international financial sectors, with central bank included. The reason is that durable goods price depends ont only on demand and supply side, but also on monetary policy, domestic financial sector, international economic environment, etc(Nakamura et al., 2013). We try to figure out 1) whether there are other methods to proxy capital augmenting technical progress, reflecting the mutual relationship mentioned above? 2) Once we adjust physical capital stock by efficiency units based on such proxies, can they reflect China's recent input-output? 3) Could the subsequent endogenous growth model be simplified then? In all, the third sub-goal of this article is, to trying simpler (while endogenizable) method to measure capital augmenting technical progress, embedded in heterogeneous physical capital, as well as the efficiency units.

Besides the three sub-goals mentioned above, in this paper we also consider two more practical questions. First question is the treatment of neutral technical progress. Among the determinants of total factor production (TFP), factors such as institutions and culture are relatively constant, while public expenditure is not(Aschauer, 1989). Guo and Jia (2006) develop a dual sector growth model including government, they find physical capital investment of government poses significant, positive effects on China's long run growth, while government's human capital investment has blur growth effects, and in the short run, the effect is even negative[4]. Zhang (2007); Zhang et al. (2007) find that regional(e.g. provincial) government competition and governance pattern transformation act as key

[4] On the contrary, Feng et al. (2012) find that China's production effect of human capital investment is higher than that of physical capital investment. The opposing conclusions might be due to following reasons. First, taking education as a HC production sector, the function reflecting sector input (individuals and education expenditure) and output (HC) relationship needs to be further discussed: due to facts such as longer period of production (e.g. it takes years to get college degree), heterogeneity of input factors (for example, individuals' different family background, intellect, hard-working spirit) and so on, education expenditure doesnât simultaneously increase HC stock. Thus in short run, the growth effect of HC investment is possibly not as obvious as that of physical capital investment. Second, in Feng et al. (2012), expenditures of education come from not only government's transfer payment, but also social education investment, as well as individuals' self-investment on education, and so on. Broader definition on the concept of 'HC investment' leads to different data utilized, and thus different results generated.

determinant factors of China's infrastructure investment. Infrastructure improvement raises TFP, and produces growth effects (Wang et al., 2009). Besides, public service is related to government consumption[5], whose increase/decrease affects TFP too. In this article, we use government expenditure as proxy of TFP's changes, and analyze its product effects on GDP.

The second question, during the research on China's economic growth, we have to deal with official data's imperfections, such as adjustment of statistic caliber, missing data, obvious fluctuations, and so on. We believe that in the field of Chinaâs growth studies, such imperfections are common and thus need to be dealt with.

2 Structure

The whole paper is divided into four parts. Firstly, we construct analytical models of China's NPF. Set physical capital stock and HC stock as input, GDP as output, all in per capita forms. Different types of technical progress are respectively embedded into different input factors. Capital- (labor-) augmenting technical progress in physical capital (HC) stock, and the neutral technical progress in increase of TFP. The production function types are assumed to be CES, baseline Cobb-Douglas (reflecting the quantity change among input-output), and adjusted Cobb-Douglas (reflecting the relative density between input factors, and between input and output), respectively.

In the second part, we proxy for input factors. 1). Measure HC stock according to employment's averaging schooling years, as well as dispersions of education attainment, 2). Measure physical capital stock according to the perpetual inventory method, 3). Make quality adjustment to the measured physical capital stock, establish efficiency units based

[5] According to (Xu, 2011, p12), government consumption is âexpenditure of public service offered by government, including public administration, national defense, education, science and technology, etc.â

on price index, industrial structure index and physical capital coefficient, respectively, 4). Proxy TFP change by the relative change of government consumption to GDP.

Third, we construct econometrical models. 1). Based on CES, the general type production functions, we choose different parameter combinations for numerical simulation, and further compare how combinations fit to reality, respectively. 2). With the testified model, we set the corresponding production function form, then choose different combinations of proxies of input factors, and by explaining China's actual intput-output, to test the proxies' validation and plausibility, respectively.

Fourth, we conclude major results, answer the questions posed in the beginning of the article, and draw prospects for future research.

3 Models

With the help of previous kowledge gained from studies conducted on endogenous growth model, we formulate our NPFs mainly in two types, three froms.

In Model I, we assume the following CES production function(Klump et al., 2012):

$$gdp(t) = \tilde{A}(t) \cdot \left[\gamma \cdot k(t)^{\frac{\sigma-1}{\sigma}} + (1-\gamma) \cdot h(t)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{1}$$

in which $gdp(t) = GDP(t)/L(t)$,$k(t) = K(t)/L(t)$ and $h(t) = H(t)/L(t)$ are GDP, physical capital and HC stock , all in per capita forms. $L(t)$ is gross employment, $\tilde{A}(t)$ is TFP. As to the two parameters, $\sigma \geq 0$ is the elasticity of substitution between $k(t)$ and

$h(t)$, and $0 < \gamma < 1$ reflects the direction of technical progress[6]. Set $\lambda = \frac{1-\gamma}{\gamma}$ï$\frac{1}{4}\rho = \frac{\sigma-1}{\sigma}$, $A(t) = \tilde{A}(t) \cdot \gamma^{\sigma/(1-\sigma)}$, then Eq.(1) is simplified as

$$gdp(t) = A(t) \cdot [k(t)^{\rho} + \lambda \cdot h(t)^{\rho}]^{\frac{1}{\rho}} \tag{2}$$

λ describes the direction of biased technical progress(Acemoglu, 2002): When $0 < \gamma < 1/2$, $\lambda > 1$, technical progree is biased toward HC; when $\gamma = 1/2$, $\lambda = 1$, technical progress is neutral; when $1/2 < \gamma < 1$, technical progree is biased toward physical capital. ρ describes the substitution relationship between input factors: when $0 < \sigma < 1$, $-\infty < \rho < 0$, input factors are more complementary [7]; when $1 < \sigma < \infty$, $0 < \rho < 1$, input factors are more subsititute [8] .

When σ is constant as 1, CES production function turns into a special form, the Cobb-Douglas form, we set it as Model IIï$\frac{1}{4}$

$$gdp(t) = A(t) \cdot \left[k(t)^{\alpha} \cdot h(t)^{1-\alpha}\right] \tag{3}$$

in which $0 < \alpha < 1$ and $1 - \alpha$ reflect the production elesticity of physical capital and HC.

Eq.(3) describes the relationship between input factors and output quantatively. On the other side, along the expansion path of production, the relative density change between the two capital stocks, tends to change capital coefficient, and to affect output. We assume Model III to describe that, by dividing Eq.(3) with $k(t)$ and $h(t)$, get Eq.(4a)-(4b)

$$\begin{cases} \dfrac{k(t)}{gdp(t)} = \dfrac{1}{A(t)} \cdot \left[\dfrac{k(t)}{h(t)}\right]^{1-\alpha}, & \text{(4a)} \\ \dfrac{gdp(t)}{h(t)} = A(t) \cdot \left[\dfrac{k(t)}{h(t)}\right]^{\alpha}. & \text{(4b)} \end{cases}$$

[6] Arrow et al. (1961) name it as the distribution parameter.
[7] In the extreme case, $\sigma = 0$, $\rho = -\infty$, it is Leontief production function$y(t) = A \cdot \min[\gamma \cdot k(t), (1-\gamma) \cdot h(t)]$, which means totoal complementarity between input factors.
[8] In the extreme case, $\sigma = \infty$, $\rho = 1$, it is linearity production function $y(t) = A \cdot [\gamma \cdot k(t) + (1-\gamma) \cdot h(t)]$, which means totally substitution between intput factors.

in which $k(t)/gdp(t)$ and $h(t)/gdp(t)$ are physical- and human- capital coefficients, $k(t)/h(t)$ is the physical-human capital density.

4 The Proxies

4.1 Physical Capital

According to the perpetual inventory method, physical capital stock $K(t)$ satisfies

$$K(t) = K(t-1) + I(t) - D(t) \tag{5}$$

in which $I(t)$ are $D(t)$ physical capital's investment and depreciation at time t. $D(t)$ satisfies

$$D(t) = \delta(t) \cdot K(t) \tag{6}$$

in which $\delta(t)$ is depreciation rate. Once depreciation rate is acquainted, we may measure the initial capital stock K_0 as well as $K(t)$.

4.2 Physical Capital in Efficiency Units

In order to measure physical capital stock in efficiency units, we need to set three proxies for capital-augmenting technical progress. The first one, price index $A^P(t)$ is derived from previous studies (Feng et al., 2012, p565). We make two adjustments though. First, divide current period index by last time period index, for both gross price index p^Y and fixed capital price p^I, to eliminate the potential biases casued by different measurement units. Second, assume technical progress does not draw back under normal circumstances (with extreme situations ruled out, such as large scale wars, natural diseases, etc.) , i.e. $A^P(t) \geq A^P(t-1) \quad \forall t \geq 1$.

$$A^P(t) = \max\left\{\left[\frac{p^Y(t)/p^Y(t-1)}{p^I(t)/p^I(t-1)}\right], 1\right\} \cdot A^P(t-1) \tag{7}$$

The second one, industrial structure index $A^S(t)$, treats the transformation/upgrade of industrial structure as proxy of technical progress:

$$A^S(t) = \max\left\{\left[\frac{\sum V_i(t)}{V_2(t) + V_3(t)}\right], 1\right\} \cdot A^S(t-1) \tag{8}$$

in which $V_i(t), i = (1, 2, 3)$ are added values of primary, secondary and tertiary industries, whose sum corresponds to income approach GDP, the $GDP^{inc}(t)$[9].

The third one, the physical capital coefficient index, considers increase of capital coefficient $\nu(t) = K(t)/GDP^{inc}(t)$ (industrial transformation from labor-intensity to capital-intensity) as a proxy of technical progress:

$$A^\nu(t) = \max\left\{\left[\frac{\nu(t)}{\nu(t-1)}\right], 1\right\} \cdot A^\nu(t-1) \tag{9}$$

Qualitatively adjust $K(t)$ by $A^P(t)$, $A^S(t)$ and $A^\nu(t)$ respectively, we get efficient physical capital stock, set as $K^P(t)$, $K^S(t)$ and $K^\nu(t)$:

$$K^P(t) = K^P(t-1) + A^P(t) \cdot [K(t) - K(t-1)], \tag{10}$$

$$K^S(t) = K^S(t-1) + A^S(t) \cdot [K(t) - K(t-1)], \tag{11}$$

$$K^\nu(t) = K^\nu(t-1) + A^\nu(t) \cdot [K(t) - K(t-1)]. \tag{12}$$

9 It is worth noting that in China's national accounting system, the value of $\sum V_i(t)$ acquainted based on industrial level added values, is slightly different from $GDP^{inc}(t)$, see Table 1.

4.3 Human Capital

Based on (Feng et al., 2012, p567), we take into consideration the HC accumulation effect of LBE, then proxy HC stock by the employment average schooling years $\mu(t)$ and dispersion $\sigma^2(t)$ (in this article, $\mu(t)$ is chosen):

$$\mu(t) = \sum_{i=0}^{6} m^{a_i} \cdot p^{a_i}(t) \tag{13}$$

$$\sigma^2(t) = \sum_{i=0}^{6} [m^{a_i} - \mu(t)]^2 \cdot p^{a_i}(t) \tag{14}$$

in which a_i represents educational levels, $i = (0, 1 \ldots 6)$ respectively refers to uneducated, preliminary school, junior high school, senior high school (including junior vocational school), junior college (including senior vocational school), college and postgraduate. $m^{a_i} = (0, 6, 9, 12, 15, 16, 19)$ are (average) schooling years needed to attain a_i education level's degree, $p^{a_i}(t)$ are percentage proportions of employees with a_i level education background, among all the employment.

4.4 Total Factor Productivity

Suppose that the relative increase or decrease of government consumption $Gov(t)$ compared to $GDP(t)$ (see Table 1) might affect TFP. By utilization of Solow residuals for calculation TFP, we extract the residual part of change of $Gov(t)$ that cannot be explained by change of $GDP(t)$, and set as the proxy of TFP change.

5 Data Descriptions

5.1 Physical Capital Stock

In order to measure physical capital stock, we need to calculate depreciation rate, and then accordingly set the depreciating years of fixed capital investment, as well as the initial capital stock.

5.1.1 Approximating Depreciation Rate

From the perspective of accounting, depreciation is not supposed to fluctuate much away from physical capital stock along time. Thus we approximately set $\delta(t)$ in Eq.(6) as a constant δ. By taking Eq.(6) into Eq.(5), δ value can be approximated:

$$I(t) - D(t-1) = (1+\delta) \cdot [I(t) - D(t)] \tag{15}$$

However, the practical use of the method mentioned above is limited by data issues. First, $D(t)$ is listed inside income approach GDP program, $GDP^{inc}(t)$, in the national accounting system, but in China there is only the summed $GDP^{inc}(t)$, with no specific data of $D(t)$; besides, under the program of gross regional product (by province, income approach) there is regional depreciation date, whose summation value $\sum D_i(t)$ might be of our interest, see Table 1, while when we approximate $D(t)$ based on $\sum D_i(t)$, we have to also consider the differences between $\sum GRP_i(t)$ and $GDP^{inc}(t)$, for example, duplicate calculations might happen when provincial data are summed as national data. Second, $D(t)$ is calculated by income approach, while $I(t)$ is calculated by expenditure approach, there might be statistical caliberation difference between the two.

Table 1: GDP, GRP and price indices

	GDP(exp. appro.)[a]			GRP(inc. appro.)[a]				
	GDP^{exp}	I	Gov	$\sum GRP_i$	$\sum D_i$	$\sum T_{Ind,i}$	$\sum Y_{L,i}$	$\sum Y_{K,i}$
1996	7528.77	2441.26	1011.46	6888.26	876.50	886.91	3532.10	1592.75
1997	8165.85	2596.50	1121.91	7633.92	995.81	1042.03	3895.45	1700.64
1998	8730.76	2882.52	1246.97	8329.89	1103.06	1187.45	4233.68	1805.71
1999	9312.79	3119.83	1401.80	9015.73	1211.03	1342.50	4505.11	1957.08
2000	9890.90	3389.92	1568.68	9866.37	1387.73	1510.30	4805.54	2162.80
2001	10700.82	3705.51	1717.38	10701.58	1483.39	1665.32	5138.15	2414.72
2002	11753.77	4256.81	1830.24	11763.29	1623.77	1833.61	5617.28	2688.63
2003	12991.98	5086.98	1905.40	13242.72	1842.71	2088.60	6112.24	3199.17
2004	14315.36	5791.52	1986.38	14905.07	2101.10	2096.17	6193.70	4514.10
2005	16040.45	6353.15	2259.31	16927.57	2526.61	2389.44	7008.30	5003.22
2006	18361.58	7251.39	2516.92	19049.23	2773.60	2698.16	7735.24	5842.23
2007	20420.24	7961.97	2749.80	21111.54	2988.66	3127.20	8389.65	6606.03
2008	22458.53	9103.86	2967.62	24075.92	3213.16	3659.81	10699.52	6503.43
2009	24941.10	11204.26	3267.33	26123.08	3530.45	3971.06	12178.23	6443.33
2010	27012.35	12313.00	3578.01	29305.13	3770.55	4466.70	13191.39	7876.49
2011	29398.82	13416.29	3928.49	32435.76	4189.10	5063.37	14575.05	8608.24

	GDP(inc. appro.)[a]					price indices[b]		employ.[c]
	GDP^{inc}	$\sum V_i$	V_1	V_2	V_3	P^Y	P^I	L
1996	7225.54	7117.66	1401.54	3383.50	2332.62	0.99	0.98	689.50
1997	7897.30	7897.31	1444.19	3754.30	2698.82	1.00	1.00	698.19
1998	8515.92	8440.23	1481.76	3900.42	3058.05	0.99	1.00	706.37
1999	9164.82	8967.72	1477.01	4103.36	3387.35	0.98	0.99	713.94
2000	9937.53	9921.47	1494.47	4555.59	3871.41	1.00	1.01	720.85
2001	10762.38	10965.53	1578.13	4951.23	4436.17	1.02	1.01	727.97
2002	11739.83	12033.28	1653.70	5389.68	4989.90	1.02	1.01	732.80
2003	12916.79	13582.29	1738.18	6243.63	5600.48	1.05	1.03	737.36
2004	14219.45	15987.84	2141.27	7390.43	6456.14	1.12	1.09	742.64
2005	15827.68	18493.74	2242.00	8759.81	7491.93	1.17	1.11	746.47
2006	17834.08	21631.45	2404.00	10371.95	8855.50	1.21	1.13	749.78
2007	20359.81	26581.02	2862.70	12583.14	11135.18	1.31	1.17	753.21
2008	22321.41	31404.54	3370.20	14900.34	13134.00	1.41	1.27	755.64
2009	24378.15	34090.28	3522.60	15763.87	14803.81	1.40	1.24	758.28
2010	26924.93	40151.28	4053.36	18738.32	17359.60	1.49	1.29	761.05
2011	29428.99	47310.40	4748.62	22041.28	20520.50	1.61	1.37	764.20

[a] sources: *Data of Gross Domestic Product of China, 1996-2002, China Statistical Yearbook. units: 100 million CNY, adjusted by 1997 base year price.*
[b] sources: *China Statistical Yearbook, set 1997=1.*
[c] sources: *China Statistical Yearbook, China Labour Statistical Yearbook. units: 1 million persons.*

Suppose Eq.(16) holds, then we would be able to calculate depreciation relative to $GDP^{inc}(t)$, defined as $D_1(t)$, see Table 5 Column 1.

$$\frac{D_1(t)}{GDP^{inc}(t)} = \frac{\sum D_i(t)}{\sum GRP_i(t)} \tag{16}$$

Generally there is no reason to expect the ratio of depreciation relative to GDP flucuate too much along time. However, if we explain $\ln GDP^{inc}(t)$ by $\ln D_1(t)$ using single variable OLS regression[10], the results in Table 2 Column 1 show that residuals are not random normal distribution. There seems to exist systematic disturbance, as shown in

[10] In this article we run all the regressions with **R** (R Core Team, 2013).

Figure 1 as solid line. In order to prove that, we set $d(t) = \sum D_i(t)/\sum GRP_i(t)$ as the percentage proportion of summed regional depreciation relative to regional GRP, Table 3 confirms the existence of disturbance. We think that is due to the change of income distribution accounting mechanism: As to the total income, if the labor and capital share $\sum Y_{L,i}(t), \sum Y_{K,i}(t)$ were increased (or decreased), meanwhile the share of indirect tax $\sum T_{Ind,i}(t)$ remained unchanged, then $\sum D_i(t)$ would have to be decreased (or increased) accordingly. Set a dummy variable $Dm(I,t)$, to represent the mechanism change, valued at 1.0, 0.5, 0, -0.5 and -1.0, in accordance with $d(t)$'s value from low to high, see Table 3. The higher the share of capital and labor's income, the lower $d(t)$, and the higher $Dm(I,t)$; vice versa. With $Dm(I,t)$ set as the second independent variable, bivariate regression Eq.(17) results in Table 2 Column 2, and Eq.(18).

$$\ln D_1(t) = c + \beta_1 \cdot \ln GDP^{inc}(t) + \beta_2 \cdot Dm(I,t) + \varepsilon \tag{17}$$

Again, extract the bivariate regressionâs residuals, depicted as dashed line in Figure 1, we can see the residuals are close to normally distributed. Eq.(17) is thus rewritten as

$$\ln D_1(t) = \underset{(0.0529^{***})}{-2.1091} + \underset{(0.0055^{***})}{1.0150} \cdot \ln GDP^{inc}(t) - \underset{(0.0053^{***})}{0.0932} \cdot Dm(I,t) + \varepsilon \tag{18}$$

Based on Eq.(18), after eliminating the systematic disturbance $Dm(I,t)$ out of $D_1(t)$, we are able to calculate the "real" depreciation $D_2(t)$:

$$D_2(t) = 0.1213 \cdot GDP^{inc}(t)^{1.0150} \tag{19}$$

We then construct econometrical equation based on Eq.(15):

$$I(t) - D(t-1) = c + \beta_1 \cdot [I(t) - D(t)] + \beta_2 \cdot Dm(D,t) + \varepsilon \tag{20}$$

Table 2: Determinants of Depreciation

	Dependent variable:	
	$\ln D_1$	
	(1)	(2)
$\ln GDP^{inc}$	1.007^{***}	1.015^{***}
	(0.027)	(0.006)
$Dm(I)$		-0.093^{***}
		(0.005)
Constant	-2.058^{***}	-2.109^{***}
	(0.256)	(0.053)
Observations	16	16
R^2	0.990	1.000
Adjusted R^2	0.990	1.000
Residual Std. Error	0.047	0.010
F Statistic	$1{,}419.947^{***}$	$16{,}798.840^{***}$
Note:	*p<0.1; **p<0.05; ***p<0.01	

Figure 1: Determinants of Depreciation. Solid line and dashed lines refer to residuals of Table 2 Column 1 and 2, respectively.

in which the coefficient β_1 corresponds to $1+\delta$. Depreciation $D_1(t)$ or $D_2(t)$ are calculated based on income approach regional accounting data; gross investment $I(t)$ is taken from expenditure approach gross fixed capital formation in China's Statistical Yearbook (henceforth CSY)[11]. The reason we enroll another dummy variable $Dm(D,t)$ is that after the second National Economic Census in 2008[12], Chinaâs National Bureau of Statistics systematically adjusted the income approach GDP as well as its components, as shown in Table 1. Before 2008 $Dm(D,t)$ is valued as 0, after 2008 it's valued as 1, see Table 3.

Table 3: Dummy variables for measuring physical capital stock

	1996	1997	1998	1999	2000	2001	2002	2003
$d(\%)$	12.72	13.04	13.24	13.43	14.07	13.86	13.80	13.91
$Dm(I)$	1.00	0.50	0.50	0.50	0.00	0.00	0.00	0.00
$Dm(D)$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2004	2005	2006	2007	2008	2009	2010	2011
$d(\%)$	14.10	14.93	14.56	14.16	13.35	13.51	12.87	12.92
$Dm(I)$	0.00	-0.50	-0.50	0.00	0.50	0.50	1.00	1.00
$Dm(D)$	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00

sources: calculated by authors.

Table 4: Estimation of depreciation rate

	Dependent variable:	
	$I(t)-D_1(t-1)$	$I(t)-D_2(t-1)$
	(1)	(2)
$I(t)-D_1(t)$	1.057^{***}	
	(0.013)	
$I(t)-D_2(t)$		1.053^{***}
		(0.009)
$Dm(D,t)$	-240.132^{***}	-100.688^{*}
	(74.120)	(50.670)
Constant	9.088	10.075
	(42.064)	(29.860)
Observations	15	15
R^2	1.000	1.000
Adjusted R^2	1.000	1.000
Residual Std. Error	59.865	42.828
F Statistic	$14{,}469.960^{***}$	$26{,}933.690^{***}$
Note:		*p<0.1; **p<0.05; ***p<0.01

Regression results of Eq.(20) are in Table 4. It is worth noting that the incercepts are non zero with slighly large variance, due to the reason that there exists statistical caliber difference between GRP and GDP.

[11]China's national accounting is mainly based on expenditure approach(Wang, 2010).

[12]Since 1950s China government has conducted two national-level economic surveys, the first one in 2004 (http://www.stats.gov.cn/ztjc/zdtjgz/zgjjpc/) and the second one in 2008 (http://www.stats.gov.cn/ztjc/zdtjgz/zgjjpc/decqgjjpc/).

With depreciation data D_1 and D_2 utilized, as in Table 4 Column (1)-(2), we get depreciation rate $\delta = \beta_1 - 1$ as 5.67% and 5.26%, corresponding to physical capital investment's depreciating years $n = 1/\delta$ as 19.0 and 17.6 respectively. By simple arithmetic mean, we set $\delta \approx 5.47\%$, $n \approx 18$ years.

5.1.2 Measuring Physical Capital Stock

In this article, the time series sample data is chosen between 1997 to 2011. Thus the initial year physical capital stock $K_0 = K(1996)$. As $n = 18$, $K(1996)$ is accumulated due to past n=18 years investment:

$$K(1996) = \frac{1}{n}\sum_{i=1980}^{1996} I(i)\cdot(i-1979) = 12509.28(100 \text{ mil. CNY, 1997 base year price}) \quad (21)$$

Take $K(1996)$ into Eq.(5), along with $D_1(t)$ and $D_2(t)$, we calculate physical capital stock $K_1(t)$ and $K_2(t)$, capital coefficient $\nu_1(t)$ and $\nu_2(t)$, as shown in Table5.

5.2 Physical Capital in Efficiency Units

The three indices of technical progress are calculated based on Eq.(7)-(9), we set the initial values of period 1997 as 1. 1) $p^I(t)$ data comes from CSY, $p^Y(t)$ data is calculated based on GDP(current year price) and GDP(base year price) of CSY, see Table 1; 2) $V_{1,2,3}(t)$ data come from CSY, see Table 1; 3) Set $\nu_2(t)$ as physical capital coefficient[13], see Table 5.

Based on Eq.(10)-(12), we do quality adjustments to physical capital stock $K(t)$, the efficiency units are shown in Table 5.

[13] We replace $\nu_2(t)$ by $\nu_1(t)$ and redo the regressions, and find the results do not change substantially. For the sake of simplification, in the following we only list results corresponding to $\nu_2(t)$.

Table 5: Gross depreciation, physical capital stock and the efficiency units

	(D_1-based calculations)			(D_2-based calculations)								
	D_1	K_1	ν_1	D_2	K_2	ν_2	A^P	K^P	A^S	K^S	A^ν	K^ν
1996	919.42	12509.28	1.73	1044.37	12509.28	1.73						
1997	1030.17	14075.61	1.78	1134.13	13971.65	1.77	1.00	13971.65	1.00	13971.65	1.00	13971.65
1998	1127.69	15830.44	1.86	1213.80	15640.37	1.84	1.00	15640.37	1.01	15655.30	1.04	15703.98
1999	1231.06	17719.21	1.93	1295.97	17464.23	1.91	1.00	17464.23	1.02	17519.71	1.08	17668.45
2000	1397.74	19711.39	1.98	1377.66	19476.49	1.96	1.01	19495.68	1.04	19611.37	1.11	19897.64
2001	1491.82	21925.08	2.04	1492.23	21689.76	2.02	1.03	21766.78	1.05	21930.15	1.14	22418.88
2002	1620.53	24561.36	2.09	1641.37	24305.20	2.07	1.03	24461.26	1.06	24691.04	1.17	25479.52
2003	1797.36	27850.98	2.16	1817.01	27575.17	2.13	1.03	27842.78	1.07	28180.70	1.21	29425.35
2004	2004.45	31638.05	2.22	2005.01	31361.68	2.21	1.05	31806.48	1.07	32221.60	1.25	34145.83
2005	2362.44	35628.76	2.25	2250.46	35464.37	2.24	1.07	36200.26	1.08	36664.13	1.27	39341.89
2006	2596.68	40283.47	2.26	2581.33	40134.42	2.25	1.10	41315.04	1.10	41779.12	1.27	45282.35
2007	2882.24	45363.20	2.23	2875.32	45221.07	2.22	1.13	47085.83	1.10	47371.93	1.27	51752.71
2008	2979.00	51488.06	2.31	3166.84	51158.09	2.29	1.13	53821.35	1.10	53902.52	1.31	59545.47
2009	3294.63	59397.69	2.44	3522.44	58839.91	2.41	1.16	62694.96	1.10	62390.08	1.38	70164.03
2010	3464.30	68246.39	2.53	3819.52	67333.39	2.50	1.19	72795.86	1.11	71799.32	1.43	82328.45
2011	3800.77	77861.91	2.65	4162.25	76587.43	2.60	1.20	83925.76	1.11	82057.76	1.49	96120.99

[a] sources: calculated by authors. Units: 100 million CNY. Adjusted by base year 1997 price.

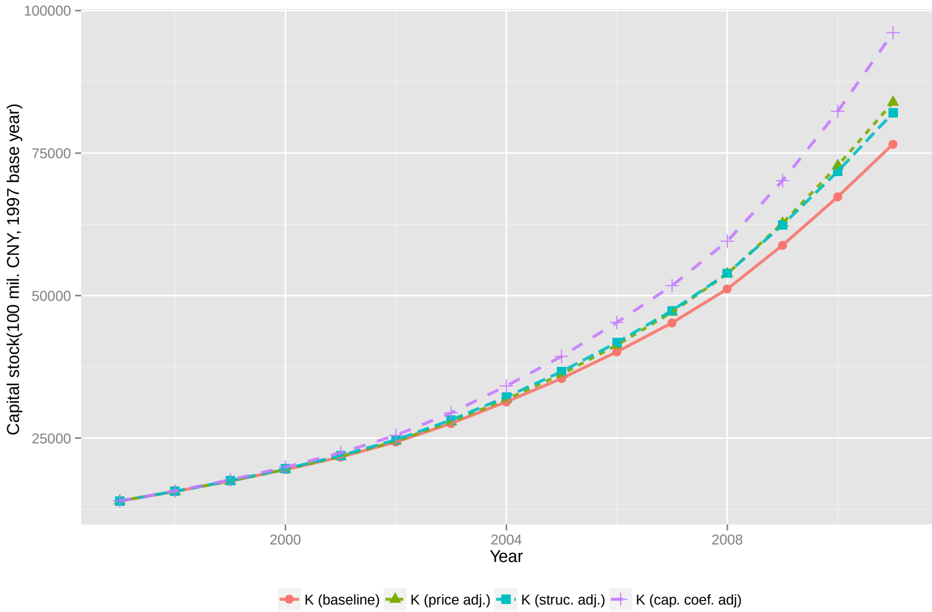
By comparing among expansion paths of physical capital stock and three efficiency units, it can be seen from Figure 2 that: 1) Augmented by technical progress indices, the efficiency units are higher than the original, un-adjusted physical capital stock; 2) Though proxied by different indices, the three efficiency units show similar expansion patterns. 3) Among the three efficiency units, the capital-coefficient-augmenting one is higher, that might be due to the mutual relationship between technical progress and capital accumulation, such as learning by investing.

5.3 Human Capital Stock

The data of total employment $L(t)$, dispersion of education attainment $p^{a_i}(t)$, are available in the China Labour Statistical Yearbook, henceforth CLSY. Based on $p^{a_i}(t)$, we calculate $\mu(t)$, shown in Table 6. From the scatterplot of $p^{a_i}(t)$ in Figure 3 we can see, around 2004 there is a obvious broken trend. The reason is after the first National Economic Census in 2004, China's National Bureau of Statistics systematically adjusted the relevant calibers. Thus it's necessary to enroll a dummy variable $Dm(HC,t)$: set its value before 2003 as 1, and after as 0, see Table 6. Suppose $p^{a_i}(t)$ could be approximated by the following time series:

$$p^{a_i}(t) = c + \beta_1 \cdot (t - 1996) + \beta_2 \cdot Dm(HC,t) + \varepsilon \tag{22}$$

Figure 2: Physical capital stock and the three efficiency units(1997-2011)



Results are shown in Table 7. Set $\hat{p}^{a_i}(t) = p^{a_i}(t) - \beta_2 \cdot Dm(HC, t)$ as adjusted dispersion, we re-calculate the average schooling years $\hat{\mu}(t)$, shown in Table 6.

5.4 Government Consumption

In order to observe whether government consumption $Gov(t)$ is expansionary relative to $GDP^{exp}(t)$[14], we establish a econometrical equation

$$Gov(t) = c + \beta \cdot GDP^{exp}(t) + \varepsilon \tag{23}$$

Extract the residuals from single variable regression results shown in Table 8, set as $G(t)$ [15], we can see $G(t)$ is neither normally nor randomly distributed (Figure 4), implying

[14] $Gov(t)$ is part of expenditure approach GDP program, thus we analyze the relationship between $Gov(t)$ and $GDP^{exp}(t)$.

[15] In order to simplify the following regressions, we taken $G(t)$ into logarithm form, set the base year value G(1996)=1, the following years' values indexed as well.

Figure 3: Dispersion of education attainment levels, of total employment (1997-2011)

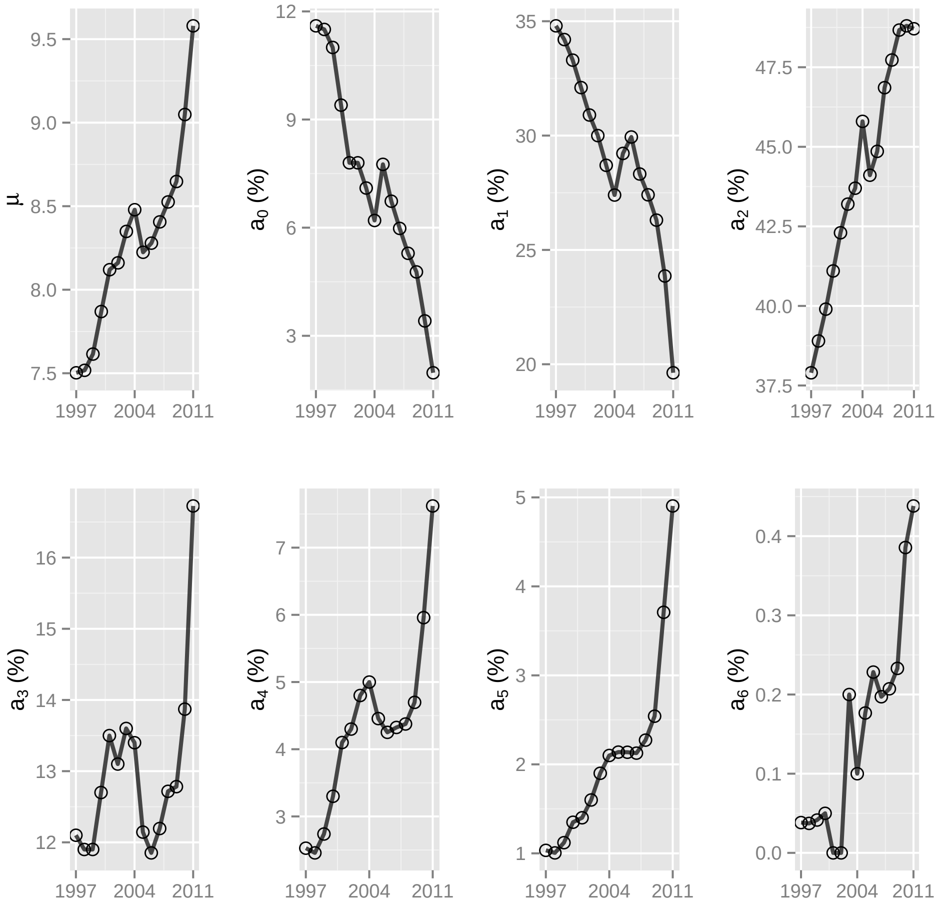


Table 6: Average schooling years and dispersion of education attainment levels, of total employment

	Before adjustment								
	L^{a}	μ	p^{a0}	p^{a1}	p^{a2}	p^{a3}	p^{a4}	p^{a5}	p^{a6}
1997	698.19	7.50	11.60	34.80	37.90	12.10	2.53	1.03	0.04
1998	706.37	7.52	11.50	34.20	38.90	11.90	2.46	1.01	0.04
1999	713.94	7.61	11.00	33.30	39.90	11.90	2.74	1.12	0.04
2000[b]	720.85	7.87	9.40	32.10	41.10	12.70	3.30	1.35	0.05
2001	727.97	8.12	7.80	30.90	42.30	13.50	4.10	1.40	0.00
2002	732.80	8.16	7.80	30.00	43.20	13.10	4.30	1.60	0.00
2003	737.36	8.35	7.10	28.70	43.70	13.60	4.80	1.90	0.20
2004	742.64	8.48	6.20	27.40	45.80	13.40	5.00	2.10	0.10
2005	746.47	8.22	7.76	29.22	44.11	12.14	4.46	2.14	0.18
2006	749.78	8.28	6.73	29.94	44.86	11.85	4.25	2.14	0.23
2007	753.21	8.41	5.98	28.32	46.86	12.19	4.32	2.13	0.20
2008	755.64	8.53	5.29	27.41	47.73	12.72	4.38	2.27	0.21
2009	758.28	8.65	4.77	26.30	48.67	12.78	4.70	2.54	0.23
2010	761.05	9.05	3.41	23.86	48.80	13.87	5.96	3.71	0.39
2011	764.20	9.58	1.97	19.63	48.71	16.73	7.62	4.90	0.44
	After adjustment								
	$Dm(HC)$	$\hat{\mu}$	$\hat{p}^{a0}$	$\hat{p}^{a1}$	$\hat{p}^{a2}$	$\hat{p}^{a3}$	$\hat{p}^{a4}$	$\hat{p}^{a5}$	$\hat{p}^{a6}$
1997	1.00	6.95	14.18	39.20	36.04	8.15	1.70	0.70	0.03
1998	1.00	6.96	14.08	38.60	37.04	7.93	1.64	0.67	0.02
1999	1.00	7.05	13.58	37.70	38.04	8.04	1.85	0.76	0.03
2000	1.00	7.30	11.98	36.50	39.24	8.95	2.33	0.95	0.04
2001	1.00	7.55	10.38	35.30	40.44	9.85	2.99	1.02	0.00
2002	1.00	7.59	10.38	34.40	41.34	9.56	3.14	1.17	0.00
2003	1.00	7.77	9.68	33.10	41.84	10.20	3.60	1.42	0.15
2004	1.00	7.90	8.78	31.80	43.94	10.06	3.75	1.58	0.08
2005	0.00	8.22	7.76	29.22	44.11	12.14	4.46	2.14	0.18
2006	0.00	8.28	6.73	29.94	44.86	11.85	4.25	2.14	0.23
2007	0.00	8.41	5.98	28.32	46.86	12.19	4.32	2.13	0.20
2008	0.00	8.53	5.29	27.41	47.73	12.72	4.38	2.27	0.21
2009	0.00	8.65	4.77	26.30	48.67	12.78	4.70	2.54	0.23
2010	0.00	9.05	3.41	23.86	48.80	13.87	5.96	3.71	0.39
2011	0.00	9.58	1.97	19.63	48.71	16.73	7.62	4.90	0.44

[a] L, μ_1, p^{ai} are measured in units of million persons, year, and %, sourced from CLSY.
[b] p^{ai} data in 2000 is unavailable. The authors approximate by linear interpolation method.

government consumption does follow some behavioral pattern different from GDP, and thus should not be ignored.

6 Regressions and Analyses

6.1 Model I

The regression equation of Eq.(2) is written as

$$\ln gdp(t) = c + \beta_1 \cdot \ln \kappa(t) + \beta_2 \cdot \ln G(t) + \varepsilon \tag{24}$$

Table 7: Smoothing of time series data, average schooling years and dispersion

	Dependent variable:			
	μ	p^{a0}	p^{a1}	p^{a2}
	(1)	(2)	(3)	(4)
$(t-1996)$	0.176***	−0.867***	−1.259***	0.981***
	(0.018)	(0.050)	(0.136)	(0.070)
$Dm(HC)$	0.595***	−2.585***	−4.403***	1.857**
	(0.157)	(0.434)	(1.176)	(0.610)
Constant	6.567***	15.537***	41.495***	35.327***
	(0.224)	(0.621)	(1.685)	(0.874)
Observations	15	15	15	15
R^2	0.937	0.981	0.930	0.977
Adjusted R^2	0.927	0.978	0.918	0.974
Residual Std. Error	0.151	0.419	1.136	0.589
F Statistic	89.471***	313.425***	79.734***	259.810***

	Dependent variable:			
	p^{a3}	p^{a4}	p^{a5}	p^{a6}
	(5)	(6)	(7)	(8)
$(t-1996)$	0.420***	0.436***	0.265***	0.024**
	(0.101)	(0.065)	(0.061)	(0.008)
$Dm(HC)$	2.738***	1.826***	0.596	−0.029
	(0.876)	(0.567)	(0.529)	(0.069)
Constant	8.148***	−0.136	−0.351	−0.020
	(1.256)	(0.813)	(0.758)	(0.098)
Observations	15	15	15	15
R^2	0.601	0.854	0.795	0.793
Adjusted R^2	0.534	0.830	0.761	0.759
Residual Std. Error	0.847	0.548	0.511	0.066
F Statistic	9.033***	35.170***	23.308***	23.027***

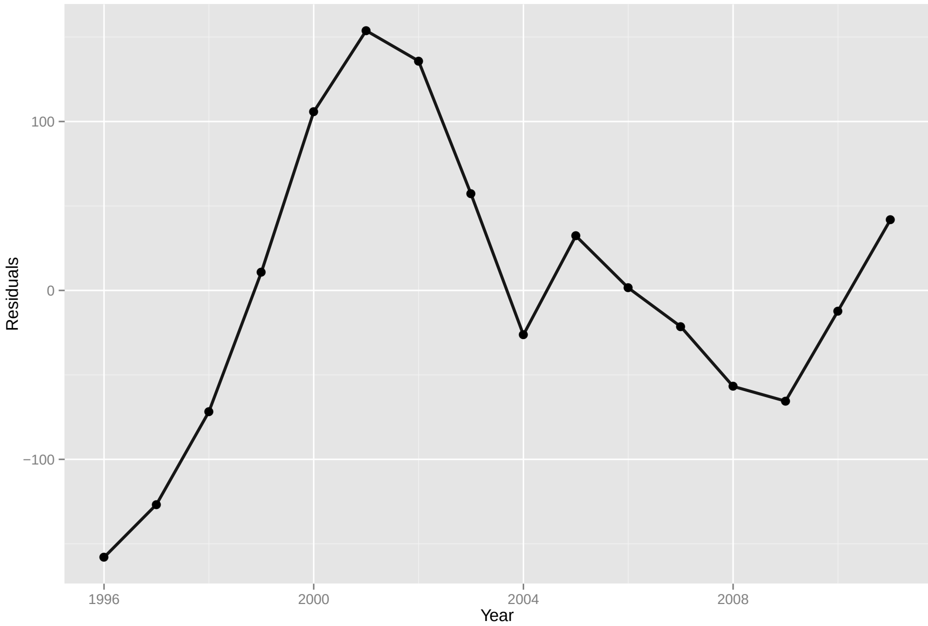
Note: *p<0.1; **p<0.05; ***p<0.01

Table 8: Government consumption and GDP, expenditure approach

	Dependent variable:
	Gov
GDP^{exp}	0.124***
	(0.003)
Constant	234.066***
	(56.004)
Observations	16
R^2	0.990
Adjusted R^2	0.990
Residual Std. Error	90.419
F Statistic	1,458.780***

Note: *p<0.1; **p<0.05; ***p<0.01

Figure 4: Residuals of regression explaining GDP by government consumption (1996-2011)



in which the independent variable $\kappa(t)$ refers to the combination of per capita physical capital stock $k(t)$ [16] and per capita HC stock $h(t)$. $\kappa(t)$'s production effect depends not only on input factors $k(t)$ and $h(t)$, but also on substitution parameter ρ and biased technical progress parameter λ:

$$\kappa(t) = k(t)^{\rho} + \lambda \cdot h(t)^{\rho} \tag{25}$$

Besides, government consumption $G(t)$ might also alter the change of TFP.

As shown in Eq.(25), it is of the nature of CES production function that estimations on λ and ρ need to be jointly considered(Klump et al., 2012). Via numerical simulation methods e.g. Ben-Gad (2012); Leè´¸n-Ledesma et al. (2010), we first simulate the value of λ, representing different biasedness levels of technical progress, that is 0.2 (high level expansion on physical capital), 0.7 (medium level expansion on physical capital), 1.0 (neutral),

[16]During the empirics of Model I, we replace $k(t)$ by $k^P(t)$, $k^S(t)$ and $k^{\nu}(t)$ respectively, and re-run the regressions. Results do not differ substantially. Thus in section 6.1, we only take $k(t)$ as instance for detailed discussions.

1.3 (medium level expansion on HC) and 1.8 (high level expansion on HC) respectively. Second, we assume the value of ρ, representing different substitution levels between physical capital and HC, with the step length 0.001, inside the interval $[-40, 0.999]$ (with 0 excluded). Third, according to simulated combinations of (λ, ρ), we calculate $\kappa(t)$ by Eq.(25), and run regressions based on Eq.(24). Results are shown in Figure 5.

In Figure 5, the five rows from top to bottom refer to five scenario settings of biased technical progress, the two columns from left to right refer to goodness of fit R^2, and the t-value of β_1. The higher the R^2 and t-value of β_1, the better Eq.(24) is in explaining China's actual input-output relationship. In case that different values of λ do not alter Model I's regression results substantially, hereby we mainly discuss the other parameter ρâs simulations, separated into two scenarios $\rho < 0$ and $\rho > 0$.

1. Inside the interval $-\infty < \rho < 0$ $(0 < \sigma < 1)$ where physical capital and HC show complementarity, as ρ gradually approaches to 0, both R^2 and $|t|$ value of β_1 monotonically increase, until $\rho \to 0(\sigma \to 1)$, the results are shown in Table 9 Column (1-5). It can be seen that when substitution parameter $\sigma \approx 1$, Model I explains the best, and the corresponding production function is Cobb-Douglas type.
2. Inside the interval $0 < \rho < 1$ $(1 < \sigma < \infty)$ where physical capital and HC show substitution, as ρ approaches to 1, R^2 and $|t|$ value of β_1 keep monotonically increasing, until $\rho \to 1$ $(\sigma \to \infty)$, the results are shown in Table 9 Column (6-10), and marked as $\bigtriangledown$ point in Figure 5. In this circumstance, CES production function turns to be a special case, the linearity one, which means input factors perfectly substitute each other. However, in real economy the linearity production function doesnât seem possible to come true. It might be reviewed from the perspective of statistics: along with the expansion path, to some extent the accumulation of physical capital accompanies the accumulation of HC, leading to multicolinearity problems during regressions. In extreme case, when the two capitals accumulate at exactly the same

rate, there will be complete multicolinearity, which means statistically, one capital can fully substitute the other. However, such statistical result undoubtedly fails to explain reality: in the real world, physical capital cannot be totally replaced by HC, and vice versa.

To sum up: 1) If we consider the two capitals to be complement, numerical simulations show that Cobb-Douglas, a special case of CES production function best fits in explaining input output. 2) If we consider the two to be substitute, then Linearity, the other special case of CES production function best fits, while the conclusion 2) is inclined to be a false statement, from the perspective of reality.

Thus we find either Cobb-Douglas or general type CES may well represent China's production, results based on the two function types do not substantially differ. The latter one enjoys higher goodness of fit, while the former one is easier to manipulate. By employing the Occam's Razor, in the following sections we choose Cobb-Douglas type to study China's NPF.

Besides, regression results of Model I also show significantly negative product effect of government consumption $G(t)$. That will be discussed further in the following section.

6.2 Model II

Based on Eq.(3), Model II can be expressed econometrically as follows

$$\ln gdp(t) = c + \beta_1 \cdot \ln k(t) + \beta_2 \cdot \ln h(t) + \beta_3 \cdot \ln G(t) + \varepsilon \tag{26}$$

in which $k(t)$ is calculated by $k_2(t)$ as well as $k^p(t)$, $k^S(t)$ and $k^\nu(t)$ respectively, shown in Table 5; $h(t)$ is proxied by $\hat{\mu}(t)$ã

Table 9: Model I regressions

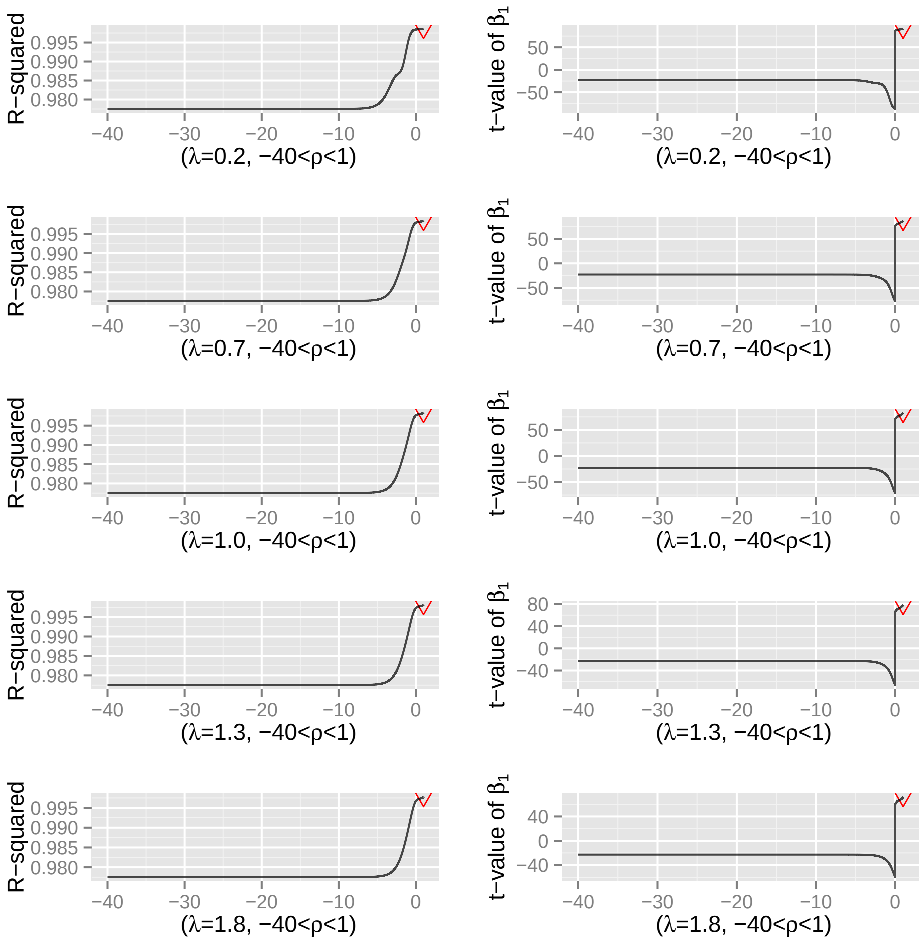
	ln gdp				
	Simulated regressions of Cobb-Douglas type				
	(1)	(2)	(3)	(4)	(5)
	($\lambda = 0.2$, $\rho = -0.001$)	($\lambda = 0.7$, $\rho = -0.001$)	($\lambda = 1.0$, $\rho = -0.001$)	($\lambda = 1.3$, $\rho = -0.001$)	($\lambda = 1.8$, $\rho = -0.001$)
$\ln \kappa$	-916.399^{***}	$-1,191.922^{***}$	$-1,336.373^{***}$	$-1,467.738^{***}$	$-1,662.045^{***}$
	(10.542)	(15.560)	(18.813)	(22.169)	(27.844)
$\ln G$	-0.027^{***}	-0.030^{***}	-0.031^{***}	-0.033^{**}	-0.035^{**}
	(0.008)	(0.009)	(0.010)	(0.011)	(0.012)
Constant	167.021^{***}	631.959^{***}	925.558^{***}	$1,221.532^{***}$	$1,709.997^{***}$
	(1.891)	(8.215)	(12.992)	(18.409)	(28.602)
Observations	15	15	15	15	15
R^2	0.998	0.998	0.998	0.997	0.997
Adjusted R^2	0.998	0.998	0.997	0.997	0.996
Residual Std. Error	0.017	0.020	0.021	0.023	0.025
F Statistic	$3,804.334^{***}$	$2,954.308^{***}$	$2,540.402^{***}$	$2,206.983^{***}$	$1,793.916^{***}$
	ln gdp				
	Simulated regressions of linearity type				
	(1)	(2)	(3)	(4)	(5)
	($\lambda = 0.2$, $\rho = 0.999$)	($\lambda = 0.7$, $\rho = 0.999$)	($\lambda = 1.0$, $\rho = 0.999$)	($\lambda = 1.3$, $\rho = 0.999$)	($\lambda = 1.8$, $\rho = 0.999$)
$\ln \kappa$	0.816^{***}	0.874^{***}	0.908^{***}	0.940^{***}	0.992^{***}
	(0.009)	(0.010)	(0.011)	(0.012)	(0.014)
$\ln G$	-0.024^{**}	-0.020^{**}	-0.018^{*}	-0.016^{*}	-0.014
	(0.008)	(0.008)	(0.009)	(0.009)	(0.010)
Constant	0.015	-0.303^{***}	-0.488^{***}	-0.668^{***}	-0.960^{***}
	(0.049)	(0.054)	(0.058)	(0.063)	(0.071)
Observations	15	15	15	15	15
R^2	0.999	0.998	0.998	0.998	0.998
Adjusted R^2	0.998	0.998	0.998	0.998	0.997
Residual Std. Error	0.017	0.018	0.018	0.019	0.021
F Statistic	$4,138.809^{***}$	$3,744.177^{***}$	$3,403.778^{***}$	$3,068.342^{***}$	$2,584.697^{***}$

Note: *p<0.1; **p<0.05; ***p<0.01

We first run single variable OLS to explain $gdp(t)$ by per capita physical capital (efficiency units) $k(t)$ and per capita HC $h(t)$, results in Table 10 Column (1-5) show positive effects on both independent variables. Obviously, they are all growth determinants of importance, during the process of China's NPF analysis.

Then we explain $gdp(t)$ by both $k(t)$ and $h(t)$, bivariate regression results are shown in Table 11. Compared with single variable regressions, the production elasticity of $k(t)$ remains positive, while that of $h(t)$ turns to be negative, see Column (1-4). Further, when government consumption $G(t)$ is also considered, multivariate regression results are in Column (5-8), showing that $h(t)$'s production elasticity is still negative; the coefficients of $\ln G(t)$ are significantly negative (except Column 6); and the intercepts are insignificant.

Figure 5: Simulated regressions of CES type



From the perspective of either theory or reality, it's unreasonable to argue that Per capita HC's stockâs production elasticity turns to be negative in multivariate analysis, with per capita physical capital and government consumption taken as extra independent variables. The statistical result does not seem to be reasonable in real economy. Perhaps it is due to the multicolinearity between two capitals (with correlation coefficient 96%). Inappropriate model design leads to unrealistic regression results, which means Model II does not fit to be Chinaâs NPF. Besides, as a byproduct it also confirms one of our arguments about Model I, that "linearity function type's best fit . . . is a false statement"(in section 6.1).

Table 10: Model II regressions: single variable

	Dependent variable:				
	$\ln gdp$				
	(1)	(2)	(3)	(4)	(5)
$\ln k$	0.788***				
	(0.011)				
$\ln k^P$		0.746***			
		(0.010)			
$\ln k^S$			0.754***		
			(0.010)		
$\ln k^\nu$				0.754***	
				(0.010)	
$\ln h$					4.139***
					(0.200)
Constant	0.031	0.169***	0.139***	0.139***	−5.583***
	(0.043)	(0.038)	(0.039)	(0.039)	(0.415)
Observations	15	15	15	15	15
R^2	0.997	0.998	0.998	0.998	0.971
Adjusted R^2	0.997	0.998	0.997	0.997	0.968
Residual Std. Error	0.022	0.020	0.021	0.021	0.073
F Statistic	4,753.045***	5,735.039***	5,367.946***	5,367.946***	428.976***
Note:					*p<0.1; **p<0.05; ***p<0.01

6.3 Model III

Model III Eq.(4a)-(4b) also takes Cobb-Douglas type, but treats the relative density of two capitals $k(t)/h(t)$ as one independent variable, and capital coefficient $k(t)/gdp(t)$ or $h(t)/gdp(t)$ as the other. The setting helps to avoid Multicolinearity problems. The corresponding econometrics are:

$$\begin{cases} \ln\left[\dfrac{k(t)}{gdp(t)}\right] = c + \beta_1 \cdot \ln\left[\dfrac{k(t)}{h(t)}\right] + \beta_2 \cdot \ln G(t) + \varepsilon & \text{(27a)} \\ \ln\left[\dfrac{gdp(t)}{h(t)}\right] = c' + \beta_1' \cdot \ln\left[\dfrac{k(t)}{h(t)}\right] + \beta_2' \cdot \ln G(t) + \varepsilon' & \text{(27b)} \end{cases}$$

A triple-check mechanism is then designed: if Model III fits to be China's NPF, then the regression results of Eq.(27a)-(27b) must satisfy the following conditions:

- Check-1 and Check-2: Both regressions show satisfying goodness of fit R^2, with significant coefficients including (c, β_1, β_2), (c', β_1', β_2'), and normally distributed, zero-means residuals ε and ε'.
- Cross-Check-3:

Table 11: Model II regressions: multiple variables

	bivariate			
	ln gdp			
	(1)	(2)	(3)	(4)
ln k	0.914***			
	(0.075)			
ln k^P		0.874***		
		(0.062)		
ln k^S			0.872***	
			(0.066)	
ln k^ν				0.872***
				(0.066)
ln h	−0.673	−0.723*	−0.668*	−0.668*
	(0.400)	(0.347)	(0.368)	(0.368)
Constant	0.955	1.185**	1.073*	1.073*
	(0.550)	(0.489)	(0.516)	(0.516)
Observations	15	15	15	15
R^2	0.998	0.998	0.998	0.998
Adjusted R^2	0.997	0.998	0.998	0.998
Residual Std. Error	0.021	0.018	0.019	0.019
F Statistic	2,712.896***	3,607.188***	3,158.740***	3,158.740***
	three variables			
	ln gdp			
	(5)	(6)	(7)	(8)
ln k	0.855***			
	(0.065)			
ln k^P		0.831***		
		(0.062)		
ln k^S			0.821***	
			(0.060)	
ln k^ν				0.821***
				(0.060)
ln h	−0.342	−0.470	−0.363	−0.363
	(0.346)	(0.352)	(0.335)	(0.335)
ln G	−0.023**	−0.015	−0.020**	−0.020**
	(0.008)	(0.009)	(0.008)	(0.008)
Constant	0.602	0.897*	0.736	0.736
	(0.465)	(0.482)	(0.457)	(0.457)
Observations	15	15	15	15
R^2	0.999	0.999	0.999	0.999
Adjusted R^2	0.998	0.998	0.998	0.998
Residual Std. Error	0.017	0.017	0.016	0.016
F Statistic	2,756.745***	2,810.533***	2,957.663***	2,957.663***

Note: *p<0.1; **p<0.05; ***p<0.01

- The production elasticity of physical capital $(1-\alpha)$, and that of HC α in Eq.(4a)-(4b), are respectively represented by β_1 and β_1'. Thus $\beta_1 + \beta_1' = 1$ should stand.
- The TFP parameter $A(t)$ in Eq.(4a)-(4b) is composed of two parts. The fixed part is represented by intercept c and c', the changing part is by β_2 and β_2'. Thus $\beta_2 + \beta_2' = 0, c + c' = 0$ should stand as well.

Regression results of Model III are shown in Table 12. From top to bottom, row (a-d) lists results with per capita physical capital valued at $k(t)$, $k^P(t)$, $k^S(t)$ and $k^\nu(t)$ respectively. From left to right, column (1-2) lists single and bivariate regression results of Eq.(27a), column (1'-2') lists those of Eq.(27b).

Results of single variable regressions show that the conditions of triple check mechanism are satisfied. Moreover, consider $\ln G(t)$ as the second independent variable, bivariate regression results still satisfies, with significant coefficient of $\ln G(t)$. Take $k(t)$ as proxy of physical capital, China's NPF can be expressed as

$$gdp(t) = 0.822 \cdot k(t)^{0.745} \cdot h(t)^{0.255} \cdot G(t)^{-0.028} \tag{28}$$

If physical capital stock is proxied as $k^P(t)$, $k^S(t)$ or $k^S(t)$, NPFs are

$$\begin{cases} gdp(t) = 0.854 \cdot k^P(t)^{0.696} \cdot h(t)^{0.304} \cdot G(t)^{-0.023} & \text{(29a)} \\ gdp(t) = 0.853 \cdot k^S(t)^{0.705} \cdot h(t)^{0.295} \cdot G(t)^{-0.026} & \text{(29b)} \\ gdp(t) = 0.917 \cdot k^\nu(t)^{0.633} \cdot h(t)^{0.367} \cdot G(t)^{-0.023} & \text{(29c)} \end{cases}$$

The coefficients' value differ from each other in Eq.(29), for example, physical capital's product elasticity vary from 0.63 to 0.71. That is due to different efficiency units utilized, measured by different methods of proxying capital-augmented technical progress. Once the measurement of technical progress is enlarged, then in the regression results, the

Table 12: Model III regressions

	Dependent variable: $\ln(k/gdp)$		*Dependent variable:* $\ln(gdp/h)$	
	(a1)	(a2)	(a1')	(a2')
$\ln(k/h)$	0.259***	0.255***	0.741***	0.745***
	(0.015)	(0.012)	(0.015)	(0.012)
$\ln G$		0.028***		−0.028***
		(0.008)		(0.008)
Constant	0.327***	0.196***	−0.327***	−0.196***
	(0.026)	(0.045)	(0.026)	(0.045)
Observations	15	15	15	15
R^2	0.957	0.977	0.995	0.997
Adjusted R^2	0.954	0.974	0.994	0.997
Res. Std. Error	0.024	0.018	0.024	0.018
F Statistic	289.261***	259.213***	2,369.201***	2,084.218***
	Dependent variable: $\ln\left(k^P/gdp\right)$		*Dependent variable:* $\ln(gdp/h)$	
	(b1)	(b2)	(b1')	(b2')
$\ln\left(k^P/h\right)$	0.307***	0.304***	0.693***	0.696***
	(0.013)	(0.010)	(0.013)	(0.011)
$\ln G$		0.023***		−0.023**
		(0.009)		(0.009)
Constant	0.266***	0.158***	−0.266***	−0.158***
	(0.024)	(0.047)	(0.024)	(0.047)
Observations	15	15	15	15
R^2	0.975	0.984	0.995	0.997
Adjusted R^2	0.974	0.981	0.995	0.996
Res. Std. Error	0.023	0.019	0.023	0.019
F Statistic	516.489***	369.509***	2,638.623***	1,874.508***
	Dependent variable: $\ln\left(k^S/gdp\right)$		*Dependent variable:* $\ln(gdp/h)$	
	(c1)	(c2)	(c1')	(c2')
$\ln\left(k^S/h\right)$	0.299***	0.295***	0.701***	0.705***
	(0.014)	(0.011)	(0.014)	(0.011)
$\ln G$		0.026***		−0.026***
		(0.008)		(0.008)
Constant	0.282***	0.159***	−0.282***	−0.159***
	(0.025)	(0.044)	(0.025)	(0.044)
Observations	15	15	15	15
R^2	0.973	0.985	0.995	0.997
Adjusted R^2	0.970	0.982	0.995	0.997
Res. Std. Error	0.023	0.018	0.023	0.018
F Statistic	461.124***	384.696***	2,545.419***	2,102.232***
	Dependent variable: $\ln(k^\nu/gdp)$		*Dependent variable:* $\ln(gdp/h)$	
	(d1)	(d2)	(d1')	(d2')
$\ln(k^\nu/h)$	0.370***	0.367***	0.630***	0.633***
	(0.013)	(0.011)	(0.013)	(0.011)
$\ln G$		0.023***		−0.023**
		(0.010)		(0.010)
Constant	0.198***	0.087**	−0.198***	−0.087
	(0.024)	(0.050)	(0.024)	(0.050)
Observations	15	15	15	15
R^2	0.984	0.989	0.994	0.996
Adjusted R^2	0.983	0.987	0.994	0.996
Residual Std. Error	0.024	0.021	0.024	0.021
F Statistic	800.756***	553.848***	2,327.263***	1,604.055***
Note:				*p<0.1; **p<0.05; ***p<0.01

production elasticity of efficient physical capital stock is diminished, vice versa. Also, the larger the measurement of labor augmenting technical progress, the less the production elasticity of HC stock. Thus it's empirically difficult to absolutely distinguish between capital-augmenting and labor-augmenting technical progress. In real economy they two might stick together and produce mixed affects on economic growth.

To sum up: from the perspective of growth expansion path, we empirically study the effects of relative density of two capitals (input), on capital coefficient (output), based on Model III. We find that Model III is effective in explaining the actual production process. Besides, government consumption negatively affects TFP change, which means over-expansionary government expenditure lowers down technical progress, and furthermore growth rate.

7 Conclusions and Prospects

1.model selection.

In this article, we first numerically simulate CES production functions with possible parameter combinations (Model I), to compare their fits. After comparisions, we choose Cobb-Douglas type to further analyze China's production, in which input/output is expressed in per capita quantity form (Model II), or relative capital density/capital coefficient form (Model III). The results show that Model II is defected due to multicolinearity problems, while Model III appropriately realizes China's past decades production. In the future research, we will employ the Cobb-Douglas type production function based on Model III, to further derive China's national economy expansion, and eventually to develop endogenous growth model.

2.proxy selection on HC.

In this article as well as the preceding one (Feng et al., 2012), we proxy HC stock by employment's average schooling years (mean index) and/or dispersion of education attainment (dispersion index). Empirical results once again confirm the argument that HC accumulation is important driving force of growth; and moreover, they are both appropriate indices to proxy Chinaâs HC stock. In the future research endeavors of China's endogenous growth model, if mean index is taken as endogenous state variable, then an extra HC sector (or education sector) need to be taken inside the model. If the model aims at some specific level's (eg. college) HC accumulation and its growth effects, then dispersion index is preferred to proxying labor augmenting technical progress, and correspondingly, in the growth model HC sectors of multiple levels are to be taken inside.

3.proxy selection on physical capital.

The difficulties in measuring China's physical capital stock are first, different calibers lead to data mismatch between investment (in expenditure approach) and depreciation (in income approach); second, when income approach GRP data are utilized to approximate national-level accounting data, we find the approximated depreciation in recent years is obviously low, which does not seem possible. Thus we deliberate an adjustment plan by empirical test, to prove the planâs plausibility.

Besides, based on vintage capital theory, in this paper we try to proxy capital augmenting technical progress by three indices, the price index, the industrial structure index, and capital coefficient index. Empirical analyses show they three are all valid proxies, when augmenting physical capital to efficiency units. In the future research, which index is to be chosen to endogenously represent capital augmenting technical progress, depends on sectoral structure settings of the growth model. 1) If the model includes the following sectors, i.e. the domestic/international financial sector (central bank included), and investment goods/ consumption goods production sector, then price index is preferred to proxying technical progress. 2) If the model includes preliminary, secondary and tertiary production sectors, then structure index is preferred. 3) If neither industrial sectors nor financial sectors are distinguished, then the preferred endogenous proxy is capital coefficient. Apparently, among the three, the last one brings the least complexity to modeling work.

4.effects of government consumption on TFP.

In TFP there embeds neutral technical progress that affects both physical capital, and HC. TFP change might be due to changes of government behavior. We build a proxy to represent the neutral technical progress, by comparing the relative expansion of government consumption to GDP. Empirical result is, as government consumption is expansionary, TFP diminishes downwardly, producing significantly negative output effect[17].

While it is worth noting, that the method of proxying government behavior by the only index, government consumption, might be insufficient, due to the reason that government behaviors do affect huge aspects of China economy. In the future research, it is also of interest to split government expenditures into detailed sub items, to further analyze their growth effects, in order to provide more policy suggestions to public policy decision making.

References

Acemoglu, D., 2002. Directed technical change. Review of Economic Studies 69, 781–809.

Arrow, K. J., Chenery, H. B., Minhas, B. S., Solow, R. M., 1961. Capital-labor substitution and economic efficiency. Review of Economic and Statistics 43, 225–250.

Aschauer, D. A., 1989. Is public expenditure productive? Journal of Monetary Economics 23 (2), 177 – 200.

[17]The finding coincides with a series of other empirical studies, for example Wang et al. (2009) argue that expansionary public administration cost negatively affects China's growth; Chen and Zhang (2008) find that even after the Tax Distribution Reform(1994), most provinces' government expenditures are lack of efficiency.

Barro, R., Lee, J.-W., 1993. International comparisons of educational attainment. Journal of Monetary Economics 32 (3), 363–394.

Barro, R., Lee, J.-W., 1996. International measures of schooling years and schooling quality. American Economic Review 86 (2), 218–223.

Barro, R. J., Lee, J.-W., 2001. International data on educational attainment: updates and implications. Oxford Economic Papers 53 (3), 541–563.

Ben-Gad, M., 2012. The two sector endogenous growth model: An atlas. Journal of Macroeconomics 34 (3), 706 – 722.

Cao, J., 2007. The aggregate production function and contribution rate of technical change to economic growth in china (woguo zongliang shengchan hanshu yu jishu jinbu gongxianlv). The Journal of Quantitative and Technical Economics 11 (8), 11–17.

Carstensen, K., Gundlach, E., Hartmann, S., November 2009. The augmented solow model with mincerian schooling and externalities. German Economic Review 10, 448–463.

Chen, S., Zhang, J., 2008. Efficiency of local government financial expenditure in china : 1978-2005. Social Sciences in China 4 (4), 65–78.

Chen, X., Lian, Y., 2012. Capital-labor elasticity of substitution and regional economic growth: An empirical investigation of the de la grandvile hypothesis. China Economic Quarter 12 (1), 93–118.

Duffy, J., Papageorgiou, C., March 2000. A cross-country empirical investigation of the aggregate production function specification. Journal of Economic Growth 5 (1), 87–120.

Fang, W., 2012. China's capital returns: A re-estimation from the perspective of the vintage capital model. China Economic Quarterly 11 (2), 521–540.

Feng, X., Zhu, Y., Huang, L., 2013. Macro- and Mesoeconomic Effects of Investment in Vocational Education (Jiaoyu yu Zhiyejiaoyu de Guomin Jingji Shengchan Xiaoguo Fenxi). Tongji University Press, Shanghai.

Feng, X., Zhu, Y., Yang, Q., 2012. A study on china's national production function based on a human capital dispersion index. China Economic Quarterly 11 (2), 559–594.

Fernández-Villaverde, J., 2010. The econometrics of dsge models. SERIEs 1 (1-2), 3–49.

Folloni, G., Vittadini, G., 04 2010. Human capital measurement: A survey. Journal of Economic Surveys 24 (2), 248–279.

Funke, M., Strulik, H., 2000. On endogenous growth with physical capital, human capital and product variety. European Economic Review 44 (3), 491 – 515.

Gao, W., 2009. Aggregate production function, economic growth and growth accounting: A survey on china's growth accounting (zongliang shengchan hanshu, jingji zengzhang yu hesuan fangfa: Zhongguo zengzhang hesuan yanjiu de yige zongshu). Economic Theory and Business Management 3, 37–40.

Golley, J., Meng, X., 2011. Has china run out of surplus labour? China Economic Review 22 (4), 555–572.

Greenwood, J., Jovanovic, B., 2001. Accounting for growth. In: Hulten, C. R., Dean, E. R., Harper, M. J. (Eds.), New Developments in Productivity Analysis. University of Chicago Press, USA, pp. 179–224.

Growiec, J., 2011. A microfoundation for normalized ces production functions with factor-augmenting technical change. National Bank of Poland Working Papers 98, National Bank of Poland, Economic Institute.

Guo, Q., Jia, J., 2006. The effects of government public capital investment on long-run economic growth. Economic Research Journal 7, 29–40.

Guo, Y., 2006. Caital accumulation, technical change and aggregate production function: A study based on empirical data from china between 1980 and 2005. Nankai Economic Studies 3, 79–89.

Hui, L., 2009. A study on capital stock measurement and investment efficiency of china (woguo ziben cunliang cesuan ji touzi xiaolv de yanjiu). Economist (China) 6, 75–83.

Jones, C., May 2005. The shape of production functions and the direction of technical change. The Quarterly Journal of Economics 120 (2), 517–549.

Jovanovic, B., Yatsenko, Y., 2012. Investment in vintage capital. Journal of Economic Theory 147 (2), 551 – 569.

Klump, R., McAdam, P., Willman, A., 2012. The normalized ces production function: theory and empirics. Journal of Economic Surveys 26 (5), 769–799.

Knight, J., Deng, Q., Li, S., 2011. The puzzle of migrant labour shortage and rural labour surplus in china. China Economic Review 22 (4), 585–600.

Koop, G., Pesaran, M. H., Smith, R. P., 2013. On identification of bayesian dsge models. Journal of Business & Economic Statistics 31 (3), 300–314.

Leè´¸n-Ledesma, M. A., McAdam, P., Willman, A., 2010. Identifying the elasticity of substitution with biased technical change. American Economic Review 100 (4), 1330–1357.

Li, B., 2011. Comparative analysis of estimates on capital stock of china. The Journal of Quantitative & Technical Economics(China) 28 (12), 21–36.

Li, H., Liang, Y., Fraumeni, B., Liu, Z., Wang, X., 2010. China's human capital measurement and index construction. Economic Research Journal 8, 42–54.

Lucas, R., Jul. 1988. On the mechanics of economic development. Journal of Monetary Economics 22 (1), 3–42.

Mankiw, G. N., Romer, D., Weil, D. N., 1992. A contribution to the empirics of economic growth. Quarterly Journal of Economics 107 (2), 407.

Mincer, J., December 1974. Schooling, Experience, and Earnings. NBER Books. National Bureau of Economic Research, Inc, US.

Nakamura, E., Steinsson, J., Liu, M., 10 2013. Are chinese growth and inflation too smooth? evidence from engel curves. Tech. rep., NBER, Chinese Econony Working Group Papers, http://www.nber.org/confer//2013/CEf13/Nakamura_Steinsson_Liu.pdf.

Park, J., 2006. Dispersion of human capital and economic growth. Journal of Macroeconomics 28 (3), 520–539.

R Core Team, 2013. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
URL http://www.R-project.org/

Shan, H., 2008. Reestimating the capital stock of china: 1952-2006. The Journal of Quantitative & Technical Economics 25 (10), 17–31.

Solow, R., 1956. A contribution to the theory of economic growth. The Quarterly Journal of Economics 70 (1), 65–94.

Solow, R., 1957. Technical change and the aggregate production function. The Review of Economics and Statistics 39 (3), 312–320.

Wang, J., Ge, Y., 2012. A study on aggregate production function of china based on time-varying parameter. The Journal of Quantitative & Technical Economics(China) 8, 150–161.

Wang, M., Yue, C., 2009. Estimation and comparison on individual returns to schooling: A semi-parametric approach. Statistical Research 6, 51–59.

Wang, X., 2010. "grey" income and national income distribution in china (huise shouru yu guomin shouru fenpei). CITIC Comparative Studies 3, 1–29.

Wang, X., Fan, G., Liu, P., 2009. Transformation of growth pattern and growth sustainability in china. Economic Research Journal 1 (4), 4–16.

Woessmann, L., 2003. Specifying human capital. Journal of Economic Surveys 17 (3), 239–270.

Xu, X., 2011. Understanding and estimating gdp (ruhe quanmian zhunque lijie he keguan pingjia gdp). Journal of China National School of Administration 3, 10–17.

Xu, Z., Lin, R., 2011. Revisit china's aggregate production function-a bayesian dsge estimation approach. World Economic Papers 2 (2), 87–87.

Yang, Q., 2013. A study on economic effects of cross-sectoral labor transformation based on china's sectoral production functions. Ph.D. thesis, School of Economics and Management, Shanghai.

Ye, Z., 2010. Re-estimating the capital stock of china: 1952-2008. Statistics & Information Forum 25 (7), 36–41.

Zhang, J., 2005. Aggregate production function: Birth, development and applications (zongliang shengchan hanshu de chansheng, fazhan he yingyong). West China Finance (Xibu Jinrong) 10, 36–38.

Zhang, J., 2007. Decentralization and growth: China context. China Economic Quarterly 10 (1), 21–52.

Zhang, J., Gao, Y., Fu, Y., Zhang, H., 2007. Why does china enjoy so much better physical infrastructure? Economic Research Journal 3 (3), 4–19.

Zhang, J., Wu, G., Zhang, J., 2004. The estimation of china's provincial capital stock: 1952-2000. Economic Research 10 (10), 35–44.

Zhang, S., 2011. Time-varying elasticity production function:productivity decomposition formula and policy implications. The Journal of Quantitative & Technical Economics 28 (7), 106–121.

Zhang, S., Xu, B., 2009. Production functions with time-varying elasticities and under the catch-up consensus: Total factor productivity. China Economic Quarterly 8 (2), 551–568.

Zhang, S., Xu, B., Gu, W., 2011. Statistical and economic tests for the time-varying elasticity production function model. Statistical Research 6, 91–96.

Zhu, Y., 2011. A study on china's national production function based on human capital's dispersion. Ph.D. thesis, School of Economics and Management, Tongji University.

In dieser Reihe sind zuletzt erschienen / Recently published:

2014

26/01 **Sell, Friedrich L. und Ernst Ruf,** Anmerkungen zum Monopson am Arbeitsmarkt II

2013

25/05 **Morasch, Karl,** Cooperation and Competition in Markets with Network Externalities or Learning Curves

25/04 **Sell, Friedrich L., Werner, Thomas, Reinisch, David C.,** Price Effects of Minimum Wages: Evidence from the Construction Sector in East and West Germany

25/03 **Bartholomae, Florian W.,** Networks, Hackers and Nonprotected Consumers

25/02 **Sell, Friedrich L. und Reinisch, David C.,** How do Beveridge and Philips curves in the Euro Area behave under the stress of the World Economic Crisis?

25/01 **Sell, Friedrich L. und Sauer, Beate,** Ist he Eurozone not a Monetary Union, bit an Extraordinary Exchange Rate Union?

2012

24/02 **Sell, Friedrich L. und David C. Reinisch,** Anmerkungen zum Monopson am Arbeitsmarkt: Der Zeithorizont macht den Unterscheid

24/01 **Sell, Friedrich L. und Felix Stratmann,** Verteilungs(un)gleichgewicht in Deutschland: Zweieinhalb theoretische Konzepte und fünf empirische Belege

2011

23/02 **Sell, Friedrich L. und Beate Sauer,** A Further View on Current Account, Capital Account and Target2 Balances: Assessing the Effect on Capital Structure and Economic Welfare

23/01 **Sell, Friedrich L. und Felix Stratmann,** Downs‘ ökonomische Theorie der Demokratie 2.0: Politische Präferenzen und Gleichheitsaversion

2010

22/03 **Morasch, Karl**, Intermediation by Heterogeneous Oligopolists

22/02 **Sell, Friedrich L.**, Desempleo, desajuste en el mercado laboral („mismatch“) e inflación: un modelo integrativo

22/01 **Sell, Friedrich L.**, Die Weltwirtschaftskrise als Exempel der Überinvestitionstheorie: Komplementäre Erklärungsansätze von v. Hayek/Garrison und Minsky

2009

21/03 **Bartholomae, Florian W., Karl Morasch und Rita Orsolya Tóth**, Smart Entry in Local Retail Markets for Electricity and Natural Gas

21/02 **Sell, F. L. und Felix Stratmann**, Equity Aversion, Inequality Aversion and Economic Welfare: On the Macroeconomic Substantiation of Microeconomic Utility Functions

Universität der Bundeswehr München
Fachgruppe Volkswirtschaftslehre an der
Fakultät für Wirtschafts- und Organisationswissenschaften
D – 85577 Neubiberg