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IZA DP No. 10749

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ABSTRACT

Wages, Innovation, and Employment in China

We investigate the role of factor-priced-induced innovation in mediating the employment impact of expanding production in China. Our empirical approach implements concepts developed in Acemoglu (2010) and complements the approaches summarized by Wei, Xie, and Zhang (2017) that focus on directly observable aspects of innovation (R&D, patent activity, etc.); labor-force characteristics including the availability of "surplus" labor, investments in human capital; and investments in physical capital. It complements work on the causes of a decline in labor's share in total output as documented in Bai and Qian (2010) and in Molero-Simarro (2017). Our empirical results to date support the hypothesis that wage-induced technology change has influenced productivity growth in China, at least in the decade of the 1990s, but perhaps less so or not at all after the middle of the next decade.

JEL Classification: O30, D22, D24, D33
Keywords: endogenous innovation, China, factor shares

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1. Introduction

We address the question of whether rising labor costs in formerly low-wage China is stimulating innovation that can support its transition from middle- to higher income status. As cogently asked by Wei, Xie, and Zhang (2017), is China transitioning from simply making goods to developing technology that changes the production process itself? This is a critical question, not only for China, but also for the impact of innovation on the employment impact of the expansion of manufacturing employment to lower-wage economies. The industrial explosion that turned China into "workshop of the world" (Gao, 2012) has led other nations to hope that the availability of low-cost labor will also lead to employment booms as manufacturers continue to seek ways of maintaining international competitiveness. However, these aspirations have been disappointed in many cases, because the employment impact of expanding output is continually damped by rising productivity (Zhong, 2015).

The impact of accelerating wage growth in China has led to an immense literature that we cannot cite here. In addition to those already cited, we note the insights in Yang, Chen, & Monarch (2010) and in the collection of papers on whether China has passed the Lewis Turning Point in *China Economic Review* (2011).

The relationship between wage- and productivity growth in China is illustrated dramatically in figures 1a, 1b, and 2. They show that there was an acceleration that began in the mid-1990s and also document that the rate of wage growth leveled off around the turn of the millennium. Figure 2 also indicates that, when corrected for the proportion of the work force with schooling at least at the level of junior middle school, the wage growth series indicates a compression of skill ratios consistent with the increasing scarcity of unskilled labor occurring about the turn of the millenium. (See, for example, the collection of papers on "The Lewis Turning Point" in China Economic Review, 2011.) Interestingly, and of critical interest in this paper, is that labor productivity growth as measured by output per unit of labor exceeded real wage growth in the 1990s, but not in the following decade.

Prima facie evidence that China entered a phase of accelerated technology advance as wages rose can be seen in rising share of capital that began in the 1980s illustrated in figures 3a and 3b and documented in recent work of Bai and Qian (2010), Gao, *et al.* (2017), and Molero-Simarro (2017). All these sources reveal a broad similarity in trends with capital's share evidently reaching a peak in the middle of the first decade of the 2000s. Interestingly, the most recent data suggests a pause and even a reversal of trend in the mid-2000s.

The path from rising input prices to technology advance in the economics literature goes back at least to J. R. Hicks' *Theory of Wages.* Following concepts presented by Acemoglu (2010) and Acemoglu and Autor (2011,) we assess evidence on the existence and time path of factor-price induced technology change in China by examining evidence that reduction in the input of labor per unit of output has exceeded the amount that can be attributed to factor substitution under fixed production parameters. Our empirical results to date support the hypothesis that wage-induced technology change has influenced productivity growth in China, at least in the decade of the 1990s, but perhaps less so or not at all after the middle of the next decade. We note that this evidence is consistent with the tapering off or ceasing of the increase in capital's factor share in the mid-2000s and perhaps by the evidence of declining or even negative growth of TFP documented by Wei, Xie, and Zhang (2017).

2. Methodology.

We base our investigation on concepts developed by Acemoglu (2010. Our adaptation of the conditions under which labor scarcity encourages technological advances is summarized briefly here and presented in detail in the Appendix.

We specify the production function

$$Y = \alpha^{-\alpha}(1-\alpha)^{-1}(K^{\theta}L^{1-\theta})^{\alpha}q(\theta)^{1-\alpha} \qquad \textbf{(1)}$$

where the $\alpha^{-\alpha}(1-\alpha)^{-1}$ is due to a convenient normalization further elaborated in the Appendix. We take $K=\overline{K}$ as exogenously determined. A technology θ is created at a cost $C(\theta)$. The unit production cost of the intermediate good embodying this technology is assumed to be denominated in units of the final good, whose price is normalized to 1.

To provide an adequate test of hypotheses related to wage-induced technology change, we add a factor-neutral productivity (total factor productivity—TFP) term A to (1):

$$Y = A\alpha^{-\alpha}(1-\alpha)^{-1}(K^{\theta}L^{1-\theta})^{\alpha}q(\theta)^{1-\alpha} \qquad \textbf{(2),}$$

and in our empirical work we rely primarily on the production function in intensive form:

$$\frac{Y}{L}=\frac{A\alpha^{-\alpha}\left(1-\alpha\right)^{-1}\left(\bar{K}^{\theta}L^{1-\theta}\right)^{\alpha}\left(A^{1/\alpha}\alpha^{-1}\left(\bar{K}^{\theta}L^{1-\theta}\right)\right)^{1-\alpha}}{L}=\frac{A^{1/\alpha}\alpha^{-1}\left(1-\alpha\right)^{-1}\bar{K}^{\theta}L^{1-\theta}}{L}$$

$$\frac{Y}{L}=A^{1/\alpha}\alpha^{-1}\left(1-\alpha\right)^{-1}\left(\frac{\bar{K}}{L}\right)^{\theta} \quad \textbf{(3)}$$

From the development of this model as shown in the Appendix, we can write (3) in terms of the real wage *W*, obtaining

$$\frac{Y}{L}=\alpha^{-1}\left(1-\alpha\right)^{-1}\frac{W\left(1-\alpha\right)}{1-\theta}=\frac{Y}{L}=\frac{1}{\alpha(1-\theta)}W \quad \textbf{(4)}$$

Defining $\phi_i=\frac{1}{\alpha(1-\theta_i)}$, we divide both sides of (4) by (*W*) and specify $\frac{\phi_0}{\phi_t}=\frac{1-\theta_t}{1-\theta_0}$ to examine the behavior of θ over time:

$$\ln\left(\frac{Y_{it}}{L_{it}}\frac{1}{W_{it}}\right)=\phi_t+\eta_i+\varepsilon_{it} \quad \textbf{(4a)}$$

where ϕ_t and η_i denote year and provincial dummies, respectively, and $\frac{1}{e^{\phi_t-\phi_0}}=\frac{1-\theta_t}{1-\theta_0}$.

Changes in either the real wage *W* or the stock of physical capital *K* can affect ϕ_t when there is endogenous technical change. To deal with these two issues, we take logs of (4) and, adding the date and location identifier, we obtain the approximations

$$\ln\left(\frac{Y}{L}\right)_{it}=\alpha_{it}+\beta\ln W_{it}+\delta\ln K_{it}+\varepsilon_{it} \text{ and}$$

$$\ln\left(\frac{Y}{L}\right)_{it}=\alpha_{it}+\beta\ln W_{it}+\delta\ln K_{it}+\gamma Z_t+\lambda Z_t\ln W_{it}+\mu Z_t\ln K_{it}+\varepsilon_{it} \quad \textbf{(5).}$$

where *Z* is a dummy variable indicating a date in time, which allows us to examine the source of induced technology change. The signs of γ and λ, are interpreted as indicating the degree to which a regime of induced technical change is more pronounced in the time period defined by Z.

Under endogenous technical change, $\frac{\partial\theta}{\partial K}>0$ and $\frac{\partial\theta}{\partial W}>0$.

In addition, we estimate (5) with year fixed effects that reflect changes in TFP (as further demonstrated in the technical appendix). Thus we test the following hypotheses:

i. $\beta>1$ (indicating induced technical change);

ii. δ >0 under (indicating induced technical change);

iii. Based on equation (4a) we hypothesize that under ongoing endogenous technical change, the ratio $\frac{1-\theta_t}{1-\theta_0}$ should be less than 1, which implies that θ_t is greater than θ_0.

Equation (3) provides still another perspective for estimating the technology parameter θ. Taking logs of (3) and adding the location and date identifiers, we obtain

$$\ln\left(\frac{Y}{L}\right)_{it} = \mathrm{B}_{it} + \theta \ln\left(\frac{\bar{K}}{L}\right)_{it} \quad \text{where}$$
$$\mathrm{B}_{it} = \frac{1}{\alpha}\ln A_{it} - \ln\alpha(1-\alpha) \tag{6}$$

for t = 0….T.

We want to know whether the technology parameter θ is a function of the price of labor. In order to adapt (6) to test this hypothesis we specify:

$$\theta = \gamma_0 + \gamma_1 f(W),$$
$$\text{where } f(W) = W \text{ or } \ln W$$

Under wage-induced technical change, we expect $\gamma_1 > 0$. Substituting the preceding specification into (6) we obtain the empirical formulation

$$\ln\left(\frac{Y}{L}\right)_{it} = B_{it} + \gamma_0 \ln\left(\frac{\bar{K}}{L}\right)_{it} + \gamma_1 f(W_{it}) \ln\left(\frac{\bar{K}}{L}\right)_{it} + \varepsilon_{it} \tag{7}$$

Hypothesis iv. $\gamma_1 > 0$

2. Data and Empirical Results.

Our two principal sources of data are official provincial employment and output statistics, and the widely used Large and Medium Enterprises data base. Provincial real capital data are obtained from Wu (2016) and detailed data, which was kindly provided by the author, Yanrui Wu.

The data for the aggregate Chinese economy represented in figure 4 suggest that in the post-Mao era, productivity growth as measured by output per unit of labor exceeded (lagged) real wage growth over the period roughly between 1983 and the year 2000, but it did not, starting around the year 2003. The contrast in the relationship between the growth of output:labor and real wages between the decade of the 1990s and 2000s is illustrated even more starkly in figure 5.

Tests with provincial data: Hypotheses (i)-(iii). Table 1 reports regression results testing hypotheses (i)-(iii). They are based on provincial aggregates over the period 1986-2012. We deal with the problem of endogenous real wages using two-stage least squares in which the principal instrumental variable is the 8-year lagged proportion of the provincial primary labor force. We postulate physical capital *K* as exogenous and predetermined, which we believe is a reasonable assumption given the very imperfect financial markets in China. The constant terms (not reported) are estimated with fixed effects as indicated above and in the notes to table 1.

We can with a moderate degree of confidence reject the null hypothesis of no factor-price induced technical change based on the estimation results reported in column (1) of table 1. The Stock-Yogo weak ID statistic is reasonably strong, and the point estimate of the coefficient of log real wage is approximately one standard error greater than the benchmark 1.0. However, the null under hypothesis (ii), that shocks to the stock of physical capital lead to induced technology change above cannot be rejected. While there is no evidence in column (2) that technology change responded differently to exogenous changes in the real wage or to changes in the stock of physical capital after the year 2000 the weak ID statistic suggests that we should be very cautious in drawing inferences based on these results.

Tests with provincial data: Hypothesis (iv) Estimation results are reported in table 2 and displayed graphically in figures 6 (a)-6 (c) along with their 95% confidence interval. They are based on the provincial data for secondary industry, as are those reported in table 1. (Recall that an increase in θ_t results in a decline in $\frac{\phi_0}{\phi_t}$, the reported parameter estimate, and that by definition $\frac{\phi_0}{\phi_t}$ = 1.0 in the base year, 1978.) The estimation results based on equation (4a) are consistent with the existence of induced technology change beginning in the late 1980s, followed by an almost steadily increasing trend through the late 1990s. The trend of wage-induced technology change then appears to have reversed, the 95% confidence interval broadening somewhat, during most of the first decade of the 21st century, although there is a suggestion of a leveling off or reversal in the year 2009. At no point does the ratio $\frac{\phi_0}{\phi_t}$ rise to the level of the base year after around 1989 or 1990, indicating an ongoing, if declining rate of induced innovation. However, as suggested by the data illustrated in figures 3-6, the decade of the 1990s appears to have been a period of greater technology advance in China than the succeeding 10 or more years.

Regional differences. We also estimate equation (4a) by major regions (defined in the notes to figure 6 (c)). The estimation of $\frac{\phi_0}{\phi_t}$ track quite closely across regions until the end of the 1990s, when they diverge in both trend and level. The path of the far west regions changes direction sharply and rises substantially above those of the other three provincial groups. We conjecture that this pattern arises from massive investments in capital-intensive projects related to mineral resources and directed investment to attack problems of regional income disparity. Such directed investments are less likely, we propose, to embody new, innovative technology. The best performing region by the $\frac{\phi_0}{\phi_t}$ metric is the northeast, and we propose that this reflects the massive reforms of SOEs that involved laying off redundant workers. We track regional provincial averages of physical capital:labor by region in figure 8. The far western regionhas clearly the highest ratios until overtaken by the northeast around the year 2010. The acceleration of capital:labor in the northeast region is attributable in part to the laying off of redundant labor as well as to the acceleration of investment activity in the latter years of the decade. The trend of the $\frac{\phi_0}{\phi_t}$ series for the northeast region suggests a greater degree of ongoing innovation that that region than is apparent in the other three regions during the decade after the year 2000.

The interior region tracks quite closely to the coastal region both in level and trend. We conjecture a degree of technology and innovation spillover from coastal innovators to those in the interior may underlie this similarity, and this interregional relationship is a target of ongoing research.

Tests with firm data: Large and Medium Enterprises.

Estimation results for equation (7) are reported in tables 3 and 3a, which is based on China's Large and Medium Enterprise (LME) sample for the years 1999-2007 and 2011. We report results based on all firms in the sample, which consist almost entirely of enterprises located in the secondary industry sector, and within that mostly in manufacturing. [1]

Estimation results are quite robust to the exclusion of all enterprises that are not located in the secondary-industry category and to whether the wage variable is entered in log-form or not. The estimation results are highly significant, which is related to the extremely large number of enterprises in the LME census. Critically, hypothesis (iv), that there is an innovation response to rising wages is strongly supported by the coefficient λ_1 in both tables 3a and 3b. Figure 7 shows our calculations of θ from equation (7), in index form, with the 1999 estimate set equal to 1.0. This variable, the direct representation of the impact of innovated technology on the production elasticity of physical capital, indicates that there was wage-induced innovation in China's large and medium enterprises from 1999 at least through the year 2007. Estimates based on the sample including 2011 track reasonably well over their common years, with the sample excluding the 2011 survey suggesting a larger growth of wage-induced technology over the eight years covered. However, the larger sample, including the over half-millions additional enterprises surveyed in 2011, indicates a dramatic decline of innovative activity. Firm conclusions based on the larger sample must wait until a more detailed examination of variable definitions and sample composition is possible.

Regional differences. The estimation results reported in the right-hand side of tables 3a and 3b reveal information about regional differences in wage-induced innovation. In both sets of regressions, the far west is clearly the least innovation, but the superiority of the northeast region that stands out in figure 10 is not apparent. In the longer time period reflected in table 3a, the

[1] We note at this point that the number of enterprises included in the 2011 LME sample is much larger than in previous surveys and that there are major changes in the mean values of important variables. The regression results excluding the 2011 data are reported in table 3a. As can be inferred from the sample sizes reported in tables 3 and 3a, the number of enterprises covered in the 2011 survey exceeds 500,000, while the average number of enterprises covered in the preceding 9 surveys somewhat exceeds 200,000. The number of enterprises included in the LME data constituted approximately 3.1% of the registered firms in China based on data reported by Wei, Xie, & Zhang (2017) and grew to approximately 4.6% of the registered enterprises by the year 2011.

northeast is in third place, but in the shorter time period covered by the results reported in table 3b, it is in a virtual tie with the coast and interior regions.

3. Conclusion. There is evidence that industry in China has been able to innovate in response to increasing labor costs, at least through the early years of the 21st century. However, there is a strong suggestion in our empirical results that beginning around the time that the wages of less-skilled workers began to accelerate relative to their better-educated counterparts, innovative activity in China has failed to offset the impact of rising labor costs.

Our estimation results are consistent with other evidence on the advance of technology in China. As Nelson (1964) and Wolff (1991) have shown, a measure of new technology embodied in physical capital is reflected in the acceleration of the physical capital stock. The data on China's physical capital stock available from a variety of sources and based on various assumptions of price deflators, rates of deprecation, etc., as presented in figures 9 and 10, indicate a significant decline of the rate of growth beginning around 2007 or 2008.

The direct evidence on whether China is innovating in response to rising labor costs (in addition to simply substituting against labor under given technology) might be also be compared with indirect evidence as reflected in research and development (R&D) and patent activity. China's "patent explosion" has been explored and documented in great detail by Hu and Jefferson (2009) and is covered thoroughly by Wei, Xie, and Zhang (2017). As illustrated in figure 11, patents granted to all types of applications grew at an annual rate of 19% during the 1995-2005 decade and the following 10 years. However, the proportion of investment patents in the total granted fell sharply from 31% to only 18%. While the link between patenting activity and its payoff in productivity may in principal subject to long and varying lags, the patent data appear to complement the implication of the gross relationship between productivity and wage growth: that technology change in China has fallen behind the need for innovation to offset rising labor costs.

Gunter (2017) shows that by different measures, capital flight from China very sharply accelerated in the second half of the 2000-2010 decade. There are a number of possible explanations for this trend; one may be that investors see fewer innovative opportunities in China than in previous years, while an alternative may be that investors' insecurity leads them to withdraw funds that might have contributed to innovative activity. Whether the cumulating evidence of a tapering off or even decline in China's innovative response to rising wages represents a purely internal phenomenon or an inevitable effect of getting closer to the world productivity frontier remains for further investigation.

Figure 1 a

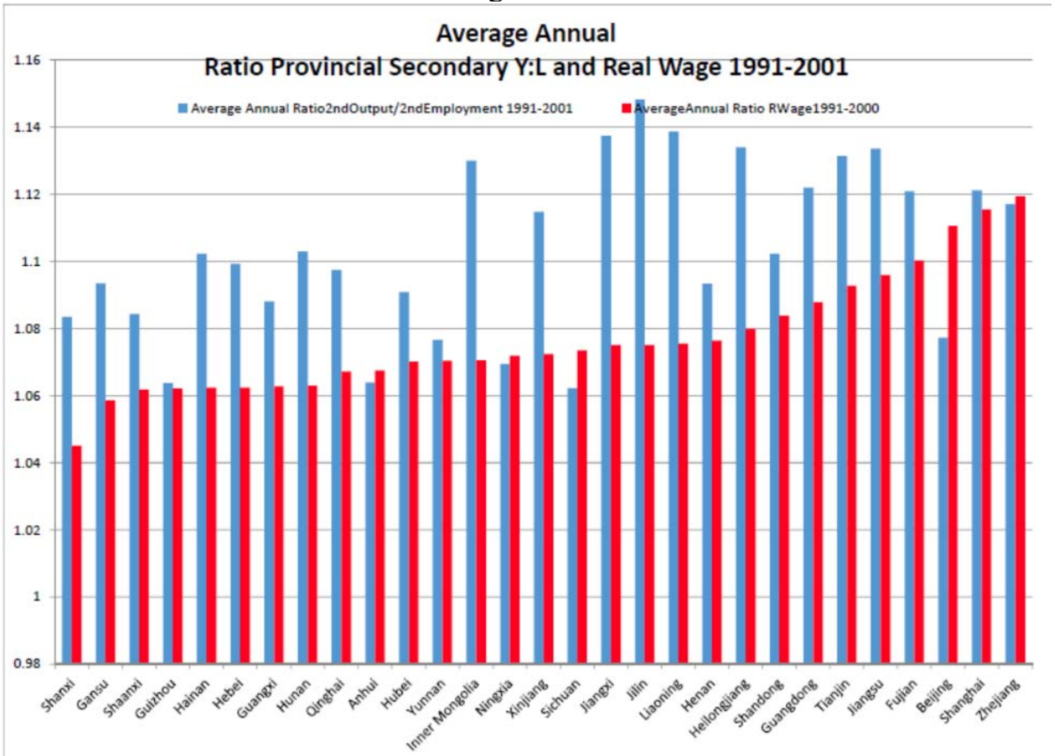


Figure 1 b

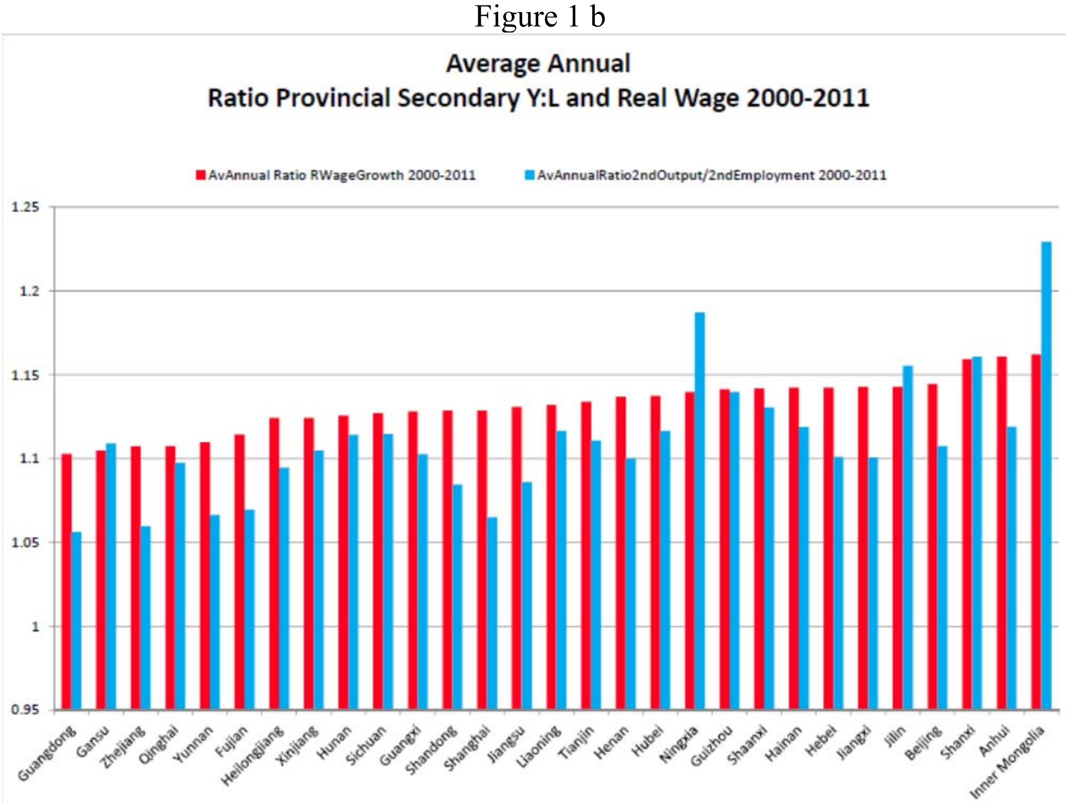


Figure 2
Real Wages in China

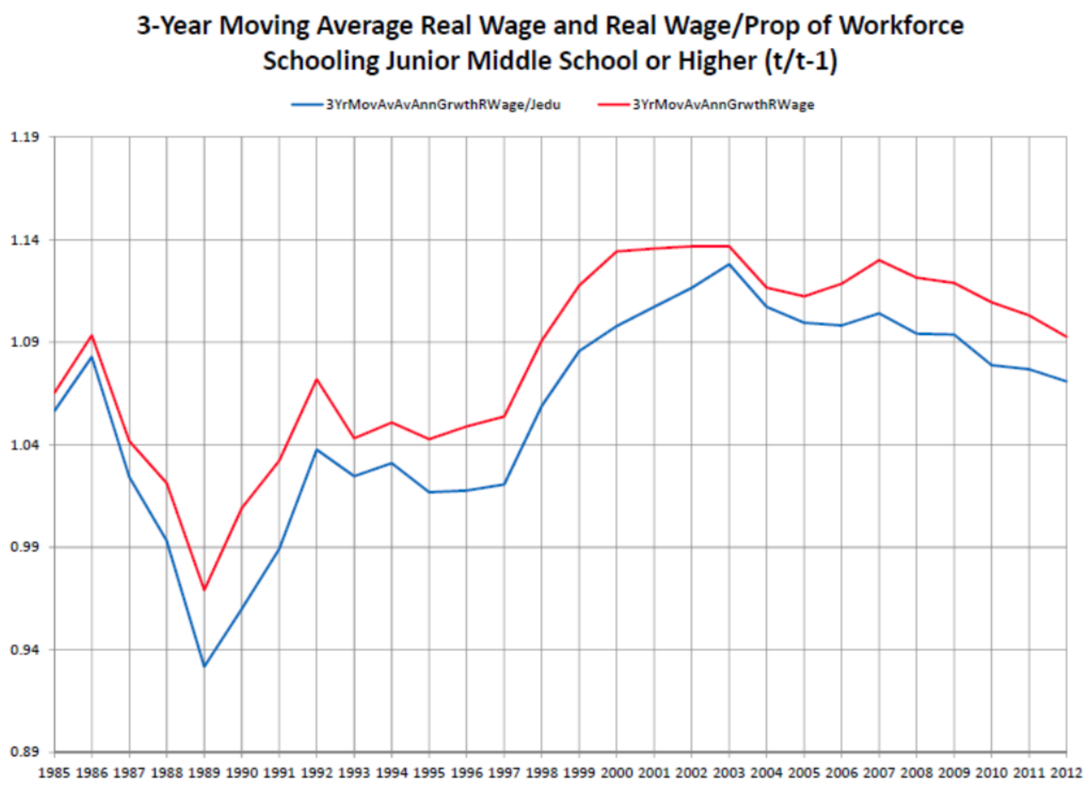
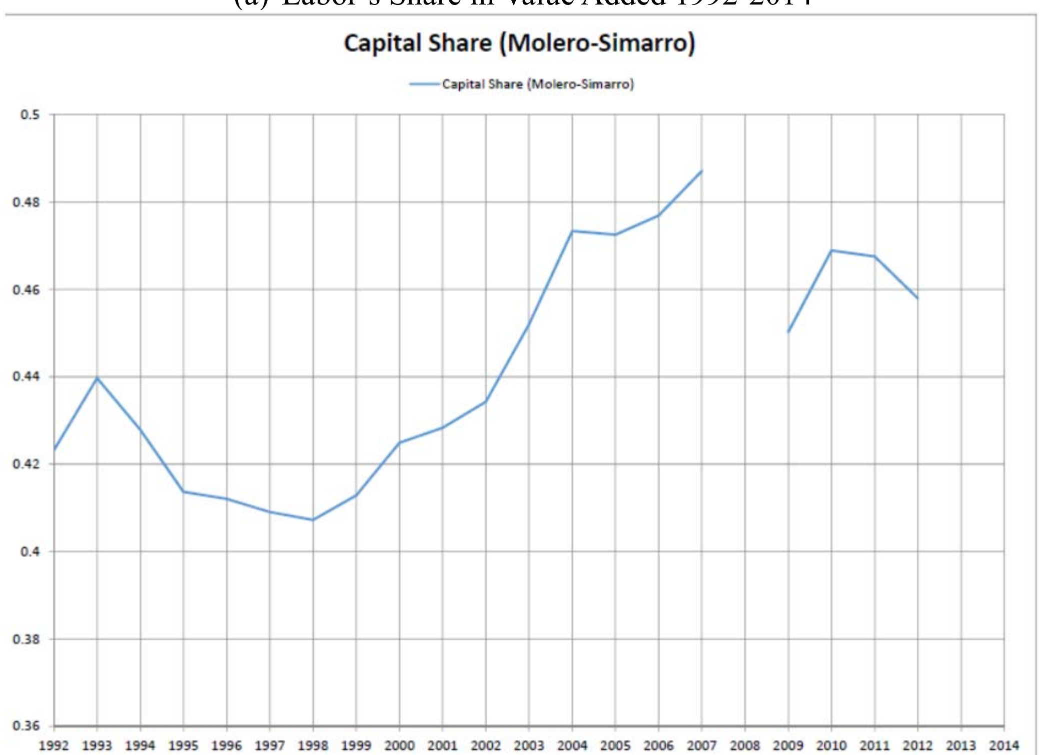


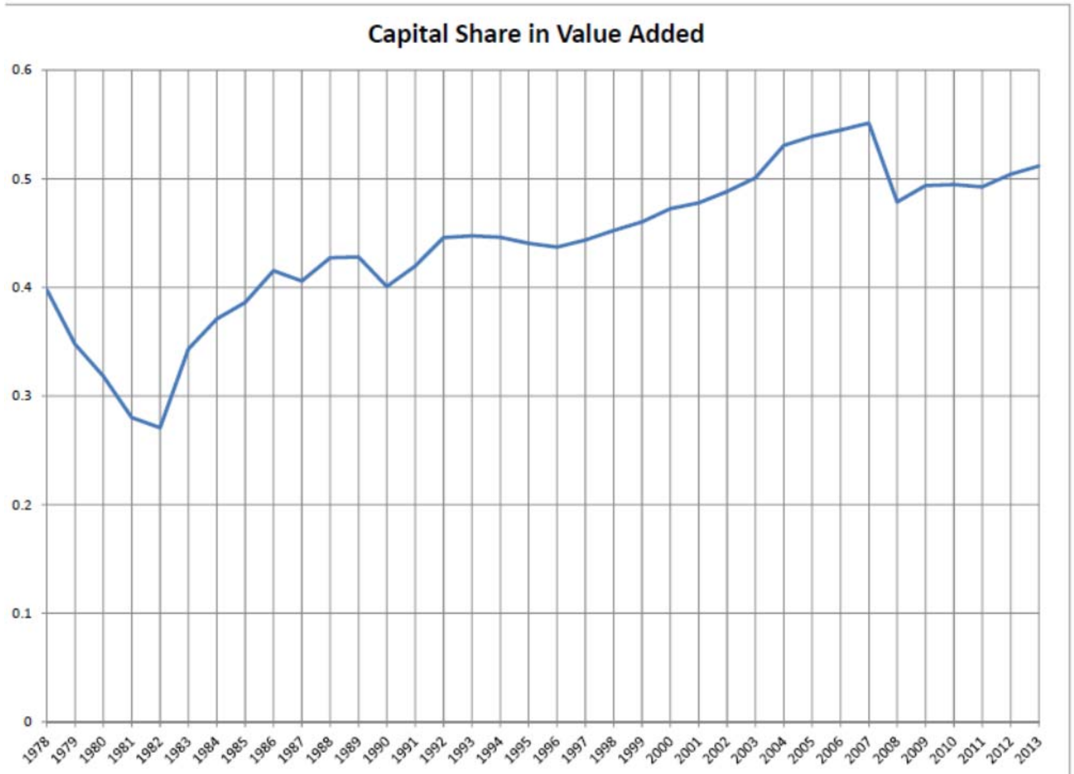
Figure 3 a

(a) Labor's Share in Value Added 1992-2014



Source: Molero-Simarro, 2017 Derived from data kindly provided from the author

Figure 3 b



Source: Gao, *et al*.(2017). Chart constructed from data kindly provided by author.

Figure 4

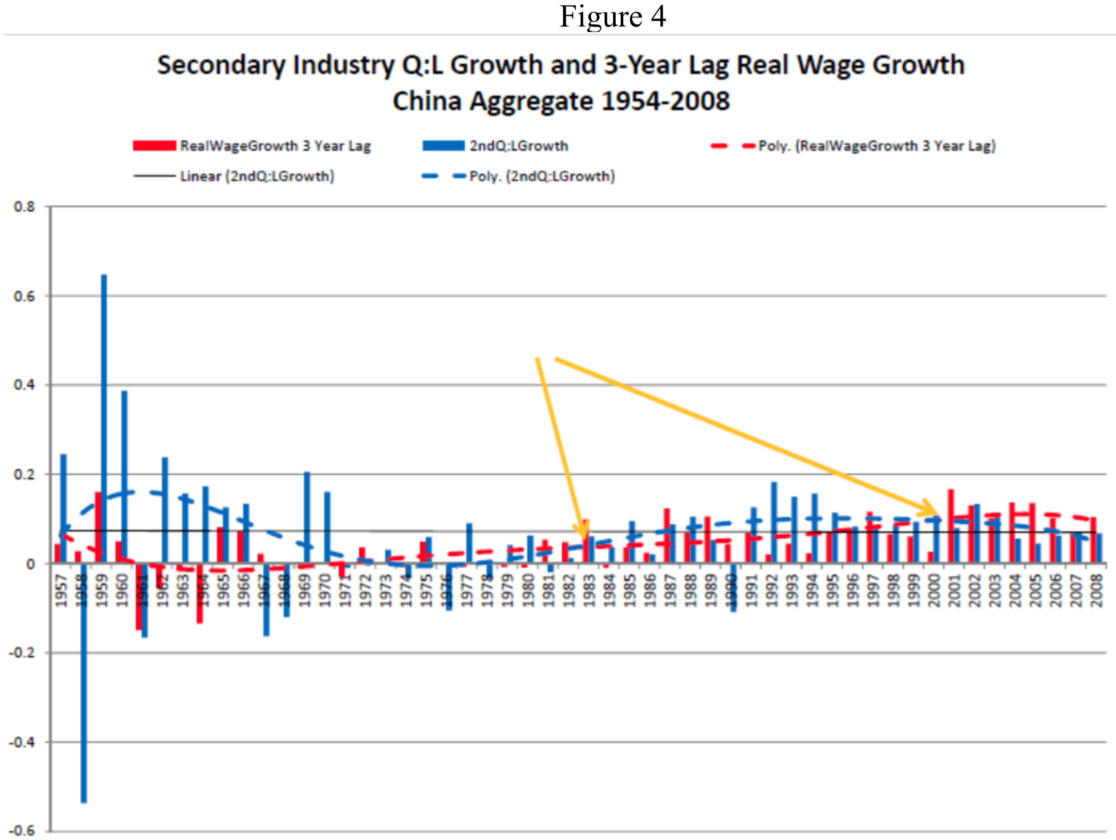


Figure 5

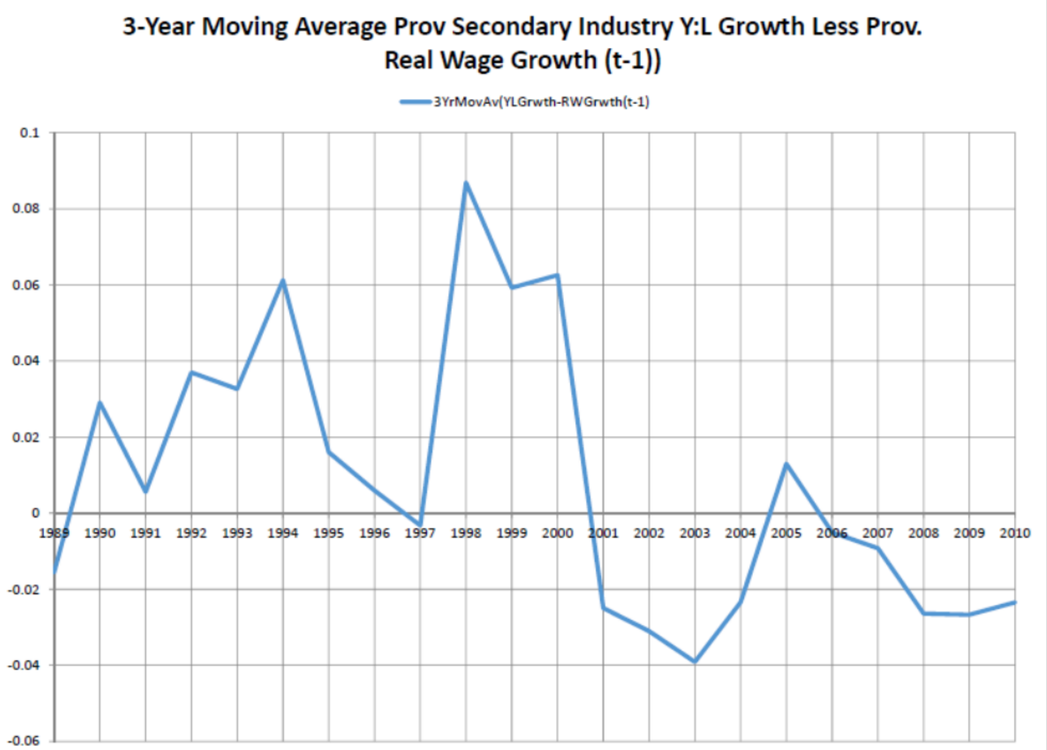


Figure6 (a) Regression of $\frac{Y_{it}}{W_{it}}$ on W_{pt} and 95% Confidence Interval

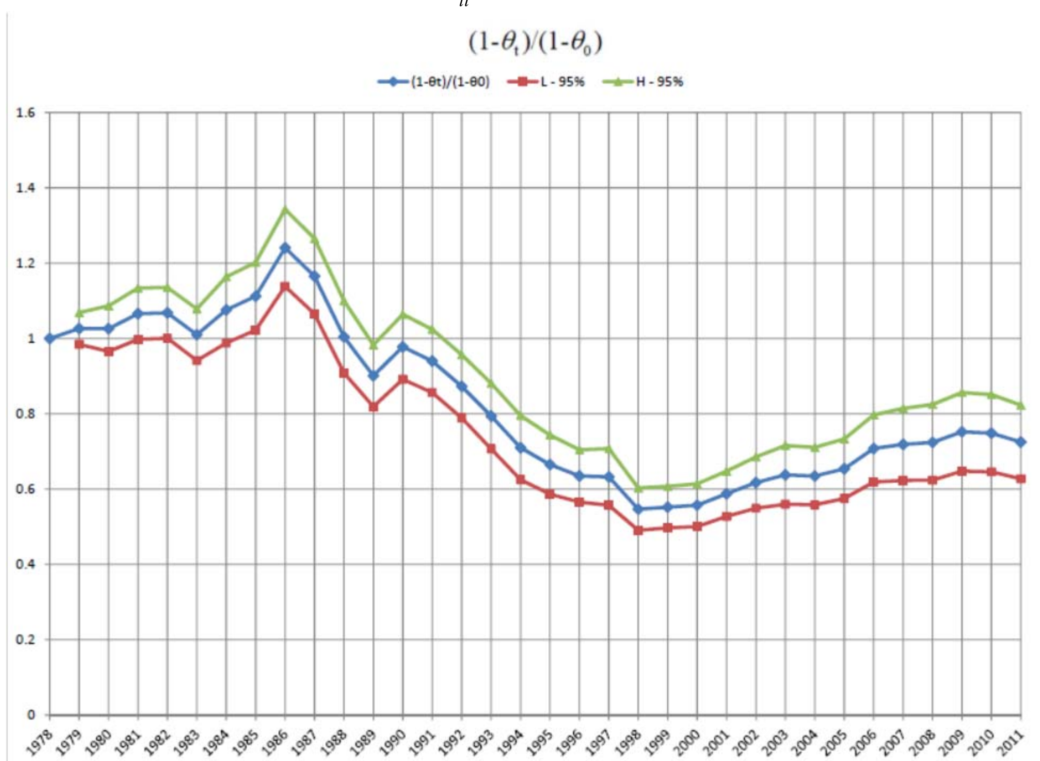


Figure 6 (b) First Difference Estimate of $\frac{Y_{it}}{W_{it}}$ on W_{pt} and 95% Confidence Interval

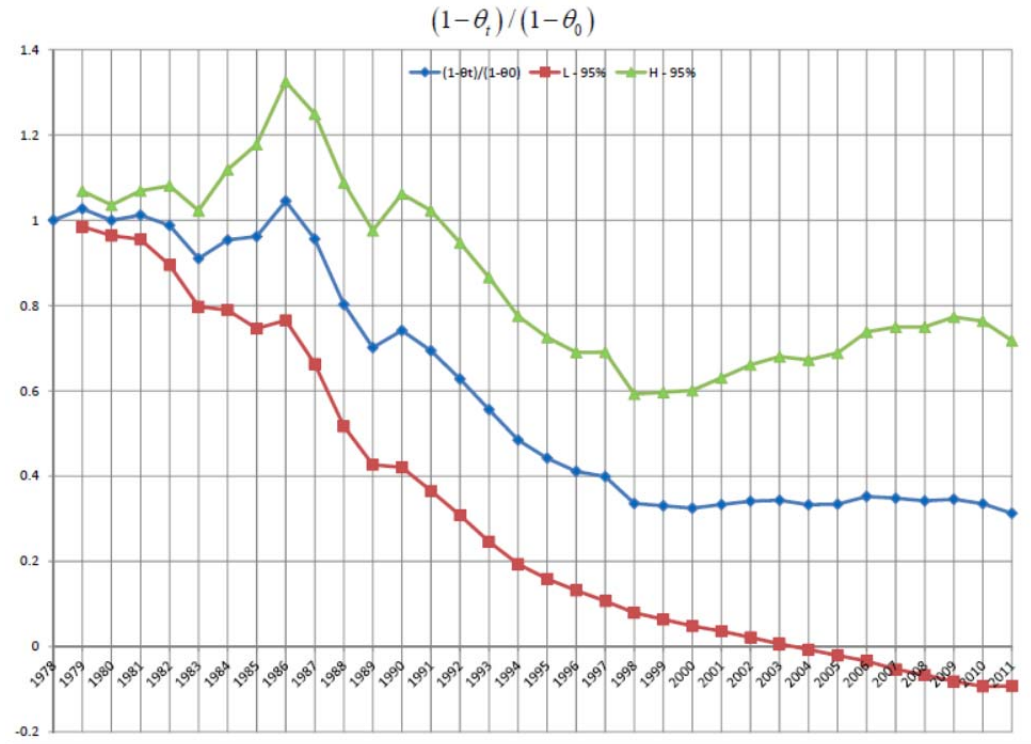
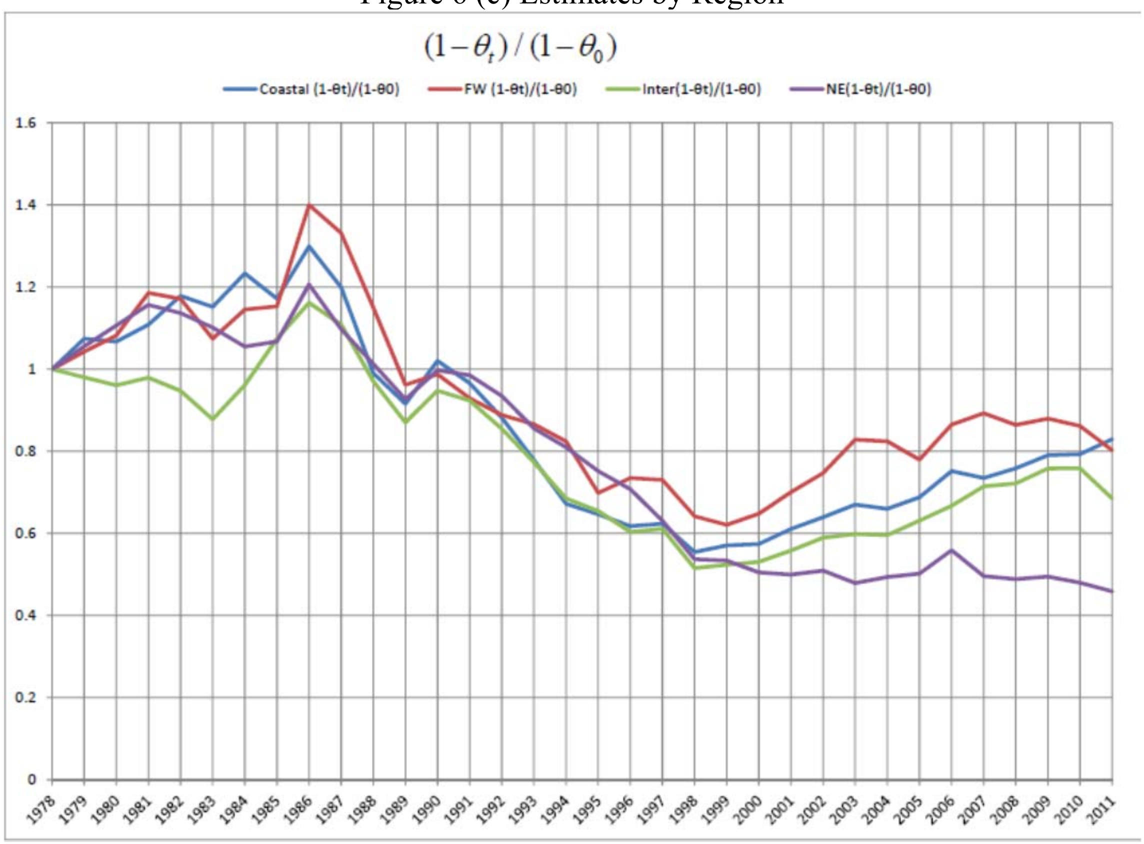
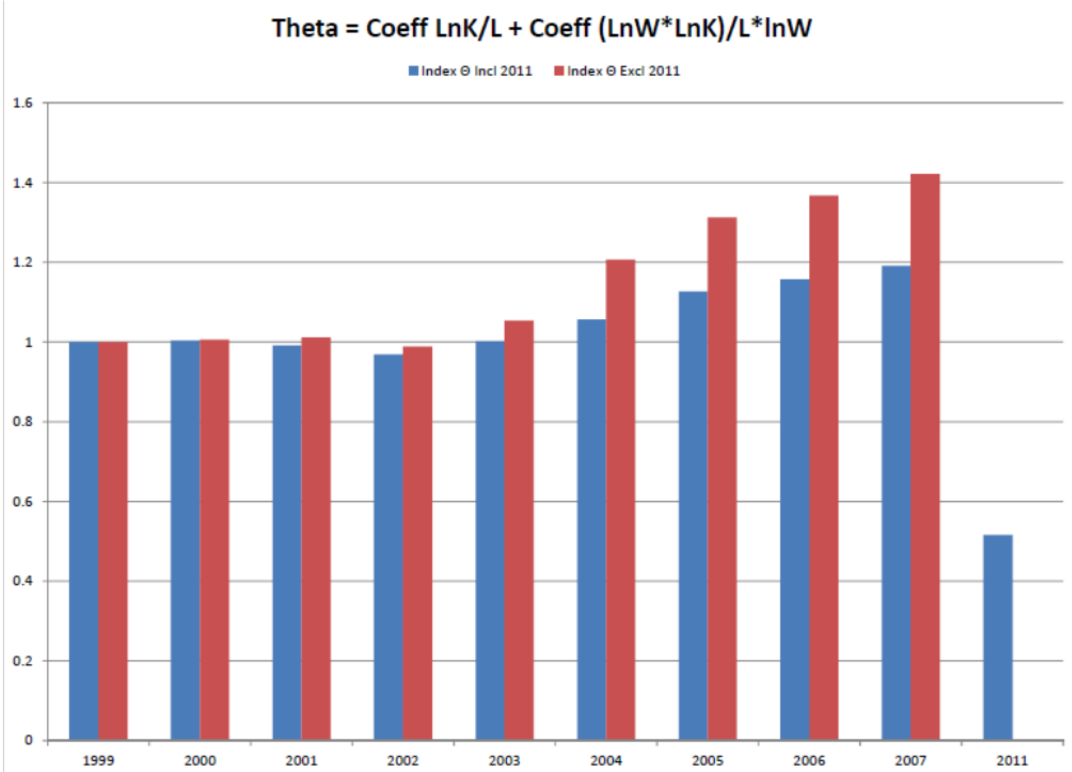


Figure 6 (c) Estimates by Region



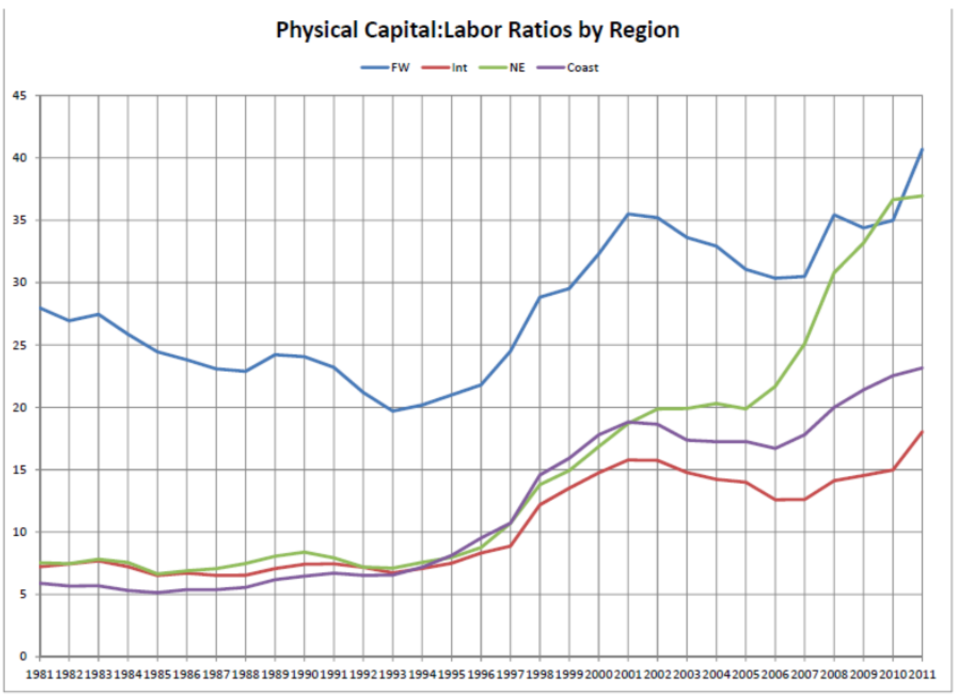
Source: Authors'calculations. Regions are Coastal (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan);Interior (Shanxi, inner Mongolia, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi, Xichuan, Chongqing, Guizhou, Yunnan, and Shaanxi); Northeast (Liaoning, Jilin, and Heilongjiang); and Far West (Gansu, Qinghai,Ningxia, and Xinjiang)

Figure 7 Estimates of θ 1999-2011



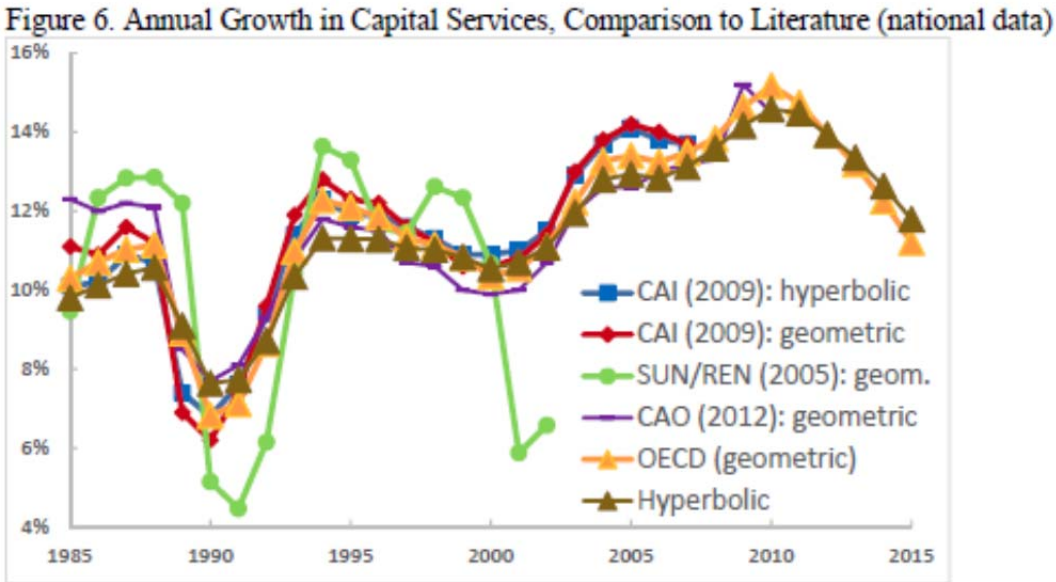
Source: Authors' calculations from LME data

Figure 8 Capital:Labor Ratios by Region



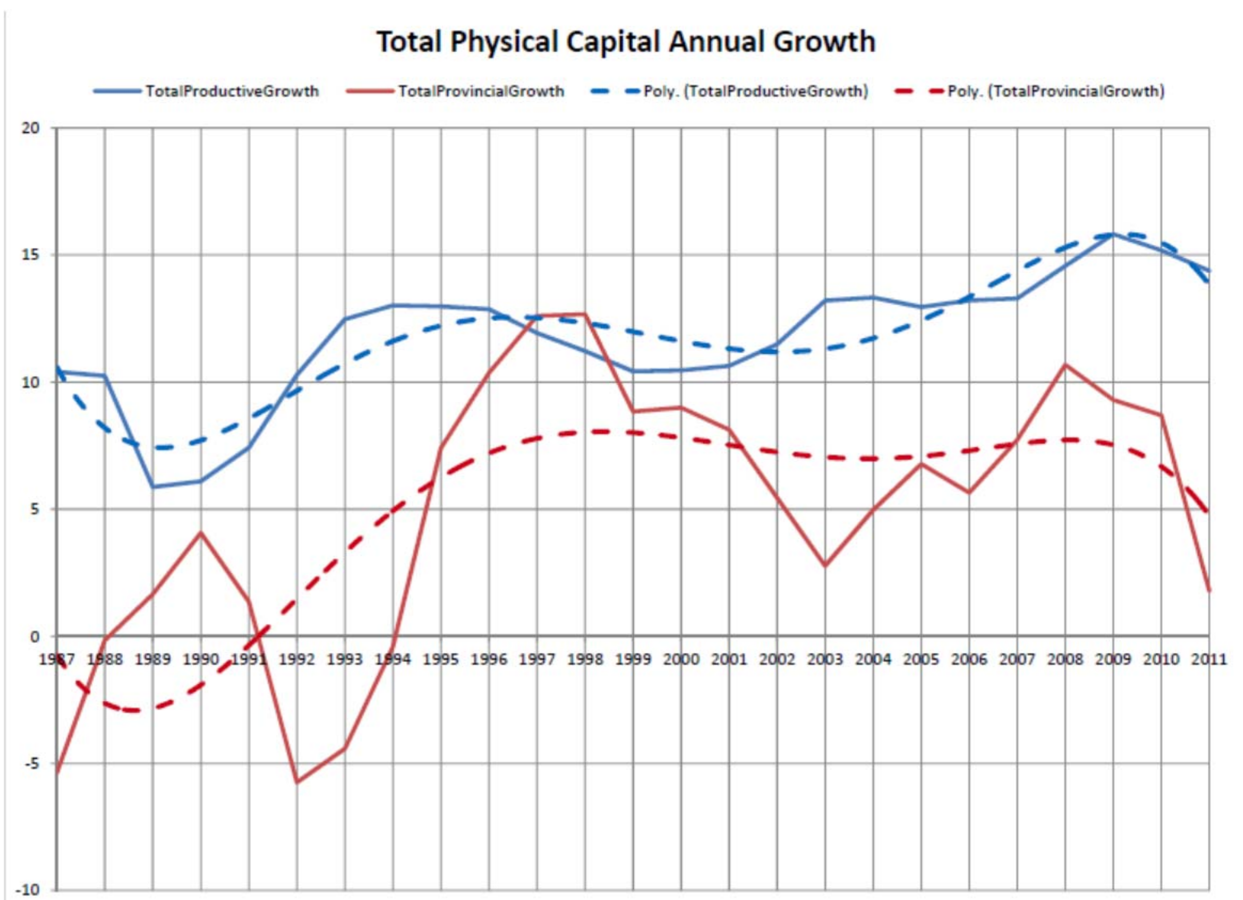
Source: Authors' calcuations. Regions are Coastal (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan);Interior (Shanxi, inner Mongolia, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi, Xichuan, Chongqing, Guizhou, Yunnan, and Shaanxi); Northeast (Liaoning, Jilin, and Heilongjiang); and Far West (Gansu, Qinghai,Ningxia, and Xinjiang)

Figure 9 Annual Growth in Capital Services %



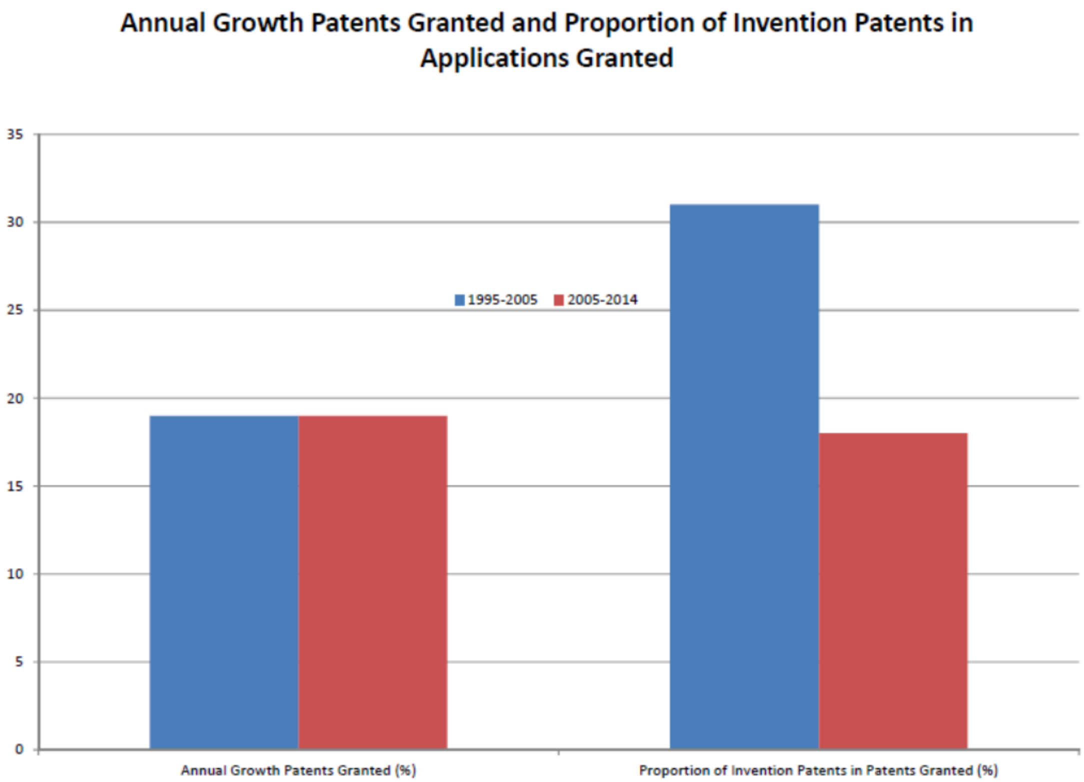
Source: Holz, 2016

Figure 10 Annual Growth of Capital Stock (%)



Source: Gao, Lu, & Meng (2017) and authors' calculations based on Wu (2017)

Figure 11



Source: Wei, Xie, & Zhang (2017)

Table 1

Secondary Industry Output:Labor Ratio

	Log Y/L	
VARIABLES	(1)	(2)
Log R Wage (t-1)	1.670* (0.746)	0.503 (0.829)
Post-2000 x Log R Wage (t-1)		0.709 (0.502)
Log K Stock (t-1)	-0.197 (0.137)	-0.048 (0.168)
Post-2000 x Log K Stock (t-1)		0.053 (0.106)
Observations	803	803
R-squared	0.982	0.984
Number of code	31	31
Years	1986-2012	1986-2012
Test Beta = 1 p-val	0.34	
Weak ID Stat	10.09	4.297

Robust standard errors in parentheses
** p<0.01, * p<0.05, * p<0.1

Notes: i K is exogenous.
ii IV for Real Wage is the size of the primary labor force lagged 8 years.
iii Regressions include year effects, year x region fixed effect for regions Coast, West, Far West, and Northeast, and Province x Current Year -1986), and Province FE.

Table 2 Secondary Industry Output:Labor Ratio

Levels				First Differences			
Year	$(1-\theta_t)/(1-\theta_0)$	L - 95%	H - 95%	Year	$(1-\theta_t)/(1-\theta_0)$	L - 95%	H - 95%
1978	1.00			1978	1.00		
1979	1.03	0.98	1.07	1979	1.03	0.99	1.07
1980	1.03	0.97	1.09	1980	1.00	0.96	1.04
1981	1.07	1.00	1.13	1981	1.01	0.95	1.07
1982	1.07	1.00	1.14	1982	0.99	0.89	1.08
1983	1.01	0.94	1.08	1983	0.91	0.80	1.02
1984	1.08	0.99	1.16	1984	0.95	0.79	1.12
1985	1.11	1.02	1.20	1985	0.96	0.75	1.18
1986	1.24	1.14	1.34	1986	1.04	0.77	1.32
1987	1.17	1.07	1.27	1987	0.96	0.66	1.25
1988	1.00	0.91	1.10	1988	0.80	0.52	1.09
1989	0.90	0.82	0.98	1989	0.70	0.43	0.98
1990	0.98	0.89	1.06	1990	0.74	0.42	1.06
1991	0.94	0.86	1.02	1991	0.69	0.37	1.02
1992	0.87	0.79	0.96	1992	0.63	0.31	0.95
1993	0.79	0.71	0.88	1993	0.56	0.25	0.87
1994	0.71	0.62	0.80	1994	0.48	0.19	0.77
1995	0.67	0.59	0.74	1995	0.44	0.16	0.73
1996	0.63	0.57	0.70	1996	0.41	0.13	0.69
1997	0.63	0.56	0.71	1997	0.40	0.11	0.69
1998	0.55	0.49	0.60	1998	0.34	0.08	0.59
1999	0.55	0.50	0.61	1999	0.33	0.06	0.60
2000	0.56	0.50	0.61	2000	0.32	0.05	0.60
2001	0.59	0.53	0.65	2001	0.33	0.04	0.63
2002	0.62	0.55	0.69	2002	0.34	0.02	0.66
2003	0.64	0.56	0.72	2003	0.34	0.01	0.68
2004	0.63	0.56	0.71	2004	0.33	-0.01	0.67
2005	0.65	0.58	0.73	2005	0.33	-0.02	0.69
2006	0.71	0.62	0.80	2006	0.35	-0.03	0.74
2007	0.72	0.62	0.81	2007	0.35	-0.05	0.75
2008	0.72	0.62	0.82	2008	0.34	-0.07	0.75
2009	0.75	0.65	0.86	2009	0.35	-0.08	0.77
2010	0.75	0.65	0.85	2010	0.34	-0.09	0.76
2011	0.73	0.63	0.82	2011	0.31	-0.09	0.72

Table 3a
Primary & Secondary Industry Output:Labor Ratio

Variables	Log Y/L				
	(1)		(2)		(3)
Log K/L	0.00148 (2.24)	Log K/L	0.0080 (11.0)	Log K/L	.0024 (3.57)
Log K/L xLogWage	0.096 (621)	*Log K/L x LogWage	.110 (174)	*Log K/L x LogWage	.096 (595)
		(LogK/LxLogW) 2000	0.104 (172)	(K:LxW) **I	0.103 (538)
		(LogK/LxLogW) 2001	0.098 (173)	(K:LxW)**NE	0.086 (331)
		(LogK/LxLogW) 2002	0.092 (169)	(K:LxW)**FW	0.069 (145)
		(LogK/LxLogW) 2003	0.092 (177)		
		(LogK/LxLogW) 2004	0.089 (189)		
		(LogK/LxLogW) 2005	0.091 (197)		
		(LogK/LxLogW) 2006	0.090 (206)		
		(LogK/LxLogW) 2007	0.088 (218)		
		(LogK/LxLogW) 2011	0.097 (560)		
Constant	2.39 (706)		2.26 (397)		2.38 (705)
Adj R-Squared	0.30		0.30		
Years	1999-2007 &2011				
N >2,450,000					

Notes: Sample consists of all large and medium enterprises in China. Industries covered include primary and secondary industries, with most enterprises in secondary industry. All regressions include year fixed-effect dummy variables. T-values in parentheses.
* The coefficient in column (2) represents that for the year 1999 and in column (3) that for the Coastal region.
** Regions are Coastal (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan);Interior (Shanxi, inner Mongolia, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi, Xichuan, Chongqing, Guizhou, Yunnan, and Shaanxi); Northeast (Liaoning, Jilin, and Heilongjiang); and Far West (Gansu, Qinghai,Ningxia, and Xinjiang).

Table 3b

Primary & Secondary Industry Output:Labor Ratio

Variables	Log Y/L				
	(1)		(2)		(3)
Log K/L	-0.095 (-98)	Log K/L	-0.093 (-96)	Log K/L	-0.091 (-92)
Log K/L xLogWage	0.116 (432)	*Log K/L x LogWage	.131 (205)	*Log K/L x LogWage	.117 (433)
		(LogK/LxLogW) 2000	0.125 (204)	(K:LxW) **I	0.116 (361)
		(LogK/LxLogW) 2001	0.120 (207)	(K:LxW)**NE	0.114 (293)
		(LogK/LxLogW) 2002	0.114 (204)	(K:LxW)**FW	0.085 (153)
		(LogK/LxLogW) 2003	0.114 (213)		
		(LogK/LxLogW) 2004	0.114 (232)		
		(LogK/LxLogW) 2005	0.116 (238)		
		(LogK/LxLogW) 2006	0.114 (248)		
		(LogK/LxLogW) 2007	0.111 (261)		
Constant	2.60 (706)		2.49 (427)		2.60 (715)
Adj R-Squared	0.26		0.26		0.26
Years	1999-2007				
N >1,910,000					

Notes: Sample consists of all large and medium enterprises in China. Industries covered include primary and secondary industries, with most enterprises in secondary industry. All regressions include year fixed-effect dummy variables. T-values in parentheses.

* The coefficient in column (2) represents that for the year 1999 and in column (3) that for the Coastal region.

** Regions are Coastal (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan);Interior (Shanxi, inner Mongolia, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi, Xichuan, Chongqing, Guizhou, Yunnan, and Shaanxi); Northeast (Liaoning, Jilin, and Heilongjiang); and Far West (Gansu, Qinghai,Ningxia, and Xinjiang).

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Technical Appendix

Purpose: use Acemoglu's model to construct an example to show how the wage-induced technology change affects the share parameters in the production function.

Acemoglu's Model (JPE 2010)

Economy M: Monopoly Equilibrium

- There is a continuum of identical firms (denoted by the set $\mathcal{F}$) that produce the final good using two factors of production, labor and capital. The price of the final good is normalized to one.
- Technologies are created and supplied by a profit-maximizing monopolist.
- In Acemoglu's M economy (Section C, p.1046), the supplies of the production factors are assumed to be given. In our setup, we assume the supply of K ($\bar{K} \geq \int_{i\in\mathcal{F}} K_i \, di$) and W are given: the goal is to show how wage affects the advancement of price-induced technologies.

Final-Good Producers

The firm i's objective function:

$$\max_{K,L,q(\theta)} \alpha^{-\alpha}(1-\alpha)^{-1}\left(K_i^{\theta}L_i^{1-\theta}\right)^{\alpha} q_i(\theta)^{1-\alpha} - W \cdot L_i - R \cdot K_i - \chi q_i(\theta)$$

θ: technology

$q_i(\theta)$: quantity of an intermediate good embodying technology θ

χ: price of the intermediate good

$\alpha^{-\alpha}(1-\alpha)^{-1}$: a convenient normalization used in Acemoglu (2010)

FOCs:

$[L]$: $W = \alpha^{1-\alpha}(1-\alpha)^{-1}(1-\theta)\left(K_i^{\theta}L_i^{1-\theta}\right)^{\alpha-1} K_i^{\theta}L_i^{-\theta} q_i(\theta)^{1-\alpha}$

$[K]$: $R = \alpha^{1-\alpha}(1-\alpha)^{-1}\theta\left(K_i^{\theta}L_i^{1-\theta}\right)^{\alpha-1} K_i^{\theta-1}L_i^{1-\theta} q_i(\theta)^{1-\alpha}$

$[q_i(\theta)]$: $\alpha^{-\alpha}(1-\alpha)^{-1}(1-\alpha)\left(K_i^{\theta}L_i^{1-\theta}\right)^{\alpha} q_i(\theta)^{-\alpha} = \chi$

⇨ $q_i(\theta) = \alpha^{-1}\chi^{-1/\alpha}\left(K_i^{\theta}L_i^{1-\theta}\right)$

$$\begin{aligned} W &= \alpha^{1-\alpha}(1-\alpha)^{-1}(1-\theta)\left(K_i^{\theta}L_i^{1-\theta}\right)^{\alpha-1} K_i^{\theta}L_i^{-\theta} q_i(\theta)^{1-\alpha} \\ &= \alpha^{1-\alpha}(1-\alpha)^{-1}(1-\theta)\left(K_i^{\theta}L_i^{1-\theta}\right)^{\alpha-1} K_i^{\theta}L_i^{-\theta} [\alpha^{-1}\chi^{-1/\alpha}\left(K_i^{\theta}L_i^{1-\theta}\right)]^{1-\alpha} \\ &= (1-\alpha)^{-1}(1-\theta)K_i^{\theta}L_i^{-\theta}\chi^{(\alpha-1)/\alpha} \end{aligned}$$

⇨ $L_i = K_i\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{\frac{1}{\theta}}\chi^{\frac{\alpha-1}{\alpha\theta}}$

The Profit-Maximizing Monopolist

Assumptions:

(1) A technology θ is created at a cost $C(\theta)$.

$\theta = \frac{1}{1+e^{\phi}}$ ➔ $\phi = \ln(\frac{1}{\theta} - 1)$

Assume $C(\theta) = \left[\ln\left(\frac{1}{\theta} - 1\right)\right]^2$.

(2) Once the technology θ is created, the unit production cost is assumed to be $\frac{1-\alpha}{1-\alpha+\alpha\theta}$ units of the final good (the price of the final good is normalized to 1) ➔ the unit production cost of the intermediate good is $\frac{1-\alpha}{1-\alpha+\alpha\theta}$).

$$\max_{\chi,\theta}\left(\chi - \frac{1-\alpha}{1-\alpha+\alpha\theta}\right)\cdot\int_{i\in\mathcal{F}}\alpha^{-1}\chi^{-1/\alpha}\left(K_i^{\theta}L_i^{1-\theta}\right)di - C(\theta)$$

By substituting $L_i = K_i\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{\frac{1}{\theta}}\chi^{\frac{\alpha-1}{\alpha\theta}}$ into the objective function of the monopolist, we can obtain

$$\max_{\chi,\theta}\left(\chi - \frac{1-\alpha}{1-\alpha+\alpha\theta}\right)\cdot\alpha^{-1}\overline{K}\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{\frac{1-\theta}{\theta}}\chi^{\frac{\alpha-1-\alpha\theta}{\alpha\theta}} - C(\theta)$$

$[\chi]$: $\chi^{\frac{\alpha-1-\alpha\theta}{\alpha\theta}} + \left(\chi - \frac{1-\alpha}{1-\alpha+\alpha\theta}\right)\frac{\alpha-1-\alpha\theta}{\alpha\theta}\chi^{\frac{\alpha-1-\alpha\theta}{\alpha\theta}-1} = 0$

⇨ $\chi = 1$

Given $\chi = 1$, The problem of the monopolist can be simplified as follows:

$$\max_{\theta}\frac{\theta}{1-\alpha+\alpha\theta}\cdot\overline{K}\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{\frac{1-\theta}{\theta}} - \left[\ln\left(\frac{1}{\theta}-1\right)\right]^2 \qquad (1)$$

FOC: $\frac{1}{1-\alpha+\alpha\theta}\overline{K}\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{(1-\theta)/\theta}\left(\frac{\alpha\theta}{1-\alpha+\alpha\theta} + \frac{1}{\theta}\ln\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)\right) = 2\ln(\frac{1}{\theta} - 1)\frac{1}{\theta-\theta^2}$

For the existence of θ^*, we require $(1-\alpha)W$ to be greater than 1: $\lim_{\theta\to 0}\frac{\theta}{1-\alpha+\alpha\theta}\overline{K}\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{(1-\theta)/\theta} = 0 < \lim_{\theta\to 0}\left[\ln\left(\frac{1}{\theta}-1\right)\right]^2$

$\lim_{\theta\to 1}\frac{\theta}{1-\alpha+\alpha\theta}\overline{K}\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{(1-\theta)/\theta} = \frac{\overline{K}}{1-\alpha} < \lim_{\theta\to 1}\left[\ln\left(\frac{1}{\theta}-1\right)\right]^2$

It is easy to show that the LHS of (1) is positive given $(1-\alpha)W > 1$ and its RHS is positive only when $\theta > 0.5$, so θ^* must be between 0.5 and 1.

The objective function of the monopolist has strictly increasing differences in (W, θ) if and only if $\frac{\partial^2 \frac{\theta}{1-\alpha+\alpha\theta}\overline{K}\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{(1-\theta)/\theta}}{\partial W \partial\theta} > 0$.

$$\frac{\partial^2 \frac{\theta}{1-\alpha+\alpha\theta}\overline{K}\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{(1-\theta)/\theta}}{\partial W \partial\theta} = \frac{1}{1-\alpha+\alpha\theta}\overline{K}\left(\frac{1-\theta}{W}\right)^{1/\theta}\left(\frac{1}{1-\alpha}\right)^{(1-\theta)/\theta}\frac{1}{\theta^2}\left[\frac{\alpha\theta^2}{1-\alpha+\alpha\theta} + \ln\left(\frac{1}{1-\alpha}\right) + \ln\left(\frac{1-\theta}{W}\right) + \frac{\theta}{1-\theta}\right]$$

$\frac{\partial^2 \frac{\theta}{1-\alpha+\alpha\theta}\overline{K}\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{\frac{1-\theta}{\theta}}}{\partial W \partial\theta} > 0$ requires that $W < \frac{1-\theta}{1-\alpha}e^{\frac{\alpha\theta^2}{1-\alpha+\alpha\theta}+\frac{\theta}{1-\theta}}$. It is easy to show that $\frac{1-\theta}{1-\alpha}e^{\frac{\alpha\theta^2}{1-\alpha+\alpha\theta}+\frac{\theta}{1-\theta}}$ is strictly increasing in θ. Then, we define W_{max} as $\frac{1-0.5}{1-\alpha}e^{\frac{\alpha\times 0.5^2}{1-\alpha+\alpha\times 0.5}+\frac{0.5}{1-0.5}}$, which should be larger than $\frac{1}{1-\alpha}$. Please note that $W < W_{max}$ is only a sufficient condition to ensure the objective function of the monopolist has strictly increasing differences in (W, θ).

Given that a the objective function is continuously differentiable in θ, b $\frac{1}{1-\alpha} < W < W_{max}$ (which ensures that the existence of the solution and the objective function of the monopolist has strictly increasing differences in (W, θ)), and (c) the solution is strictly between 0.5 and 1, Topkis's theorem implies that $\frac{\partial\theta^*}{\partial W} > 0$. In other words, the increase in W encourages technological advancement, which we can call it as the wage-induced technical change.

$$\frac{\partial^2 \frac{\theta}{1-\alpha+\alpha\theta}\overline{K}\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{(1-\theta)/\theta}}{\partial \overline{K} \partial\theta} = \frac{1}{1-\alpha+\alpha\theta}\left(\frac{1-\theta}{1-\alpha}\frac{1}{W}\right)^{(1-\theta)/\theta}\left[\frac{1-\alpha}{1-\alpha+\alpha\theta} + \frac{1}{\theta}\ln\left(\frac{W(1-\alpha)}{1-\theta}\right) - 1\right].$$

Given $\frac{1}{1-\alpha} < W < W_{max}$, it is easy to show that $\frac{1-\alpha}{1-\alpha+\alpha\theta} + \frac{1}{\theta}\ln\left(\frac{W(1-\alpha)}{1-\theta}\right) - 1 > 0$. In other words, the objective function of the monopolist has strictly increasing differences in $(\overline{K}, \theta)$. Then, by the same token, Topkis's theorem implies that $\frac{\partial\theta^*}{\partial\overline{K}} > 0$. In this regime, the increase in capital will also encourage technological advancement.

Output Per Worker

$$\frac{\alpha^{-\alpha}(1-\alpha)^{-1}\left(\overline{K}^{\theta}L^{1-\theta}\right)^{\alpha}q(\theta)^{1-\alpha}}{L} = \frac{\alpha^{-\alpha}(1-\alpha)^{-1}\left(\overline{K}^{\theta}L^{1-\theta}\right)^{\alpha}\left(\alpha^{-1}\left(\overline{K}^{\theta}L^{1-\theta}\right)\right)^{1-\alpha}}{L}$$

$$= \frac{\alpha^{-1}(1-\alpha)^{-1}\overline{K}^{\theta}L^{1-\theta}}{L}$$

$$= \alpha^{-1}(1-\alpha)^{-1}\overline{K}^{\theta}L^{-\theta}$$

$$= \alpha^{-1}(1-\alpha)^{-1}\frac{W(1-\alpha)}{1-\theta}$$

$$= \frac{W}{\alpha(1-\theta)}$$

If θ is fixed, the output per worker increases with W. If the wage-induced technical change is allowed ($W \uparrow \Rightarrow \theta \uparrow$), it will further increase the output per worker.

There is a wage-induced technical change that increases the output-labor ratio more than what would be expected on the basis of a pure substitution of K for L under fixed technology.

In addition, an increase in K will not affect the output per worker under fixed technology. If a price-induced technical change is allowed, an increase in K will increase the output per worker.

Marginal Product of Capital (MPK)

$$MPK = \frac{\partial\left\{\alpha^{-\alpha}(1-\alpha)^{-1}\left(\bar{K}^{\theta}L^{1-\theta}\right)^{\alpha}q(\theta)^{1-\alpha}\right\}}{\partial\bar{K}}$$

$$= \frac{\theta\alpha^{1-\alpha}(1-\alpha)^{-1}\left(\bar{K}^{\theta}L^{1-\theta}\right)^{\alpha}\left(\alpha^{-1}\left(\bar{K}^{\theta}L^{1-\theta}\right)\right)^{1-\alpha}}{\bar{K}}$$

$$= \theta(1-\alpha)^{-1}\left(\frac{\bar{K}}{L}\right)^{\theta-1}$$

$$= \theta(1-\alpha)^{-1}\left(\frac{1-\theta}{(1-\alpha)W}\right)^{\frac{1-\theta}{\theta}}$$

$$\Rightarrow \left.\frac{\partial MPK}{\partial W}\right|_{\theta} < 0 \text{ and } \frac{\partial MPK}{\partial \theta} = -\frac{1}{\theta}\left(\frac{1-\theta}{(1-\alpha)W}\right)^{\frac{1-\theta}{\theta}}\ln\left(\frac{1-\theta}{(1-\alpha)W}\right) > 0$$

Under fixed technology, an increase in wage will lower MPK. A wage-induced technical change will attenuate the negative impact of the wage increase on MPK.

Holding W constant, an increase in K will not affect MPK under fixed technology. If there is induced technical change, an increase in K will increase MPK ($\frac{\partial MPK}{\partial \theta} > 0, \frac{\partial \theta^*(K)}{\partial K} > 0$).

Summary

In the model, the policy variables are K and W.

(i) Given K, θ^* increases with W: an increase in W will encourage technological advancement, which we could call it as a wage-induced technical change .

(ii) Given W, θ^* increases with K: an increase in K will encourage technological advancement.

(iii) Under fixed technology, the output per worker will increase with W (holding K fixed).

(iv) A wage-induced technical change will increase the output per worker more than what would be expected on the basis of a pure substitution of K for L under fixed technology.

(v) An increase in K will not affect the output per worker under fixed technology (holding W fixed). If there is a wage-induced technical change, an increase in K will increase the output per worker.

(vi) Holding K fixed, an increase in W will lower MPK under fixed technology. A wage-induced technical change will attenuate the negative impact of the wage increase on MPK.

(vii) Holding W constant, an increase in K will not increase MPK under fixed technology. There is induced technical change, an increase in K will increase MPK ($\frac{\partial MPK}{\partial \theta} > 0, \frac{\partial \theta^*}{\partial \bar{K}} > 0$).