Centre for International Capital Markets

Discussion Papers

ISSN 1749-3412

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No 2010-6

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London Metropolitan University, UK

March 2010

Abstract

This paper carries out an empirical investigation of the contribution of rural transformation, which can produce efficiency gains over and above those associated with technical progress, to total factor productivity in China during 1970-2008. For the first time for China, the roles of rural transformation and technical progress are examined whilst structural breaks are taken into account. We employ Bai and Perron (1998, 2003a, b) methods which allow for multiple structural breaks at unknown dates and can be applied for both pure and partial structural changes. We also evaluate the robustness of our results by employing alternative production functions and two capital series. A structural break near the end of the pre-reform period is identified for both capital series and another one near the Tiananmen Square incident in 1989 for the extended Chow and Li (2002) capital series. We found the contribution of rural transformation to total factor productivity to be significant and positive across all regimes. In contrast, the effect of technical progress was negative in the pre-reform period but positive in the post-reform period.

Keywords: Structural breaks; Rural transformation; Total factor productivity; China

JEL classification: O30, O47, O53

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* *Acknowledgement:* We would like to thank Fung Kwan, Wei Chi, Xiaoye Qian and Xiaobo Zhang for their comments on an earlier version of the paper presented at the Chinese Economists Society 2008 Macao Conference, University of Macau. The opinions expressed in the paper and any remaining errors are our responsibility. We are also very thankful to Professor Bai and Ms Zhenjie Qian for sending us data of real capital stock 1952-2005.

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1. Introduction

A few studies have highlighted the efficiency gains in the post-reform period resulted from the reallocation of labor across sectors in China. For instance, World Bank (1996) finds that during 1985-1994, the movement of labor from agriculture to industry and to a lesser extent services contributes about one percentage point to aggregate GDP growth. More recently, Brandt, Hsieh and Zhu (2008) employ data during 1978-2004 and also find the contribution of labor reallocation from agriculture to non-agriculture is about one percentage point to output growth. Bosworth and Collins (2008) divide the post reform period into two sub-periods 1978-1993 and 1994-2004 and find labor reallocation out of agricultural sector accounts for 1.7 and 1.2 percentage points of aggregate GDP growth. As argued by Woo (1998), intersectoral shift of labor (away from agriculture to other sectors) increases aggregate output when the marginal product of labor in the agricultural sector is lower than that in the industrial and services sectors.

However, these studies are based on growth accounting rather than on an econometric investigation. More crucially, none of the above papers or other studies on China's productivity take structural breaks into account. There have been dramatic economic and political changes in China in the past few decades (e.g. the implementation of reform and opening up policy in 1978, Tiananmen Square incident in 1989, Deng Xiaoping Southern Tour in 1992). Ignoring structural breaks could lead to inaccurate inferences on China's productivity growth. This is true not only for studies covering both pre- and post-reform periods, but also for those that cover only the post-reform period. In order to investigate the possibility of multiple structural changes, we employ the Bai and Perron (1998, 2003a, b) stochastic multiple structural break model which tests for the presence of multiple structural breaks occurring at unknown dates and provides an estimate of the breakpoints. It also has the flexibility of allowing for partial structural breaks, where only some of the coefficients are allowed to change over time, as well as pure structural breaks, where all coefficients are allowed to change over time.

Furthermore, most studies that investigate China's productivity growth employ only the Cobb-Douglas production function, which assumes unity elasticity of substitution and constant returns to scale[1]. We also examine the role of rural transformation under two alternative production functions, i.e. Constant Elasticity of Substitution (CES) and Variable Elasticity of Substitution (VES) functions, which allow these two restrictions to be relaxed in order to investigate whether the role of rural transformation remains robust.

We employ two alternative capital series to evaluate whether the results are sensitive to the choice of capital measurement[2]. The two capital series are extended from Chow and Li (2002) and Bai *et al*. (2006a). To our knowledge, it is the first time the capital series of Bai et al (2006a) is used to estimate production functions for China.

The paper is organised as follows: Section 2 specifies the Cobb-Douglas production function that incorporates rural transformation. Section 3 explains the structural break test. Section 4 discusses measurement of variables and data sources. Section 5 reports the estimates of break dates and estimates of the Cobb-Douglas production function. Section 6 applies the break dates to CES and VES production functions. Section 7 presents the estimates of total and net factor productivity and discusses the contribution of rural transformation to total factor productivity. Section 8 compares our findings with previous studies. Section 9 concludes.

[1] To our knowledge, existing studies examining alternative forms of production functions for China are not at aggregate level (e.g. Jia, 1991; Bairam, 1999; Xu, 1999) or include China in a large panel (e.g. Duffy and Papaggeorgiou, 2000; Karagiannis *et al*, 2004).

[2] It is interesting to note that all previous studies have used only one capital series.

2. The Production Function

Following Chow and Li (2002), the Cobb-Douglas production function can be written as

$$y = Ak^{\alpha} = e^{\beta t}k^{\alpha}; \tag{1}$$

where y and k denote real output per labor and real capital stock per labor respectively, A measures total factor productivity (TFP), β measures the effect of technical progress, and α is the capital share of income.

China's transformation from central-planned to market-oriented economy is characterized by "rural transformation". It refers to both rural-urban migration and rural industrialization. The former refers to the internal labor migration from countryside to cities (Zhao, 1999a, b; Zhang and Song, 2003). The latter refers to the establishment of rural enterprises (e.g. Town and Village Enterprises) which attracts farmers out of the field (Wang 1999; Zhu, 2000). Both result in shifts of labor from low productivity agricultural sector to more productive industrial and services sectors. Therefore, even if the levels of technology in different sectors remain unchanged, labor flows from sectors with lower marginal productivity of labor to sectors with higher marginal productivity of labor will increase the TFP. In other words, for a country like China with enormous labor surplus, it is not only the total number of effective labor that matters for output growth; the distribution of effective labor also matters.

Therefore, in our study we decompose TFP into net factor productivity (NFP) and rural transformation (RT). NFP captures the pure technical progress and RT captures the effeciency gains resulted from rural transformation. Hence the production function takes the following form:

$$y = TFPk^{\alpha} = (NFP)(RT^{\gamma})k^{\alpha} = (e^{\beta t})(RT^{\gamma})k^{\alpha} \tag{2}$$

where γ measures the effect of RT on TFP.

Taking logarithms of equation (2) yields the following equation which is used in the econometric estimations in Section 5:

$$\ln y_t = c + \alpha \ln k_t + \beta t + \gamma \ln(RT)_t + u_t \tag{3}$$

3. Structural Break Test – Bai and Perron (1998, 2003a, b)

As emphasised earlier, China's economy had been subjected to major political and economic policy changes in the past few decades. In order to identify these structural changes, we use the multiple structural break model of Bai and Perron (1998, 2003a, b) (BP thereafter). They consider the following multiple linear regression with m breaks:

$$y_t = x_t'\beta + z_t'\delta_j + u_t \qquad t = T_{j-1}+1,...,T_j \tag{4}$$

for $j = 1,...,m+1$. In this model, y_t is the dependent variable; $x_t(p\times 1)$ and $z_t(q\times 1)$ are vectors of covariates and β and δ_j are corresponding vectors of coefficients; u_t is the error term. The breaks points ($T_1,...,T_m$) are treated as unknown and conventionally $T_0 = 0$ and $T_{m+1} = T$. As β is not subject to structural change whilst δ_j is, this model is a pure structural break model when $p = 0$ and a partial structural break model when otherwise.

Regarding the method of estimation, the following objective function is employed

$$(\hat{T}_1,...,\hat{T}_m) = \arg\min_{T_1,...,T_m} S_T(T_1,...,T_m) \tag{5}$$

where the sum of the squared residuals

$$S_T(T_1,...,T_m) = \sum_{i=1}^{m+1} \sum_{T_{i-1}+1}^{T_i} (y_t - x_t'\beta - z_t'\delta_j)^2 \ . \tag{6}$$

The breakpoints estimators ($\hat{T}_1,...,\hat{T}_m$) are obtained such that the objective function is minimized. As the minimization is taken over all partitions ($T_1,...,T_m$) (note that $T_i - T_{i-1} \geq q$), the break-point estimators are global minimizers of the objective function and the coefficients estimators $\hat{\beta}$ and $\hat{\delta}_j$ are ones associated with the $m-$partition $\{\hat{T}_j\}$.

In order to choose the number of breaks, BP first consider the F-statistics ($SupF_T(k)$ test) to test the null of no structural breaks ($m = 0$) against the alternative that there are breaks ($m = k$). Then they consider the double maximum ($UD\max$ and $WD\max$) tests, both testing the null of no structural break against an unknown number of breaks given some upper bound M. $UD\max = \max_{1\leq m\leq M} SupF_T(m)$ and $WD\max$ attaches different weights to the individual F tests so that the marginal p-values are equal across values of m. BP also provide a third set of tests, the $SupF_T(l+1|l)$ test, which rejects in favour of a $(l+1)$ breaks model if the overall minimal value of the sum of squared residuals is sufficiently smaller than the sum of squared residuals from the l break model.

The BP method has some flexible features. First, it can consider autocorrelation and heteroscedasticity in the residuals. Second, it allows for different moment matrices for the repressors in different regimes. To allow for all these features, we adopt the most general BP specification[3].

Regarding the procedure of identifying the number and location of breakpoints, BP suggest to first look at the $UD\max$ or $WD\max$ tests to see if at least one break is

[3] To be more specific, following notation of Bai and Perron (2003a), we consider the most general BP specification, i.e. cor_u=1, het_z=1. Trimming is set at $\varepsilon = 0.20$, higher than the conventional 0.15 used by most structural break studies employing the BP methods as Bai and Perron (2003a) recommend a higher value of trimming when these flexible features are allowed. Correspondingly, we have $m = 3$, i.e. a maximum of 3 breaks is allowed. GAUSS program used in BP is available from Pierre Perron's home page at http://econ.bu.edu/perron/.

present. If there is, then the number of breaks can be decided based on the $SupF_T(l+1|l)$ statistics, selecting m such that the tests $SupF_T(l+1|l)$ are insignificant for $l \geq m$. Critical values for all tests are provided by Bai and Perron (1998, 2003b, c)

4. Variable Measurement and Data Source

All data used in our study are collected from 1952 to 2008. However, Chow (1993) and Chow and Li (2002) consider the period 1958-1969 as being abnormal due to great upheavals of the Great Leap Forward movement and the Cultural Revolution. Hence we estimated the Cobb-Douglas production function for the period 1970-2008. To evaluate the robustness of the results to the choice of the capital series, we employ two real capital stock series. The first capital series, K1, is the extended series of Chow and Li (2002). The second capital series, K2, is the extended series of Bai *et al* (2006a). The other series include real GDP (Y), labor (L) and rural transformation (RT). All data are described in detail in the Appendix B. K1, K2 and Y are divided by labor and denoted by k1, k2 and y.

5. Empirical Results

We use the partial structural break model to estimate equation (3). Specifically, the constant and the coefficient for capital labor ratio are fixed for the whole sample period and coefficients for the time trend and rural transformation are allowed to vary across different regimes[4]. The results are presented in Table 1.

[4] Initially we allowed for a pure structural break (i.e. all parameters were allowed to change) in the production function. The statistics suggested there was no structural break. Then we tested the partial structural break model. First we kept the constant fixed and all other coefficients were allowed to change. When k1 was employed, one break at 1977 was identified, but the coefficient of time trend was insignificant in the second regime. When k2 was employed, one break at 1977 was identified, but the coefficient of capital share was close to unity (0.98) in the first regime, which is rather unrealistic.

When $k1$ is used, two significant breaks are identified in 1977 and 1989, dividing the whole sample period into three regimes (1970-1977, 1978-1989, 1990-2008). The first break occurred at the end of pre-reform period, and the second break happened on the year of the Tiananmen Square incident. The capital share (α), 0.3883, is highly significant but much lower than reported in Chow and Li (2002), 0.5577, where the same capital series is used for 1952-1998 (excludes 1958-1969). This implies that the inclusion of RT in the production function reduces capital share since rural transformation captures the originally ignored part of change of TFP.

The coefficient for the time trend is negative ($\beta_1 = -0.0257$) and significant in the first regime, suggesting negative technical progress before the reform and opening up policy in 1978. This finding contrasts to Chow and Li (2002) and Chow (1993), who find zero technical progress growth before 1978. For the next two post-reform regimes, we find positive ($\beta_2 = 0.0278$ and $\beta_3 = 0.0372$) and highly significant coefficients for the time trend. The highest growth rate (3.72%) for technical progress is in the last nineteen years (1990-2008) after the Tiananmen Square incident. Compared with Chow and Li (2002), who find a technical progress growth rate of 3.03% for 1978-1998, we observe a lower growth rate of technical progress during 1978-1989 but a higher one during 1990-2008 when the structural break in 1989 is accounted for.

Across all regimes, RT is positive and highly significant. It confirms our expectation that rural transformation is an important contributor to China's economic growth. In addition, we found that the coefficients of RT display a declining pattern ($\gamma_1 = 0.9062$, $\gamma_2 = 0.7436$, $\gamma_3 = 0.6593$). This implies that despite the importance of

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Second we kept the coefficient of capital fixed and all other coefficients were allowed to change. When k1 was employed, one break at 1978 was identified, but again the coefficient of time trend was insignificant in the second regime. When k2 was employed, no structural break was found. Overall the estimates were not satisfactory.

rural transformation, the share of its contribution has been descending as the technical progress has taken off after 1978. It indicates that the Chinese economy is moving towards a more sustainable pattern of growth, relying more and more on technological development.

For capital series $k2$, only one structural break was identified at 1979, indicating two regimes 1969-1979 and 1980-2008. It seems that the number of structural breaks is sensitive to the choice of capital. Nevertheless, a break date close the reform and opening up year of 1978 is found for both capital series. The capital share (α), 0.5198, is much higher than that for k1 but still lower than Chow (1993) and Chow and Li (2002). We find negative and positive coefficients (both highly significant) for technical progress for the regimes 1969-1979 and 1980-2008 respectively, but both are lower than when capital series k2 is employed. Interestingly, we observe highly significant but declining coefficients of rural transformation for k2 ($\gamma_1 = 0.7434$, $\gamma_2 = 0.5835$), a pattern similar to that obtained with capital series k1[5].

6. Alternative Production Functions

The Cobb-Douglas production function assumes unity elasticity of substitution and constant returns to scale. In this section we further investigate the contribution of rural transformation within the framework of CES and VES specifications, where these restrictions can be relaxed. The sample period is 1970-2008. We apply the same break

[5] Following World Bank (1996) and Brandt et al (2008), we also investigated the contribution of another form of labor reallocation, namely ownership transformation, in the Cobb-Douglas production function. Ownership transformation refers to labor reallocation out of State Owned Enterprises (SOEs) to non-SOEs and is measured as the ratio of SOE employees to urban employees. However, BP methods suggested no breaks for both k1 and k2 when ownership transformation is included, which was rather counter-intuitive, and more importantly, the OLS estimates for the whole sample period (without structural breaks) showed that ownership transformation was insignificant and when it was included, time trend also became insignificant. Therefore, in contrast to World Bank (1996) and Brandt *et al* (2008), we did not find that ownership transformation contributed to China's productivity growth. For an explanation for why ownership transformation may not contribute to productivity growth, please refer to Bai *et al* (2006b).

dates identified in Section 5[6], i.e. 1977 and 1989 for K1 and 1979 for K2, to CES (equation 7) and VES (equations 8) production functions[7].

$$\ln Y = c + \beta t + \gamma \ln RT - (\varphi/\rho)\ln\left(\delta K^{-\rho} + (1-\delta)L^{-\rho}\right) \quad (7)$$

$$\ln Y = c + \beta t + \gamma \ln RT + \varphi\theta \ln K + \varphi(1-\theta)\ln\left(L + \eta\theta K\right) \quad (8)$$

and results are reported in Table 2 and Table 3 for CES and VES production function respectively. In all equations, the coefficients for RT are highly significant and positive in all regimes for both K1 and K2. They display a decreasing trend, namely higher in the pre-reform period and lower in the more recent regimes. The coefficients for time trend are negative in all pre-reform regimes and positive afterwards; but, in contrast to that for RT, they are insignificant in all cases except β_3 for K1 and β_1 for K2 in the CES function.

Wald tests for the returns to scale parameter, φ, show that constant return to scale, i.e. $\varphi = 1$, cannot be rejected in all cases. Wald tests suggest that unity elasticity of substitution, i.e. $\eta = 0$ for the CES specification and $\rho = 0$ for VES specification cannot be rejected in all cases except for K2 in VES specification. However, as the coefficients for time trend are counter-intuitively insignificant in both regimes in VES specification when K2 is employed, we conclude that overall, no evidence in favour of CES or VES over Cobb-Douglas production function is found.

Results in Tables 2 and 3 confirm the important role played by rural transformation in total factor productivity growth in China throughout the pre- and post-reform periods,

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[6] To our knowledge, structural break test for nonlinear models is rather limited and may not be applicable to the specific cases of CES and VES production functions. For instance, Kapetanios (2002) proposes testing for structural breaks in nonlinear dynamic models using artificial neural network approximations. But the methods do not allow for partial structural change and the neural network is specified using the radial basis function and logistic function. In addition, we expect that break dates to be the same irrespective of econometric methods used to detect them. Therefore, we applied the break dates obtained using the BP methods in the previous section to CES and VES specifications.

[7] Please refer to Appendix A for a brief introduction to CES and VES specifications and the derivations of equations (7) and (8). Both production functions were estimated by non-linear least squares.

irrespective of the production function and capital series employed. Also empirical evidence reported in Tables 1, 2 and 3 supports Cobb-Douglas production function compared with CES and VES specifications.

7. Productivity

The levels of productivity contributed by rural transformation (CRT), technical progress (NFP) and total factor productivity (TFP) are calculated based on coefficients in Table 1 and are reported in Table 4. Growth rates of these variables (GCRT, GNFP and GTFP) are reported in Table 5[8]. The levels and growth rates are further depicted in Figure 1 and Figures 2-3 respectively.

Table 4 and Figure 1 show that for both capital series k1 and k2, the levels of both NFP and TFP are higher in more recent regimes. It is worth noticing there are decreasing levels of NFP1 and NFP2 before the structural break in 1977 and 1979 respectively. A considerable proportion of the TFP level is attributed to rural transformation (CRT). For instance, when we use k1, CRT accounts for (on average) 79%, 68% and 56% of the TFP level for the three corresponding regimes (1970-1977, 1978-1989 and 1990-2008). When k2 is employed, CRT accounts for (on average) 77% and 63% of the TFP level for 1970-1979 and 1980-2008 respectively. Despite being very large, these proportions are getting smaller in more recent periods.

Looking at the growth rates, Figures 2-4 show consistent pattern between series obtained using k1 and series obtained using k2. Table 5 illustrates that the average growth rates of CRT are 3.65%, 2.06% and 1.52% during 1970-1977, 1978-1989 and 1990-2008 respectively when using k1; 3.73% and 1.37% during 1970-1979 and

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[8]Levels are calculated as: $NFP1_t = \ln y_t - \hat{\alpha}\ln k1_t - \hat{\gamma}_j \ln(RT)_t$; $TFP1_t = \ln y_t - \hat{\alpha}\ln k1_t$; $CRT1_t = TFP1_t - NFP1_t$; where $j = 1,\dots,m+1$, and m is the number of breaks. Note levels are in natural logarithms. Growth rates are calculated as the first difference of the natural logarithms. Same applies when k2 is used.

1980-2008 respectively when using k2. On the other hand, for the corresponding regimes, the average growth rates of NFP are -2.75%, 2.53% and 3.91% respectively when using k1; -3.30% and 1.64% respectively when using k2. Therefore, there is an interesting contrast between the average growth rates of CRT and NFP that the former are positive across all regimes but show a declining trend whilst the latter are negative during the pre-reform period but turn to positive and display a strong increasing tendency after that. This contrast is further demonstrated in Figures 2 and 3.

When positive growth rates of CRT are taking into account, we observe positive TFP growth in the pre-reform regime (0.90% during 1970-1977 when employing k1 and 0.43% during 1970-1979 when employing k2) despite the negative impact of NFP. This results show that negative or zero productivity growth rates reported by previous studies for the pre-reform period are due to the fact that rural transformation was ignored. In the post-reform periods, NFP becomes the main drive behind TFP growth. Rural transformation continues to make significant but much smaller contribution to TFP growth. When capital series k1 is used, rural transformation only accounts for about 45% of TFP growth during 1978-1999 and the ratio further decreases to 28% during 1990-2008. When capital series k2 is used, the ratio is about 46% during 1980-2008. Nevertheless, with the positive contribution of rural transformation and stronger growth rates of NFP, the growth rates of TFP1 in the post-reform period increase to 4.58% and 5.43% during 1978-1989 and 1990-2008 respectively, and the growth rate of TFP2 is increased to 3.01% during 1980-2008.

In Table 5 and Figures 2-4, we observe negative growth rates in all series around the 1989 Tiananmen Square incident (GCRT1, GNFP1 and GTFP1 in 1989 and GCRT2, GNFP2 and GTFP2 in 1990). We also observe significant slowdown in all growth rates near 1998 due to the Asian financial crisis and in 2008 due to the global financial crisis.

8. Comparative Analysis

We compare our findings with previous literature in Tables 6 and 7. Most previous studies calculate productivity growth using pre-specified capital shares (e.g. World Bank, 1996; Hu and Khan, 1997; Maddison, 1998; Woo, 1998; Bosworth and Collins, 2008; Brandt *et al*, 2008)[9]. In our study, all parameters are estimated, including the one for capital share. Capital series K1 is extended from Chow and Li (2002), but our estimations report a much lower capital share than Chow and Li (2002) when contribution made by rural transformation to TFP is taken into account. Capital share when we use K2 is higher than that of K1 but still lower than Chow (1993) and Chow and Li (2002).

For the pre-reform period, most studies find zero or negative productivity growth in pre-reform period (e.g. Chow, 1993; Chow and Li, 2002; Borensztein and Ostry, 1996; Maddison, 1998) except Hu and Khan (1997). We find negative technical progress in the first regime for both capital series (1970-1977 for K1 and 1970-1979 for K2). However, when the positive contribution of rural transformation to TFP is accounted for, productivity growth turns to positive for both capital series, which contrasts with all previous studies (except Hu and Khan, 1997)..

For the post-reform period, the contribution of rural transformation using K1 is the highest (2.06% in 1977-2008 and 1.52% in 1990-2008) compared with previous studies that use data of similar periods (e.g. World Bank, 1996; Woo, 1998; Bosworth

[9] Different capital series has been used in previous studies. For instance, capital stock data of Woo (1998), Maddison (1998) and Borensztein and Ostry (1996) is based on Li (1992), World Bank (1996) is based on Nehur and Dhareshwar (1993) and Bosworth and Collins (2007) is based on Hsueh and Li (1999), all with updating for recent years; whilst Hu and Khan (1997) and Brandt *et al* (2008) construct their own capital stock series.

and Collins, 2008; Brandt *et al*, 2008). The same is true when using K2, except it is lower than Bosworth and Collins (2008)[10]. TFP growth rates using K1 is higher than all previous studies that ignore the role of rural transformation (e.g. Chow and Li, 2002; Borensztein and Ostry, 1996; Hu and Khan, 1997; Maddison, 1998). Same can be said about TFP growth rates using K2, except they are lower than Borensztein and Ostry (1996) and Hu and Khan (1997) because of relatively lower NFP growth rates. Compared with studies that account for the role of rural transformation, TFP growth rates using K1 is higher than World Bank (1996) and Woo (1998) but lower than Bosworth and Collins (2008) and Brandt *et al* (2008); whilst that using K2 is higher than Woo (1998) but lower than all others.

All studies are based on given capital shares and growth accounting methods (except Chow (1993) and Chow and Li (2002)), and none of them have examined the role of rural transformation when structural breaks are taken into account. We therefore believe our results are more reliable.

9. Conclusions

This paper carries out an empirical investigation of the contribution of rural transformation, which can produce efficiency gains over and above those associated with technical progress, to total factor productivity in China during 1970-2008. For the first time for China, the roles of rural transformation and technical progress in productivity growth are examined whilst structural breaks are taken into account. We employ Bai and Perron (1998, 2003a, b) methods which allow us to test for multiple structural breaks at unknown dates and can be applied for both pure and partial

[10] Bosworth and Collins (2008) study productivity growth of China and India. The sample period 1978-2004 was divided into 1978-1993 and 1994-2008 as after 1993 is India's post-reform era. They then apply growth accounting to both sub-periods to obtain productivity growth rates.

structural changes. We also evaluate the robustness of our results by employing alternative production functions and two capital series.

The structural break test identified a significant break near the end of pre-reform period for both capital series and another one near the Tiananmen Square incident in 1989 for the extended Chow and Li (2002) capital series. We found the contribution of rural transformation to total factor productivity is positive and significant across all regimes and in contrast, technical progress is negative in the pre-reform period but positive and significant in the post-reform period. We further investigate the contribution of rural transformation by applying the break dates within the framework of VES and CES production functions. The empirical evidence supports the Cobb Douglas production function over the VES and CES specifications for modeling China’s aggregate production. More importantly, we find that rural transformation remains a significant contributor to total factor productivity and output growth in China irrespective of the production function and capital series employed, even when we allow for different regimes.

Appendix A. CES and VES Production Functions with Rural Transformation

The CES production function assumes varied returns to scale and an elasticity of substitution different from unity. Following Brown and De Cani (1963), CES production function takes the form:

$$Y = A\left[\delta K^{-\rho} + (1-\delta)L^{-\rho}\right]^{-\varphi/\rho}; \tag{A1}$$

where ρ is the substitution parameter that determines the elasticity of substitution σ. δ is the distribution parameter; for any given value of σ (or ρ), δ determines the functional distribution of income. φ is the returns to scale parameter. The elasticity of substitution (σ) equals to $\sigma = 1/(1+\rho)$. When $\varphi = 1$ and $\rho = 0$, equation (A1) collapses to the Cobb-Douglas production function.

In contrast to CES production function, the VES production function assumes that the elasticity of substitution is a linear function of capital over labor ratio (Revankar, 1971). We consider the following VES production function:

$$Y = AK^{\theta\varphi}\left[L + \eta\theta K\right]^{(1-\theta)\varphi}; \tag{A2}$$

where φ is the returns to scale parameter. Both θ and η determine the capital share and the labor share of income. The elasticity of substitution is derived as $\sigma = 1 + \eta(K/L)$. Hence σ varies linearly with the capital-labor ratio around unity. If $\varphi = 1$ and $\eta = 0$, equation (A2) collapses to the Cobb-Douglas production function.

Similar to equation (2), we decompose total factor productivity into net factor productivity and rural transformation for equations (A1) and (A2), and then by taking natural logarithms we obtain equations (7) and (8) respectively:

$$\ln Y = c + \beta t + \gamma \ln RT - (\varphi/\rho)\ln\left(\delta K^{-\rho} + (1-\delta)L^{-\rho}\right) \tag{7}$$

$$\ln Y = c + \beta t + \gamma \ln RT + \varphi\theta \ln K + \varphi(1-\theta)\ln(L + \eta\theta K) \tag{8}$$

Appendix B. Data Sources and Variable Measurement

The main data sources include *50 Years of New China* (*50YNC*), various issues of *China Statistical Yearbook* (*CSY*) including *CSY 2009* of China National Statistical Bureau. Data are collected for 1952-2008 but only period 1970-2008 is used in estimations in Sections 5 and 6. Data are in 1978 prices.

CSY 2009 reports most of the data from 1978. *50YNC* reports data from 1952-1999. Due to the National Economics Consensus in 2004, since *CSY 2005* some data series have been updated back to 1978. Therefore, to obtain the consistency between *50YNC* and *CSY 2009*, we compare data from *50YNC* with data from *CSY 2009* for the overlapping period 1978-1999. If the two data series are identical, we use "original data" during 1952-1977 from *50YNC*; if not, we adjust original data during 1952-1977 from *50YNC* by an adjustment factor, which is calculated as the ratio of the 3 years' (1978, 1979 and 1980) average of data from *CSY 2009* to the same 3 years' average of data from *50YNC*, and label them "adjusted data" during 1952-1977 from *50YNC*.

1. Real GDP of China (Y): it is constructed by adjusting nominal GDP using GDP deflator. Data of nominal GDP for 1952-1977 is from adjusted data *50YNC* and for 1978-2008 is from *CSY2009*. The GDP Deflator is calculated using the same methodology as Jun (2003)[11].

2. Total Number of Employed Persons (L): data during 1952-1977 is from original data *50YNC* and during 1978-2008 is from *CSY2009.*

3. Rural Transformation (RT) (%): it is defined as the ratio of employed persons by non-agricultural sectors (which include industrial and services sectors) to total number of employed persons. A higher percentage implies a higher level of rural

[11] *World Development Indicators (WDI) 2009* provides GDP for China (current local currency unit) from 1960 to 2008, which is consistent with the combined nominal GDP data of *50YNC* and *CSY 2009.* We also converted our GDP deflator with the base year 1990 and compared it with GDP deflator data from *WDI 2009*. For the overlapping years 1960-2008, these two series are consistent with each other.

transformation, i.e. proportionally fewer farmers work in the field. Data of the employed persons by industrial and service sectors during 1952-1977 is from original data from *50YNC* and during 1978-2008 is from *CSY 2009*.

4. Real Capital Stock (K1): it is obtained by extending the real capital series of Chow and Li (2002) from 1952-1998 to 1952-2008 using same methods. Detail of the methods can be found at Chow and Li (2002) and hence is not repeated here. Data needed for our extension include real GDP, GDP deflator, real consumption, real net export and depreciation. Data for nominal net exports and nominal consumption are from *CSY 2009* and are adjusted by the GDP deflator and Consumer Price Index (data of which is from *CSY 2009*) respectively to obtain the real values. Total depreciation is the sum of provincial depreciation, data of which is from various issues of *CSY*.

5. Real Capital Stock (K2): it is obtained by extending the real capital series of Bai *et al* (2006a) from 1952-2005 to 1952-2008 using same methods. For detailed methods of data construction, please refer to Bai et al (2006a). Data needed for our extension include investment in construction and installation, investment in equipment and instruments, price index of investment in construction and installation and price index of investment in equipment and instruments. All data are collected from *CSY 2009*.

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Table 1. Structural Break Tests and Parameter Estimates of the Cobb-Douglas Production Function

Capital Series $K1$			Capital Series $K2$		
Tests			Tests		
$UD\max$ [a]	$WD\max$ (1%) [b]		$UD\max$	$WD\max$ (1%)	
76368.38***	127309.08***		242637.22**	404485.73***	
$SupF_T(1\|0)$ [c]	$SupF_T(2\|1)$ [d]	$SupF_T(3\|2)$ [e]	$SupF_T(1\|0)$	$SupF_T(2\|1)$	$SupF_T(3\|2)$
34.58***	96.73***	0.52	11.41**	0.25	0.01
Breakpoint(s)			Breakpoint(s)		
1977 1989			1979		
Regime 1	Regime 2	Regime 3	Regime 1		Regime 2
1970-1977	1978-1989	1990-2008	1969-1979		1980-1989
Parameter estimates with two breaks			Parameter estimates with one break		
β_1	β_2	β_3	β_1		β_2
-0.0257***	0.0278***	0.0372***	-0.0352***		0.0175**
(0.0057)	(0.0032)	(0.0058)	(0.0097)		(0.0070)
γ_1	γ_2	γ_3	γ_1		γ_2
0.9062***	0.7436***	0.6593***	0.7434***		0.5835***
(0.1538)	(0.1480)	(0.1185)	(0.1285)		(0.1180)
c	α		c		α
0.8631**	0.3883***		0.8745		0.5198***
(0.3859)	(0.0821)		(0.7170)		(0.0660)

Note: ****, ** and * denote statistic significant at 1%, 5% and 10% level respectively. The asymptotic distributions for these tests in BP with trending and non-trending data are fairly similar and Bai and Perron (2003a) suggest that one can safely use the same critical values at the presence of trending data. In brackets are hetroscedasticity and auto-correlation consistent standard errors.

[a] 1%, 5% and 10% critical values are 14.92, 11.16 and 9.66 respectively

[b] 1% critical value is 16.52

[c] 1%, 5% and 10% critical values are 14.92, 10.98 and 9.37 respectively

[d] 1%, 5% and 10% critical values are 16.69, 12.55 and 10.92 respectively

[e] 1%, 5% and 10% critical values are 17.41, 13.46 and 11.90 respectively

Critical values are from Bai and Perron (2003c), which is available at Pierre Perron's home page at http://econ.bu.edu/perron/.

Table 2. Estimates of the CES Production Function

Capital Series $K1$			Capital Series $K2$	
Parameter estimates with two breaks			Parameter estimates with one break	
β_1	β_2	β_3	β_1	β_2
-0.0252	0.0283	0.0365*	-0.0358**	0.0251
(0.0188)	(0.0258)	(0.0209)	(0.0159)	(0.0199)
γ_1	γ_2	γ_3	γ_1	γ_2
0.9025***	0.7400***	0.6631***	0.7191***	0.5351***
(0.1665)	(0.1520)	(0.1365)	(0.1313)	(0.1149)
c	α		c	α
1.3930	0.3346		5.5310	0.9992***
(13.6037)	(0.6521)		(8.3857)	(0.0040)
φ	η		φ	η
0.9858	-0.0314		0.7075**	0.7317
(0.7323)	(0.2904)		(0.3403)	(0.5428)
Wald Test			Wald Test	
$\varphi = 1$	$\eta = 0$		$\varphi = 1$	$\eta = 0$
0.0004	0.0117		0.7833	1.8171
(0.9845)	(0.9138)		(0.3900)	(0.1777)

Note: Nonlinear least square─in brackets are hetroscedasticity and auto-correlation standard errors. ****, ** and * denote statistic significant at 1%, 5% and 10% level respectively.
Wald Test─Chi-square(1)-statistics value is used and probability in brackets.

Table 3. Estimates of the VES Production Function

Capital Series $K1$			Capital Series $K2$	
Parameter estimates with two breaks			Parameter estimates with one break	
β_1	β_2	β_3	β_1	β_2
-0.0288	0.0231	0.0322	-0.0252	0.0340
(0.0187)	(0.0244)	(0.0190)	(0.0197)	(0.0279)
γ_1	γ_2	γ_3	γ_1	γ_2
0.8986***	0.7409***	0.6559***	0.7799***	0.5998***
(0.1690)	(0.1550)	(0.1453)	(0.1663)	(0.1358)
c	α		c	α
-1.6951	0.3549**		8.5764	0.7294***
(14.2914)	(0.1560)		(10.9843)	(0.1920)
φ	ρ		φ	ρ
1.1265	0.000011		0.6245	0.000048**
(0.7008)	(0.000023)		(0.4942)	(0.000023)
Wald Test			Wald Test	
$\varphi = 1$	$\rho = 0$		$\varphi = 1$	$\rho = 0$
0.0326	0.2319		0.5773	4.2323
(0.8567)	(0.6301)		(0.4474)	(0.0385)

Note: see note of Table 2 for an explanation

Table 4. Levels of NFP, TFP and CRT

Year	K1			K2		
	NFP1	TFP1	CRT1	NFP2	TFP2	CRT2
1970	0.83	3.51	2.68	0.83	3.03	2.20
1971	0.80	3.52	2.73	0.79	3.03	2.24
1972	0.76	3.53	2.76	0.75	3.02	2.27
1973	0.79	3.56	2.77	0.77	3.04	2.27
1974	0.76	3.54	2.78	0.72	3.00	2.28
1975	0.75	3.59	2.83	0.70	3.03	2.33
1976	0.65	3.53	2.89	0.59	2.96	2.37
1977	0.64	3.57	2.93	0.59	2.99	2.41
1978	1.12	3.64	2.52	0.53	3.05	2.52
1979	1.15	3.68	2.53	0.54	3.07	2.53
1980	1.16	3.72	2.56	1.08	3.09	2.01
1981	1.16	3.74	2.57	1.07	3.09	2.02
1982	1.21	3.79	2.57	1.10	3.12	2.02
1983	1.26	3.86	2.60	1.13	3.16	2.04
1984	1.29	3.95	2.66	1.14	3.23	2.09
1985	1.32	4.02	2.70	1.17	3.29	2.12
1986	1.33	4.05	2.73	1.17	3.30	2.14
1987	1.37	4.11	2.74	1.19	3.34	2.15
1988	1.40	4.16	2.75	1.22	3.38	2.16
1989	1.40	4.14	2.74	1.23	3.39	2.15
1990	1.62	4.05	2.43	1.17	3.32	2.15
1991	1.66	4.10	2.44	1.21	3.37	2.16
1992	1.74	4.19	2.46	1.28	3.45	2.17
1993	1.78	4.27	2.49	1.31	3.52	2.20
1994	1.82	4.34	2.52	1.34	3.57	2.23
1995	1.84	4.39	2.55	1.35	3.61	2.26
1996	1.86	4.44	2.57	1.36	3.63	2.28
1997	1.90	4.48	2.58	1.37	3.66	2.28
1998	1.93	4.51	2.58	1.39	3.67	2.29
1999	1.97	4.54	2.58	1.41	3.69	2.28
2000	2.01	4.59	2.58	1.43	3.71	2.28
2001	2.05	4.63	2.58	1.45	3.73	2.28
2002	2.09	4.67	2.58	1.48	3.76	2.28
2003	2.13	4.73	2.59	1.49	3.78	2.29
2004	2.16	4.78	2.62	1.49	3.81	2.32
2005	2.19	4.83	2.64	1.49	3.83	2.34
2006	2.23	4.90	2.67	1.50	3.86	2.36
2007	2.30	4.99	2.69	1.53	3.91	2.38
2008	2.33	5.03	2.70	1.54	3.93	2.39
Mean rates in selected periods						
1970-1977	0.75	3.55	2.80			
1978-1989	1.27	3.91	2.64			
1990-2008	1.98	4.55	2.57			
1970-1979				0.68	3.02	2.34
1980-2008				1.31	3.52	2.21

Note: NFP: net factor productivity (technical progress); TFP: total factor productivity; CRT: contribution of rural transformation to total factor productivity; 1 and 2 indicate they are obtained using capital series 1 or 2 respectively. All series are in natural logarithm.

Table 5. Growth Rates of NFP, TFP and RTC (%)

Year	K1			K2		
	GNFP1	GTFP1	GRTC1	GNFP2	GTFP2	GRTC2
1970	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1971	-3.38	1.43	4.81	-4.36	-0.41	3.95
1972	-3.20	0.47	3.67	-4.20	-1.18	3.01
1973	2.58	3.23	0.65	1.66	2.20	0.53
1974	-2.89	-1.72	1.17	-4.27	-3.30	0.96
1975	-1.11	4.12	5.23	-2.22	2.08	4.29
1976	-10.36	-5.13	5.23	-10.67	-6.38	4.29
1977	-0.86	3.91	4.77	-0.83	3.09	3.91
1978	n.a.	n.a.	n.a.	-5.15	5.64	10.80
1979	2.59	4.41	1.82	0.34	2.15	1.82
1980	1.20	3.74	2.54	n.a.	n.a.	n.a.
1981	0.11	1.63	1.52	-1.22	-0.03	1.19
1982	5.05	4.98	-0.07	3.09	3.04	-0.05
1983	4.38	6.78	2.40	2.90	4.79	1.88
1984	2.76	9.32	6.56	1.80	6.95	5.15
1985	3.83	7.12	3.29	2.80	5.38	2.58
1986	0.51	3.37	2.86	-0.60	1.64	2.24
1987	3.89	5.69	1.80	2.51	3.93	1.41
1988	3.63	4.79	1.17	2.90	3.82	0.92
1989	-0.15	-1.43	-1.29	1.39	0.38	-1.01
1990	n.a.	n.a.	n.a.	-6.31	-6.38	-0.07
1991	4.29	4.95	0.66	4.19	4.77	0.58
1992	7.12	9.05	1.93	6.27	7.99	1.71
1993	4.51	7.76	3.25	3.79	6.67	2.88
1994	4.00	7.11	3.10	2.65	5.39	2.75
1995	2.24	5.20	2.96	0.95	3.57	2.62
1996	2.15	4.45	2.30	0.71	2.75	2.04
1997	3.48	4.28	0.80	1.83	2.54	0.70
1998	3.08	3.21	0.13	1.30	1.41	0.12
1999	3.59	3.19	-0.39	1.97	1.62	-0.35
2000	4.09	4.22	0.13	2.33	2.44	0.12
2001	3.86	3.86	0.00	2.07	2.07	0.00
2002	4.78	4.78	0.00	2.53	2.53	0.00
2003	4.09	5.26	1.18	1.41	2.45	1.04
2004	2.38	5.17	2.79	-0.24	2.23	2.47
2005	3.21	5.76	2.56	-0.03	2.23	2.26
2006	4.39	6.95	2.56	1.27	3.53	2.26
2007	6.08	8.09	2.01	3.17	4.95	1.78
2008	3.04	4.45	1.41	0.38	1.63	1.25
Mean rates in selected periods						
1970-1977	-2.75	0.90	3.65			
1978-1989	2.53	4.58	2.06			
1990-2008	3.91	5.43	1.52			
1970-1979				-3.30	0.43	3.73
1980-2008				1.64	3.01	1.37

Note: GNFP: growth rate of net factor productivity (technical progress); GTFP: growth rate of total factor productivity; GCRT: growth rate of contribution of rural transformation to total factor productivity; 1 and 2 indicate they are obtained using capital series 1 or 2 respectively.

Table 6. Comparison with Previous Studies: Capital Share %

<table>
<tr><th rowspan="2">Sources</th><th rowspan="2">Periods</th><th colspan="2">Capital Share %</th></tr>
<tr><th>Pre-reform</th><th>Post-reform</th></tr>
<tr><td>This Study</td><td>1970-2008</td><td colspan="2">k1: 0.3883
k2: 0.5198</td></tr>
<tr><td>Chow (1993)</td><td>1952-1988</td><td colspan="2">0.6317</td></tr>
<tr><td>Chow and Li (2002)</td><td>1952-1998</td><td colspan="2">0.5577</td></tr>
<tr><td>Borensztein and Ostry (1996)</td><td>1953-1994</td><td colspan="2">na</td></tr>
<tr><td>World Bank (1996)</td><td>1985-1994</td><td colspan="2">0.5</td></tr>
<tr><td>Hu and Khan (1997)</td><td>1953-1994</td><td>0.614</td><td>0.547</td></tr>
<tr><td>Maddison (1998)</td><td>1952-1995</td><td colspan="2">0.3</td></tr>
<tr><td>Woo (1998)</td><td>1979-1993</td><td></td><td>0.4, 0,5 and 0.6</td></tr>
<tr><td>Bosworth and Collins (2008)</td><td>1978-2004</td><td></td><td>0.4</td></tr>
<tr><td>Brandt et al (2008)</td><td>1978-2004</td><td></td><td>0.5</td></tr>
</table>

Table 7. Comparison with Previous Studies: Productivity Growth Rates (%)

<table>
<tr><th>Sources</th><th>Periods</th><th colspan="6">Average Growth Rate (%)</th></tr>
<tr><td rowspan="4">This Study</td><td rowspan="4">1970-2008</td><td colspan="3">k1</td><td colspan="3">k2</td></tr>
<tr><td>Regime 1
(1970-1977)</td><td>TFP:0.90</td><td>NFP: -2.75
CRT1: 3.65</td><td>Regime 1
(1970-1979)</td><td>TFP: 0.43</td><td>NFP: -3.30
CRT1: 3.73</td></tr>
<tr><td>Regime 2
(1977-1989)</td><td>TFP: 4.58</td><td>NFP: 2.53
CRT1: 2.06</td><td>Regime 2
(1980-2008)</td><td>TFP: 3.01</td><td>NFP: 1.64
CRT1: 1.37</td></tr>
<tr><td>Regime 3
(1990-2008)</td><td>TFP: 5.43</td><td>NFP: 3.91
CRT1: 1.52</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Pre-reform (%)</td><td colspan="3">Post-reform (%)</td></tr>
<tr><td>Chow (1993)</td><td>1952-1988</td><td colspan="3">0</td><td colspan="3">n.a.</td></tr>
<tr><td>Chow and Li (2002)</td><td>1952-1998</td><td colspan="3">0</td><td colspan="3">3</td></tr>
<tr><td>Borensztein and Ostry (1996)</td><td>1953-1994</td><td colspan="3">-0.7</td><td colspan="3">3.8</td></tr>
<tr><td>World Bank (1996)</td><td>1985-1994</td><td colspan="3"></td><td colspan="2">GTFP: 3.6</td><td>GCRT: 1.00</td></tr>
<tr><td>Hu and Khan (1997)</td><td>1953-1994</td><td colspan="3">1.1</td><td colspan="3">3.9</td></tr>
<tr><td>Maddison (1998)</td><td>1952-1995</td><td colspan="3">-0.78</td><td colspan="3">2.23</td></tr>
<tr><td>Woo (1998)</td><td>1979-1993</td><td colspan="3"></td><td colspan="3">GNFP: 1.1 to 1.3
GCRT: 1.1</td></tr>
<tr><td>Bosworth and Collins (2008)</td><td>1978-2004</td><td colspan="3"></td><td colspan="2">GTFP: 6.4 (1978-1993)
GTFP: 8.5 (1994-2004)</td><td>GCRT: 1.7
GCRT: 1.2</td></tr>
<tr><td>Brandt et al (2008)</td><td>1978-2004</td><td colspan="3"></td><td colspan="2">GTFP: 6.96</td><td>GCRT: 1.02</td></tr>
</table>

Figure 1. Levels of NFP and TFP and CRT (in natural logarithm)

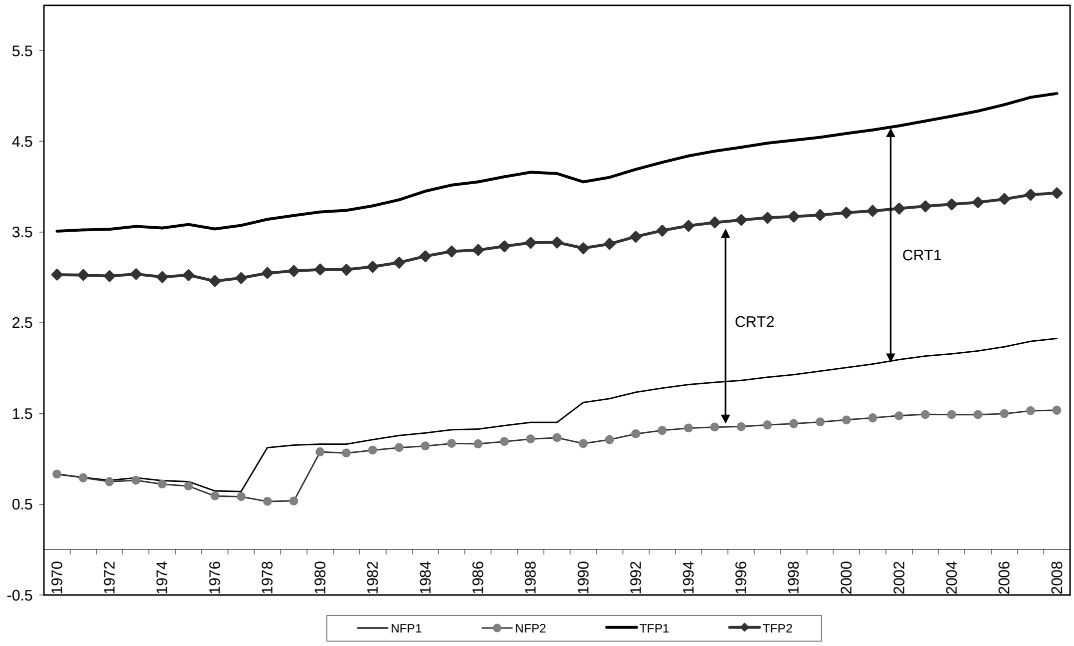

Figure 2. Growth rate of NFP

Figure 3. Growth rate of CRT

Figure 4. Growth of TFP