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Productivity Growth in China Before and After 1978 Revisited

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Abstract: This paper analyses total factor productivity growth in China, and discusses the evidence regarding whether or not it increased after the implementation of market reforms in 1978. The paper addresses to two major issues. The first considers the case when technical progress in China was biased in a labour-saving direction and the elasticity of substitution was substantially less than unity.[§] Secondly, it is shown that the notion of total factor productivity growth used in most analyses is problematic and misleading since it is based on the concept of aggregate production function. It is shown that the aggregate production function is subject to insurmountable problems that limit its usefulness for empirical exercises.

JEL Classification: O47, O53

Key words: Cobb-Douglas production function, elasticity of substitution, technical change

Introduction

During the last decade a number of papers have studied the performance of the Chinese economy since market-oriented reforms were launched in 1978 (see, for example, Borensztein, *et al.*, 1996; Chen, *et al.*, 1992, 1998; Chow 1993, 1994; Hu *et al.*, 1997; Jefferson 1989, 1992; Jefferson *et al*, 1994a. 1994b, 1996; Li, 1992; Perkins, 1998, and Wan, 1995). The conventional wisdom is that market-oriented reforms have led to an increase in total factor productivity (*TFP*) growth compared with the central planning period of 1952-78. These studies have applied the standard techniques of neoclassical economics to study *TFP* growth, namely, growth accounting and the econometric estimation of the aggregate production function, with a time trend to capture the rate of technical change or, more accurately, the growth of

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total factor productivity. The findings, nevertheless, are somewhat inconclusive. While Chen *et al.* (1988), Li (1992) and Chow (1993) found that *TFP* growth before 1978 was virtually zero (or even negative), Hu and Khan (1997) concluded that 'although productivity performance differed sharply before and after 1978, it was positive in the pre-reform era' (Hu and Khan 1997, p. 116). For the period 1953-78 they estimate an annual average growth rate of *TFP* of 1.1 per cent and, for the period 1979-94, a rate of 3.9 per cent. More recently, Jefferson *et al.* (2000) find that *TFP* growth rates have declined during the 1990s.

The growth of labour productivity has improved since 1978, and it is likely that, one way or another, this improvement was related to the implementation of market-oriented reforms (although verifying this causality is an altogether different issue).[1] However, we argue that there are serious problems inherent in the techniques that have been used in the literature to dichotomise this increase in labour productivity growth into that due to increased technical change (increased *TFP* growth) and that due to an increase in the growth of the capital-labour ratio. As a consequence, it is argued that some of the discussions and conclusions that have been drawn must be considerably qualified.

There are two main issues that are addressed in this paper. The first one is a critique within the neoclassical framework of standard growth accounting studies, and thus, while it questions the conclusions drawn from these exercises, it does not challenge the concept of *per se*. The second, and perhaps a more important, issue is a critique of the neoclassical methodology itself, which has serious implications for the interpretation of applied work in this area.

The first problem was initially raised by Nelson (1973) and examined more specifically in the context of the debate of the East Asian Miracle by Nelson and Pack (1999).[2] (See also Rodrik, 1997.) Felipe and McCombie (2001) have recently elaborated the Nelson and Pack argument, and evaluated its importance empirically by means of a simulation exercise. The essence of the argument is as follows. Technical change in the East Asian economies may well be biased. Once an allowance has been made in the values of factor shares for the effect of biased technical change, the growth accounting estimates of TFP growth become indeterminate in the absence of information about the elasticity of substitution and the degree of bias in the rate of technical change.[3] (This is a consequence of Diamond *et al's* (1972) 'impossibility theorem'.)

When technical change is biased and the elasticity of substitution is different from unity, the value of the factor shares will be affected by technical change. In these circumstances, it is not possible for the conventional approach to estimate accurately how much of growth can be explained by movements along a production function and how much should be attributed to technical change.

The important aspect, for purposes of this paper, is that with technical change, an elasticity of substitution of less than one, and a positive growth in the capital-labour ratio, the use of the observed capital shares as weights in the growth accounting studies is, except under exceptional circumstances, theoretically incorrect. If the true elasticity of substitution is lower than that implied by the change in the actual shares, the observed value of capital's share in the terminal period will be too large. The use of a lower capital share, obtained by correcting the observed share for the effect of technical progress, leads to a higher rate of growth of *TFP*.

The converse is also true. If the actual elasticity of substitution is greater than that implied by the change in the observed shares, the actual growth of

The second problem with these studies stems from the fact that the notion of *TFP* growth, deemed to be the most satisfactory concept of productivity growth in neoclassical economics, and the techniques used to measure it, namely growth accounting and the estimation of aggregate production functions, are dependent upon the existence of a well-defined aggregate production function. However, there is an extensive literature on the aggregation of production functions that has proved that aggregate production functions can be derived theoretically only under extremely restrictive conditions and which actual economies most likely do not satisfy (Fisher, 1993; a survey of this literature is provided by Felipe and Fisher, 2001). The conclusion of this literature is that aggregates such as output, capital, labour, or investment do not have a sound theoretical underpinning when regarded as arguments of an aggregate production function.[4] The corollary is that the consideration of the aggregate production function as the extension, by analogy, of the micro-production function can lead to serious interpretative errors. Equally seriously, questions have also been raised by the Cambridge Capital Theory Controversies about the theoretical foundations of the aggregate production function (Harcourt, 1972, McCombie, 2002). Given these problems, it seems that a pertinent question to ask is how can we interpret the results obtained in applied work, e.g., the estimated coefficients of a (putative) aggregate production function, or the value of the residual or *TFP* growth? They cannot be regarded as technological parameters (because the aggregate production function does not exist). This question, and the answer put forward in this paper, could potentially have important implications for the correct understanding and evaluation of the literature on productivity growth in China, as well as for policy and theoretical discussions concerning economic growth in general (Shaikh, 1980, Felipe, 1999, and Felipe and McCombie, 2002).

The rest of the paper is structured as follows. We discuss, in Section 2, the problem that using the standard growth accounting procedure faces when technical change is biased and the elasticity of substitution differs from unity. In Section 3, China's growth rate of *TFP* is re-calculated using the methodology developed by Felipe and McCombie (2001). It is found that, under certain assumptions, *TFP* growth increased in China both before and after the reforms were introduced, although it grew faster in the latter period. In Section 4, the problems inherent in the aggregate production function are considered from an empirical point of view. Section 5 revisits the seminal work of Chow (1993) using regression analysis and it is argued that his approach is problematic and that his conclusions are far from robust. Section 6 shows why the estimation of a Cobb-Douglas production function may give a good fit to the data, even though surplus labour exists. Section 7 concludes.

Biased Technical Change and Total Factor Productivity Growth in China

In this section, the arguments of Nelson and Pack (1999) are summarised and the rate of *TFP* growth for China is re-calculated, following the procedure proposed in Felipe and McCombie (2001). The original critique of Nelson and Pack (1999) arises from the observation that capital shares remained high in the East Asian countries during the period of the so-called economic miracle (from the mid-1960s until the mid-1990s) despite a substantial increase in the capital-labour ratio. They argue that the most likely explanation for this is that the elasticity of substitution was less than unity and that technical progress was biased in a labour-saving direction. Theoretically, in a growth accounting exercise one should use as weights for the growth of the factor inputs, the value of the factor shares that would have occurred had there been no technical change.[5] If, in the East Asian countries, the stability of the observed shares was due, for example, to an elasticity of substitution that is less than unity and biased technical change that is labour-saving, Nelson and Pack's argument may make a substantial difference in that the re-calculated estimates of *TFP* growth (using the factor shares that would have occurred in the absence of technical change) explain a greater proportion of output growth than the conventional calculations suggest (Felipe and McCombie, 2001).

As Felipe and McCombie (2001) point out, if this is true for the East Asian economies, there is the possibility that it will be also true for many other economies, and this would include China.

The conventional neoclassical growth accounting approach uses observed factor shares as the weights for the growth of the factor inputs. These estimates of *TFP* growth are based on the Divisia index, which weights inputs by their factor shares at any moment of time. This means that the weights, which also equal the output elasticities when markets are perfectly competitive, are continuously rebased. The instantaneous growth of *TFP* given by the conventional growth accounting method is $tfp_t = q_t - \ell_t - a_t(k_t - \ell_t)$ where tfp, q, ℓ and k are the growth rates of *TFP*, output, labour, and capital respectively, and a_t is the observed share of capital. In practice, for discrete periods of time, following Diewert (1976) the average of the shares in the initial (a_0) and terminal years (a_T) are used, that is, $\bar{a} = 1/2(a_0 + a_T)$.

In order to understand the critique it is necessary to consider why a_0 and a_T may differ, or, alternatively, what determines the rate of change of capital's share, namely $\hat{a}$. Consider a production function with factor-augmenting technical change:

$$Q = F(A_L L, A_K K) \tag{1}$$

where Q, L, and K are output, labour and capital. A_L and A_K are factor-augmenting technical change that occur at the rates λ_L and λ_K respectively. The growth rate of output over a discrete period of time, under the conventional growth accounting approach, is given by (dropping the time subscript for convenience):

$$q = (1-\bar{a})\lambda_L + \bar{a}\lambda_K + (1-\bar{a})\ell + \bar{a}k \tag{2}$$

The rate of change of capital's share is given by (see Ferguson, 1969):

$$\hat{a} = \left[(1-\bar{a})(1-\sigma)/\sigma\right]\left[(\lambda_L + \ell) - (\lambda_K + k)\right] \tag{3}$$

where σ is the elasticity of substitution and the degree of bias is given by $B = \left[(1-\sigma)/\sigma\right](\lambda_L - \lambda_K)$.

From equations (2) and (3), it follows that if the value of capital's share does not change very much over time, as was observed in the Asian Tigers, it could be due to one of two reasons. First, the elasticity of substitution may be equal to unity, in which case the production function is a Cobb-Douglas.

But, secondly, from equation (3), the stability of the shares could have occurred because the degree of bias of technical change is such that $\lambda_L - \lambda_K = k - \ell$. In the absence of technical change, capital's factor share will fall over time. In the case under consideration here, the rate of biased technical change is such as to keep the factor shares constant.

Therefore, the conventional growth accounting approach is subject to error, unless technical progress is Hicks-neutral, because of its use of current factor shares as weights in the terminal period. As we have seen, the value of the capital share in the terminal period is high only because of the impact of biased technical change. Thus, if capital's current share in the terminal period is used to calculate $\bar{a}$, it will incorporate the effect of biased technical change to the extent that the latter has prevented the observed share from falling as much as it should have. As the growth of capital exceeds that of labour, assigning a higher weight to the former and a lower weight to the latter increases the contribution of the growth of the factor inputs to output growth. Hence, the 'true' contribution of TFP growth to that of output will be underestimated. To obviate this problem, the preferable procedure is to use $\bar{a}$ constructed with the value of capital's share in the terminal period *that would have occurred in the absence of technical change.* We refer to these unobserved and hypothetical weights as the 'constant-technology' factor shares.

It is plausible that the production process of China and the technological progress that occurred are described better by a low elasticity of substitution and technical progress that is biased towards labour-saving rather than by a production function with Hicks-neutral technical change.

There is a complication, however, in that capital's share in China, unlike the case of the East Asian Tigers, did not remain constant. There is a marked fall in its value from 0.70 in 1952 to 0.63 in 1979 and even further to 0.47 in 1994. This implies that under the orthodox approach with Hicks-neutral technical change, the elasticity of substitution must be less than unity. In fact, the implied values of the elasticity of substitution are 0.86 (1952-78); 0.53 (1979-94) and 0.70 (1952-94). We may take these values as a benchmark, as the constant-technology-shares approach using these values of the elasticity of substitution will give precisely the same values of TFP growth as the conventional approach. The reason is straightforward. Under the orthodox approach, these are the shares that occur with Hicks-neutral technical change, i.e., they are the values of the shares that occur where there is, by definition, no effect of technical change on them. If we adopt the 'constant-technology' approach, the value of the share in the terminal period will be the same as the observed share. Consequently, the constant-technology rate of growth of TFP will be greater than the orthodox calculation only to the extent that the elasticity of substitution is smaller than the benchmark value and vice versa.

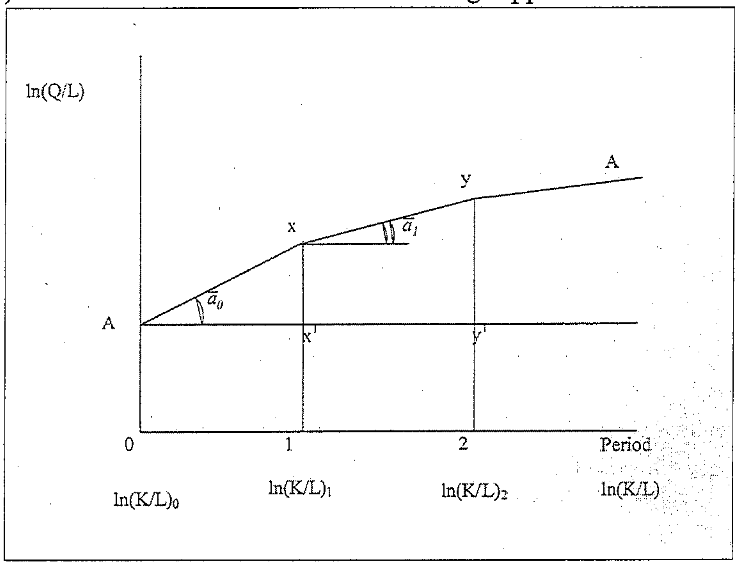
We may illustrate the effect on the growth of *TFP* of using current and constant-technology shares with the help of a diagram. In Figure 1(a), the line AA depicts the logarithm of the production function in intensive form with an elasticity of substitution of less than unity. It consists of a series of linear segments, convex from above, where the slope of each segment is $\bar{a}_i$ (where $i = 0, 1 \ldots T$) and is the average observed share over the time period being considered. The distance xx^1 gives the proportional increase in labour productivity, $\Delta ln(Q/L)$, over the period [0, 1] when the logarithm of the capital –labour ratio increases from $ln(K/L)_0$ to $ln(K/L)_1$, i.e. by $\Delta(K/L)$. The increase in labour productivity is also equal to $\bar{a}_0 \Delta ln(K/L)$ over this period. Consequently, there is no increase in total factor productivity, a result that some of the conventional growth accounting approaches find for pre-reform China. Similarly, in the period [1, 2] there is no increase in *TFP*. The increase in *TFP* over [0, 2], which in this case is zero, may be calculated by taking the average of the periods [0, 1] and [1, 2]. It may also be determined by calculating $\bar{a}$ over [0, 2] in which case the linear segment is given by Ay, (this line is not shown in Figure 1(a)).

Figure 1(b) depicts the case where there is biased technical change and constant-technology shares are used in calculating the increase in *TFP*. Over the period [0, 1] the average constant-technology share (using the base-year technology) is $\bar{a}_0^* < \bar{a}_0$.

Consequently, the contribution to the increase in *ln(Q/L)* given by the factor inputs is equal to the distance x^2x^1 or $\bar{a}_0^* \Delta ln(K/L)$. The distance xx^2 equals $\Delta \ln TFP$ which is positive.

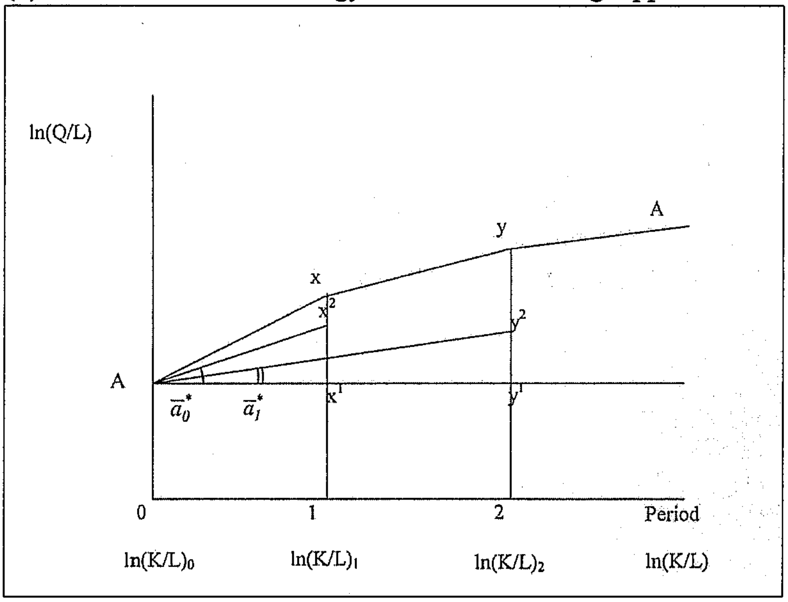
However, the longer the time period over which we calculate the proportional increase in *TFP*, the lower the constant-technology share will be. As may be seen from Figure 1(b), for the period [0, 2] the increase in *lnTFP* is given by yy^2 and the contribution of the increase in the capital-labour ratio by y^2y^1.

Figure 1.(a): The Conventional Growth Accounting Approach



Thus, the proportion of the increase in labour productivity over the period [0,2] explained by the increase in *ln(K/L)* is larger than the proportion explained over the period [0,1]. As we lengthen the time period over which we are calculating the increase in *ln(Q/L)*, so the proportion explained by the change in the logarithm of the capital-labour ratio falls (as the average value of the constant-technology share decreases). Eventually, if the period over which we are calculating these changes is long enough, it will become zero and the *whole* of the increase in labour productivity will be attributed to the increase in *TFP*. The fact that the contribution of the growth of *TFP* to output (and labour productivity) increases solely as a result of increasing the period of time over which the growth rates are calculated is disconcerting, but it is inherent in this procedure.

Figure 1.(b): The Constant-Technology Growth Accounting Approach



The conventional approach does not suffer from this problem, but of course, requires the restrictive assumption of Hicks-neutral technical change.

Recalculating the Impact of Technical Change on China's Growth

We next follow the procedure developed by Felipe and McCombie (2001) and calculate the growth of *TFP* using as weights the constant-technology, rather than observed, factor shares. We denote the terminal constant-technology share of capital as a_T^*. Thus, we calculate the adjusted rate of *TFP* growth as:

$$tfp' \equiv q - \ell - \bar{a}^*(k - \ell) \quad (4)$$

where $\bar{a}^*$ is some measure of the average value of the constant-technology shares and the technology is that of the base year. Note that this is not the same as using the share in the base year as the initial and terminal share. The values of the shares will change, even in the absence of technical change, as the capital-labour ratio changes over time. The exact extent of the change in the factor shares will depend on the value of the elasticity of substitution and the growth of the capital-labour ratio. One procedure for calculating the constant-technology average share is to use the formula

$\bar{a}^* = 1/2(a_0 + a_T^*)$. However, this has the undesirable property that as T, the length of time over which the growth rates are calculated, becomes large and a^*_T tends to zero, so $\bar{a}^* \rightarrow$ ½(a_0), whereas, ideally, $\bar{a}^* \rightarrow 0$. Felipe and McCombie (2001) show that $\bar{a}^* = (a_T^* - a_0) / \hat{a}^* T$ where $\hat{a}^*$ is growth of a^* is a better approximation which avoids this problem. (For small values of T the two methods give virtually identical results.) The equation used to calculate the corrected growth of TFP is:

$$tfp' = q - \ell - \left[(a_T^* - a_0) / \hat{a}^* T\right](k - \ell) \tag{5}$$

where $\hat{a}^* = -\left[1 - \left\{(a_T^* - a_0)/\hat{a}^* T\right\}\right]\left[1-\sigma)/\sigma\right](k - \ell)$ is the rate of change of capital's share in the absence of technical change. Consequently, we calculate capital's terminal share under the assumption of no technical change as $a_T^* = a_0 \exp(\hat{a}^* T)$. This equation indicates that we need to know the growth of the share under the assumption of no technical change to calculate a_T^*. To this purpose, we adopt an iterative procedure to calculate a_T^*. First, we take observed values for q, k, ℓ, a_o, and T and assume a value for σ. Secondly, we calculate the initial average share of capital as $\bar{a} = (a_T - a_0) / \hat{a} T$, where $\hat{a} = \ln(a_T / a_0) / T$. Thirdly, we estimate the change in capital's share with the base-year technology as $\hat{a}^* = -(1 - \bar{a})\left[(1 - \sigma)/\sigma\right](k - \ell)$. Fourthly, we calculate capital's share under the base-year technology as $a_T^* = a_0 \exp(\hat{a}^* T)$. Fifthly, we re-calculate the change in capital's share with the base-year technology using a_T^* from step four as $\hat{a}^* = -\left[1 - \left\{(a_T^* - a_0)/\hat{a}^* T\right\}\right]\left[1-\sigma)/\sigma\right](k - \ell)$. We next iterate steps four and five until $\hat{a}^*$ converges. Finally, we calculate the annual rate of TFP growth as $tfp' = \left[q - \ell - \left\{(a_T^* - a_0)/\hat{a}^* T\right\}\right](k - \ell)$, where a_T^* is the value from the final iteration.

In practice, obtaining an estimate of a_T^* that is consistent with the growth of a^* required only a few iterations. As we have noted, the value of a_T^* is also a function of the period of time over which it is calculated. If the growth rate of *TFP* were instantaneous, the conventional and the constant-technology methods would be identical. Thus, the degree of bias is likely to be small for *TFP* growth calculated over a short period, say a year. However, as the period lengthens, the value of a* in the terminal year, i.e., a_T^*, will become progressively smaller, given the above assumptions. Thus, as we have also noted above, the growth of the constant-technology *TFP* will be a function of both the elasticity of substitution and the length of time, T. The value of *TFP* growth calculated by the conventional approach are independent of these two factors.

To determine the empirical importance of this argument, we calculated *TFP* growth for China using the constant-technology shares, with different values of the elasticity of substitution (σ), together with the growth of *TFP* obtained by using the standard growth accounting methodology. The data for the growth rates of output, labour and capital, as well as the factor shares, are taken from Hu and Khan (1997).

However, as we have noted above, there is an important difference between the observed factor shares for China and for the East Asian Tigers. In the latter, the observed shares remained constant over the period in spite of a rapid growth of the capital-labour ratio. In the case of China, the observed share of capital fell substantially over the period concerned.

This is confirmed in Table 1. The table reports the constant-technology value of the terminal share, a_i^*, where i is the number of years in the period. It further reports the average constant-technology share, $\overline{a}_i^*$ and the adjusted or constant –technology rate of growth of *TFP*, namely tfp_i'.

For the period 1952-78 (before the implementation of the reforms) it can be seen that for $\sigma = 0.6$, a value not far off the benchmark elasticity of substitution, the rate of growth of *TFP* calculated using the constant-technology shares is 1 per cent per annum, which is virtually the same as that of the conventional approach, namely, 0.9 per cent per annum. (It will be recalled that some studies found no *TFP* growth over this period.) If the elasticity of substitution exceeds the benchmark value, the constant-technology *TFP* growth rate is *lower* than the conventional estimates, but not by much (an elasticity of substitution of near unity gives a value of *tfp'* of 0.7 per cent per annum). [6] However, if the elasticity of substitution is low, the value of *tfp'* increases dramatically. If $\sigma = 0.1$ then the growth of *TFP* is 2.9 per cent per annum. This is over three times the rate of growth of the conventional growth accounting estimate, which is a substantial increase.

This occurs because there is a non-linearity between the rate of growth of *TFP* and the elasticity of substitution. A decline of the elasticity of substitution from 1.0 to 0.6 raises the *TFP* growth by only 0.3 percentage points. A decline from 0.6 to 0.2, however, raises the growth rate by 1.4 percentage points.[7] Consequently, for China to have had a rapid growth of total factor productivity over this period, the elasticity of substitution would have had to have been very low. (Nelson and Pack (1999) in their theoretical model of the East Asian growth miracle, in fact, assume fixed coefficients.)

Table 1.: Constant-Technology Factor Shares and Adjusted TFP Growth Rates

1952-78; T=26; ℓ=0.0254; k=0.0616; q=0.0581; a_0=0.70; a_T=0.63; tfp=0.0087			
σ	a_{26}^*	$\overline{a}_{26}^*$	tfp'_{26}
0.1	0.0003	0.0908	0.0294
0.2	0.0383	0.2277	0.0244
0.6	0.5527	0.6234	0.0101
0.8	0.6482	0.6738	0.0083
1	0.7000	0.7000	0.0073
1.2	0.7319	0.7158	0.0067

1979-94; T=16; ℓ=0.0266; k=0.0771; q=0.0934; a_0=0.63; a_T=0.47; tfp=0.0390			
σ	a^*_{16}	$\bar{a}^*_{16}$	tfp'_{16}
0.1	0.0008	0.0956	0.0619
0.2	0.0528	0.2328	0.0550
0.6	0.4973	0.5610	0.0384
0.8	0.5817	0.6055	0.0362
1	0.6300	0.6300	0.0350
1.2	0.6608	0.6452	0.0342
1952-94; T=42; ℓ=0.0259; k=0.0675; q=0.0715; a_0=0.70; a_T=0.47; tfp=0.0213			
σ	a^*_{42}	$\bar{a}^*_{42}$	tfp'_{42}
0.1	0	0.0466	0.0436
0.2	0.0014	0.1126	0.0409
0.6	0.4109	0.5427	0.0230
0.8	0.6004	0.6489	0.0186
1	0.7000	0.7000	0.0164
1.2	0.7576	0.7284	0.0152

Source: Authors' calculations. Original data from and Khan (1997).
Notes:
(i) σ is the elasticity of substitution.
(ii) a^*_T is the constant-technology capital's share after T years, where T = 16, 26, and 42 years.
(iii) $\bar{a}^*_T$ is the constant-technology average share after T years, where T= 16, 26, and 42 years.
(iv) q = annual growth rate of output; ℓ = annual growth rate of employment; k = annual growth rate of stock of capital; a_0 = observed share of capital initial period; a_T = observed share of capital final period.
(v) $tfp = (q-\ell)-[1/2(a_0+a_T)(k-\ell)]$
(vi) $tfp'_T = (q-\ell)-\bar{a}^*_T(k-\ell)$ is the annual growth of TFP over a period of T years under the assumption of constant technology;
(vii) For σ = 1 the algorithm gives an error. (See footnote 5.) We use = 0.99999 as an approximation and this is reported in that table as σ = 1.

For the post-reform period, 1979-94, the increase in *TFP* growth with a low elasticity of substitution is also significant in absolute terms. It increases from 3.90 per cent per annum calculated by the conventional approach to 5.50 per cent under the constant-technology approach with σ = 0.2 and 6.19 per cent with σ = 0.1. This represents an increase of just under 60 per cent, which is considerably less than in the first period.

Finally, for the complete period, the *TFP* rate doubles from 2.13 per cent to 4.09 per cent (σ = 0.2) and 4.36 per cent (σ = 0.1). Thus, using constant-technology shares, we conclude that *TFP* growth still grew faster after 1978, although the difference between the two periods is about the same as that given by the standard procedure.

In other words, the conventional growth accounting approach gives an increase in *TFP* growth between the two periods of 3.0 percentage points, from 0.9 per cent per annum (1952-78) to 3.9 per cent per annum (1979-94). With an elasticity of substitution of 0.1, the constant-technology shares approach gives figures of 3.3 percentage points, 2.9 per cent per annum (1952-78) and 6.2 per cent per annum (1979-94). However, it should be emphasised that the constant-technology approach shows that the conventional growth accounting approach considerably understates the true rate of TFP growth for both periods, if the elasticity of substitution is low. In particular, *TFP* growth during the pre-reform period was not zero as has been asserted by some. With $\sigma = 0.1$, it represents almost half of overall growth and 90 per cent of the growth in labour productivity. The figures for the post-reform period are similar, namely, 66 per cent of output growth and around 90 per cent of labour productivity growth.[8] But it is clear that these results are very sensitive to the elasticity of substitution, and to get a substantial rate of *TFP* growth in, especially, the pre-reform period requires a very low elasticity of substitution.

If we assume that the elasticity of substitution is close to unity, then the growth rates of *TFP* are much lower, 0.7 per cent over the period 1952-78 and 3.50 per cent (1979-94). For values of the elasticity of substitution above the benchmarks note above (e.g., 0.70 for the whole period), the growth of *TFP* declines. This provides a further illustration of the fact that the rate of *TFP* growth depends crucially on the assumption made concerning the elasticity of substitution. So what is plausible value for the elasticity of substitution? Here a problem arises. Econometric estimations of aggregate production functions using time-series data will not help provide an answer. For example, suppose that the observed factor shares do not change over time (as in the case of the East Asian Tigers). Using these data, the estimate of the aggregate production function that will give the best fit will be the Cobb-Douglas production function, with Hicks (and Harrod) neutral technical change. But it could be that technical change is biased and the 'true' elasticity of substitution is less than unity, with the degree of bias in the rate of technical change keeping the observed shares constant. But the estimation of an aggregate production function using the observed data will not, and cannot, show this and will give misleading estimates. [9]

What do Estimates of Aggregate Production Functions Show?

The purpose of this section is to provide an answer to the conundrum posed in the introduction, namely, if aggregate production functions do not exist, can we provide an alternative interpretation of the results obtained in growth accounting exercises and econometric estimation of putative aggregate production functions?

To begin with, consider the income accounting identity that relates output to inputs in the national accounts:

$$Q_t \equiv w_t L_t + r_t K_t \tag{6}$$

where Q denotes real value added, w is the average real wage rate, L is employment, r is the average profit rate, and K is the value of the stock of capital.[10] Notice that this identity is not the result of Euler's theorem. It simply says that all output is distributed as the wage bill and total profits. There are no assumptions underlying equation (6) such as constant returns or competitive markets, and thus w and r are not, in general, the marginal products of labour and capital.

If this identity is expressed in growth rates, the following result is obtained:

$$\begin{aligned} q_t &\equiv a_t \hat{w}_t + (1-a_t)\hat{r}_t + a_t \ell_t + (1-a_t)k_t \\ &\equiv \varphi_t + a_t \ell_t + (1-a_t)k_t \end{aligned} \tag{7}$$

where the lower case letters denote the growth rates of output (q), employment (ℓ), and the stock of capital (k). The growth of the wage rate is $\hat{w}$, and the growth of the profit rate is $\hat{r}$. The labour and capital shares in total output are given by $a_t = (w_t L_t)/Q_t$ and $1-a_t = (r_t K_t)/Q_t$ and $\varphi_t = a_t \hat{w}_t + (1-a_t)\hat{r}_t$.

It should be emphasised again that equation (7) is just an identity. Now assume, without affecting the argument, that factor shares are constant. Equation (7) becomes:

$$q_t \equiv a\hat{w}_t + (1-a)\hat{r}_t + a\ell_t + (1-a)k_t \tag{8}$$

Integrating this equation and taking the anti-logarithm yields:

$$Q_t \equiv C w_t^a r_t^{(1-a)} L_t^a K_t^{(1-a)} \equiv C(t) L_t^a K_t^{(1-a)} \tag{9}$$

where lnC is the constant of integration, and $C(t) \equiv C w_t^a r_t^{1-a}$. Equation (9), the income identity rewritten under the assumption that factor shares are constant, resembles a Cobb-Douglas production function. The only difference is that equation (9) contains the wage and profit rates. But suppose that in this economy wage and profit rates grow at constant rates such that $w_t = w_0 \exp(\hat{w}t)$ and $r_t = r_0 \exp(\hat{r}t)$. Then equation (9) becomes:

$$Q_t = C e^{\varphi t} L_t^a K_t^{(1-a)} \tag{10}$$

where $\varphi = a\hat{w} + (1-a)\hat{r}$. As a 'stylized fact', the real wage exhibits a strong trend, whereas, over the long run, the rate of profit remains roughly constant[11]. In these circumstances, $\varphi = a\hat{w}$.

Equation (10) is identical to the Cobb-Douglas production function with a time shift function. It should be stressed, nevertheless, that equation (10) is not a production function, i.e., it is not a technological relationship. It is the income accounting identity rewritten under the assumptions of (i) constant factor shares and, consequent upon this, that (ii) φ is constant. This simple derivation has a series of important implications. Suppose that the two assumptions made in deriving equation (10) happen to be true for the economy under consideration, and one estimates econometrically equation (10) in the unrestricted form as: $Q_t = Ae^{\lambda t} L_t^{\alpha} K_t^{\beta}$. It is obvious that the estimates will give $\alpha = a$, $\beta = (1-a)$, $\lambda = \varphi = a\hat{w} + (1-a)\hat{r}$, and $R^2 = 1$[12] These results, however, are solely due to the fact that all that is being estimated is an identity. Nothing can be inferred from the estimates about the structure of production and that rate of technical progress. In other words, it is not possible, for example, to verify the marginal productivity theory of factor pricing, whether or not constant returns to scale occur, and whether or not there are diminishing returns to each factor of production. It is also not possible to determine a numerical value for the rate of technical progress.

If, on the one hand, one or both assumptions above are incorrect and one nevertheless estimates the equation $Q_t = Ce^{\lambda t} L_t^{\alpha} K_t^{\beta}$, then these results will not hold. The greater is the inappropriateness of the two assumptions of constant factor shares and a constant φ, the worse will be the statistical results. But even in this case, the argument that all that is being estimated is an underlying identity remains correct. We just need to find out what are the exact paths of the factor shares and of the growth rates of the wage and profit rates. Substituting these into equation (7) and integrating will lead to more flexible functional forms that will resemble other 'production functions' such as the CES or the translog.[13] We will still find that the putative output elasticities equal the observed factor shares.

On the other hand, if, instead of estimating the production function, a growth accounting exercise is undertaken, it will be noted that equation (7) is equivalent to the standard growth accounting equation derived by differentiating the production function $Q_t = A(t)F(L_t K_t)$, where *A(t)* is the level of technology, or more accurately, the level of total factor productivity. This is because equation (7) can be rewritten as:

$$tfp_t = q_t - a_t \ell_t - (1-a_t)k_t = a_t \hat{w}_t + (1-a_t)\hat{r}_t \quad (11)$$

There are, however, two important differences between the standard growth accounting equation and equation (11), which is derived here from the accounting identity. First, in order to derive the standard growth accounting equation one needs to assume that firms are profit maximizers and that markets are competitive. No assumptions are made in order to derive equations (7) or (11). Thus, for example, Hu and Khan's (1997, p. 108) comment that: 'The estimates of productivity growth for

China may be biased in either direction if there are deviations from the assumptions imposed by the adopted methodology' is unwarranted.[14] The measure of *TFP* derived from estimating a supposed aggregate production function must always equal the calculation from the growth accounting equation (11), because the accounting identity must always hold. Secondly, since equations (7) or (11) are derived from an identity, the interpretation of the residual as a measure of technical change becomes problematic. Under the orthodox interpretation and assumptions, *TFP* growth is a measure of technical change because it is derived from the aggregate production function. But as argued above, the latter most likely does not exist, and thus the only inference that should be made about the 'residual' is that it is a weighted average of the growth rates of the wage and profit rates, i.e., the right-hand-side of equation (11). As this is derived from an identity, it is a tautology and can only be interpreted as a measure of distributional changes.[15] Moreover, the production function, if it is estimated correctly, will always indicate 'constant returns to scale', and there is no way to test (and hence potentially refute) the hypotheses underlying the growth accounting approach, i.e., the existence of competitive markets and profit maximisation. (See, for example, Felipe, 2001a & b, McCombie, 2001.)

Finally, our derivation implies that even in the case where the aggregate production function exists (i.e., Fisher's aggregation conditions were satisfied), there is still a problem of interpretation since the derivation above will still hold. The problem is that it is not possible to determine whether what has been estimated is the true aggregate production function or the identity rewritten as equation (11). In other words, there is no way to identify the production function.

Estimating the Rate of Technical Change in China: A Critique

A good example of the problems involved in the interpretation of the aggregate production function may be illustrated by considering Chow's (1993) influential study of China's postwar economic growth. Chow estimates a Cobb-Douglas production function by OLS. He considers that his results yield the important conclusion that technical progress was absent in 1952-80. Furthermore, he argues that the evidence has important policy implications, as it suggests that for China 'much government direction in industrial investment does not lead to an increase in total factor productivity' (Chow 1993, p.842). He derives these inferences almost entirely from the results of the statistical estimation of the Cobb-Douglas production function. However, the problem posed by the use of value data and the accounting identity means that such a fit is not surprising, but, as we have seen above, provides no independent evidence of the existence of an aggregate production function. At the very least, Chow's conclusions must be qualified and treated with a great deal of caution.

Chow fitted Cobb-Douglas production functions to data for Chinese total output and five sectors (agriculture, industry, construction, transportation, and commerce) for 1952-80. After carefully compiling data for income, employment and capital, Chow first runs various regressions (with different estimates of the capital stock) for total output data which exclude the years 1958 to 1969. This is because of the *assumption* that the years from 1958 to 1969 are abnormal because of the great upheavals of the Great Leap Forward movement and the Cultural Revolution (the number of observations is thus reduced from 28 to 17). Chow argues that 'to exclude the years from 1958 to 1969 in estimating an aggregate production function is a reasonable and rewarding procedure' (Chow 1993, p. 821). In other words, Chow argues that during the Cultural Revolution China was not on the production possibility frontier. Hence, observations from that period should not be taking as reflecting the same production function as from other periods. From the statistical point of view, however, this can be viewed as an exercise in data mining, since the t-statistics can no longer be referred to the conventional statistical tables to determine their probability values. Even though these excluded years saw a collapse in total output (the value in 1962 was only 64 per cent of the value of 1959) followed by a rapid recovery (1966 was 177 per cent of the 1962 value), this should not affect the parameters of the production function, if indeed the data were estimating the latter. The fall in the flow of the services of inputs should lead to a decline in output that should be closely predicted by the production function.[16] However, Chow argues that 'if a reader still wishes to question the exclusion of these years, my answer is that it is *interesting* to find out how abnormal the excluded years are *if* the remaining years up to 1980 are *assumed* normal years [...] Data are provided in this paper for any reader who wishes to select some other years as abnormal to draw her own conclusions' (Chow, 1993, pp. 821-822; italics in the original). We accepted Chow's invitation and used his data set. However, instead of repeating his exercise and eliminating some other years, it will be shown that there is no need to eliminate any single year in order to obtain excellent estimates of the Cobb-Douglas.

The estimation of the Cobb-Douglas production functions with the coefficients constrained to sum to unity and using the data in log-levels encounters a problem notwithstanding the fact that the R^2 is always in excess of 0.98 (Chow, 1993, Table VII). This is that the results prove to be very sensitive to the exact way in which the constant value series of the capital stock is calculated, and different measures result in very disparate estimates of, especially, the output elasticity with respect to capital. When the constant-returns-to-scale Cobb-Douglas relationship, with a linear time trend included, is estimated for total output, the estimated output elasticities of capital range from 1.282 (t-value of 2.41) to the statistically insignificant value of 0.538

(1.27). In spite of the potentially serious problems of errors in variables and misspecification, the results always show that the coefficient of the time trend is statistically insignificant. This is sufficient for Chow to interpret his regressions as indicating that during the period 1952-80 technological progress was absent in the Chinese economy due to the Great Leap Forward and the Cultural Revolution, notwithstanding the fact that estimated output elasticities are either implausible (an output elasticity of capital of 1.282 with constant returns to scale imposed implies that labour's elasticity is 0.282) or statistically insignificant. He surprisingly argues that 'the failure to estimate accurately the relative effects of capital and labour does not prevent the data from throwing light on the existence of technological change from 1952 to 1980' (Chow 1993, pp. 822-23).

His results, however, would suggest that a Cobb-Douglas production function does *not* provide a good explanation for China's output growth and that, even on his own assumptions, the finding that the coefficient of the time trend was statistically insignificant has very little meaning because of the likelihood of a serious misspecification problem. No doubt, though, he is reassured by the fact that if capital's share is taken to be 0.6 and labour's 0.4, a 'growth accounting' calculation also suggests an insignificant residual (Chow 1993, p.826).

A similar set of results is found for the individual sectors. However, it should be noted that once again a number of years (not always the same for each sector) are omitted from the regression, 'chosen partly for the goodness of fit' (Chow, 1993, p.832).[17] The poor fit is almost certainly due to the inclusion of a linear time trend that proves to be a poor proxy for φ_t.

We may illustrate this with data for the construction sector. Chow dropped the years 1961, 1962, and 1968 from the sample and restricted estimation to the period 1954-80 (Chow 1993, Table XII). By doing this, Chow obtained a negative time trend, which could be interpreted as showing increasing inefficiency in the sector. On the other hand, the estimated output elasticities were values that could be interpreted as the factor shares. For reference, including all the time years available, i.e., 1952-85, the regression gives a markedly different results which are as follows (t-values in parentheses):

$$\ln Q = \underset{(4.46)}{1.873} + \underset{(3.90)}{0.045t} + \underset{(7.43)}{0.489\ln L} - \underset{(-0.08)}{0.010\ln K} \qquad R^2 = 0.947,\ DW = 2.10$$

For the period 1952-80, the regression results are:

$$\ln Q = \underset{(4.06)}{1.897} + \underset{(3.30)}{0.045t} + \underset{(6.32)}{0.485\ln L} - \underset{(-0.05)}{0.007\ln K} \qquad R^2 = 0.911,\ DW = 2.10$$

and for the period 1954-80 (the same period as Chow uses):

$$\ln Q = 1.755 + 0.043t + 0.488\ln L + 0.024\ln K \qquad R^2 = 0.885, DW = 2.09$$
$$(1.43) \quad (1.25) \quad (5.71) \quad (0.06)$$

It is worth noting that the rate of 'technical progress' is now rapid at 4.5 per cent per year and is statistically significant (t-statistics in parenthesis). However, the statistical insignificance of the logarithm of the capital stock, which occurred in a number of other sectors, suggests a misspecification. The effect of eliminating the years 1952-53 on the estimated coefficient of the stock of capital in the regression for the period 1950-84 should also be noticed.

Given our arguments in the previous sections we know, first, that the reason why the regressions above display such implausible results is that they are not the correct approximations to the accounting identity; and secondly, that it was not necessary for Chow to eliminate certain years from the regression in order to obtain acceptable results. All it is needed is to find the correct approximation to the identity (Shaikh, 1980, Felipe and Holz, 2001). It is found that no simple linear or logarithmic function will fit C(t) in equation (11).

However, by some experimenting resulting in the introduction of a non-linear time trend, denoted by t*, we were able to obtain the following results also for the complete period 1952-85 (t-values in parentheses):

$$\ln Q = 0.928 + 0.040t^* + 0.398\ln L + 0.477\ln K \qquad R^2 = 0.932, DW = 1.55$$
$$(2.42) \quad (2.39) \quad (5.67) \quad (11.79)$$

The non-linear time trend was given by $t^* = \text{sine } t^2 + \text{sine } t^3 + \text{sine } t^4 + \text{cosine } t - \text{cosine } t^2 - \text{cosine } t^3 + \text{cosine } t^5$.

For the period 1952-80, the regression results are:

$$\ln Q = 1.037 + 0.044t^* + 0.384\ln L + 0.471\ln K \qquad R^2 = 0.893, DW = 1.51$$
$$(2.27) \quad (2.17) \quad (4.98) \quad (9.77)$$

The predictive-failure test for the 1952-80 regression yields a value of $F(5,23) = 0.29$, and Chow's stability test a value of $F(4,24) = 0.37$. This implies that there was no structural break with respect to 1981-85 and that the regression coefficients are stable. Similarly, for both regressions the recursive estimates show a high degree of stability. For 1954-80 the results are:

$$\ln Q = 0.322 + 0.036t^* + 0.431\ln L + 0.552\ln K \qquad R^2 = 0.895, DW = 1.90$$
$$(0.67) \quad (1.96) \quad (6.09) \quad (10.75)$$

with predictive-failure test of value of $F(5,25) = 0.26$ and Chow's stability test, a value of $F(4,26) = 0.33$.

These results indicate that as we more accurately approximate the identity, the closer are the values for 'output elasticities' to those of the factor shares, including that of the capital stock. As argued above, all we are doing is tracking the income identity with a different functional form.[18] Of course, the reason for the introduction, and meaning, of t* may be questioned. The answer is that nothing in neoclassical production theory requires that technical progress must grow at a constant rate, i.e., that it must be proxied by a linear time trend. Linearity is merely a convenient assumption.

It has been seen the growth of labour productivity increased substantially after the introduction of the market reforms, namely, from 3.27 per cent in 1952-78 to 6.68 per cent in 1979-94. It has been argued in this paper that it is not possible, using value data, to decompose the growth of labour productivity into the proportion due to an increase in the rate of technical change (measured as an increase growth rate of total factor productivity) and that due to a faster growth of the capital-labour ratio. However, it is plausible that market reforms were at least partly responsible for the increase in the growth of labour productivity, through either or both of these two mechanism or by ensuring a more efficient use of the existing factors of production.

Another possibility would be to include in the regression, instead of the time trend, variables that could potentially be correlated with the weighted average, for example, changes in capacity utilisation, human capital, and foreign direct investment (see McCombie, 2000-01). Of course, in this case the regression would also give a good statistical fit, but would be subject to the same criticism.

Mention should also be made of the possibility that the Cobb-Douglas approximation to the accounting identity used by Chow is a spurious regression, as it introduces a time trend with integrated process. The general econometric implications of de-trending the series and the relationship with the production function and the accounting identity have been analysed by Felipe and Holz (2001) who, using Monte Carlo simulations, showed that the main reason behind the high fit is the accounting identity, and not spuriousness; and that the only way to explain the proximity of the estimates to the factor shares is through the identity.

The Cobb-Douglas Production Function and Surplus Labour

Chow also calculated the value of the marginal products from the estimates of the Cobb-Douglas, although he admitted that their values had large standard errors. However, the Cobb-Douglas production function rules out, *ab initio*, the possibility of surplus labour (i.e., a zero or negative marginal product of labour) which is likely to be relevant for the Chinese, or for any less developed, economy. Under the usual neoclassical assumptions, the marginal product of labour in the Cobb-Douglas case is given by $w = \partial Q / \partial L = \alpha Q / L$, and since is equal to labour's share (a) from the first order condition and $Q/L > 0$, the estimate of marginal productivity must be positive. Nevertheless, because of the identity, even though the data give an excellent fit to the Cobb-Douglas production function, it is not possible to rule out the existence of surplus labour.

To see this, let us assume that there is a well-defined underlying physical production function and surplus labour exists and so the 'true' marginal product of labour is zero. Furthermore, let us assume that the state takes a certain fraction of the gross output in value terms for investment and let us call this share (1-a). Because of the co-operative nature of the Chinese economy, each worker is paid the average net product. The net product is total output less that taken by the state for investment purposes, aQ, (recalling that Q is value added – a value measure). Thus each worker receives a wage, w, equal to aQ/L. If this is a relatively stable proportion of total output, then fitting a Cobb-Douglas will give a good fit to the value data because 'factor shares' are constant. As noted above, the imputed marginal product will be aQ/L, which is actually the average net product. Thus, the misleading inference will be drawn that production is not occurring in the 'uneconomic region' of input space. The data will suggest that the production function is a Cobb-Douglas no matter what the true production function is. In other words, the data cannot differentiate between this hypothetical case and the Cobb-Douglas production function. Indeed, using the Hu and Khan (1997) data set, estimation of $w = aQ/L$ yields (t-values in parentheses): $a = 0.460$ (42.56) for 1952-94; $a = 0.378$ (39.94) for 1952-78; and $a = 0.481$ (31.83) for 1979-94. The corresponding average labour shares are very close to these estimates and are $\bar{a}$=0.410 for 1952-94; $\bar{a}$=0.385 for 1952-78; and $\bar{a}$=0.452 for 1979-94.

This example merely serves to emphasise further that the estimation of production functions with value data can say nothing about the underlying technical conditions production. Chow argues that if one accepts that there was no technical change (as his estimates suggest) then it is easy to explain why this was the case. 'There is no reason to assume that technical progress occurred during the period up to 1980. Economic co-operation with the Soviet Union ended in the 1960s. Without incentive from private enterprises, where could technological progress have come? I have found no theory to support the assertion that central planning will produce technological progress' (Chow 1993, p.841).[19] The same data, however, could equally tell another story; one of rapid technological progress but where a fast growth of the labour force, together with the existence of surplus labour, led to a situation where the weighted average of the growth rates of the wage and the (implied) profit rates did not increase markedly over time. The data simply cannot differentiate between these two very different cases. Indeed, as we have emphasised before, the data cannot tell us even whether or not there is a well-defined aggregate production function.

Finally, to gain a better understanding of the results discussed in the literature, we use again the data set compiled by Hu and Khan (1997), who concluded that TFP growth had increased in both pre- and post-reform periods, and decompose the residual inherent in the accounting identity, $tfp_t = \varphi_t = q_t - a_t\ell_t - (1-a_t)k_t = a_t\hat{w}_t + (1-a_t)\hat{r}_t$, into its two components, namely $a_t\hat{w}_t$ and $(1-a_t)\hat{r}_t$. Recall that we argued that this is simply a measure of distributional changes and that, if the production function does not exist, there is no reason for interpreting it as a measure of technical progress. This decomposition is shown in Table 2.

Table 2.: Decomposition of the Residual in the Accounting Identity

1952-94	0.412	5.92	2.34	0.588	-0.54	-0.22	2.12
1952-78	0.388	4.07	1.30	0.612	-0.75	-0.25	1.05
1979-94	0.452	8.92	4.05	0.548	-0.20	-0.17	3.88

Note: $\hat{w}_t$, $a_t\hat{w}_t$, $\hat{r}_t$, $(1-a_t)\hat{r}_t$, tfp_t are expressed as percentage growth rates. Averages for the period of $a_t\hat{w}_t$, $(1-a_t)\hat{r}_t$, and tfp_t are calculated as Tornqvist approximations, that is, taking the average of the factor shares in periods t and (t-1). Then, we take the average for the whole period. Hence the slight difference from the values reported in Table 1.

Sources: Authors' calculations and Hu and Khan (1997).

The results indicate that the main contributor to the positive residual in all three periods considered was $a_t\hat{w}_t$, and that, in fact, $(1-a_t)\hat{r}_t$ was slightly negative due to the fact that the growth rate of the profit rate was negative. The decomposition in Table 4 indicates that the reason why the residual was substantially larger in the post-reform period is that the wage rate grew twice as fast than during the pre-reform period. In fact, the rate of profit displays a slightly negative trend.

If we decompose the profit rate into the product of the profit share ($P = rK/Q$) and the output-capital ratio (*Q/K*), i.e., $r = (P/Q) \times (Q/K)$, the results indicate that the decline in the profit rate is more the result of the decline in the profit share, since the output-capital ratio remained essentially constant, although it is difficult to reach a definite conclusion.[20]

The profit share suffered two serious blows. The first one was around 1961-62, and the second one was more recent, around 1989-90. Why the profit share declined (and the labour share increased) in China is a topic worth further research, in particular whether the evolution of this variable is any way related to the implementation of market reforms. It may be that the increasing participation of the non-state sector, and in particular of private and foreign business, has increased the bargaining power of workers and enabled them to gain a higher share of total income at the expense of capitalists.

Conclusions

This paper has presented a methodological critique of the concept of *TFP* growth used in empirical analyses in the discussion of whether technical change growth in China increased after the implementation of market reforms in 1978. Two main points have been considered. First, if, as is likely, technological progress in China is biased, and the elasticity of substitution is substantially less than unity, the value of the factor shares will be affected by technical change. Under these circumstances, and the assumptions made, the use of the observed shares in the National Accounts is incorrect. Use of the more appropriate constant-technology shares increases significantly the rate of *TFP* growth in the pre-reform period (1952-78) from 0.87 per cent per annum to a non-negligible 2.44 per cent and 2.94 per cent per annum, when the elasticity of substitution is 0.2 and 0.1 respectively. This represents almost half of overall growth rate and more than three-quarters of the growth in labour productivity.

It was also shown that that econometric estimation using time-series data would not give the 'true' value of the elasticity of substitution. While cross-sectional estimations do not suffer from this difficulty, they have another problem due to the lack of variation in the factor-price, and hence capital-labour, ratios. Moreover, the use of time-series data in estimating production functions is far more common. Thus, estimates of *TFP* growth must be largely indeterminate. While, using the growth accounting approach, it is possible to get a range of values consistent with varying elasticities of substitutions, without knowledge of the latter, it is difficult to draw any firm conclusions.

A second problem was identified. The underlying theoretical tool in *TFP* growth analyses is the aggregate production function. However, aggregate production functions do not have a sound theoretical basis. The literature on aggregation clearly concluded that the conditions for successful aggregation are so stringent that one can hardly believe that actual economies satisfy them. The Cambridge Capital Theory Controversies have also cast doubt on the theoretical foundations of the aggregate production function. A proposed reinterpretation of the standard *TFP* growth calculations was suggested. It was shown that the measure of *TFP* growth can be interpreted as a measure of distributional changes because it can be derived as an algebraic transformation of the income accounting identity. In this view, the TFP growth residual need not be a measure of technical progress. It has been shown, using Chow's (1993) data set, that, if estimated correctly, any production function can be specified in such a way as to give a perfect fit, where the estimates of the output elasticities equal the factor shares. This, alone, should be enough to cast doubt on the empirical results of estimations of aggregate production functions.

Finally, we have shown that the reason why TFP growth in China was positive during all periods considered was that the growth of the wage rate was positive and high. On the other hand, the growth rate of the profit rate showed a slight decline both during the pre- and post-reform periods.

Summing up, while the study of growth and the efficiency of production in China, and the question of whether technical change has increased since the implementation of market reforms are topics worth of further research, it has been shown that most of the analyses carried out up to date, based on either the growth accounting approach or the estimation of aggregate production functions, suffer from serious methodological shortcomings. It is to be hoped that this literature does follow the same road as that regarding the East Asian Miracle, that is, concerning itself with the unanswerable question of whether growth driven by the growth of factor inputs or the rate of technical change (Felipe, 1999, Felipe and McCombie, 2002).

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NOTES

[§] This implies, following Nelson and Pack (1999) and Felipe and McCombie (2001), that the observed capital share used in standard growth accounting exercises (taken from the National Accounts) has to be corrected for the effect of technical change. Once the capital share is appropriately adjusted (i.e., in these circumstances reduced), it is found that total factor productivity growth in China was significantly larger both before (1952-78) and after (1979-94) the implementation of market reforms, compared with that obtained using the conventional growth accounting approach and observed factor shares.

[1] Hu and Khan (1997) give the following reasons as to why productivity growth increased: (i) there has been a significant reallocation of labour from agriculture to industry and services; (ii) output of the non-state sector has risen; (iii) China's open-door policies and 'special economic zones' helped attract massive foreign direct investment; and (iv) during the 1990s China's exports increased substantially. Competition in world markets has probably exerted strong pressure on Chinese industry to adopt best manufacturing practices and improve efficiency. On this see also Chen *et al.* (1992). *The Asian Development Outlook* (2001, p.70), published by the Asian Development Bank, indicates that an unpublished study by the Bank "shows that the relationship between per capita GDP and the share of private sector employment in total employment in 30 provinces clearly indicates the contribution of private sector employment to the level of income. On average among provinces, for every 1 percent

increase in the share of private employment, there is a corresponding increase of Y164 ($20) in per capita GDP".

2 The countries concerned are Hong Kong, Singapore, South Korea, and Taiwan.

3 If factor shares are unaffected by technical change, i.e., it is Hicks-neutral, or the Divisia index is used, there is no problem with the conventional growth accounting approach.

4 In other words, a problem does not arise in regarding output in a closed economy as the straightforward sum of the components of demand: consumption, investment and government expenditure, i.e., $Y = C + I + G$. The same cannot be said for considering output as given by an aggregate production function, i.e., $Y = F(K, L, t)$. There are aggregation problems involved in, for example, the consumption function, but they are not nearly as serious as those inherent in the aggregate production function.

5 If the production function is Cobb-Douglas, this makes no difference to the conventional estimates. It would also not make any difference if technical change were Hicks-neutral and the elasticity of substitution differed from unity. However, in this case, the observed factor shares would change over time. For example, with a growing capital-labour ratio, an elasticity of substitution less than one, and Hicks-neutral technical change, the observed capital share would fall. This did not happen in the case of the East Asian Tigers.

6 It clearly cannot be exactly unity, otherwise the observed factor shares could not have changed over time.

7 The reason for this is straightforward. The faster the decline of capital's constant-technology share, the more rapid the growth of *TFP*. The relationship between and *(1-)/* is follows:

σ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$(1-\sigma)/\sigma$	*9.0*	*4.0*	*2.33*	*1.5*	*1.0*	*0.67*	*0.43*	*0.25*	*0.11*	*0.0*

Hence, from $\hat{a}^* = -[1 - \{(a_T^* - a_0)/\hat{a}^* T\}][(1-\sigma)/\sigma](k - \ell)$, it can be seen that the absolute change in $\hat{a}^*$ as σ falls is greater, the lower the value of σ.

8 These results contrast with the contributions of *TFP* growth to output and labour productivity growth using the conventional methodology, which are 15 per cent and 40 per cent for the pre-reform period, and 42 per cent and 58 per cent in the post-reform period.

9 The use of cross-section (e.g., regional) data for a particular year avoids this problem provided that each firm or industry has the same level of technology. It is also necessary for the factor-price ratios to show sufficient variation for there to be a significant systematic difference in the capital-labour ratios. Under the assumption of perfect competition, however, the latter will not be the case as the ratio of the wage rate and the rental price of capital, and hence the capital-labour ratio, should be the same for each observation. Most estimations of production functions have used time-series data.

10 The argument developed in the following paragraphs is for the time-series case. A similar argument can be presented for cross-section data. A similar argument can be developed introducing intermediate materials, i.e., writing the identity for gross output. This yields a 'production function' with capital, labour, and intermediate materials as inputs.

[11]However, in the case of some of the East Asian Tigers and China (discussed below), there is evidence that the rate of profit has fallen over a couple of decades or so.

[12]Note that while measurement problems in the China data series are an important issue (Jefferson 1992), they do not affect the essence of our argument.

[13]A corollary of these results is that the standard problems discussed in the literature on estimation of (aggregate) production functions, such as simultaneity, are not problems at all.

[14]Their justification afterwards for using growth accounting is unconvincing from a methodological point of view: "However, since this methodology is widely used in studying sources of economic growth for member of the Organization for Economic Cooperation and Development, the newly industrialised economies of East Asia, and many developing countries with divergent income levels and economic structures, it is of interest certainly as a first step, to apply the same analysis to the Chinese economy to obtain what could be viewed as a "benchmark" estimates" (Hu and Khan, 1997, p.108).

[15]The right hand side of equation (11), i.e., $a_t\hat{w}_t + (1-a_t)\hat{r}_t$, cannot be interpreted as the dual measure of *TFP* growth as in the standard neoclassical derivation. There, the interpretation of the right hand side of (11) as the rate of cost diminution follows because it is derived from the neoclassical cost function. The latter, however, suffers form the same conceptual problems as the production function. Here it follows from the identity and there is no link with the cost function.

[16] Borensztein and Ostry (1996) justify Chow's approach on the following grounds: "One approach is to see which combinations of output, labour, and capital, are consistent with the hypothesis of a stable aggregate production function. On this basis, Gregory C. Chow (1993) excludes the period from 1958 (when the Great Leap Forward began) to 1969 (the first year of positive growth following the end of the Cultural Revolution), finding that for the remaining years, combinations of (logs of) output and capital per worker are fairly close to a straight line."

[17] The non-agricultural sectors were estimated using the full data sample (1952-1985). What emerges is that in a number of cases the coefficient of the time trend is now statistically significant, but the estimated elasticities of, especially, capital are often insignificant, again throwing doubt on the specification of the regression model. Introducing dummies for the anomalous years does, for certain sectors, significantly alter the values of the estimated coefficients, but nevertheless the results remain implausible. (The results are not reported here. They are available on request from the authors.)

[18]The results are not yet perfect. No doubt a better approximation exists although as the factor shares change over time, this will not be given by the Cobb-Douglas. The exercise is simply an example to illustrate the main argument.

[19] Arrow (1962), however, concluded that the socially managed economy appeared to solve the problem of technological innovation and diffusion in a way that capitalist economies had seemed unable to do. He drew specific attention on the Soviet Union.

[20]The regressions of the profit rate and profit share on a time trend show a significantly negative coefficient; while in the case of the capital-output ratio the coefficient is insignificant.

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