

Biased Technical Change, Growth Accounting, and the Conundrum of the East Asian Miracle¹

Jesus Felipe

Georgia Institute of Technology, Atlanta, Georgia 30332-0610

E-mail: jesus.felipe@inta.gatech.edu

and

J. S. L. McCombie

Downing College and University of Cambridge, Cambridge, United Kingdom

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The standard neoclassical growth accounting approach suggests that much, if not all, of the fast growth rates of the East Asian Tigers, was input driven. R. R. Nelson and H. Pack (*Econ. J.* 109, 457:416–436, July 1999) have pointed out that these estimates may be subject to substantial errors caused by the presence of biased technical change and an elasticity of substitution that is less than 1. This paper proposes a method for implementing empirically their arguments. We find that, while indeed the total factor productivity (TFP) growth rates of these countries increase with the adoption of the modified growth accounting methodology, so also do the TFP growth rates of a group of developed countries. Thus, the standard conclusions about the role of technical progress in the region do not change substantially in relative terms. *J. Comp. Econ.*, September 2001, 29(3), pp. 542–565. Georgia Institute of Technology, Atlanta, Georgia 30332-0610; Downing College and University of Cambridge, Cambridge, United Kingdom. © 2001 Academic Press

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1. INTRODUCTION

One of the most controversial aspects of the East Asian economic miracle is whether it can be called legitimately a miracle at all. In two papers, Young's (1992, 1995) careful statistical work using the growth accounting approach indicates that, surprisingly, the growth of Hong Kong, South Korea, Singapore, and Taiwan could be accounted for largely by the growth of factor inputs. In the case of Singapore, total factor productivity (TFP) growth since the mid-1960's has been approximately zero and actually was negative during certain periods. Kim and Lau (1994), using econometric estimation, reached similar conclusions. This has been referred to as the accumulationist or fundamentalist view of East Asia's growth. These results are controversial and have not commanded universal assent. In an extensive survey of TFP growth estimates for the East and Southeast Asian countries, Felipe (1999) concludes that this type of research has become a war of figures.

Subsequent to the publication of the papers mentioned above, a number of other authors have presented their own estimates of TFP growth rates. However, the large variation in these estimates makes it difficult to draw any definite conclusions about the role of technological progress in the region. For example, for Singapore, the most controversial case, over the period 1970 to 1985, Kawai (1994) calculated an annual rate of TFP growth of 0.7%, Young (1994) 0.1%, and Marti (1996) 1.49%. For the slightly different period of 1966 to 1990, Young (1995) estimated an annual rate of TFP growth of 0.2%, while Kim and Lau (1994) provided three estimates under different assumptions of 0, 1.9, and 0.4%. For South Korea, from 1970 to 1985, Young (1994) calculated an annual rate of TFP of 1.14%, while Marti (1996) estimated it to be 1.60%. For the period 1966 to 1990, Young (1995) calculated South Korea's TFP growth as 1.7%, while Kim and Lau's (1994) three estimates were 0, 1.2, and -0.5% (Felipe 1999, Tables 1 and 2). "Often one is led to contradictory results. It seems that by reworking the data one can show almost anything. This should be a warning sign in drawing conclusions out of this literature. If anything, it indicates a general fragility about the empirical studies on the nature and sources of growth in East Asia" (Felipe, 1999, p. 20).²

² Felipe (1999) summarizes the main theoretical and empirical problems in the literature on sources of growth that could lead to biases in the estimates. He draws attention to problems with the theoretical concept of technical progress, measurement problems, and difficulties in deriving conclusions and making public policy inferences. To these problems, add the critique of Jorgenson and Griliches (1967), according to whom TFP growth is the result of mismeasurement of factor inputs; i.e., the fruits of technical change can be imputed largely to changes in the quality of the factors. After adjusting the inputs appropriately, in particular the stock of capital, they found that the residual was virtually nil for all of the U.S. private domestic economy over the years 1945 to 1965. However, Denison (1972a,b) claimed that their argument was faulty, which led to an upward revision of the figures by Jorgenson and Griliches (1972a,b). This debate is summarized in Scott (1989, pp. 79 and 89). See also Hulten (2000, pp. 17-20). Scott's work is itself a critique of orthodox growth theory; see, in particular, his Chapter 3. An important

However, the problems do not stop there. There are two further serious shortcomings with all these estimates of total factor productivity growth. The first, which shall not be discussed further, arises from the question of whether an aggregate production function reflects the underlying technology of an economy and whether it can actually be empirically tested. This issue, together with a discussion of the literature on the subject and its implications for the debate over the East Asian miracle, is considered by Felipe and McCombie (2002).

The second issue is posed by Nelson and Pack (1999), who question the methodological foundations of the conventional growth accounting approach in which the growth rates of the inputs are weighted by the factor shares at the corresponding time period, and propose a preferable approach. However, their analysis remains within the neoclassical framework; i.e., there exists a well-behaved aggregate production function, markets are perfectly competitive, and factors are paid their marginal products. These authors argue that their methodology ascribes a much greater part of TFP growth of the Asian Tigers to technical change than does the conventional approach.

Over a quarter of a century ago, Nelson (1973) argued that the growth accounting approach had reached a dead end.³ His reason is that once an allowance is 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. Thus, 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 in the broad sense. From this perspective, it is theoretically impossible to distinguish between alternative explanations of growth paths without arbitrary *a priori* assumptions.

Nelson and Pack (1999) apply this critique to the discussion of East Asia's putative economic miracle. They offer an alternative explanation of the sources of

aspect of Scott's theory is that the most useful capital stock for the explanation of economic growth is cumulative gross investment, so that he dismisses growth accounting as fundamentally flawed. A summary and discussion of Scott's proposal appears in Chapter 1 of McCombie and Thirlwall (1994); see also Scott (1992, 1993). Kaldor (1957) and Pasinetti (1959) argued earlier that the ultimate objective of growth accounting exercises, namely, estimating how much growth can be explained by movements along a production function and how much should be attributed to advances in technology, is not a meaningful one. This view led Kaldor to propose the concept of a technical progress function as an alternative to the neoclassical aggregate production function. This position has been taken up recently by Rodrigo (2000). Rodrigo argues that the problem with the debate about the sources of growth in East Asia is the misconception that technological change is distinct from accumulation; he rejects the neoclassical decomposition of growth. Rodrigo advocates a systemic approach in which productivity is the result of accumulation of physical, human, and social capital because these three types of capital are complementary.

³ See Nelson (1998) for a further critique of the conventional approach to economic growth and Nelson and Winter (1982) for an alternative method of analysis.

growth in East Asia and question seriously the meaning of the standard growth accounting exercises. If factor shares are unaffected by technical change, there is no problem with the conventional growth accounting approach. However, if technical change is biased and the elasticity of substitution is different from unity, the value of the factor shares will usually be affected by technical change. The conventional growth accounting procedure does not take this into account. Therefore, Nelson and Pack argue that "unless there is a strong basis for assuming the existence of Hicks-neutral technical change, calculations of TFP growth using Tornqvist indices provide estimates that are subject to unknown errors" (Nelson and Pack, 1999, p. 426). Hicks-neutral technical change will, by definition, not affect the values of the factor shares.

With biased technical change and an elasticity of substitution less than 1, the use of the observed capital shares, taken from the national accounts, as weights in the growth accounting studies of the East Asian countries is theoretically incorrect. As the capital-labor ratio is growing, the observed values are too large. The use of a lower capital share that excludes the influence of technical change leads to a higher rate of growth of TFP. Hence, Nelson and Pack argue that standard growth accounting results should be treated with caution, if not discarded. On this premise, they call for a more realistic theory of productivity and output growth capable of explaining adequately the East Asian miracle. This theory should incorporate the influence of entrepreneurship, innovation, and learning, all of which have played a major role in the growth of East Asia during the past 30 years. This is the basis for the assimilationist theories of the East Asian miracle that Nelson and Pack defend and stands in marked contrast to the accumulationist explanation that receives support from the results of Young (1992, 1995) and Kim and Lau (1994).

In this paper we propose an algorithm for operationalizing Nelson and Pack's arguments. We then apply the methodology to the four East Asian Tigers by recalculating TFP growth estimates and compare the results with those of Young (1995). In Section 2, we summarize the critique of Nelson and Pack and discuss the Impossibility Theorem due to Diamond *et al.* (1972). Section 3 proposes a simple procedure for implementing empirically Nelson and Pack's argument. We recalculate the rate of TFP growth for the four East Asian NIEs and for a group of developed countries for comparison purposes. Using the assumptions most favorable to the Nelson-Pack thesis, we conclude that while the adjusted estimates of TFP growth are higher than the conventional estimates, the differences are not as great as might have been initially expected, unless the elasticity of substitution is extremely low, around 0.2. Nevertheless, the interpretation of the results might be a question of whether the glass is regarded as half-empty or half-full. Our exercise also demonstrates that a wide variety of estimates of TFP growth can be generated from the same set of data, depending upon the precise assumptions adopted. Section 4 discusses some implications of growth accounting and Nelson and Pack's method. Section 5 concludes.

2. THE CONVENTIONAL GROWTH ACCOUNTING APPROACH, NELSON AND PACK'S CRITIQUE, AND THE IMPOSSIBILITY THEOREM

The critique of Nelson and Pack (1999) arises from the observation that capital shares remained rather high in the East Asian countries during the miracle period despite a substantial increase in the capital–labor ratio. How can this be explained? There are two alternative explanations (Nelson, 1973). First, the underlying elasticity of substitution of the aggregate technology is unity, and with a Cobb–Douglas production function, technical change is Hicks (and Harrod) neutral. Second, the elasticity of substitution differed from unity and technical progress was biased to the extent that, despite a rapidly growing capital–labor ratio, factor shares remained constant.

This is an important distinction because the central tenet of the Nelson and Pack critique is that the shares used as weights for the growth of the factor inputs should be those that would have occurred if there had been no technical change. 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 factor shares would change over time. For example, with a growing capital–labor ratio, an elasticity of substitution less than 1, and Hicks-neutral technical change, the capital share would fall, although there is no empirical evidence that this was indeed the case in the East Asian economies over the period under consideration. However, if the stability of the shares is due, for example, to an elasticity of substitution that is less than unity (as is plausible) and a labor-saving technical change, the Nelson and Pack method may make a substantial difference to the estimates of TFP growth. In particular, the authors argue that a greater proportion of overall output growth would be attributed to technical change and that this is likely to be especially true of the East Asian economies.

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.⁴ The instantaneous growth of TFP given by the conventional growth accounting method is

$$\text{tfp}_t = q_t - \ell_t - a_t(k_t - \ell_t), \quad (1)$$

where tfp , q , ℓ , and k are the growth rates of TFP, output, labor, and capital respectively, and a_t is the observed capital's share.⁵ Since the data used are for discrete

⁴ Throughout this paper, the terms factor shares and output elasticities will be used interchangeably when discussing the weighting of the growth of factor inputs.

⁵ For notational convenience, the t subscripts will not be used further except where the use aids clarity.

time periods, the Tornqvist approximation of the Divisia index is used in practice (Diewert, 1976). Instead of using a_t , the average of the share at the initial (a_0) and the terminal year (a_T) is used as a weight, namely,

$$\bar{a} = 1/2(a_0 + a_T). \quad (2)$$

In the early growth accounting studies, the growth rates of TFP were calculated over short periods, e.g., annually, and then averaged to obtain the growth rate of over a longer period, e.g., Solow (1957). However, Star and Hall (1976) have shown that Eq. (2) gives a close approximation to this procedure even when the initial and terminal years are far apart.

In order to understand the Nelson and Pack 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 $Q = F(A_L L, A_K K)$ where Q , L , and K are output, labor, and capital. A_L and A_K are factor-augmenting technical change occurring at 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

$$q = (1 - \bar{a})\lambda_L + \bar{a}\lambda_K + (1 - \bar{a})\ell + \bar{a}k. \quad (3)$$

The rate of change of capital's share is given by (Ferguson, 1968, 1969)⁶

$$\hat{a} = [(1 - \bar{a})(1 - \sigma)/\sigma] [(\lambda_L + \ell) - (\lambda_K + k)], \quad (4)$$

where σ is the elasticity of substitution and the degree of bias is given by $B = [(1 - \sigma)/\sigma](\lambda_L - \lambda_K)$. Substituting Eq. (3) into Eq. (4), we obtain an expression for the growth of capital's share as

$$\hat{a} = [(1 - \sigma)/\sigma] [q - k - \lambda_K] \quad (5)$$

and that of labor's share as

$$1 - \hat{a} = [(1 - \sigma)/\sigma] [q - \ell - \lambda_L]. \quad (6)$$

We have noted above that the values of the factor shares did not change very much in East Asia over the past 30 years or so. As may be seen from Eq. (4), this may be due to an elasticity of substitution equal to unity and a Cobb–Douglas production function. Alternatively, it could have occurred because the degree of bias of technical change is such that $\lambda_L - \lambda_K = k - \ell$. Suppose that there is

⁶Nelson and Pack (1999) confine their attention to the restricted case where there is only labor-augmenting technical change; i.e., they assume $\lambda_K = 0$. We shall see below that the data do not support this assumption.

a rapid growth of the capital–labor ratio, as occurred in these economies. In the absence of technical change, capital’s observed share will fall. In the case under consideration here, the rate of biased technical change is such as to keep the factor shares constant.

Nelson and Pack argue that 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 $\bar{\alpha}$, it will incorporate the effect of biased technical change to the extent that the latter has prevented the observed share from falling. This, in turn, will erroneously cause the contribution of the growth of the factor inputs to output growth to be overstated, with the result that the true contribution of total factor productivity growth is underestimated. As the growth of capital exceeds that of labor, 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. To obviate this problem, Nelson and Pack (1999) argue that the preferable procedure is to use the value of capital’s share in the terminal period that would have occurred in the absence of technical change in constructing $\bar{\alpha}$. Thus, one should use the unobserved constant-technology factor shares.⁷

As may be seen from Eq. (4), capital’s share in the terminal period will be lower, and the growth of total factor productivity will be higher, the lower is the elasticity of substitution and the faster is the rate of growth of the capital–labor ratio. To summarize, if capital’s current share is used as a weight for the growth of capital, it will incorporate the effect of biased technical change that occurred during the period to the extent that this prevented the observed share from falling. This is incorrect in the sense that, by definition, the objective of growth accounting is to decompose overall growth into the movement along the production function and the contribution of technical progress, i.e., the shift of the production function over time. In these circumstances, the movement along the production function contains the effect of technical progress, insofar as this is incorporated in the observed factor shares used to weight the growth of inputs. Consequently, the higher weight due to biased technical change will actually increase the contribution of the growth of factor inputs to output growth in a misleading way.

⁷ Alternatively, one could use the current share in the terminal year as the base and calculate the constant-technology share in the initial year. This will alter dramatically the results. For the East Asian countries, the actual shares in 1960 and 1990 were roughly constant. If we use the 1990 share as the base, the constant-technology initial-year share will be above this value and so the constant-technology average share will exceed the average share using observed values. On the other hand, if we use 1960 values, as in the text, the constant-technology average share will be below the average share using the observed values. As it is not intuitively clear how to interpret the factor shares in 1960 that would have existed with 1990 technology, i.e., at a time before the 1990 technology had even been invented, we have confined our attention to the former case. Nevertheless, this does pose problems for the growth accounting methodology.

Nelson and Pack argue that the production processes of the East Asian countries and the technological progress that occurred are described better by a low elasticity of substitution and labor-saving technical progress rather than by a Cobb–Douglas production function.⁸ Conventional estimates of TFP growth have missed this and yielded the controversial low TFP growth rates. The conventional growth accounting exercises cannot accommodate the complexities of the phenomenal growth that occurred in East Asia, in particular, the absorption or assimilation of increasingly modern technology and the profound sectoral shift from traditional to advanced industries. In their words: “The learning that underlay assimilation was instrumental in preventing a decline in the marginal product of capital despite the rapid growth in the capital–labor ratio generated by the very high investment ratios in these economies. In turn, learning reflected the interaction of a favorable policy environment (in which innovation was rewarded) and the entrepreneurial efforts of firms” (Nelson and Pack, 1999, pp. 416–417).

To understand fully the implications of Nelson and Pack’s argument, it is important to note that the conventional growth accounting approach does not suffer from the problem identified by Nelson and Pack, and that it is not necessary to know the value of the elasticity of substitution. As the Impossibility Theorem due to Diamond *et al.* (1972) shows, neither the elasticity of substitution nor the degree of bias affects the measure of TFP growth if a Divisia index is used; see also Nerlove (1967) for an early discussion of the Impossibility Theorem. The implication of the theorem is that, for any given data set, the conventional method will give a unique value of TFP growth regardless of the degree of bias in technical change and of the value of elasticity of substitution. Two production functions with factor-augmenting technical change are said to be consistent with the data if and only if

$$Q = F(A_L L, A_K K) = G(B_L L, B_K K), \quad (7)$$

where A_i and B_i , for i equal to L or K , are factor-augmenting technical change.⁹ Taking logarithms, differentiating the production functions with respect to time, and using the marginal productivity conditions gives

$$q = (1 - \bar{a})(\lambda_L + \ell) + \bar{a}(\lambda_K + k), \quad (8)$$

and

$$q = (1 - \bar{a})(\gamma_L + \ell) + \bar{a}(\gamma_K + k), \quad (9)$$

⁸ This implies that a high rate of labor-saving technical change is compatible with a low rate of TFP growth where the latter is calculated using the conventional Divisia index.

⁹ Nerlove (1967) also includes neutral technical change in the production function, i.e., $Q = F(A_L L, A_K K, t)$. We ignore this for expositional ease because it does not affect the argument.

where λ_i and γ_i are the rates of labor- and capital-augmenting technical progress, and \bar{a} is given by Eq. (2). Since both production functions must be consistent with the same data, the observed values of \bar{a} , $(1 - \bar{a})$, q , k , and ℓ are the same in both equations. Thus, it follows that

$$\text{tfp} \equiv (1 - \bar{a})\lambda_L + \bar{a}\lambda_K \equiv (1 - \bar{a})\gamma_L + \bar{a}\gamma_K. \quad (10)$$

The total contribution of technical progress to the growth of output is identical for the same data set, even though the various components of technical change may differ between the production functions depending on the elasticity of substitution, for example. From Eq. (10), the growth rate of TFP is identified uniquely regardless of the underlying form of the production function and the degree of bias in the rate of technical change.¹⁰

In conclusion, the conventional growth accounting approach does not suffer from the problems discussed by Nelson and Pack because it uses a Tornqvist approximation to the Divisia index so that TFP growth does not vary with the size of the elasticity of substitution. Hence, knowledge of the latter is not required. However, this approach does not make any allowance for the fact that the size of the output elasticities, or factor shares, may be determined by the past rate of biased technical change, in which case the rebasing inherent in the Divisia index, or the Tornqvist approximation to it, is incorrect. In this case the Divisia index is not the appropriate index to use to the extent that it rebases the factor shares continually and thus these shares incorporate the effect of biased technical progress. Therefore, the use of the Divisia index requires the additional assumption that all technical change is Hicks neutral, although there is no evidence that this is necessarily the case.

However, for growth rates calculated over small time periods starting with the same initial values, the two methods are virtually the same because, even though capital's constant-technology share may fall rapidly, the difference between the constant-technology and the current share in the terminal year is likely to be small. If we consider instantaneous growth rates the two procedures will be formally identical. However, as the length of time over which the growth rates are calculated lengthens, the two methods are likely to produce diverging estimates of TFP growth.

¹⁰ Rodrik (1996) criticizes Collins and Bosworth's (1996) traditional growth accounting results based on problems putatively posed by the possible existence of biased technical change. Thus, our argument would suggest that Bosworth (1996) is correct when he states that "Our decomposition of growth between capital accumulation depends on the stability of capital's share, not on the elasticity of substitution. If the constancy is the result of a low degree of substitution and labor augmenting technical change, the contribution of capital is not missed by our methodology: in the context of a Divisia index, capital's share of income is still the correct measure of its role, and the technology gains still show up as an increase in TFP" (p. 197).

3. RECALCULATING THE IMPACT OF TECHNICAL CHANGE ON EAST ASIAN GROWTH

In this section, we calculate the growth of TFP under Nelson and Pack's methodology using constant-technology, rather than observed, factor shares as weights. We denote the terminal constant-technology share of capital as a_T^* . Note that this is not the same as using the shares in the base year. The values of the shares will change, even in the absence of technical change, as the capital-labor 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-labor ratio. In this approach, an impasse arises unless we know the value of the elasticity of substitution (see Nelson (1973)). By not adjusting \bar{a} in Eq. (2) to correct for the effect of technical change, the conventional growth accounting approach of Eq. (1) would erroneously ascribe part of the contribution of TFP growth to the growth of the capital-labor ratio. To avoid this, the following equation should be used to calculate the corrected growth of TFP,

$$tfp' \equiv q - \ell - \bar{a}^*(k - \ell), \quad (11)$$

where \bar{a}^* is the average value of the constant-technology shares and the technology is that of the base year. We could use Star and Hall (1976) approximation for \bar{a}^* , namely, $\bar{a}^* = 1/2(a_0 + a_T^*)$, in which we assume $a_0 = a_0^*$. However, there is no alternative to using the current share in the initial or base year; otherwise we would be involved in an infinite regress. Nevertheless, the use of the current share in the initial period is acceptable if we are interested in estimating the growth rate of TFP from a given starting date.¹¹

A better approximation for \bar{a}^* is $(a_T^* - a_0)/(\hat{a}^*T)$, where \hat{a}^* is the growth of the constant-technology capital share, namely, $\hat{a}^* = (\ln a_T^* - \ln a_0)/T$ and T is the length of time in years under consideration.¹² With an elasticity of substitution of less than unity and $k > \ell$, the value of a_T^* decreases as T increases. Under the Star and Hall approximation, the limiting value of \bar{a}^* is $(1/2 a_0)$, but ideally \bar{a}^* should tend to 0. Intuitively, as the period increases and progressively more years in which capital's share is effectively zero are added, the average share should become commensurately smaller and tend to, but never equal, 0. Our approximation has this desirable property.

¹¹ However, this is not an innocuous assumption and we discuss it further in Section 4.

¹² This is derived as follows. Star and Hall (1976) show that when factor inputs grow at a constant rate, which is the case in practice as exponential growth rates calculated over the relevant period are used, the appropriate constant share is $\bar{a} = \frac{1}{T} \int_0^T a(t) dt$. When capital's share declines at a constant exponential rate \hat{a} , $\bar{a} = (a_T - a_0)/\hat{a}T$. In practice, for short periods or when there is not very much difference between the values of the initial and terminal shares, the two approximations give very similar results.

The following equation is used to calculate the corrected growth of TFP:

$$\text{tfp}' = q - \ell - [(a_T^* - a_0)/\hat{a}^*T](k - \ell). \quad (12)$$

As we have noted, a_T^* is capital's constant-technology share in the terminal year. The conventional growth accounting Tornqvist approximation is

$$\text{tfp} = q - \ell - [(a_T - a_0)/\hat{a}T](k - \ell). \quad (13)$$

Equation (12) is an estimate of TFP growth, given the level of technology in the initial year. Since a_T^* is less than a_T , assuming labor-augmenting technical change, $k > \ell$, and an elasticity of substitution of less than 1, a comparison of Eq. (12) with (13) indicates that Nelson and Pack's approach will lead to an estimate of TFP growth higher than that of the conventional method. A corollary raised by Nelson and Pack is that use of the constant-technology shares will give rise to different estimates of TFP growth depending on the degree of bias in technical change and the value of the elasticity of substitution.

Are the surprisingly low TFP growth rates for the East Asian economies a consequence of the use of unadjusted factor shares? To gain some perspective on the degree of error involved, we calculate a_T^* assuming the elasticity of substitution is constant over the period of interest.¹³ The instantaneous rate of change of capital's share in the absence of technical change is given by

$$\hat{a}^* = -(1 - \bar{a}^*)[(1 - \sigma)/\sigma](k - \ell). \quad (14)$$

Clearly, if $(k - \ell) > 0$ and $\sigma < 1$, the share of capital will decrease. Hence, information about the value of the elasticity of substitution is required. As Nelson (1973) noted, calculating the path of the shares under the assumption of no technical change "requires that one be able to specify the original production function which was the original impasse" (Nelson 1973, p. 464). The best that one can do is to use a variety of estimates of σ and see how sensitive the results are to the specific values used. If we approximate instantaneous growth rates by exponential growth rates using the approximation given in Footnote 12, Eq. (14) becomes

$$\hat{a}^* = -[1 - \{(a_T^* - a_0)/\hat{a}^*T\}] [(1 - \sigma)/\sigma](k - \ell). \quad (15)$$

Consequently, we calculate capital's share under the assumption of no technical

¹³ Nelson and Pack's analysis is based on a two-sector Leontief production system with a zero elasticity of substitution, while here we use implicitly a continuously differentiable production function. The evidence regarding the size of the elasticity of substitution is not clear, except that it seems to be higher than 0.

change as

$$a_T^* = a_0 \exp(\hat{a}^*T). \quad (16)$$

Equation (16) indicates that we need to know the growth of the share under the assumption of no technical change to calculate a_T^* . Therefore, we adopt an iterative procedure for calculating a_T^* . First, we take observed values for q , k , ℓ , a_0 , and T and assume a value for σ . Second, we calculate the initial share of capital as $\bar{a} = (a_T - a_0)/\hat{a}T$, where $\hat{a} = \ln(a_T/a_0)/T$. Third, we estimate the change in capital's share with the base-year technology as $\hat{a}^* = -(1 - \bar{a})[(1 - \sigma)/\sigma](k - \ell)$. Fourth, we calculate capital's share under the base-year technology as $a_T^* = a_0 \exp(\hat{a}^*T)$. Fifth, we recalculate the change in capital's share with the base-year technology using a_T^* from step four as $\hat{a}^* = -[1 - \{(a_T^* - a_0)/\hat{a}^*T\}][(1 - \sigma)/\sigma](k - \ell)$. Sixth, we iterate steps four and five until \hat{a}^* converges. Finally, we calculate the annual rate of TFP growth as $\text{tfp}' = [q - \ell - \{(a_T^* - a_0)/\hat{a}^*T\}](k - \ell)$, where a_T^* is the value from the final iteration and T is the length of the period.

In practice, obtaining an estimate of a_T^* that is consistent with the growth of a^* required only a few iterations. The degree of bias in the conventional estimate of the growth of TFP is given by $\text{tfp}' - \text{tfp}$; i.e., Eq. (12) minus Eq. (13).¹⁴ However, there is a further complication. The value of a_T^* will also be a function of the period of time over which it is calculated. For example, 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 will become progressively smaller, given the above assumptions. Thus, the growth of Nelson and Pack's TFP will be a function of both the elasticity of substitution and the length of time, T . The values of TFP growth calculated by the conventional approach are independent of these two factors.¹⁵

To determine the empirical importance of Nelson and Pack's critique, we calculate TFP growth for the four Asian Tigers using the constant-technology-shares methodology. The data for the growth rates of output, labor and capital are taken from Young (1995, Tables V, VI, VII, and VIII) and were calculated by him from 1966 to 1990, or 1991. The initial factor share is also taken from Young, but is for

¹⁴ Rodrik (1997) also derives an expression for the degree of bias following Nelson and Pack (1999). However, his expression for the bias involves unobservable rates of technical change and he uses the Star and Hall approximation. Our procedure avoids both these problems.

¹⁵ Nelson and Pack tried to show the relevance of their argument using a small example reported in Table 3 (Nelson and Pack 1999, p. 427). In our view, their calculations do not support their theoretical argument, i.e., that a high rate of labor-augmenting technical change is compatible with a low rate of conventionally measured total factor productivity growth. The calculations in Table 3 are not based on constant-technology shares. A more detailed justification of this criticism is available from the authors on request. However, this does not undermine their general argument and they are correct when they state that Tornqvist indices will be subject to errors when constant-technology shares are used. Their point is shown in our simulations in the next section, for which we use constant-technology shares.

the average of the first five-year subperiod from 1966 to 1970. As our calculations are intended to give orders of magnitude only, this does not present a problem. Moreover, using the average has the advantage of removing any cyclical bias to which the use of a single year may be subject.

Table 1 reports the terminal and average capital shares for the four countries for a variety of elasticity of substitutions and time periods. When the elasticity of substitution is unity, technical change has no effect on the factor shares so that Nelson and Pack's and the conventional approaches are formally equivalent. Table 2 presents the corresponding TFP growth rates. The question arises as to what are plausible empirical values for the magnitude of the elasticity of substitution. Jorgenson (1974) suggests that the elasticity is not often different from unity.

TABLE 1
Constant-Technology Factor Shares for Singapore, Hong Kong,
South Korea, and Taiwan

σ	a_1^*	a_{10}^*	a_{20}^*	a_{30}^*	\bar{a}_1^*	\bar{a}_{10}^*	\bar{a}_{20}^*	\bar{a}_{30}^*
Singapore								
0.2	0.439	0.083	0.008	0.000	0.467	0.232	0.119	0.077
0.6	0.487	0.401	0.312	0.233	0.492	0.447	0.397	0.348
0.8	0.493	0.460	0.425	0.389	0.495	0.478	0.460	0.441
1.0	0.497	0.497	0.497	0.497	0.497	0.497	0.497	0.497
1.2	0.499	0.521	0.545	0.569	0.498	0.509	0.520	0.532
Hong Kong								
0.2	0.298	0.069	0.010	0.001	0.318	0.170	0.094	0.062
0.6	0.332	0.272	0.213	0.164	0.336	0.304	0.271	0.241
0.8	0.337	0.313	0.288	0.264	0.338	0.326	0.313	0.300
1.0	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340
1.2	0.341	0.358	0.376	0.395	0.341	0.349	0.358	0.367
South Korea								
0.2	0.251	0.023	0.001	0.000	0.279	0.110	0.056	0.036
0.6	0.299	0.216	0.144	0.093	0.305	0.260	0.217	0.181
0.8	0.036	0.272	0.237	0.206	0.308	0.291	0.272	0.254
1.0	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310
1.2	0.312	0.336	0.364	0.393	0.311	0.323	0.323	0.350
Taiwan								
0.2	0.208	0.017	0.000	0.000	0.233	0.090	0.046	0.030
0.6	0.251	0.177	0.116	0.074	0.256	0.216	0.179	0.148
0.8	0.257	0.227	0.196	0.168	0.259	0.243	0.227	0.211
1.0	0.261	0.261	0.261	0.261	0.261	0.261	0.261	0.261
1.2	0.263	0.285	0.311	0.338	0.262	0.273	0.285	0.298

Source. Authors' calculations.

Note. σ is the elasticity of substitution. a_T^* is the constant-technology capital's share after T years, where $T = 1, 10, 20,$ and 30 years, respectively. \bar{a}_T^* is the constant-technology average share after T years, where $T = 1, 10, 20,$ and 30 years, respectively.

TABLE 2
Growth Accounting Simulations for Singapore, Hong Kong, South Korea, and Taiwan

Singapore: $q = 0.087$; $\ell = 0.057$; $k = 0.115$; $a_0 = 0.497$; $a_T = 0.494$; $\text{tfp} = 0.0012$ Hong Kong: $q = 0.073$; $\ell = 0.032$; $k = 0.080$; $a_0 = 0.340$; $a_T = 0.391$; $\text{tfp} = 0.0234$								
Singapore					Hong Kong			
σ	tfp'_1	tfp'_{10}	tfp'_{20}	tfp'_{30}	tfp'_1	tfp'_{10}	tfp'_{20}	tfp'_{30}
0.2	0.0028	0.0165	0.0230	0.0255	0.0257	0.0328	0.0364	0.0380
0.6	0.0014	0.0040	0.0069	0.0097	0.0248	0.0263	0.0280	0.0294
0.8	0.0012	0.0022	0.0033	0.0044	0.0247	0.0253	0.0259	0.0265
1.0	0.0011	0.0011	0.0011	0.0011	0.0246	0.0246	0.0246	0.0246
1.2	0.0011	0.0004	-0.0002	-0.0008	0.0242	0.0242	0.0238	0.0233
South Korea: $q = 0.103$; $\ell = 0.064$; $k = 0.137$; $a_0 = 0.31$; $a_T = 0.261$; $\text{tfp} = 0.0181$ Taiwan: $q = 0.094$; $\ell = 0.049$; $k = 0.123$; $a_0 = 0.261$; $a_T = 0.251$; $\text{tfp} = 0.0260$								
South Korea					Taiwan			
σ	tfp'_1	tfp'_{10}	tfp'_{20}	tfp'_{30}	tfp'_1	tfp'_{10}	tfp'_{20}	tfp'_{30}
0.2	0.0185	0.0309	0.0349	0.0363	0.0277	0.0383	0.0416	0.0427
0.6	0.0167	0.0199	0.0231	0.0258	0.0260	0.0289	0.0317	0.0340
0.8	0.0165	0.0177	0.0191	0.0204	0.0258	0.0270	0.0282	0.0293
1.0	0.0163	0.0163	0.0163	0.0163	0.0256	0.0256	0.0256	0.0256
1.2	0.0162	0.0154	0.0144	0.0134	0.0256	0.0248	0.0238	0.0230

Source. Authors' calculations.

Note. q = annual growth rate of output (1966–1990; Hong Kong 1966–1991); ℓ = annual growth rate of employment (1966–1990; Hong Kong 1966–1991); k = Annual growth rate of stock of capital (1966–1990; Hong Kong 1966–1991); a_0 = average share of capital initial subperiod (1966–1970; Hong Kong 1966–1971); and a_T = average share of capital final subperiod (Singapore, Taiwan 1966–1970; Hong Kong 1986–1991; South Korea 1985–1990).

σ is the elasticity of substitution.

$\text{tfp} = (q - \ell) - [1/2(a_0 + a_T)(k - \ell)]$.

$\text{tfp}'_T = (q - \ell) - \bar{a}_T^*(k - \ell)$ is the annual growth of TFP over a period of T years under the assumption of constant technology.

Kalt (1978), using a CES production function, estimated an elasticity of substitution of 0.76 for the U.S. private domestic economy from 1929 to 1967. More recently, Hamermesh (1993) has surveyed a number of studies estimating the elasticity of substitution and suggesting an average value of 0.75. On the other hand, Rowthorn (1999) argues that the elasticity of substitution must be rather low, perhaps with the possible exception of some services, and considers a value of 0.58 to be appropriate. Note that these values are higher than those assumed by Nelson and Pack (1999). In order to cover the widest possible range of elasticities, we use values of 0.2, 0.6, 0.8, 1, and 1.2 for the simulations.

Turning first to the case of Singapore, Table 2 shows that the absolute differences in the growth rates of TFP are not substantial with the exception of $\sigma = 0.2$. The traditional growth accounting approach gives TFP growth of only 0.12% per annum. An elasticity of substitution of 0.6, together with a three-decade period, yields a

TFP growth rate of 1% per annum. However, this still explains only about 11% of the growth of total output, compared with just over 1% using the conventional accounting procedures. However, with $\sigma = 0.2$, tfp'_{30} , the TFP growth rate over a 30-year period rises to 2.55% per annum, which accounts for 29% of output growth.

On the other hand, Hong Kong's TFP growth is much higher at 2.34% per annum under the conventional approach. Again, Nelson and Pack's approach makes little difference. Over 30 years, with an elasticity of 0.6, the growth of TFP is 2.94%, only half a percentage point faster than under the conventional approach. While the adjusted TFP growth explains 40% of output growth with an elasticity of substitution of 0.6, this is only 8 percentage points more than under the conventional assumptions. Once again capital's adjusted share falls dramatically, this time from 0.34 to 0.16.

In the case of South Korea, the effect is more noticeable. The growth of conventionally measured TFP is 1.81% per annum or 17% of output growth. Over three decades and with an elasticity of substitution of 0.6, the growth of TFP is 2.58% or 25% of output growth. Nevertheless, this is still a relatively small percentage of output growth if compared with the achievement of most of the industrial countries during the period 1950 to 1973, the so-called Golden Age of economic growth (Maddison, 1982). Even with an elasticity of substitution equal to 0.2, only about 35% of South Korea's output growth is explained by TFP growth.

Taiwan also shows a more marked increase in TFP growth. The conventional TFP growth is 2.60% or 27% of total output growth, while the adjusted values are 4.27% for $\sigma = 0.2$ and 3.40% for $\sigma = 0.6$. These explain 45 and 36% of output growth, respectively. Capital's share once again falls dramatically.¹⁶

However, there is another interpretation of these results determining how much of the conventional and adjusted TFP growth rates were explained by the growth of labor productivity (p).¹⁷ In other words, we calculate the ratios (tfp_{30}/p) and (tfp'_{30}/p) , both expressed as percentages. In the case of (tfp'_{30}/p) , the lower the adjusted share of capital, a^* , and the higher the share of labor, $1 - a^*$, the closer the index will be to 1. The results are reported in Table 3. In the case of Singapore, the percentage of labor productivity explained by adjusted TFP growth is markedly higher than when the conventional measure is used. With an elasticity of 0.6, TFP growth explains 1% of output growth but 32% of labor productivity growth over a 30-year period. For the other countries, the proportion of the growth of labor productivity explained increases by between 15 and 20 percentage points for an elasticity of 0.6. However, with an elasticity of 0.2 and over a period of 30 years, the adjusted growth of TFP for the other three countries explains over 90% of productivity growth, which could be interpreted as evidence supporting Nelson and Pack's position.

¹⁶ If the elasticity of substitution exceeds unity, the adjusted growth rate of TFP is smaller, rather than larger, than that under the conventional approach.

¹⁷ We are grateful to Richard Nelson for this point.

TABLE 3
 Percentage of Labor Productivity Growth Explained by the Conventional
 and Adjusted Total Factor Productivity Estimates

Country	σ	p	tfp	tfp' ₃₀	tfp as % of p	tfp' ₃₀ as % of p
Singapore	0.2	0.030	0.0012	0.0255	4	85
	0.6	0.030	0.0012	0.0097	4	32
	1.0	0.030	0.0012	0.0011	4	4
	1.2	0.030	0.0012	-0.0008	4	-2.66
Hong Kong	0.2	0.041	0.0234	0.0380	57	93
	0.6	0.041	0.0234	0.0294	57	72
	1.0	0.041	0.0234	0.0246	57	60
	1.2	0.041	0.0234	0.0233	57	57
South Korea	0.2	0.039	0.0181	0.0363	46	93
	0.6	0.039	0.0181	0.0258	46	66
	1.0	0.039	0.0181	0.0163	46	42
	1.2	0.039	0.0181	0.0134	46	34
Taiwan	0.2	0.045	0.0260	0.0427	58	95
	0.6	0.045	0.0260	0.0258	58	76
	1.0	0.045	0.0260	0.0256	58	57
	1.2	0.045	0.0260	0.0230	58	51

Note. p is the growth rate of labor productivity. See also the footnote to Table 2.

If technical progress is labor-augmenting worldwide, the above arguments concerning the elasticity of substitution, biased technical change, and constant-technology shares will apply equally to other countries. Thus, a more meaningful exercise is to compare the adjusted TFP growth rates with the adjusted TFP growth rates of other countries. *A priori*, we would expect the use of constant-technology shares to improve the East Asian countries' TFP growth performance relative to most other countries, since the former exhibited faster growth of the capital-labor ratio. Hence, using the constant-technology rather than the higher observed capital share should reduce the contribution of the growth of the capital-labor ratio and hence raise the contribution of the adjusted TFP growth rate to output growth proportionally more in East Asia than in most other countries. However, the outcome will also depend on the initial values of the factor shares.

The benchmark case is undoubtedly Japan, whose growth rates during the early postwar period measured by output, TFP, or exports were truly miraculous. How do the economic performances of the East Asian economies compare with that of Japan? During the Golden Age (data for the period 1953 to 1973), Japan's output grew at 10% per annum, which is on a par with the East Asian economies. However, this was accompanied by a conventionally measured TFP growth of 5.48%, double that of Taiwan, the East Asian country with the highest conventional TFP growth. The top part of Table 4 reports the standard and adjusted TFP rates

TABLE 4
Unadjusted (tfp) and Adjusted TFP (tfp'_{30}) Growth Rates for Japan,
West Germany, UK, and United States

tfp'_{30}			
$\sigma = 0.2$	$\sigma = 0.6$	$\sigma = 1.0$	$\sigma = 1.2$
Japan, $tfp = 0.0548$			
0.0728	0.0638	0.0568	0.0547
West Germany, $tfp = 0.0262$			
0.0427	0.0427	0.0242	0.0233
UK, $tfp = 0.0228$			
0.0324	0.0254	0.0216	0.0205
United States, $tfp = 0.015$			
0.0169	0.0129	0.0118	0.0115

Source. Japan and United States, Jorgenson and Nishimizu (1978); West Germany and UK, OECD Analytical database. Growth rates: Japan, 1953–1973; West Germany, 1961–1973; UK, 1961–1973; United States, 1953–1973.

Note. See also the footnote to Table 2.

for Japan. Regardless of the elasticity of substitution, the growth of TFP of all the East Asian economies was substantially below that of Japan. Thus, by this yardstick, the performance of the East Asian economies cannot be considered miraculous.

We also calculated adjusted TFP growth rates for three other advanced economies, West Germany, the UK, and the United States in the Golden Age period. The data for West Germany and the UK are for the period 1961 to 1973.¹⁸ For the United States, the period is 1953 to 1973. These rates are reported in Table 4.¹⁹ The growth rates of TFP for Hong Kong and Taiwan were on the same order of magnitude as that of West Germany, whereas those of South Korea, and especially Singapore, were lower. Altering the elasticity of substitution does not

¹⁸ Certainly this analysis should not be taken to imply that the economic performance in the region was poor, because it should not be judged only on the basis of TFP growth. We are grateful to a referee for pointing this out. The same referee also indicated that the growth of TFP in the East Asian countries was not below that of Japan and other developed countries at comparable stages of development. The problem is that it is very difficult to know the growth rate of TFP for the developed countries at comparable stages of development. It is not very enlightening to compare the United States when it had a per capita income of \$8000 in the 1950's with Singapore in 1980 since the international environments were so different and the United States was the most advanced technological country in the world. To discuss whether East Asia's performance was miraculous, we find it more meaningful to compare the periods of fastest growth for the East Asian countries, i.e., 1965–1990, and for the developed countries, i.e., 1950–1973.

¹⁹ The complete results for these countries are not reported here for reasons of space. They are available from the authors on request.

change the general picture. The UK's TFP growth over the postwar boom has been low compared with most of the other advanced countries. Nevertheless, as may be seen by comparing the results in Tables 2 and 4, the growth rates of Hong Kong, Taiwan, and South Korea were only slightly better for elasticities of substitution less than unity and Singapore performed significantly worse. The East Asian countries did perform better than the United States, again with the exception of Singapore except for the case in which $\sigma = 0.2$. However, this is not a remarkable feat given that the United States exhibited a very low growth rate of overall TFP.

4. ADDITIONAL IMPLICATIONS

With respect to the above results, there are two important further issues that need to be considered. First, from Eqs. (5) and (6), it is possible to calculate the values of λ_L and λ_K that are necessary to keep factor shares constant. The values are reported in Table 5. It is now readily apparent why the constant-technology approach gives a higher rate of TFP growth than the conventional approach. The latter is given by $\text{tfp} = (1 - a)\lambda_L + a\lambda_K$, where $(1 - a)$ and a are the appropriately measured factor shares of labor and capital. As factor shares are constant, λ_L and λ_K are also constant over the period being considered and do not vary with, the elasticity of substitution. Under the constant-technology-shares approach, using the initial-year technology, the weight given to λ_K decreases and that given to λ_L increases as the elasticity of substitution falls and as the time period under consideration increases. Hence, in both cases, the calculated value of TFP growth increases. However, all the countries experienced a negative rate of capital-augmenting technical change, although this was small in the case of Hong Kong. This result is not completely unexpected. The rate of change of capital's share is $\hat{a} = \hat{r} + k - q$, where \hat{r} is the growth of the rate of return. From Eq. (6), as $\hat{a} = 0$, it follows that $\hat{r} = \lambda_K$.

TABLE 5
Rates of Growth of Labor and Capital Augmenting Technical
Progress Necessary to Keep Factor Shares Constant

	λ_L	λ_K
Singapore	3.00	-2.80
Hong Kong	4.10	-0.70
South Korea	3.90	-3.40
Taiwan	4.50	-2.90
Japan	7.50	1.25
West Germany	4.26	-0.66
United Kingdom	2.65	-0.48
United States	2.00	-0.14

Note. λ_L and λ_K were calculated from Eqs. (5) and (6).

One of the facts that gives rise to the question of whether the East Asian economic miracle was indeed a miracle is the rapid decline in the rate of return that some of these countries experienced.

The finding that the growth rate of capital-augmenting technical change is negative is certainly a puzzle, especially if technical progress is regarded as exogenous. One possible answer, although we advance it as no more than a tentative hypothesis, is based on the account in Young (1992) for Singapore's absence of TFP growth. The rate of capital accumulation and the movement into high-tech industries were so rapid that there was no time for productivity gains to accrue from learning by doing. The early stages of production for new industries, in which there was previously little managerial, organizational, or production experience, may actually have led to a significantly negative capital productivity growth, and consequently, a rate below that found in other countries with a longer tradition of production in these industries. The expectation was that this disadvantage would be extinguished rapidly and capital productivity growth would cease to decline and perhaps even increase. However, as long as a country leapfrogs into progressively more advanced industries, it may never reap these benefits. Why this policy of targeting high-tech industries should result in a fall in capital-augmenting, as opposed to labor-augmenting, technical change is a moot point. It is notable that Nelson and Pack (1999) also emphasize the importance of assimilation in the East Asian growth experience. They claim that the introduction of new technologies in less-developed countries often requires a considerable learning period and note that even the best firms in developing countries often fail to achieve the efficiency levels of firms in developed countries when they use the same technology. However, these authors disagree with Young in that they do not regard this simply as a movement along an international production function.

From Table 5, it can be seen that Japan and the other advanced countries did not suffer large negative rates of capital-augmenting technical change during their period of high growth. Japan is particularly interesting because, from 1953 to 1973, it was experiencing roughly the same stages of development as the East Asian countries have been over the past three decades. However, high value of λ_L was not accompanied by a large negative value for λ_K , in marked contrast to the situation in Singapore, South Korea, and Taiwan.

Second, the calculation of adjusted TFP growth is more complicated than our simulations suggest. As we noted above, we took the initial share in 1966 as given and calculated the contribution of TFP growth to output growth over subsequent periods of varying lengths. However, if we were to consider the contribution of adjusted TFP growth using much earlier technology, the constant-technology share of capital would be approximately zero in most recent years. Hence, if we take the initial level of technology to be far enough in the past, virtually all of the contribution of the growth of the capital-labor ratio would be ascribed to technical progress.

The implications of this point may be seen more clearly by considering the following two equations for the instantaneous growth of conventionally measured

TFP growth over a long period, say, the past century. Equation (17) is the familiar expression for the conventionally measured TFP growth:

$$\text{tfp} \equiv (q - \ell) - \bar{a}(k - \ell). \quad (17)$$

For convenience, assume that the observed factor shares in the initial and the terminal periods are roughly the same. Equation (17) may be written as

$$\text{tfp} \equiv (q - \ell) - [\bar{a}^*(k - \ell) + \bar{a}^{TC}(k - \ell)]. \quad (18)$$

In Eq. (18), capital's share, namely \bar{a} , is dichotomized into the value that would have occurred if the technology had remained at the level in the initial year t_0 , namely \bar{a}^* , and the value due to the impact of technical change since t_0 , namely \bar{a}^{TC} . Consequently, $\bar{a}^{TC} \equiv (\bar{a} - \bar{a}^*)$ is the value of capital's share due to the impact of biased technological change since year t_0 . In the conventional approach, this distinction is of no importance, but it is crucial for the Nelson and Pack method. Recall that TFP growth under the constant-technology assumption is given by

$$\text{tfp}' \equiv (q - \ell) - \bar{a}^*(k - \ell), \quad (19)$$

and

$$\text{tfp}' \equiv \text{tfp} + \bar{a}^{TC}(k - \ell). \quad (20)$$

From Eq. (19), $\bar{a}^{TC}(k - \ell)$ is assumed to be part of the contribution of technical progress that is correctly measured TFP growth and so it is not deducted from output growth, as in the conventional calculation of TFP growth.

As the date of the technology that we are holding constant becomes progressively earlier compared with the terminal year, \bar{a}^* tends to 0 and \bar{a}^{TC} tends to \bar{a} , which is approximately equal to its share in the terminal year, 2000, because we have assumed that capital's observed factor share has not changed much. Thus, from Eq. (19), the constant-technology rate of TFP growth will tend to the growth of labor productivity as the period under consideration increases. The fact that TFP growth is a function of the period over which the growth rates are calculated is disconcerting, although it is inherent in the constant-technology approach.

In the constant-technology methodology, $\bar{a}^{TC}(k - \ell)$ is not deducted from $(q - \ell)$ on the right-hand side of Eq. (19), as in Eq. (18), to derive TFP growth because it is implicitly assumed to be part of adjusted TFP growth rate. Equation (20) indicates that constant-technology TFP growth exceeds the conventional measure by $\bar{a}^{TC}(k - \ell)$. By definition, the term $\bar{a}^{TC}(k - \ell)$ is a function of both the impact of technical change on the capital's share and the growth of the capital-labor ratio. Consequently, it cannot be treated solely as a component of exogenous technical progress. For example, a faster rate of capital accumulation would increase adjusted TFP growth by increasing $\bar{a}^{TC}(k - \ell)$ through a rise in the growth of the

capital–labor ratio. Therefore, the growth of the capital stock is also an important determinant of correctly measured TFP growth, as the term $\bar{a}^{TC}(k - \ell)$ reflects the contribution of both technical change and capital accumulation to growth.²⁰ Consequently, the modified growth accounting approach faces the difficulty that it is simply not possible, or meaningful, to try to separate the contributions of factor–input growth and technical change. Moreover, this conclusion does not rely on the assumption that capital growth induces technical change as in the endogenous growth models. It occurs even when technical change is exogenous, provided that such change is biased and that the elasticity of substitution differs from unity.

5. CONCLUSIONS

In this paper, we considered Nelson and Pack's argument that the surprisingly low growth rates of TFP growth found in the East Asian Tigers could be the result of a downward measurement bias due to the failure to allow for the possibilities that the bias in technical change was labor-augmenting and that the elasticity of substitution was below unity. In these circumstances, the capital share used in standard growth accounting exercises to weight the growth rate of the capital–labor ratio incorporates the effect of biased technical change to the extent that the latter prevents the observed share from falling. This effect is more important the longer is the period of analysis. Thus, a correct growth accounting exercise must eliminate such effect. The observed capital share was prevented from declining in East Asia by the absorption and assimilation of modern technology and change in the industrial structure. These are important contributions to the growth process that standard growth accounting exercises do not take into account.

We construct a procedure for examining this argument empirically for the four East Asian Tigers and apply it also to four advanced countries. On the one hand, when we modify the standard growth accounting methodology to eliminate the contribution that biased technical change makes to the growth of the capital–labor ratio by preventing capital's share from declining, we find that it only makes a significant difference to the estimates of TFP growth when the elasticity of substitution is implausibly low at around 0.2. On the other hand, the effect is much more significant when we consider the proportion of the growth of labor productivity explained by adjusted TFP growth. Nevertheless, the growth rates of adjusted TFP remain substantially below those of Japan for all elasticities of substitution. We also find that the rate of capital-augmenting technical progress is negative for the four East Asian countries. We are led to the conclusion that the interpretation of our results depends on whether the glass is regarded as half-empty or half-full.

²⁰ From a slightly different point of view, Hulten (1979) argues that part of the historically observed growth rate of the capital stock is the result of productivity change and that this must be taken into account when computing productivity measures.

A final implication of the analysis is that, given a long enough period, adjusted TFP growth will be approximately equal to the growth of labor productivity, regardless of the value of the elasticity of substitution. This raises the question, to which there is no satisfactory answer, of how to apportion the contributions to overall growth between the weighted growth of the factor inputs and the combined direct and indirect effects of TFP growth.²¹ In the final analysis, the Nelson and Pack (1999) contribution reveals an important problem with the standard neoclassical methodology but it does not resolve the important issues raised. Technical progress continues to be treated as a residual. Even if one took the least favorable interpretation of our results for the Nelson and Pack arguments, one should not underestimate the importance of their critique of standard growth accounting exercises and the contribution of assimilation theory to a general theory of development.

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²¹ Suppose that the true elasticity of substitution is different from unity and biased technical change keeps the shares constant. A researcher wants to know what elasticity of substitution to use, and estimates the production function. Because factor shares are constant, econometric estimation will indicate that the production function is Cobb–Douglas. The researcher will mistakenly conclude that the elasticity of substitution is unity. In these circumstances it is impossible to get an estimate of the true elasticity of substitution.

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