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SOME CAVEATS IN MODELLING TECHNICAL PROGRESS AND INVESTMENT: THE CASE OF CHINA[*]

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Since the early 1990s, the number of studies using neoclassical models to understand the Chinese economy has mushroomed. In this paper, we review two examples of estimation of the rate of technical progress and one attempt at modelling investment. We identify their shortcomings and the problems with the alleged policy implications. We show that econometric estimation of neoclassical models may result in apparently sensible results for misinformed reasons. We conclude that modelling the Chinese economy requires a deeper understanding of its inner workings as a transition and as a developing economy.

Keywords: China; identity; investment; neoclassical model; total factor productivity growth.

JEL Classification: E22, E62, C20, O23, P41

1. Introduction

In this paper, we raise some queries about the usefulness of widely used approaches to model technical progress and investment, based on neoclassical analyses. We use these criticisms to question how an important part of the literature on China has advanced since the early 1990s. This literature has taken an approach that we think must be carefully analysed and evaluated.[1] Many papers on China assume that factor markets are competitive, that firms are profit maximisers, and that they respond to the same incentives that firms in market economies do. In this vein, Chow (1994), for example,

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[1]One important caveat: we do not claim that all work on China suffers from the problems that we discuss this paper.

argued that most "economic analysis" is applicable to China (Chow, 1994:124). Chow clearly referred to the *orthodox neoclassical economic analysis*. In this same article, Chow concluded: "The above examples have illustrated the proposition that most of existing economic analysis is applicable to China […] Before new tools are developed for China, *one should understand the usefulness as well as the limitations of the existing tools*" (Chow, 1994:133, italics added).[2] Therefore, many researchers appear to believe that the methods and models of neoclassical economics are appropriate to understand the Chinese economy. Likewise, application of the latest econometric techniques to modelling different aspects of the Chinese economy has become standard (e.g., Sun, 1998).

The objective of this paper is to discuss if these views and approach toward understanding the Chinese economy, exemplified in Chow's statements, are sound. As many assumptions underlying neoclassical economics (e.g., profit maximisation; marginal productivity theory of factor pricing) do not appear to conform to what is known about the Chinese economy, in this paper we discuss what we view are some serious limitations of a number of the "existing tools." As readers and researchers of the China economics literature, we perceive an almost permanent tension between the premises inherent in the models of neoclassical economics and their application to the Chinese economy, often pushed through *corset justifications*. For example, Hu and Khan's (1997) justification for using growth accounting is most unconvincing from a methodological point of view. After stating 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", they continue: "However, since this method-ology is widely used in studying sources of economic growth for members of the Organisation 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, 1997:108).

Other times, authors need to justify *perverse findings*. For example, Blanchard and Giavazzi (2005, Table 4) summarise various estimates of *TFP* [total factor productivity] growth for China. They indicate that these estimates are about 3 percent per year since reforms started, but that *TFP* growth appears to have slowed significantly in recent years. The authors, however, explain that the finding of a low *TFP* growth is com-patible with a very high GDP growth: "The implication of this computation should not be however that there is no technological progress in China. The assumption underlying the computation is that *factors are paid their marginal products*. If, in fact, capital has been misallocated, then contrary to this assumption, the marginal productivity of capital

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[2] In this paper, Chow argued as follows: "The evidence has suggested that the Cobb-Douglas production function fits the data for Chinese state-owned industry very well" (Chow, 1994: 125); "This theory [theory of consumer behaviour] appears to be universal, being applicable to China as well as other countries" (Chow, 1994: 125).

in those sectors where there has been excessive investment could be negative. Therefore, the right way to interpret the computation is that, while technological progress is surely present, it is partly offset by capital misallocation" (Blanchard and Giavazzi, 2005:11, italics added).

Although the profession has advanced a great deal in terms of asking questions about the performance of the Chinese economy, it has not advanced enough in terms of asking if the peculiarities of the Chinese economy demand radically different theoretical (and perhaps empirical) approaches. Certainly, this is not to say that *China economists* have not discussed whether the peculiarities of the Chinese economy call for a specific approach. Qin (2000), for example, provided an in-depth review of the state of macro-modelling in transition economies with special reference to China and raised serious concerns.

The somewhat unfortunate tendency in recent years to apply standard neoclassical models to the study of the Chinese economy is reinforced by the application of the latest econometric refinements, in particular the analysis of unit roots and cointegration in time-series analyses. This has led, at times, to the use of stereotyped theories camouflaged in complicated technical devices. The conclusion, in our view, is that a number of China economists seem to believe that the models used must explain Chinese economic behaviour adequately simply because the results obtained are apparently good. This attitude involves an element of instrumentalism, the view that (realistic) assumptions do not matter in evaluating a model; what matters is its predictive ability.

To discuss the implications of these problems, we review three examples of how modelling and estimating technical progress and investment in China has proceeded. In Sec. 2, we review the methods proposed by Wan (1995) and Chow (1993) to quantify technical progress. In Sec. 3, we discuss the specification of the neoclassical model of investment proposed by He and Qin (2004). We argue that these empirical exercises can be interpreted as approximations to accounting identities. Indeed, we shall show that expressions almost identical to the models derived in these papers can be obtained by rewriting the income accounting identity according to which value added equals the wage bill plus total profits. It is for this reason that the expressions these authors estimated appear to work empirically and thus produce seemingly sensible results. However, for being approximations to identities, estimation of these models cannot, therefore, reject the null hypotheses that they purport to test. We conclude that if knowledge about the Chinese economy is to improve, China economists have to pay serious attention to the theories and statistical techniques that they use: not only do they have to be relevant to the Chinese reality but also their testing has to allow statistical rejection.

2. The Measurement of Technical Progress in China

In this section, we discuss two attempts at estimating the rate of technical progress in China which, in different ways, suffer from the problems mentioned in the Introduction,

namely, the belief that neoclassical economics can explain Chinese economic behaviour; and that the methods used are no more than approximations to an accounting identity. The first one is that of Wan (1995) and the second one is that of Chow (1993).

2.1. *Wan's measure of technical progress*

Wan (1995) proposed a seemingly assumption-free non-parametric approach to esti-mate the rate of total factor productivity (*TFP*) growth. The rationale behind Wan's method was two-fold. First, he pointed out quite correctly that the derivation of the traditional growth accounting equation depends on assumptions such as profit max-imisation and perfect competition. These are, most probably, inappropriate for a cen-trally planned economy like China. Second, Wan claimed that the conventional approach requires the explicit introduction of time in the production function. This, in the words of the author, "precludes the possibility of studying cross-sectional technical change" (Wan, 1995:309). As is well known, the standard method to estimate the growth rate of *TFP* — the proxy for the growth of technical progress —, is to assume an aggregate production function, typically with Hicks-neutral technological progress $Y_t = A_t F(L_t, K_t)$, where Y denotes output, L is employment, K is the stock of capital, A is the level of technology and the subscript t denotes time. In growth rates, the production function becomes $\hat{Y}_t = \lambda_t + \alpha_t^L \hat{L}_t + \alpha_t^K \hat{K}_t$, where the symbol $^\wedge$ denotes the growth rates of the corresponding variables, α_t^L and α_t^K are the elastcities of output with respect to labour and capital, respectively and λ_t is the rate of Hicks-neutral technical progress. Assuming profit maximisation and competitive markets, the factor elasticities are equal to the corresponding factor shares in output and thus the previous equation becomes $\hat{Y}_t = \lambda_t + s_t^L \hat{L}_t + s_t^K \hat{K}_t$, where s_t^L and s_t^K are the labour and capital shares in output, respectively. From here, λ_t can be estimated residually as $\lambda_t = \hat{Y}_t - s_t^L \hat{L}_t - s_t^K \hat{K}_t$.

In order to avoid these problems and define technical change (*TE*) appropriately, Wan (1995) drew the isoquants of the production function with output Y_0 as the base year. See Fig. 1. The total cost (*TC*) of producing the observed level of output Y_0 is definitionally given by $Y_0 = TC_0 = w_0 L_0 + r_0 K_0$, where w is the average wage rate, L denotes employment, r is the user cost of capital, and K is the stock of capital, with all values measured in real terms. Isoquant and isocost lines intersect at point $a(L_0, K_0)$. Point $b(L_1, K_1)$ represents the observed output given by another production function, where the functional form has changed because of technical change. At b, $Y_1 = TC_1 = w_1 L_1 + r_1 K_1$. Finally, at point $c(L_2, K_2)$ the same level of output as at b (i.e., $Y_1 = Y_2$) is produced assuming the same level of technology as at a. In other words, the increase in output from Y_0 to Y_2 is entirely the result of increased inputs.

Technical change is defined as the difference between the cost of producing output Y_2 at c using the same technology as at a, and the cost of producing Y_1 with a different technology, but with the base-year factor prices, i.e., w_0 and r_0. Thus, using the cost identities, the increase in total efficiency is given by $TE = (w_0 L_2 + r_0 K_2) - (w_0 L_1 + r_0 K_1)$. Consequently, this definition of technical change is the saving in costs
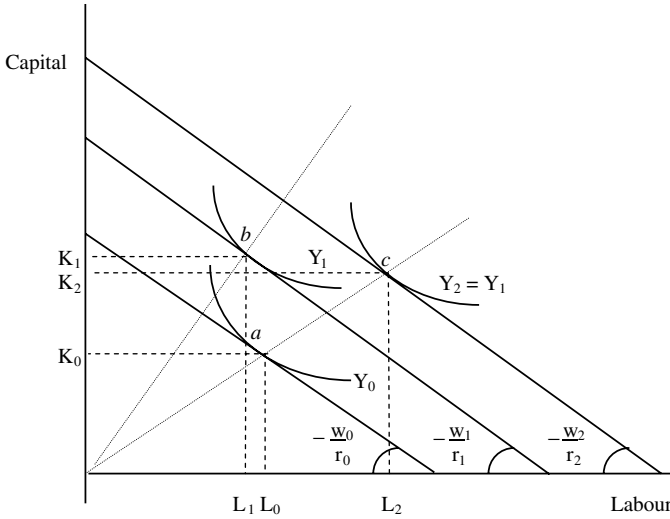
Figure 1. Wan's Measure of Technical Change without Relative Factor Price Changes

resulting from the need to use less inputs at b compared with what would have been used at c as a result of benefits of technical progress. Since $Y_1 = w_0 L_2 + r_0 K_2$ is not directly observable, Wan assumed $L_2 = \gamma L_0$ and $K_2 = \gamma K_0$, where γ is some constant. Then it follows that, with constant returns to scale, the only assumption Wan claims it is necessary to make, $Y_2 = \gamma Y_0$. This implies that $TE = (w_0 \gamma L_0 + r_0 \gamma K_0) - (w_0 L_1 + r_0 K_1)$.

Wan's measure the rate of technical progress (or total factor productivity) as the ratio of TE over year 1's output (Y_1) is (since $\gamma = Y_2/Y_0$ and $Y_2 = Y_1$):

$$\frac{TE}{Y_1} = \frac{(Y_1/Y_0)(w_0 L_0 + r_0 K_0) - (w_0 L_1 + r_0 K_1)}{(w_1 L_1 + w_1 K_1)} \tag{1}$$

where TE denotes technical efficiency and measures the saving in costs resulting from the need to use less inputs due to the benefits of technical progress, and all the variables on the right-hand side are observable.

It is important to note that Wan did not use the marginal productivity conditions, made no assumption about the state of competition, and that parameters such as the elasticity of substitution did not even play an indirect role in his calculations. The reason, as we shall show, is that Wan derived his results simply from the manipulation of the National Income and Product Accounts (NIPA) accounting identity, according to which value added (Y) equals the wage bill (W) plus profits (Π), that is, $Y \equiv W + \Pi$. As algebraically, $W_t \equiv w_t L_t$ and $\Pi_t \equiv r_t K_t$, where w and r are the average wage rate and the ex-post average profit rate, then,

$$Y_t \equiv W_t + \Pi_t \equiv w_t L_t + r_t K_t \tag{2}$$

This accounting identity does not depend on any state of competition, or on the marginal productivity theory of factor pricing, and is not derived from Euler's theorem.

Hence it is not a behavioural relationship (the symbol $\equiv$ denotes that expression (2) is true by definition).

We can express now the NIPA identity in growth rates as

$$\hat{y}_t \equiv s_t^L \hat{w}_t + s_t^K \hat{r}_t + s_t^L \hat{L}_t + s_t^K \hat{K}_t \tag{3}$$

where the symbol $^\wedge$ denotes the growth rates of the corresponding variables in the identity and $s_t^L \equiv W_t/Y_t \equiv (w_t L_t)/Y_t$ and $s_t^K \equiv \Pi_t/Y_t \equiv (r_t K_t)/Y_t$ are the labour and capital shares in output, respectively. Expression (3) can be rewritten as:

$$s_t^L \hat{w}_t + s_t^K \hat{r}_t \equiv \hat{y}_t - s_t^L \hat{L}_t - s_t^K \hat{K}_t \equiv \lambda_t \tag{4}$$

However note that Wan's definition of total factor productivity growth, Eq. (1), can be rewritten as:

$$\frac{TE}{Y_1} = \frac{Y_1 - (w_0 L_1 + r_0 K_1)}{Y_1} = \frac{(w_1 L_1 + r_1 K_1) - (w_0 L_1 + r_0 K_1)}{Y_1}$$

$$= \frac{(w_1 - w_0)L_1 + (r_1 - r_0)K_1}{Y_1} \tag{5}$$

or

$$\frac{TE}{Y_1} = s_1^L[(w_1 - w_0)/w_1] + s_1^K[(r_1 - r_0)/r_1] = s_1^L \hat{w}_t + s_1^K \hat{r}_t \tag{6}$$

where $s_1^L \equiv (w_1 L_1)/Y_1$ and $s_1^K \equiv (r_1 L_1)/Y_1$ are the factor shares. Equation (6) is equivalent to expression (4), the accounting identity.[3]

The discussion above leads to the conclusion that Wan's approach is problematic. Wan started off by writing the value added accounting identity and he simply transformed it into an equivalent form. However, since one cannot infer anything about the rate of technical change solely from an identity, it must be concluded that his method suffers from serious limitations.

2.2. *Chow's estimation of technical progress*

We move to a different type of critique. It is an extension of the argument in Sec. 2.1, which we take to its logical conclusions. In a well known paper to China specialists, Chow (1993) estimated Cobb-Douglas aggregate production functions for the Chinese economy (for the total economy and sectors) and estimated the rate of total factor productivity growth for 1952–1980. His results yielded the important conclusion that technical progress had been absent in China during 1952–1980. In a more recent paper, Chow (2006) used the same method (i.e., estimation of aggregate production

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[3] This is true except for the fact that the growth rates of the wage and profit rates are defined as $(X_1 - X_0)/X_1$ instead of $(X_1 - X_0)/X_0$. This is certainly a minor issue. There is also the issue of the difference between the ex-post profit rate and the user cost of capital. On this see Felipe and McCombie (1999, 2007).

functions) and emphasised the validity of the procedure. However, as we shall show, the method is problematic.

Chow (1993) fitted aggregate Cobb-Douglas production functions $Y_t = A_o \exp(\lambda t) L_t^{\theta_1} K_t^{\theta_2} \varepsilon_t$, where t is a time trend and ε_t is the disturbance term, to data for Chinese total output and five sectors, agriculture, industry, construction, transportation, and commerce. Here, λ measures the annual rate of *TFP* growth.[4] After carefully compiling data on income, employment and capital, Chow first ran various regressions (with different estimates of the capital stock) for total output data excluding the years 1958 to 1969. This is due to the *assumption* that the years 1958–1969 were abnormal due to the great upheavals of the Great Leap Forward movement and the Cultural Revolution (the number of observations was thus reduced from 28 to 17). Chow argued that "to exclude the years from 1958 to 1969 in estimating an aggregate production function is a reasonable and rewarding procedure" (Chow, 1993:821). In other words, Chow argued that during the Cultural Revolution, China was not on the production possibility frontier. Hence, observations from that period should not be taken as reflecting the same production function as observations from other periods. From the statistical point of view, however, this can be viewed as an exercise in data mining. Even though these excluded years saw a collapse in total output (the value in 1962 was only 64 percent of the value of 1959) followed by a rapid recovery (1966 was 177 percent 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.[5] Indeed, Fig. 2 for the construction sector shows such decline. Chow argued 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, 1993:821–822).[6]

Chow's work suffers from two related problems. First, it has been known for decades that aggregate production functions can be justified theoretically only under extremely restrictive assumptions. For practical purposes this means that they do not

[4] The model assumes that technical progress is Hicks-neutral. See Felipe and McCombie (2001) for a discussion of the problems that underlie this assumption.

[5] Borenzstein and Ostry (1996), surprisingly, 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, 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" (Borenzstein and Ostry, 1996: 225).

[6] It is worth noting that something similar happened to Cobb and Douglas in their pioneering study. There, they estimated their production function for 1899–1922. However, they noted that 1920–1921 saw a fall in output of just under 30 percent, and 1921–1922 saw a recovery of a similar magnitude However, in this case, if the last three years are dropped from the regression, it yields very poor results. Only the regression with the complete period yields sensible results. See Felipe and Adams (2005).
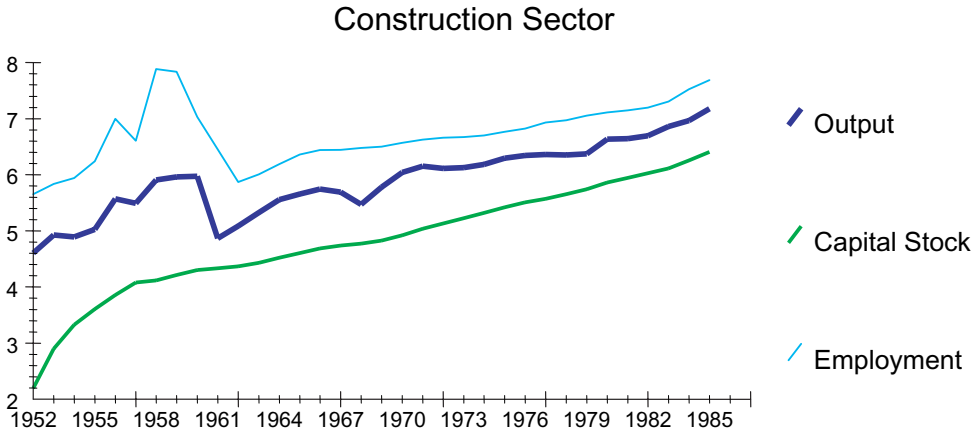
Construction Sector

Figure 2. Output, Capital Stock, Employment, China
Source: Chow (1993). Logarithmic scale.

exist (Felipe and Fisher, 2003, 2006). Economists continue using them because it seems that at times they yield seemingly sensible results in empirical estimations. This is, implicitly, Chow's (2006:192) argument. Chow (2006:191) self-reassurance that his results are meaningful because they agree with Mankiw *et al.*'s (1992) findings is also dubious, for Mankiw *et al.* (1992) estimated the steady state solution of Solow's model, unrelated to Chow's exercise (on this see Felipe and McCombie, 2005).[7] This point is not just an obscure theoretical result without implications for empirical work. On the contrary, it undermines the whole rationale for estimating aggregate production functions and interpreting their results (i.e., coefficients, elasticity of substitution) in the standard manner.

The second concern with Chow's work provides an explanation for why despite that aggregate production functions do not exist, they appear to work at times in empirical work. It can be shown, *pace* Chow, that there is no need to eliminate any year whatsoever to obtain excellent estimates of the Cobb-Douglas production function. The reason is that the regressions Chow estimated (Cobb-Douglas "aggregate production functions") can be derived as an algebraic transformation of the NIPA accounting identity expression (2). As an implication, we shall show that Chow's (1993) argument about the lack of total factor productivity growth in the Chinese economy during 1952–1980 is the result of a peculiar misspecification problem.

We can show that a form that resembles a Cobb–Douglas production function can be easily derived from the NIPA identity, expression (2). This identity in growth rates is expression (3) above. Suppose now, first, that in China factor shares were constant during the period under consideration; and second, that wage and profit rates grew at

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[7] Holz (2006: 196), in his reply to Chow (2006), questioned "the existence of an economy-wide aggregate production function." Holz was clearly referring to the aggregation problem in production functions. Personal correspondence with Carsten Holz.

constant rates (i.e., the sum of the growth rates of the wage and profit rates, each weighted by its factor share, is a constant). This implies that expression (3) becomes

$$\hat{y}_t \equiv \lambda + s^L \hat{L}_t + s^K \hat{K}_t \tag{7}$$

where $\lambda \equiv s^L \hat{w} + s^K \hat{r}$. If we integrate expression (7) and take the anti-logarithm we obtain

$$Y_t \equiv A_o \exp(\lambda t) L_t^{s^L} K_t^{s^K} \tag{8}$$

This expression, and this is the key issue, *is not* the Cobb-Douglas production function, but the NIPA identity rewritten under the two said assumptions about the factor shares and the wage and profit rates. This deceptively simple argument explains what Chow (1993) did and the reason why he was led to believe that neoclassical production theory can explain growth and productivity in China. Before we go in more detail into the argument and its far-reaching implications, let us take a look at the four regressions in Table 1 for the Chinese construction sector, estimated using Chow (1993) data set.

The first regression reproduces Chow's (1993, Table XII) results. This regression was estimated for 1954–1980, but eliminating the years 1961, 1962 and 1968. The statistical insignificance of the time trend (also found in similar regressions for other sectors of the economy) led Chow to the conclusion that there had not been any positive technological progress in China during the period analysed. The second regression was estimated using the complete period provided by Chow (1993) in his paper and without eliminating a single year. The problem with this regression is that the stock of capital bears a negative sign, hence it could not be accepted. This is the problem Chow encountered and putatively solved by arguing that the Cultural Revolution was an anomalous period, and for this reason the years corresponding to this period had to be excluded from the analysis. Notwithstanding the results, it is worth indicating that the proxy for the rate of technical progress, the time trend, is

Table 1. Production Functions for China's Construction Sector.

	Estimation Period	Years eliminated	c	t	$\ln L$	$\ln K$	t^*
Chow (1993)	1954–1980	1961, 1962, 1968	2.672 (2.93)	−0.002 (−0.11)	0.362 (7.02)	0.545 (2.26)	
This paper	1952–1985	None	1.873 (4.46)	0.045 (3.90)	0.489 (7.43)	−0.010 (−0.08)	
This paper	1952–1985	None	0.967 (2.43)		0.412 (5.70)	0.412 (8.17)	0.034 (1.92)
This paper	1954–1980	None	0.385 (0.80)		0.441 (6.16)	0.489 (8.37)	0.032 (1.81)

Source: Authors' estimations using Chow's (1993) data set
Note: *t*-statistics in parentheses. Data: Chow (1993)

statistically significant. However, the statistical insignificance of the logarithm of the capital stock, which occurred in a number of other sectors (after eliminating certain years), suggests a misspecification of the regression.

The third regression in Table 1 has been also estimated for the full period 1952–1985 and also without excluding a single year. The difference is that now this regression includes the variable t^*, which is not an exponential time trend but the function $t^* = \sin(t^2) + \sin(t^3) + \sin(t^4) + \cos(t) - \cos(t^2) - \cos(t^3) + \cos(t^5) + \log(t^2)$, where *sin* denotes the sine function, *cos* the cosine function, *log* is the logarithmic function and *t* represents time. The regression was also estimated for different subperiods (1954–1980, the same as Chow, shown in the last row) to test its robustness. The predictive failure test, recursive estimates and Chow's stability test indicate no structural break and stable coefficients. Moreover, the estimated coefficients resemble, as in Chow's regression, the factor shares. Finally, the coefficient of the variable t^* is statistically significant.

Why these substantial differences in results and why the trigonometric function? The derivation of Eq. (8) above indicates that if it were estimated with the coefficients unrestricted, it should have to work very well empirically *provided* factor shares are approximately constant and wage and profit rates grow at constant rates, that is, *if* $\lambda \cong s^L \hat{w} + s^K \hat{r}$. In other words, if these two assumptions happen to be correct in China, and one gets data on output, labour and capital, estimation of $Y_t = A_o \exp(\lambda t) L_t^{\theta_1} K_t^{\theta_2} \varepsilon_t$, will yield a very high fit (close to one), $\theta_1 \cong s^L$ and $\theta_2 \cong s^K$. This is exclusively because of the underlying accounting identity.

Most likely, factor shares in China have been sufficiently constant (see Young, 2000, Table XXIII) for purposes of econometric estimation, as factor shares do not fluctuate widely from period to period. Therefore, if estimation of the Cobb-Douglas function $Y_t = A_o \exp(\lambda t) L_t^{\theta_1} K_t^{\theta_2} \varepsilon_t$ did not result in a good approximation to the identity (second regression in Table 1) it was most likely because the second assumption (that wage and profit rates grew at constant rates) was incorrect. This is very plausible as it is unlikely that $\lambda_t \equiv s_t^L \hat{w}_t + s_t^K \hat{r}_t$ is a constant. Hence, the approximation of λ_t through the linear trend was erroneous and led to the biased estimates that resulted when all years were included in his regressions. This was caused by a *misspecification* error, though not in the usual sense in econometrics, but in the sense of choosing an incorrect approximation to the income identity. What can be done? Returning to expression (3), if we make only the assumption that factor shares are constant, substitution into expression (3) and integration yields (taking antilogarithms) $Y_t \equiv A_o w_t^{s^L} r_t^{s^K} L_t^{s^L} K_t^{s^K}$, an even more general approximation to the accounting identity than expression (8), as it only depends on one assumption, the constancy of factor shares.

The previous arguments imply that the way to improve upon Chow's poor results when all years are included is to search for the correct approximation to $w_t^{s^L} r_t^{s^K}$ (or $s^L \ln w_t + s^K \ln r_t$ in logarithms) as a function of time (but not a linear trend). Given that this variable most likely fluctuates cyclically around an upward trend in the case of China, a trigonometric function probably would do a better job, as indeed

was the case (the variable t^* above), which led to the approximation to the identity. This way, the latter (strictly speaking, a very good approximation to it) was recovered.

To complete the argument, it is important to emphasise that the function t^* is simply a trigonometric function of time whose only purpose is to track the movements of $w_t^{s^L} r_t^{s^K}$.[8] Nothing in neoclassical economics indicates that the function of time in the production function (which supposedly captures technical progress) has to be linear: linearity is merely a convenient assumption. Figure 3 plots $(0.034t^*)$ for 34 periods (1952–1985), where 0.034 is the estimate of t^* (see third regression in Table 1).

Chow argued that it is easy to explain why there was no technical change in China before the reforms started. "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, 1993:841). The same data, however, could equally tell another story, namely, 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 rate did not increase markedly over time.

This analysis leads us to question Chow's overall conclusions about the lack of technical progress in China. Even under the very unlikely assumption that China's aggregate production function exists, we have shown that one does not need to
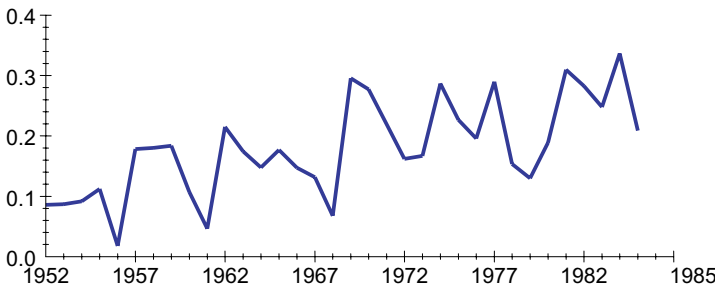

Figure 3. Trigonometric approximation to the weighted average of the growth rates of the wage and profit rate

Note: Graphical representation of the function $0.034t^*$, where $t^* = \sin(t^2) + \sin(t^3) + \sin(t^4) + \cos(t) - \cos(t^2) - \cos(t^3) + \cos(t^5) + \log(t^2)$ and 0.034 is the estimated coefficient (see third regression in Table 1).

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[8] A word of caution: the expression $0.967 + 0.034t^* + 0.412LnL + 0.412LnK$ is not a perfect approximation to the accounting identity. The perfect approximation would perhaps involve more complicated terms (and hours in front of the computer). The main purpose of the exercise is to show intuitively why Chow's exercise and conclusions are questionable. Besides, we do not have the wage and profit rate series to construct the full identity. The reader may wonder how we found out such complicated trigonometric function. This was the result of trial and error. Knowing that we were searching for an approximation to the accounting identity, we graphed $\ln Y_t - \theta_1 \ln L_t - \theta_2 \ln K_t$ for different values of θ_1 and θ_2. It is a series with an upward trend that fluctuates. This indicated that we were looking for a trigonometric function.

eliminate certain years from the regression to obtain "good" results, including a statistically significant estimate of the proxy for the rate of technical progress. Second, under the premise that the aggregate production function does not exist, Chow's exercise can be viewed as simply one for the search of a good approximation to the income accounting identity. It may well be that technical progress in China between the 1950s and 1980s was zero. Our point is simply that the methodology used by Chow is not suited to answer this question.

3. The Neoclassical Model of Investment

In this section, we further elaborate upon the same two themes, i.e., the problems posed by the underlying accounting identity and the question of whether or not the neoclassical model suits the Chinese conditions, in the context of modelling investment in China. In a recent paper, He and Qin (2004) (H&Q hereafter) (see also Song *et al.*, 2001) have made a worthy attempt at answering the important and difficult question of what are the driving forces behind China's fast-growing domestic investment. This is a very complex task given that modelling investment has always been a very hard undertaking, which in the case of China is compounded by the fact that the country has been in a state of transition for about 30 years. Hence it is not clear which theoretical approach one should follow. The Polish economist Kalecki (1971) once commented that: "The determination of investment decisions by, broadly speaking, the level and rate of change of economic activity […] remains the "pièce" de *résistance* of economics" (Kalecki, 1971:165). Years later, Blanchard still felt the same way: "The discrepancy between theory and empirical work is perhaps nowhere in macroeconomics so obvious as in the case of the aggregate investment function" (Blanchard, 1986:153).

3.1. *Chinese business sector investment*

H&Q divided Chinese domestic investment into business sector investment (I_B), composed of state-owned enterprises, collective-owned enterprises, and private enterprises; and government investment (I_G). Following Song *et al.* (2001:232), H&Q argued that in the light of the fact that China's investment system has changed profoundly since the transition process began, and that the business motives of most Chinese firms have become more market oriented since the 1990s, it is appropriate to model I_B by the "orthodox factor-input demand model" (H&Q, p. 103). By this, the authors meant the neoclassical model of investment (see Jorgenson, 1963). In this section we discuss the modelling of I_B. Regarding government investment (I_G), H&Q modeled it as a mixture of policy targets and supply-side constraints. We review this in the next section.

   In the neoclassical theory of investment (Jorgenson, 1963), output and the cost of capital are the variables determining the optimal capital stock, while investment

represents the adjustment from the actual to the optimal (desired) capital stock. Jorgenson assumed that firms choose their long-run desired capital stock (K_B^*) by optimising their factor demand subject to a constant returns-to-scale Cobb-Douglas production function (the assumption about the form of the production function is not a crucial feature of the model). This leads to the first-order condition $K_B^* = \theta(Y/r)$, where θ is the elasticity of output (Y) with respect to capital, and r is the user cost of capital. Desired investment (I_B^*) follows the equation $I_{Bt}^* = (K_t^* - K_{t-1}^*) + \delta K_{t-1}^*$, where δ is the constant depreciation rate. From the first-order condition and the motion of investment, it is easy to derive the basic equation used to model business investment, namely:

$$\Delta I_{Bt}^* = \theta \Delta \left(\frac{Y_t}{r_t} \right) - \left[I_{Bt-1}^* - \theta\delta \left(\frac{Y_{t-1}}{r_{t-1}} \right) \right] \tag{9}$$

where the symbol Δ denotes the difference in the values of a variable between two consecutive periods. H&Q argue that this equation resembles a standard error correction model (ECM), where the term in squared brackets implies the long-run relationship $I_B^* = \theta\delta(\frac{Y}{r})$. Moreover, the authors argue that "considering the possibility that the Chinese business-sector investment may also be affected by the government policies, we extend that equilibrium relation by adding government direct investment as a new explanatory variable" (H&Q, p. 104). Thus, the hypothesised long-run relationship becomes $I_B^* = \theta\delta Y^{\alpha_1} r^{\alpha_2} (I_G^*)^{\alpha_3}$, which in logarithms is $\ln I_B^* = \alpha_0 + \alpha_1 \ln Y + \alpha_2 \ln r + \alpha_3 \ln I_G^*$, with expected estimates $\alpha_0 = \ln(\theta\delta)$, $\alpha_1 = 1$, and $\alpha_2 = -1$.

For econometric purposes, this long-run relationship was embedded in a dynamic specification of Eq. (9), to which an error term with the standard assumptions was added:

$$\Delta \ln I_t = \alpha_0 + \sum_{i=1}^{d} \alpha_{0i} \Delta \ln I_{t-i} + \sum_{j=0}^{d} \alpha_{1j} \Delta \ln Y_{t-j} + \sum_{j=0}^{d} \alpha_{2j} \Delta \ln r_{t-j}$$

$$+ \sum_{j=0}^{d} \alpha_{3j} \Delta \ln I_{Gt-j} + \lambda E_{t-1} + \varepsilon_t \tag{10}$$

where $E = I_B^* - \theta\delta Y^{\alpha_1} r^{\alpha_2} (I_G^*)^{\alpha_3}$ denotes the disequilibrium term (the ECM term) and ε is the disturbance. The equation was estimated with quarterly data using the actual values of investment (that is, for practical purposes, all variables used were the actual values, without the asterisk) for the period 1994Q4–2001Q4. The authors showed that the estimated model passed the standard diagnostic tests (autocorrelation, normality, heteroscedasticity and functional form) and they could not reject the hypothesis that $\alpha_1 = 1$, and $\alpha_2 = -1$. Based on the good econometric results obtained, H&Q (p. 110) concluded that the long-run solution derived from their alleged model suggests "strongly that aggregate business investment demand is now largely market-driven in the PRC."

3.2. *Once again the underlying accounting identity*

To see the problem with Eq. (9) above, consider first the definition of the capital share (s_t^K) in output (which is obviously part of the accounting identity (2)), namely, $s_t^K \equiv \Pi_t/Y_t$, where $\Pi_t \equiv r_t K_t$ denotes total profits (surplus in the NIPA terminology), written as the product of the average *ex-post* profit rate (r_t) times the stock of capital (K_t), and Y_t is GDP. From here it follows that:

$$s_t^K \equiv \frac{r_t K_t}{Y_t} \tag{11}$$

The symbol $\equiv$ denotes that expression (11) is true by definition, in the sense that it is an accounting identity, not a behavioural relationship.[9] Likewise, define the law of motion of the stock of capital as:

$$K_t \equiv I_t + (1 - \delta)K_{t-1} \tag{12}$$

which obviously is also an accounting identity.

By rewriting expression (12) for investment, substituting for the stock of capital from identity (11), and *assuming only* that the capital share is constant (i.e., $s_t^K = s^K$), we obtain

$$I_t \equiv s^K \left[\frac{Y_t}{r_t} - \frac{Y_{t-1}}{r_{t-1}} \right] + s^K \delta \frac{Y_{t-1}}{r_{t-1}} \tag{13}$$

Finally, subtracting I_{t-1} from both sides yields:

$$I_t - I_{t-1} \equiv \Delta I_t \equiv s^K \Delta \left[\frac{Y_t}{r_t} \right] - \left[I_{t-1} - s^K \delta \frac{Y_{t-1}}{r_{t-1}} \right] \tag{14}$$

The obvious point behind expression (14) is that it is identical to equation (9), the one specified by H&Q. It must be stressed that expression (14) is an *accounting identity* that has been derived as a transformation of two other accounting identities. The only assumption made to derive expression (14) is that the capital share is constant ($s_t^K = s^K$), something that can be verified or refuted very easily. The conclusion is that expression (14), like all near tautologies, is consistent with any macroeconomic dataset, and therefore is not useful for testing theories.

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[9] Likewise, the labour share in output can be written as $s_t^L \equiv 1 - s_t^K \equiv W_t/Y_t$, where W_t denotes the total wage bill. The latter can be written as the product of the average wage (w_t) rate times employment (L_t), that is, $W_t \equiv w_t L_t$. It should be clear that any system of consistent accounts (e.g., the National Income and Product Accounts (NIPA) of any country, including those of China, from which the factor shares can be inferred) provides output (Y) as the sum of the total wage bill (W) plus total profits (Π), that is $Y_t \equiv W_t + \Pi_t$. Hence, it is arithmetically possible and correct to express output as $Y_t \equiv w_t L_t + r_t K_t$. The fact that some countries do not collect data that allow the construction of $Y_t \equiv W_t + \Pi_t$ does not undermine the theoretical argument. Nevertheless, this is not the case of China.

Provided the capital share is (sufficiently) constant, econometric estimation of expression (14) as

$$\Delta I_t \equiv b_1 \Delta \left[\frac{Y_t}{r_t}\right] + b_2 \left[I_{t-1} + \zeta_1 \frac{Y_{t-1}}{r_{t-1}}\right] \qquad (15)$$

where $\zeta_1 = -s^K \delta$, will be a pointless exercise since one knows, *ex-ante*, that the result will be $b_1 = s^K$ and $b_2 = -1$ (the supposed speed of adjustment to the long-run equilibrium in an error correction model!), and a perfect statistical fit (there is no error term of any kind).[10] Certainly, if the assumption about the constancy of the capital share were incorrect then estimation of expression (15) using standard regression methods (e.g., OLS, IV) would not yield a perfect fit, and the estimated parameters would diverge from the theoretical values. But such result would only mean that capital's share is not sufficiently constant.[11] The general argument about expression (15) would remain valid. The conclusion is that the hypothesis that expression (13) is a good explanation of investment in China can never be rejected statistically; hence it cannot be postulated as a model to explain investment behaviour because it is not falsifiable.

H&Q, however, did not obtain a perfect fit when they estimated their model. This is because they did not estimate Eq. (9). As noted above, they estimated Eq. (10), which includes lags of the variables, and estimated an error correction model. This led to the introduction of important differences with respect to the original model, Eq. (9). Moreover, H&Q introduced government investment (I_G) into the specification.[12]

Summing up, in our view, H&Q's (p. 110) conclusion that the long-run solution derived from their alleged model suggests strongly that aggregate business investment demand is now largely market-driven in the PRC is unwarranted. The conclusion of this subsection is that the autoregressive distributed lag (ADL) the authors estimated is only vaguely related to the theoretical framework that they argue underlies it, namely, the neoclassical model of investment. While the authors started by assuming a relationship derived from this theory, the equation they end up estimating is so different that it virtually has no relationship with the model. Hence, it is impossible to interpret it.

3.3. *Modelling Chinese Government Sector Investment*

Given the lack of a sound theory to model the Chinese government sector investment, the authors take a very simple approach. They propose the long-run relationship:

$$\ln I_G^* = \beta_0 + \beta_1 \ln G_R + \beta_2 \ln (Y/Y^T) + \beta_3 u \qquad (16)$$

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[10] Of course, no actual data set will display a perfect constancy of the factor shares. For econometric purposes, this condition must be understood as "roughly" constant.

[11] The general expression without assuming that the capital share is constant is:

$$I_t \equiv s_t^K \left[\frac{Y_t}{r_t} - \frac{Y_{t-1}}{r_{t-1}}\right] + (s_t^K - s_{t-1}^K)\frac{Y_{t-1}}{r_{t-1}} + s_{t-1}^K \delta \frac{Y_{t-1}}{r_{t-1}}.$$

[12] There is a slight conceptual difference worth mentioning. In neoclassical specifications, authors use the "user cost of capital" instead of the profit rate. The conceptual difference is discussed in Felipe and McCombie (2007).

where I_G^* is the desired level of government investment, G_R is government revenue, Y is actual output, Y^T is the long-run trend of output (thus (Y/Y^T) measures the deviations of actual output from its long-run trend), and u is the unemployment rate, with expected signs $\beta_1 > 0$, $\beta_2 < 0$, and $\beta_3 > 0$. As in the case of the business-sector investment, this hypothesised long-run relationship is inserted into a dynamic equation in growth rates. Again, empirically, actual values (without asterisk) were used. Despite that the authors did not model government sector investment according to the neo-classical model, they tried to interpret the results within the framework of neoclassical theory, as we shall see.

A key aspect of Eq. (16) is that it contains the long-run trend of output Y^T which is unobservable and hence has to be estimated. The authors argue that they define Y^T as the "*symbolically market-driven* Cobb-Douglas production function with constant returns to scale to reflect the long-run prospect $Y^T = AK^\theta L^{1-\theta}$" (H&Q, 2004: 105). This is certainly a most unusual definition of a production function and there is no explanation of what it means. The procedure followed to estimate Y^T is the standard one of fitting the production function $\ln(Y/L)_t = \ln A + \theta \ln (K/L)_t$ and then using the fitted value to approximate the long-run trend Y^T.[13] For empirical purposes, H&Q used also an autoregressive distributed lag specification with a view to splitting short and long-run dynamics. What is interesting is the result obtained for the elasticity of output with respect to capital: $\theta = 0.95$. Since the authors thought that there was something wrong with this result, they "experimented" (H&Q, p.112) and settled for a not much different value of $\theta = 0.85$.

Given the authors' statement that "this parameter is normally found to be well below 0.5 in most market economies" (H&Q, p.112), it seems that what they mean by a "symbolically market-driven" production function is simply a production function such that when estimated, the results are consistent with the existence of competitive markets, that is, that the factor elasticities equal the factor shares in the NIPA.[14] The NIPA of the advanced countries report a capital share in the neighborhood of 0.25–0.30. Why the authors did not obtain a value of θ close to the capital share is easy to explain, as the reason is the same as that outlined in Sec. 2.2, in the context of Chow's (1993) work. It seems odd that the postulated production function does not include any variable to account for technological progress (presumably a very important factor in China during the period of estimation, 1994Q4–2001Q4), not even the standard exponential time trend, i.e., $Y_t = A \exp(\lambda t) K_t^\theta L_t^{1-\theta} \varepsilon_t$. We conjecture that the reason is poor econometric results as a consequence of the fact that the linear trend provides a bad approximation to the weighted average of the growth rates of the wage and profit rates. Hence H&Q had to settle for a production function which, although in

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[13] For a similar procedure see Heytens and Zebregs (2003).

[14] The empirical evidence, however, does not corroborate this statement (see Sylos-Labini, 1995). In general, estimation of Cobb-Douglas functions with time series data leads to poor results (see the discussion in Sec. 2.2). The implausible results that often appear with time-series data estimating the simple Cobb-Douglas with a time trend is a well-known problem to those who estimate production functions. See also Felipe and Adams (2005).

neoclassical terms missed an important feature of the Chinese economy (technical progress), it had, at least, factor elasticties that could be explained. For purposes of H&Q's work, our argument implies that if they had used the correct approximation to the identity, the fitted value of output from the aggregate production function $(\hat{Y})$ would have to be (almost) identical to the actual value of output, hence $\hat{Y} \cong Y^T \cong Y$, and deviations from "trend" $(Y - Y^T)$, i.e., the output gap, should be very close to zero. A corollary of this result is that the production function approach to estimating potential output and the output gap is a questionable method.

4. Conclusions

This paper has delved on the general question of the validity of the neoclassical theory to model technical progress and investment in China. Our overall assessment is that this is a very problematic route. In the three cases analysed here, the equations used in the analysis have led to apparently sensible results for misinformed reasons. The reason is that they can be interpreted as approximations to accounting identities. Chow, quoted in the Introduction, argued that "before new tools are developed for China, one should understand the usefulness as well as the limitations of the existing tools." Perhaps such time has arrived.

Is there any alternative? One view, rather nihilistic, is that there is no way out, as aggregate "technical progress" and "investment" are problematic concepts due to the aggregation problems in production functions (Felipe and Fisher, 2003, 2006). It has been known for decades that the conditions to derive theoretically an aggregate production function are so stringent that it is difficult to believe that real economies can satisfy them. On the quantification of the role of technological progress, the neoclassical aggregate production function, with its emphasis on splitting the alleged contributions of factor accumulation and technical progress to overall output growth, is an avenue that should be discarded (Scott, 1989; Nelson, 1973, 1981, 1998). Moreover, simulation analyses by Felipe and McCombie (2006) show that the true rate of technical progress, estimated with physical data, differs substantially from the rate of *TFP* growth calculated with aggregate data in value terms. The latter is simply, as usually estimated, a measure of changes in distributional income.

Although the above is a position that we fundamentally believe is correct, perhaps there are some other options that allow researchers to gain useful insights. Estimation of technical progress should abandon the neoclassical framework (either growth accounting exercises or estimation of aggregate production functions). The recent work of Hausmann *et al.* (2007) and Hidalgo *et al.* (2007) is a welcome advance (the latter using network theory) towards understanding how countries progress by looking at the products that they export successfully and the capabilities needed to do so. A measure of the sophistication of a country's export basket has proven to be a good predictor of future growth: controlling for initial income, countries with a more sophisticated export basket (also initially) grow faster. Hidalgo *et al.* (2007) argue that development

has to be understood as a process of accumulating more complex sets of capabilities and finding paths that create incentives for those capabilities to be accumulated and used. To this purpose, they introduce measures of export sophistication at the product and country level (measured by the income content of the products exported), and of connectivity among products (a well-connected export basket is one that allows an easy jump to other potential exports); as well as a new analytical tool called the *product space*. Felipe, Kumar and Abdon (2010), Felipe *et al.* (2011), and Felipe, Kumar, Usui and Abdon (2010) use it to study China's performance and show that the progress that the country has seen for decades cannot be explained without understanding how it transformed, upgraded and diversified its export basket; and this could be done only through the mastering of more complex capabilities.

On modelling investment in China, one option is to consider aggregate investment as a meaningful economic concept, but then model it outside the realm of neoclassical economics. Efforts must be developed towards: (i) incorporating elements from development theory that apply to the Chinese economy; (ii) incorporating the role of expectations, a crucial aspect of any realistic model of capital accumulation (e.g., see Heye, 1995); and (iii) incorporating the role of profits as a source of investment. Kalecki (1971) emphasised the importance of reinvested profits as a source of investment, profit rates (in particular the difference between the expected rate of profitability and the interest rate) and capacity utilisation.[15] The idea that investment depends upon profits is amongst the oldest of macroeconomic relations. If indeed China's private sector is behaving more like a market economy, then surely a proxy for the profitability of investment (e.g., the average profit rate) and profits themselves will play an important role in modelling investment.

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[15] For estimates of profitability for China see Holz (2002).

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