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TECHNICAL CHANGE AND AGRICULTURAL SUPPLY-DEMAND ANALYSIS PROBLEMS OF MEASUREMENT AND PROBLEMS OF INTERPRETATION

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Introduction

The purpose of the present paper is to explore various issues related to the measurement of technical change and incidentally to the measurement of total factor productivity growth rate.

As some degree of temporariness is likely to characterize the equilibrium of most industries and especially agricultural activity, many empirical studies on supply-demand analysis are based on a restricted or short-run partial equilibrium framework, fixing certain inputs such as capital, land and/or family labour (BROWN and CHRISTENSEN, 1981). Equally important fixities may exist among production outputs. Consequently the first objective of this study is to show the importance of taking into account the quasi-fixity of some inputs and/or outputs (non-marginal cost pricing, production quotas) in order to estimate the patterns of technical change and total factor productivity (section 1).

The problem with defining and measuring technical change biases when some inputs are treated as being quasi-fixed is then explored on the basis of a restricted (or short-run) cost function : the relevant concepts of biases are defined and related to different possible equilibria (section 2). This analysis can be easily extended to technical change biases on the output side.

Section 3 is devoted to econometric issues. In the empirical literature on technical change, one often encounters regression equations that include a linear time trend as a proxy for technical change. However, as was shown in several papers on non-stationarity, empirical results of such equations can be highly misleading and can be subject to the spurious regression phenomenon. As a result, the estimated coefficients of time and exogeneous variables can widely overstate the size of autonomous and incorporated technical change. In order to avoid such problems, non-stationarity properties of time series data must be carefully examined. We show that standard regression methods including a time trend can lead to erroneous conclusions on technical change when data series are not stationary around a function of time, but rather are stationary in first difference. Tests for stationarity in difference as opposed to stationarity around a trend line developed by DICKEY and FULLER (1981) can be used to determine the appropriate transformation of time series data (section 3).

1 Total factor productivity growth and technical change: Theoretical background and empirical implications

1.1. Theoretical background

There is no single generally accepted way to measure productivity or productivity growth. Following SOLOW (1957), the more common procedure directly related to the structure of production begins with a production function representation of the process of transformation of inputs to output. Total factor productivity is then defined in terms of the efficiency with which inputs are transformed into output, assuming that homogeneous inputs produce a homogeneous output. More precisely, in the context of a production function, it is tradional to measure total factor productivity growth by the residual method, that is the growth in output quantity minus the growth in input quantities. In other words the multifactor productivity residual measure is linked to outward shifts in product long-run isoquant whereas the input effect, that is the effect measured by weighted growth rates of inputs, is associated with substitution effects along the isoquant. Under certain regularity conditions to be specified below, in the context of a total or long-run cost function, the dual total factor productivity measure can also be defined by the growth rate of average total cost minus the Divisia index of input prices : this residual is linked to downward shifts in unit or average long-run cost curves.

In numerous empirical studies, the continuous growth rates are replaced by the annual differences in the logarithms of the variables and the shares used as weights are replaced by annual arithmetic averages. The resulting indexes are the Tornquist indexes of total factor productivity growth, respectively primal and dual (see, for example, BERNDT and FUSS, 1986).

$$(\dot{TFP}/TFP) = \dot{Y}/Y - \Sigma_i \; (w_i X_i / \; p \; Y) \; (\dot{X}_i / X_i) \qquad (P_1)$$

$$\approx \log Y(t) - \log Y(t-1) - \Sigma_i \; [M_i(t) + M_i(t-1)]/2 \; (\log X_i(t) - \log X_i(t-1)) \qquad (P_2)$$

$$(\dot{TFP}/TFP) = \dot{CT}/CT - \dot{Y}/Y - \Sigma_i \; (w_i \; X_i/CT)(\dot{w}_i/w_i) \qquad (D_1)$$

$$\approx (\log CT(t) - \log CT(t-1)) - (\log Y(t) - \log Y(t-1)) - \Sigma_i \; [S_i(t) + S_i(t-1)]/2.(\log w_i(t) - \log w_i(t-1)) \qquad (D_2)$$

where $Y \geq 0$ is the output with price $p \geq 0$, $X' = (X_1,...,X_N) \geq 0$ the row vector of inputs with associated row price vector $w' = (w_1,...,w_N) \geq 0$, CT the total cost function, M_i the income input shares and S_i the cost input shares. Dots over variables indicate derivatives with respect to time. P_1 (respectively D_1) is the primal (respectively dual) Divisia index of total factor productivity growth, P_2 (respectively D_2) its Tornquist approximation.

How such measures, easy to compute, of total factor productivity are related to technical change measured by the rate at which the production function shifts? SOLOW has shown that technical change and total factor productivity primal measure are two equivalent concepts if the following assumptions are satisfied : constant returns to scale, Hicks neutral technical change and perfect competition in both output and input markets. Furthermore, under these three restrictive assumptions, OHTA (1974) has shown that primal and dual non parametric measures are the negatives of one another. Assuming a translog representation of either the production function or the cost function, BERNDT and JORGENSON (1975), DIEWERT (1976) have proved that the assumption of neutral technical change is not necessary to have this equivalence. In other words, the non-parametric measures of total factor productivity growth rates equal the rate of technical change (the rate at which the production function shifts or the rate at which the long-run total cost function shifts) if the three following assumptions are verified:

- constant returns to scale
- input and output markets are competitive
- inputs and outputs are in long-run Marshallian equilibrium.

When one of these assumptions is violated, simple corrections can be applied to relate the non-parametric indexes of growth rate of total factor productivity to technical change. Assuming that some inputs are quasi-fixed, we partition the input vector X into a subvector X^0 of variable inputs and a subvector X^1 of quasi-fixed inputs. Indeed, the hypothesis that all inputs instantaneously adjust to their long-run equilibrium levels seems restrictive, especially for the agricultural technology since certain factors cannot vary freely within the period of observation. The principal source of fixity is the lack of mobility of self-employed farm labour which is enhanced by high unemployment in other economic sectors (BROWN and CHRISTENSEN, 1981; GUYOMARD and VERMERSCH, 1989). At the farm level, available agricultural land is often fixed over short to medium adjustment periods . At the macroeconomic level, land can be considered as a fixed factor even over long adjustment periods . A similar partition applies to output vector $Y = (Y^0, Y^1)$ in order to take into account the quasi-fixity (cattle) or the fixity (production quotas) of some outputs and also in order to take into account the possibility of a non-marginal cost pricing of certain outputs. Furthermore, we do not assume long-run returns to scale.

Total costs are variable (or restricted) costs plus fixed costs, that is, $CD(Y^0,Y^1,w^0,w^1,X^1,t)= CR(Y^0,Y^1,w^0,X^1,t) + {}^{1}{}_{j}\, w^1_j\, X^1_j$. The calculated rate at which total factor productivity primal measure changes is always equal to :

$$(\dot{TFP}/TFP)_P = \Sigma^0{}_r \; R_r \; \dot{Y}^0{}_r/Y^0{}_r + \Sigma^1{}_s \; R_s \; \dot{Y}^1{}_s \,/Y^1{}_s - \Sigma^0{}_i \; S_i \; \dot{X}^0{}_i/X^0{}_i - \Sigma^1{}_j \; S_j \; \dot{X}^1{}_j/X^1{}_j \,. \quad [1]$$

where R_r (respectively R_s) is the cost share of output $Y^0{}_r$ (respectively $Y^1{}_s$).

Technical change is defined by - log CD/ t, that is the rate at which the disequilibrium total cost function CD shifts. Then, it can be shown that technical change and the traditional total factor productivity non-parametric measure are related by the following equation[1)].

$$
\begin{aligned}
-\delta \log CD/\delta t = {} & \Sigma^{o}_{r} \left(p^{o}_{r}\, Y^{o}_{r}/CD - p^{o}_{r}\, Y^{o}_{r}/RT\right) \dot{Y}^{o}_{r}/Y^{o}_{r} \\
& + \Sigma^{1}_{s} \left(\hat{p}^{1}_{s}\, Y^{1}_{s}/CD - p^{1}_{s}\, Y^{1}_{s}/RT\right) . \dot{Y}^{1}_{s}/Y^{1}_{s} \\
& - \Sigma^{1}_{j}\, \hat{w}^{1}_{j}\, X^{1}_{j}/CD . \dot{X}^{1}_{j}/X^{1}_{j} + \Sigma^{1}_{j}\, w^{1}_{j}\, X^{1}_{j}/CD . \dot{X}^{1}_{j}/X^{1}_{j} \\
& + (\dot{TFP}/TFP)_{p}
\end{aligned}
\qquad [2]
$$

where p^{1}_{s} and w^{1}_{j} are the dual or shadow prices of "quasi-fixed" outputs and inputs, respectively, RT the total revenue function.

1.2 Consequences for empirical studies

Equation [2] shows that when some netputs are in disequilibrium (quasi-fixities and/or non-marginal cost pricing) the non-parametric measure of total factor productivity TFP/TFP does not equal the rate of technical change. Nevertheless when all markets are in long-run Marshallian equilibrium and if returns to scale are constant, equation [2] collapses to the usual expression[2)].

$$
\dot{TFP}/TFP = -\,\delta \log CT/\delta t \qquad [3]
$$

In order to analyse the consequences of the simplifying assumptions allowing to show the equivalence between total factor productivity growth rate and technical change, we consider a particular case where returns to scale are constant, all inputs variable (no quasi-fixity on the input side) but some output markets in disequilibrium[3]. Assuming that all outputs may be in disequilibrium, equation [2] becomes :

$$
(\dot{TFP}/TFP)_{p} = -\,\varepsilon_{CTt} + \Sigma_{s} \left(p_{s} Y_{s}/RT - \hat{p}_{s} Y_{s}/CD\right) . \dot{Y}_{s}/Y_{s} \qquad [4]
$$

The direction of the bias induced by a non-marginal tarification of outputs depends on the gap between market output shares $p_S Y_S/RT$ and "marginal" output shares $p_S Y_S/CD$, where p_S = CR/ Y_S is the marginal cost of output Y_S. As an example, let us consider the case of the dairy quota which is binding since its implementation in 1984 in EEC. Using a theoretical model developed by Mahé and Guyomard (1989), which links

1 see Guyomard, Tavera (1989) for more details.

2 In such a case, CT=CD ; $p^{1}_{s} = \hat{p}^{1}_{s}$ for all s, $w^{1}_{j} = \hat{w}^{1}_{j}$ for all j = 1 and CT = RT

3 In the first version of the paper (Guyomard, Tavera, 1989), two other cases are examined : the first corresponds to the situation of non constant returns to scale, the second to the problem of quasi-fixed inputs.

the endogeneous dual price of milk p^M_s to its determinants (output and variable input prices, quasi-fixed input levels and prices, milk-quota level and technical change), it is possible to calculate the dual milk price growth rate for each year. The results for France and Germany are presented in table 1.

Table 1: Observed and dual milk nominal price growth rate, milk quota rate; France and Germany, 1984 to 1988, national prices (preliminary results, in percent)

	FRANCE		
	dual price/	market price/	quota level
1984	-2.2	+4.1	-2.0
1985	-4.1	+4.1	+0.0
1986	-2.8	+3.0	+0.2
1987	-11.3	+1.3	-5.6
1988	-5.8	+2.5	-2.6
	GERMANY		
	dual price /	market price/	quota level
1984	-3.3	-2.6	-6.7
1985	-1.0	-1.1	-0.3
1986	-3.5	+1.3	0
1987	-8.6	-0.2	-5.9
1988	-3.2	-0.03	-2.7

Assuming that dual and market prices are equal for the base period 1984, that is assuming that the milk market is in equilibrium in 1984, we can compute the dual price level of milk for each year and consequently we can calculate the bias induced by the milk quota system in measuring technical change by the traditional non-parametric index of total factor productivity. As an example, in 1984 the bias is equal to -0.031 % in France and -0.017 % in Germany. The bias, which depends not only on the gap between dual and market prices but also on the milk quota growth rate, increases with time since the difference between dual and observed milk prices increases too (see table 1).

2 Neutral or biased technical change: Problems of definitions

Technical change is often characterized as neutral or biased. Based on original Hick's definition and assuming a two input - one output linearly homogeneous technology, technical change is said to be neutral if it leaves unchanged the marginal product of input X_1 relatively to that of input X_2. However, as noted by BLACKORBY, LOVELL and THURSBY (1976), "to compare situations before and after technical change, something must be held constant. Exactly what is to be held constant has been the subject of some debate and constitutes the crux of the issue at hand". KENNEDY and THIRLWALL (1972) among others argue that factor endowments must be held constant at least at the macro level and consequently technical change effects must be measured with respect to a ray where factor proportions remain unchanged. At the firm level and also at the macro level in a sector like agriculture where enterprises are more often assumed price-takers, it is most useful to define neutrality holding factor price ratio constant (BINSWANGER, 1974). Consequently in this study like in most studies applied to agricultural technologies, biases and neutrality are defined with respect to an expansion path, that is in terms of the proportional change in the input ratio holding factor price ratio constant. In other words,

$$\frac{\delta(X_1/X_2)}{\delta t} \cdot \frac{1}{(X_1/X_2)} \quad \begin{array}{|l} > 0 \text{ input } X_2 \text{ saving} \\ = 0 \text{ neutral} \\ < 0 \text{ input } X_2 \text{ using} \\ \\ \text{factor price ratio } (w_1/w_2) \text{ constant.} \end{array} \qquad [5]$$

In the two input case, the previous definition can easily be transformed into a definition in terms of factor shares at constant factor price ratio. Furthermore the share approach can be generalized to the manyinput case. The measure of bias for each factor proposed by BINSWANGER is given by,

$$B_{it} = \frac{\delta S_i}{\delta t} \cdot \frac{1}{S_i} \quad \begin{array}{|l} > 0 \text{ input } X_i \text{ using} \\ = 0 \text{ input } X_i \text{ neutral} \\ < 0 \text{ input } X_i \text{ saving} \\ \\ \text{factor price ratio } (w_i/w_j) \text{ constant.} \end{array} \qquad [6]$$

where S_i is the share of input X_i in total costs. Technical change biases are then defined on the basis of a dual representation of the technology, assuming that there exists a long-run total cost function CT(Y, w, t) where all inputs are variable. It is interesting to note that if the long-run technology is not homothetic with respect to Y, it is necessary to hold constant not only relative factor prices but also output levels. Following SATO (1970), the bias B_{it} can be interpreted using the following decomposition,

$$\begin{aligned} B_{it} &= \delta S_i/\delta t \ . \ 1/S_i \Big|_{Y,\ w_i/w_i} \\ &= \delta\log(w_i X_i(Y,w,t)/CT(Y,w,t))/\delta t \qquad [7] \\ &= \delta\log X_i(Y,w,t)/\delta t - \delta\log CT(Y,w,t)/\delta t \\ &= \varepsilon_{it} - \varepsilon_{CTt} \end{aligned}$$

Consequently the bias is the difference of two effects: the percentage change in demand for the input X_i minus the average percentage variation in inputs. The sign of this second effect is known unambiguously if technical change occurs ($_{CTt} < 0$). Then a technical change which is input X_i saving decreases expenditure on that factor because the reduction in X_i from a change in t is greater than average. This technical change is input X_i using, when it increases expenditure on that factor, that is when the average effect is greater than the specific effect. An alternative interpretation perhaps less intuitive is given by MORRISON (1988) : she notes that each technical change bias B_{it} may be expressed as $B_{it} = 1/S_i(\ ^2\log CT/\ \log w_i\ t) = 1/S_i\ (\ _{CTt}/\ \log w_i)$ and consequently B_{it} measures also the effect on total cost diminution from a change in w_i. Finally, note that if there are n inputs, there will be n measured biases B_{it}. Nevertheless it may be useful to define biases as follows:

$$Q_{ij} = B_{it} - B_{jt} = \delta \log S_i/\delta t - \delta \log S_j/\delta t \qquad [8]$$

In this case there will be n!/2(n-2)! measures. Q_{ij} greater than zero implies that technical change has resulted in using more of factor X_i relative to factor X_j.

The assumption that a long-run Hicksian equilibrium can be achieved by the observed technology is crucial to the development of the previous analysis in terms of total cost shares. However, we have shown that such an assumption is too restrictive and unrealistic. When one input is quasi-fixed it appears as an argument in the restricted cost function $CR(Y,w^o,X^1,t)$ and in the total disequilibrium cost function $CD(Y,w^o,w^1,X^1,t)$. Consequently two short-run measures of technical change may be defined,

$$\begin{aligned} B^{CR}_{it} &= \delta \log S^{CR}_i/\delta t \Big|_{w^o_i/w^o_1,\ Y,\ X^1} \\ &= \delta \log X^{oCR}_i\ (Y,w^o,X^1,t)/\delta t - \delta \log CR(Y,w^o,X^1,t)/\delta t \qquad [9] \\ &= \varepsilon^{CR}_{it} - \varepsilon_{CRt} \end{aligned}$$

where S^{CR}_i is the restricted cost share of input X^o_i.

$$\begin{aligned} B^{CD}_{it} &= \delta \log S^{CD}_i/\delta t \Big|_{w^o_i/w^o_1,w^1,Y,\ X^1} \\ &= \delta \log X^{oCR}_i\ (Y,w^o,X^1,t)/\delta t - \delta \log CD(Y,w^o,w^1,X^1,t)/\delta t \\ &= \varepsilon^{CR}_{it} - \varepsilon_{CDt} \qquad [10] \end{aligned}$$

where S^{CD}_i is the disequilibrium total cost share of input X^o_i.

Both derivations are based on constant relative variable input prices as well as output and quasi-fixed input levels. Furthermore the second definition implies also that fixed input rental prices are constant. B^{CR}_{it} and B^{CD}_{it} are linked by the following equality,

$$\begin{aligned} B^{CD}_{it} = \varepsilon^{CR}_{it} - \varepsilon_{CDt} &= \varepsilon^{CR}_{it} - \varepsilon_{CRt} - (\varepsilon_{CDt} - \varepsilon_{CRt}) \\ &= B^{CR}_{it} - \varepsilon_{CRt}\ (CR/CD - 1) \\ &= B^{CR}_{it} - \varepsilon_{CRt}(-\Sigma^1{}_j\ w^1{}_j\ X^1{}_j\ /CD) \qquad [11] \end{aligned}$$

Consequently, $B^{CD}_{it} \leq B^{CR}_{it}$. If technical change is short-run equilibrium input X^o_i saving, then it is also short-run disequilibrium input X^o_i saving. In the same way, if B^{CD}_{it} is greater than or equal to zero, then B^{CR}_{it} is also greater than zero. Finally note that technical change can be short-run equilibrium input X^o_i using ($B^{CR}_{it} \geq 0$) and short-run disequilibrium input X^o_i saving ($B^{CD}_{it} \leq 0$). In such a case, a change in t implies that $^{CR}_{it} \leq {}_{CDt}$ so that the specific effect of t on X^o_i is greater than the average effect measured with respect to the disequilibrium cost function but this specific effect is smaller than average as measured with respect to the restricted cost function. This analysis shows that certain biases can be difficult to interpret and consequently that policy implications must be derived with caution. Nevertheless it is more useful to analyse technical change biases defined in terms of disequilibrium cost shares because these definitions are more easily visualized and more directly comparable to long-run equilibrium biases. Finally note that if we define short-run biases in terms of differences, $Q^{CR}_{ij} = B^{CR}_{it} - B^{CR}_{jt} = B^{CD}_{it} - B^{CD}_{jt} = Q^{CD}_{ij}$, the previous difficulty of interpretation vanishes.

Short-run, equilibrium or disequilibrium, technical change biases do not take into account the ability to adjust the quasi-fixed inputs in the long run. Consequently, these measures are not calculated with respect to the global expansion path relative to all inputs insofar as the quasi-fixed factors are not necessarily initially at their optimal levels. In order to take into account the full response of variable and quasi-fixed inputs, we use the fact that long-run responses can be deduced solely from the estimated parameters of the short-run cost function. This property has been extensively used to derive long-run price elasticities from their short-run counterparts (see, for example, BROWN and CHRISTENSEN, 1981). This property can easily be extended to technical change biases. As a consequence, long-run measures take into account the adjustment of quasi-fixed inputs induced by time.

$$
\begin{aligned}
B_{it} &= \delta \log S^{CD}_i(Y, w^o, X^1(Y, w^o, w^1, t), t)/\delta t \Big|_{w^o_i/w^o_1,\, w^1_j/w^o_1,\, Y} \\
&= \delta \log X^{oCR}_i.(Y, w^o, X^1(Y, w^o, w^1, t), t)/\delta t \\
&\quad - \delta \log CD(Y, w^o, w^1, X^1(Y, w^o, w^1, t), t)/\delta t \\
&= \varepsilon^{CR}_{it} + \Sigma^1_j\ \delta \log X^{oCR}_i/\delta \log X^1_j.\delta \log X^1_j(.)/\delta t \\
&\quad - (\varepsilon_{CDt} + \Sigma^1_j\ \delta \log CD/\delta \log X^1_j.\delta \log X^1_j(.)/\delta t) \\
&= B^{CD}_{it} + \Sigma^1_j\ (\delta \log X^{oCR}_i/\delta \log X^1_j - \delta \log CD/\delta \log X^1_j).\delta \log \\
&\quad X^1_j(.)/\delta t \\
&= B^{CD}_{it} + \Sigma^1_j\ (\varepsilon^{CR}_{ij} - \varepsilon_{CDj}).\delta \log X^1_j(.)/\delta t \\
&= B^{CD}_{it} + \Sigma^1_j\ \varepsilon^{CR}_{ij}\ \delta \log X^1_j(.)/\delta^t
\end{aligned}
\qquad [12]
$$

since in the long-run, $\delta CD/\delta X^1_j = 0$.

This equation shows that the long-run technical change bias B_{it} is the sum of two effects: the short-run disequilibrium bias and the "expansion" technical change bias. The signs of B_{it} and B^{CD}_{it} may differ depending on the relative magnitude of this "expansion" effect which can be either positive or negative. In other words, technical change may be input X^o_i long-run saving and short-run disequilibrium using.

3 Use of time trend as a proxy for technical change

A great deal of empirical works on technical change use a time trend as a proxy for technical change (or, more precisely, for the Autonomous Component of Technical Change (ACTC)) in regressions such as :

$$Y_t = \alpha + \beta t + \sum_{i=1}^{K} \delta_i Z_{it} + e_t \qquad [13]$$

where Y_t is the log of output, $Z_t = (Z_{1t},..., Z_{Kt})$ a set of K exogeneous variables (each taken in log), t a linear time trend and e_t a series of white noise (o, $^2{}_e$) residuals.

However, several recent papers on non-stationarity have shown that results from the estimation of equation [13] are strongly subject to the spurious regression phenomenon and have to be interpreted with caution if Y_t and the Z_{it} (i=1,...,K) are non-stationary. More precisely, model [13] implicitely assumes that the ACTC can be written as :

$$ACTC_t = Y_t - \sum_{i=1}^{K} \delta_i Z_{it} = \alpha + \beta t + e_t \qquad [14]$$

The ACTC is thus assumed purely deterministic (the ACTC is said to follow a Trend Stationary (TS) process) and forecasts made with such a model are thus based on the hypothesis that only the Stochastic Component of Technical Change (SCTC) can be altered by a given policy in the long run.

However if the ACTC is not deterministic but instead fluctuates stochastically according to (in such a case, the ACTC is said to follow a Difference Stationary (DS) process),

$$ACTC_t = Y_t - \sum_{i=1}^{K} \delta_i Z_{it} = ACTC_{t-1} + \beta + e'_t \qquad [15]$$

then using first differences of [13], that is,

$$(Y_t - Y_{t-1}) = \beta + \sum_{i=1}^{K} \delta_i . (Z_{it} - Z_{it-1}) + e'_t \qquad [16]$$

would put it in the form suitable for estimation. This is due to the fact that if the ACTC is DS, estimating a relationship such as [13] amounts to estimate a relationship similar to :

$$Y_t = Y_o + \beta t + \sum_{i=1}^{K} \delta_i Z_{it} + \sum_{j=1}^{t} e'_{t-j} \qquad [17]$$

with non-stationary residuals.

NELSON and KANG (1984) have discussed the consequences of estimating the relationship in levels [13] when the differenced relationship [16] is in fact the one with

stationary disturbances. Their main results can be summarized as follows :
a) OLS estimates of ’=($_1$, ..., $_K$) and ß in [17] are unbiased but inefficient since the disturbances between time periods in [17] are correlated.

b) OLS estimates of ’ in levels are subject to the spurious regression phenomenon. That is, conventional t and R^2 tests are biased in favour of indicating a relationship between the variables when none is present. This is due to the fact that an OLS estimation of ’ in [17] can be thought of as a regression of detrented Y on detrended Z according to :

$$Y^*_t = \sum_{i=1}^{K} \delta_i Z^*_{it} + e^*_t \qquad [18]$$

where stars denote detrented variables.

However if Z_t and e_t are both DS processes in equation [13], then Y_t is also DS. In this case, relation [18] shows that estimating ’ by OLS in [17] is equivalent to a regression where the independent variable and the error term are both detrented random walks and thus have the same autocorrelation function (CHAN-HAYYA, Ord, 1977)[4]. As a result, the precision of the estimate of ’ will be greatly overstated if serial correlation in the regression errors is ignored.

c) A related issue is that R^2 will exagerate the extend to which movement of the data is actually accounted for by time and exogeneous Z variables. Using a Monte Carlo experiment, Nelson and Kang have shown that time and a random walk will typically explain about 50 % of the variation in a random walk which are in fact unrelated to either.

d) Estimating a relationship similar to [17] leads to spurious sample autocorrelations of residuals which exponentialy decline as it is the case in a first order autoregressive process. If the investigator believes the regression disturbances to be stationary, then he can use the value of autocorrelation at lag one f_1 as an estimate of the autoregressive coefficient in the following transformed regression equation :

$$(Y_t - f_1 Y_{t-1}) = \alpha.(1-f_1) + \beta.(t-f_1(t-1)) + \sum_{i=1}^{k} \delta_i.(Z_{it} - f_1 Z_{it-1}) + (e_t - f_1 e_{t-1}) \qquad [19]$$

Regression [19] would be properly specified if f_1 were set at unity. Only in this case, which is equivalent to take first differences of equation [13], residuals $(e_t - e_{t-1})$ would be random. However, as was pointed out by Nelson and Kang the empirical standard deviation of f_1 is only 0.064 around the mean of 0.852 and sample values of f_1 are thus rarely close to unity. The problem of non-random and non-stationary disturbances is still present in [19]. It can be shown that the problem of spurious relationship of Y to time is partly alleviated by the transformation but it is still very strong. Lastly, continued

4 Chan-Hayya and Ord (1977) have shown that when the true model of a time series is a random walk (or more generally a DS model), the use of a linear deterministic time trend to eliminate a suspected trend will produce large spurious positive autocorrelations in the first few lags.

iteration of the Cochrane-Orcutt procedure improves the properties of estimates but only taking first differences is the correct and adequate procedure.

In order to avoid such problems, non-stationarity properties of time series data must be carefully examined. Thus, the tests for stationarity in difference as opposed to stationarity around a linear trend (DICKEY and FULLER, 1981) should be conducted prior to modelisation of non-stationary series in order to adequately determine the appropriate transformation of time series data. Most of the time, such tests can help avoiding to overestimate the size of the ACTC.

4 Concluding remarks

Although a great deal of empirical research on productivity and technical change measurement has taken place in the last decade, some important problems, which have been reviewed in this paper, have not been treated in a completely satisfactory manner. As an example, the existence of the dairy quota in the EC requires further analysis in order to correctly measure the impact of this policy instrument on the traditional index of total factor productivity. More generally, lessons derived from economic theory and time series analysis can contribute to a better understanding of the sources of variations in the patterns of productivity growth and technical change.

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