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GROWTH, TECHNOLOGY AND DIFFUSION. A CRITICAL REVIEW

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CRECIMIENTO, TECNOLOGÍA Y DIFUSIÓN: UNA REVISIÓN CRITICA

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RESUMEN

De acuerdo a la interpretación neoclásica del crecimiento, éste, en última instancia, sólo puede tener su origen en el aumento de los factores de producción. Sin embargo, cuando se procedió a aplicar esta metodología al análisis empírico, la mayor parte de los estudios encaminados a contabilizar el crecimiento, es decir, a asignar a cada factor su contribución al aumento del output, encontraron que una buena parte del mismo permanecía inexplicado. Aunque, en principio, ello debía obeceder al efecto, exógeno, del progreso técnico, en realidad, el porcentaje de crecimiento derivado del mismo parecía ser excesivo. Todo ello motivó que se realizaran una serie de críticas a la metodología utilizada, tanto en lo referente a su vertiente empírica como a sus fundamentos teóricos. En el presente trabajo se pretende llevar a cabo una revisión de dichas críticas así como de los estudios que las motivaron. Paralelamente, se analiza el papel jugado por la tecnología en los análisis sobre la dinámica económica.

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INTRODUCTION

Growth accounting exercises have been devoted to identify the factors governing output and to measure their partial contributions to economic growth. The pioneering works on this topic were based on a neoclassical framework according to which most part of growth should be explained by changes in the amounts of capital and labour entering the production function. Yet, when growth accountants proceeded to estimate the share of the increase in output generated by those factors, they found that frequently it did not exceed fifty per cent. The unexplained share was what in the Solow's model was labelled... the residual!. Obviously, such an important determinant of growth did not deserve that name and, hence, growth accountants tried to reduce it, mainly by adding more components to the production function.

The paper is divided in three parts. First section deals with the relation between Solow's model and growth accounting exercises. In addition, we summarize a list of problems stemming from growth accounting methodology. The second part comprises a review of the main explanatory variables added by growth accountants to the Solow's decomposition of growth. Finally, the third part is devoted to what is the most elusive problem in this sort of analysis: technological progress.

1. GROWTH ACCOUNTING AND SOLOW'S GROWTH MODEL

From its beginnings the aims of growth accounting have been to specify the sources of economic growth and to estimate the contribution of each factor to the expansion of output. Although some of the empirical research preceded a formal model, Solow's model of growth (Solow 1956) provided the theoretical framework to carry out these exercises. Therefore, we think that the best way to start this paper is by developing a brief summary of the model.

Solow's model follows the standard neoclassical assumptions such as perfect competition, perfect information, positive and decreasing marginal productivity for capital and labour, a constant returns to scale production function, etc. It is also assumed that the saving-output ratio is constant and, of course, that saving equals investment. The model predicts that in the long run all the variables grow at the same rate and, therefore, in equilibrium the growth rate of output per worker is zero. Then, one may wonder how is it possible to explain the growth of per capita income observed in many countries. The model explains this fact as the result of technical progress. Disregarding this variable, in the way towards long run equilibrium output growth can be decomposed in a weighted sum of the increases in capital and labour. To see this, let us define the production function as

$$Y_t = L_t^{\alpha} K_t^{\beta} \qquad \alpha + \beta = 1, \tag{1.1}$$

where Y is output, L is labor, K is capital and subscript t stands for time. Then, taking logs and derivatives with respect to time we get[1]

$$\frac{dY}{Y} = \alpha \frac{dL}{L} + \beta \frac{dK}{K}, \tag{1.2}$$

Equation (1.2) says that the growth rate of output equals the growth rate of labor weighted by α plus the growth rate of capital weighted by β. This is a good starting point to account for growth. However, we must first define α and β. If the marginal income distribution theory holds, then we can write

[1]Throughout this work we will denote time derivatives by a *d* before the variable.

$$w = \frac{\partial Y}{\partial L} = \alpha L^{\alpha-1} K^{\beta}$$

and (1.3)

$$r = \frac{\partial Y}{\partial K} = \beta L^{\alpha} K^{\beta-1}, \tag{1.4}$$

where w and r are the rewards to labour and capital, respectively. Multiplying (1.3) by L and (1.4) by K and dividing both equations by Y, we get

$$\alpha = \frac{wL}{Y} = S_L$$

and (1.5)

$$\beta = \frac{rK}{Y} = S_K. \tag{1.6}$$

Therefore, α and β are the shares of labour and capital in national income (S_L and S_K, respectively). Substitution of (1.5) and (1.6) into (1.2) yields

$$\frac{dY}{Y} = S_L \frac{dL}{L} + S_K \frac{dK}{K}. \tag{1.7}$$

Equation (1.7) shows how a growth account can be carried out. First we calculate the output growth, then, we estimate the weighted sum of inputs growth, using as weights the inputs share in national income and, finally, we compute the difference between both magnitudes. This difference is named the residual and it stands for technical progress.

When this theoretical framework was applied to actual data, the results were amazing: only about a half the increase in output was explained by the contribution of capital and labour (Abramovitz (1956), Solow (1957)). The residual should reflect technological progress but it was surprisingly large. This fact raised two main problems. On one hand, since technology is an exogenous variable, a major part of growth remained unexplained. On the other hand, according to neoclassical assumptions technology is a free good and, therefore, growth rates should show similar patterns across countries[2].

Two ways were followed in order to reduce the residual. One was to embody technical progress as much as possible into the factors, adjusting them for quality compositions, etc. Another was to add more factors to the production function. To the first approach belongs the work of Jorgenson and Griliches (1967) in which a deep adjustment in the measure of capital is implemented. Total stock of capital was corrected for biases in deflators and its components and adjusted by the rate of utilisation and by using the flow price of capital instead of its asset price. These modifications forced the residual to vanish almost completely. Yet, they were dramatically reduced in ulterior studies after being severely criticized by Denison (1969) and Gordon (1969) who argued that capital was so overadjusted that if proper corrections were set up on other factors the residual could be negative.

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[2]Needless to say that growth rates across nations equalize once they have converged to their steady states, which according to the neoclassical theory is the same for all countries with the same population growth rate and depreciation rate. However, the speed of convergence in principle is quite high. See Barro and Sala i Martin (1990).

Since the publication of Denison's pioneering work (Denison 1967) the second approach became dominant among growth accountants[3] and more explanatory variables were added in order to reduce the residual. Some of the new factors entering the production function are supposed to be systematic while others are ad-hoc and, hence, they do not apply to all nations and epochs. They range from changes in economic structure or a catching up bonus to economies of scale. However, although the inclusion of these factors has made possible to explain a larger part of growth, this part does not exceed on average 75% of total growth and for some countries in some periods it is no more than 50%. For example, Denison (1979) ascribes 15% of the US average growth during the period 1948-1973 to an increase in capital and another 15% to changes in employment and working hours; fourteen per cent is credited to increased capabilities of workers; improvement in resources allocation contributed 10% and economies of scale 11% while changes in legal and human environment reduced growth by 2%. The residual, 37%, was the result of technical advances. Thus, despite the inclusion of others variables, technology was still by far the most important single source of economic growth.

To these factors or variables will be devoted the next section of the paper but first let us expound some remarks on growth accounting methodology.

[3]Among others, it has been undertaken by Denison (1967, 1979), Kendrick (1981) and Maddison (1987).

1.1 The measurement of output[4]

As pointed out by Griliches (1979) the definition of output is a crucial point in growth accounting exercises because their results and conclusions change according to the measurement of production. In other words, it is not the same to consider production as GNP, as the change in national wealth or as a broader concept of economic welfare. For instance, a large part of the impact of technical progress on output is not included in national accounts as usually measured and, therefore, its contribution to growth is underestimated.

This problem has never been seriously considered by growth accountants. In their analysis they usually measure output as some aggregate of national accounts in which housing and government sectors are often excluded due to their limited character of market pricing. Thus, Denison (1967) uses net national product at factor cost, Kendrick (1981) uses private gross domestic product at factor cost and Maddison (1987) uses gross domestic product at factor cost.

1.2 Factor shares.

The lack of consensus on the measure of output raises

[4]Deliberately we do not deal with the problem of the measurement of capital. First, because it has already been mentioned within growth accounting framework and, second, because it would drive us to the strong controversy that took place between the two Cambridges some decades ago and this issue goes beyond the scope of the paper.

another problem: since it serves as denominator for the estimate of factor weights, it influences the contribution to growth of each factor and the size of the residual. Thus, the weight of capital ranges from 23% in Denison's works to 39% in Helliwell, Sturm and Salou (1985)[5].

However, the problem concerning factor shares is deeper than merely one of definition of output and inputs. As pointed out by Nelson (1973), the crucial question is the difficulty to distinguish between alternative explanations of growth without strong a priori assumptions. Growth accounting exercises have not proceeded by trying to specify a particular production function and estimate its parameters but by building up an input index that measures the contribution of input quantity. The weights given to the inputs rest on assumptions about factor shares that cause two sorts of problems when trying to explain growth. One is quite obvious: since weights are calculated as factor shares in total output, then, their sum can not be greater than one and, therefore, in principle increasing returns to scale are not allowed. The second problem refers to the moment in which shares should be calculated because they change over time due to changes in factor ratios and technological progress. Moreover, if we want to attribute to inputs growth only what output growth would have been had technology not changed, then, we should use the time path of shares as they would have been had technology been constant

[5]It must be noticed that such a big difference is not only the result of the measurement of output but also of the measurement of capital. Helliwell, Sturm and Salou include consumer durables, raising, therefore, the capital share.

rather than actual shares. According to the method proposed by Solow,

$$\frac{dY*}{Y*} = \frac{dY}{Y} - \frac{dA}{A} = S_L\frac{dL}{L} + S_K\frac{dK}{K}, \qquad (1.8)$$

where Y, L, K, S_K and S_L have the usual meaning and A stands for the stock of knowledge. Then, the growth of output had technology not changed is

$$\log Y*(T) - \log Y*(0) = \int_0^T (S_L(t)\,\frac{d\log L(t)}{dt} + S_K(t)\,\frac{d\log K(t)}{dt})\,dt, \qquad (1.9)$$

Yet, factor shares should be S_i (K/L(t) A(0)) (i=L,K) instead of S_i (t).

1.3 The interdependence of factors

Following Denison's approach most growth accountants have added new determinants of growth to their studies: catching up, economies of scale, etc. Since those variables are interdependent, this methodology faces a problem of causality, as it has been emphasized by Nelson (1964 and 1973), Matthews (1969), Maddison (1987) and Fagerberg (1992). A classical source of interdependence is that between technology and capital. If technology is embodied in new capital goods, then, capital accumulation increases the impact of technical progress on growth. Many other interactions may exist as is the case for economies of scale and structural change, being difficult to identify the contribution of each individual factor to growth.

Indeed, Nelson (1973) shows that the relative attribution to different factors is not independent of the time period considered and, hence, it is not possible to know how much actual growth is attributable to capital or to labour or to technology. In other words, the percentage of growth explained by, let us say, technology depends on the evolution of capital and labour.

To see this, let us call λ_K and λ_L the instantaneous growth rates associated with the yearly growth rates of capital and labour, respectively, and λ_A the instantaneous rate of technological progress estimated by the Solow's method. If by attribution to a factor we mean output growth that would have occurred had only that factor changed, then, in the case of infinitesimal changes it is possible to calculate the attribution of each factor to total growth. But now consider a finite time period, let us say between 0 and T. We have

$$Y_T=A_T L_T^{S_L} K_T^{S_K}, \quad (1.10)$$

$$L_T=L_0 e^{\lambda_L T}, \quad (1.11)$$

$$K_T=K_0 e^{\lambda_K T} \quad (1.12)$$

and

$$A_T=A_0 e^{\lambda_A T}, \quad (1.13)$$

and, therefore, from (1.10), (1.11), (1.12) and (1.13)we can get

$$\frac{Y_T}{Y_0}-1=e^{(\lambda_L S_L+\lambda_K s_K+\lambda_A)T}-1, \quad (1.14)$$

and

$$\frac{A_T}{A_0}-1=e^{\lambda_A T}-1. \qquad (1.15)$$

From (1.15) and (1.16) we can obtain the following ratio

$$\frac{\text{Attribution to Technical Progress}}{\text{Total Growth}}=\frac{e^{\lambda_A T}-1}{e^{(\lambda_K s_K+\lambda_L s_L+\lambda_A)T}-1}.$$

This expression shows that the percentage of output growth generated by technical change depends on T. This is because the efficiency of one factor is sensitive to changes in other factors (here time is related to changes in factors). In other words, the percentage of the expansion of output explained by any particular factor is linked to the evolution of all inputs. As Nelson points out, *the problem is the same one that plagued the profession many years ago when it was trying to attribute total product between the different factors. We learnt that it was impossible. We could attribute at the margin. But there was no way to attribute shares of the total (Nelson 1973, p. 465).*

To sum up, the question of interdependence is a crucial one for growth accounting. If the interactions existing among variables are very strong, the decompositions of growth carried out in these studies as well as their conclusions may rest on a shaky ground.

1.4 The accounting identity and Kaldorian *stylised* facts

As we have already noted, growth accounting exercises showed that the percentage of growth explained by technical advance was surprisingly large. Yet, Thirlwall and McCombie (1994) have argued that this result far from being surprising is the logic consequence of a wrong methodology. Following Shaikh (1980), they argue that the estimates of the aggregate production function reflect merely an underlying accounting identity. To see this, let us define the value of total output as

$$Y_t \equiv w_t L_t + r_t K_t, \tag{1.16}$$

where Y, w, L, r, k, and t have the usual meanings. Taking logs and time derivatives we get

$$\frac{dY}{Y} \equiv \varphi_t + a_t \frac{dL}{L} + (1-a)\frac{dk}{k}, \qquad (1,17)$$

where

$$\varphi \equiv a_t \frac{dw}{w} + (1-a)\frac{dr}{r}, \tag{1.18}$$

being a labour's share in total output. Under the assumption that φ may be taken to approximate to a constante rate, integrating (1.17) with respect to time we obtain

$$Y_t \equiv A_o e^{\varphi t} L_t^{a} K_t^{(1-a)} \tag{1.19}$$

where A_0 is a constant. Comparing this equation with the Cobb-Douglas production function we see that technical progress (λ) is formally equivalent to φ, defined as above.

The so-called Kaldorian stylised facts of growth are the basic assumptions of the demonstration. This propositions are the following:

(i) factor shares are constant, and

(ii) the rental price of capital is constant.

Then, if the assumptions hold we get

$$\lambda=\varphi=a\left(\frac{dY}{Y}-\frac{dL}{L}\right). \tag{1.20}$$

Since a takes a value of about 0,75, it follows that technology must explain 75% of the increase of output per worker. If, in addition, labour growth is small, then, technical progress must explain a great deal of output growth. In other words, it is no surprising that using growth accounting methodology we find such a large residual.

2. SUPPLEMENTARY VARIABLES ADDITIONAL TO CAPITAL AND LABOUR

2.1 Externalities and economies of scale

Denison (1962) estimated that economies of scale contributed to growth by about 9% and a similar percentage is found in other studies (Kendrick (1981), Maddison (1987)). Indeed, he emphasized the relevance of this factor to explain the high growth rates experienced by Japan in comparison with other countries.

However, the introduction of economies of scale in growth accounting exercises raises a very important problem. If an increasing returns to scale (IRS) production function is postulated we run into trouble since it is not possible to find a set of prices to support a general competitive equilibrium. One way to get around this problem was already mentioned by Marshall and it consists of introducing IRS at the aggregate level but constant returns to scale (CRS) at the firm level. Each firm's performance affects all other firms production but none of them take this into account. Thus, economies of scale are formulated through externalities or spillovers. As it is well known, under this conditions the competitive equilibrium solution is not optimal, since the rate of investment falls below its social optimal level.

Romer (1987) argues that a large positive externality is necessary to explain the strong positive relation existing between the residual and the capital stock across countries and epochs. He also suggests that the social marginal productivity of this factor is about two or three times its private marginal productivity and, therefore, as we have mentioned above, the equilibrium level of investment falls short of its social optimal level. Yet, Jovanovic and Benhabib (1991) assert that under plausible assumptions there is no support for capital externalities. They show that different growth rates among countries are consistent with a common CARS production function and with a common stochastic process for technological change starting from different initial positions. They build a model of the type

$$Y_t = K_t^{\alpha} L_t^{1-\alpha} K_t^{\theta} A_t, \tag{2.1}$$

where log (A_t) follows an ARMA (1,2) process. The parameter θ represents the external effect from K. It is important to notice that the individual firm ignores the presence of K^{θ} in its production function, so the competitive solution is permitted. Looking at the postwar US data, they find that θ is not significantly different from zero.

However, to test for externalities and economies of scale at a high level of aggregation may cause serious mistakes, since they may mask each other. Caballero and Lyons (1989 a and b) have emphasized this point using a model in which total factor productivity is linked to other firms production (externalities) and to technological progress, allowing for possible increasing returns to scale. Then, the production function of the representative firm is

$$Y = L^{\alpha}K^{\beta}EV, \tag{2.2}$$

where L, K and Y have their usual meaning, E stands for an externalities index and V is a technology index. Taking logs and derivatives with respect to time we get

$$\frac{dy}{y} = \alpha\frac{dL}{L} + \beta\frac{dK}{K} + \frac{dE}{E} + \frac{dV}{V} \; . \tag{2.3}$$

Under the assumption that firms face a downward slope demand with a price elasticity η, if we maximize the profit function with regard to capital and labour, taking into account (2.2), we get

$$\alpha = \frac{wL}{pY(1+\frac{1}{\eta})} \tag{2.4}$$

and

$$\beta = \frac{rK}{py(1+\frac{1}{\eta})}. \tag{2.5}$$

where p is the value added price, w refers to wage and r stands for the price of capital services. Substitution of (2.4) and (2.5) into (2.3) yields

$$\frac{dY}{Y} = \frac{wL}{pY(1+\frac{1}{\eta})}\frac{dL}{L} + \frac{rK}{pY(1+\frac{1}{\eta})}\frac{dK}{K} + \frac{dE}{E} + \frac{dV}{V}. \tag{2.6}$$

For convenience and without any loss of generality we can consider the case where dL/L = dK/K = dX/X. Then, we can rewrite (2.6)as

$$\frac{dY}{Y} = \frac{wL + rK}{pY(1+\frac{1}{\eta})}\frac{dX}{X} + \frac{dE}{E} + \frac{dV}{V}. \tag{2.7}$$

Therefore, the decomposition of growth carried out by Caballero and Lyons includes Solow's decomposition as a special case where (wL+rK)/(pY) = 1, constant returns to scale, $(1+1/\eta) = 1$, perfect competition, and E = 0, no externalities.

To see the problems stemming from working at an aggregate level let us define the growth rate of the externalities received by the firm as

$$\frac{dE_{ij}}{E} = a_i\frac{dY_i}{Y_i} + b\frac{dY}{Y}, \qquad j=1..n, \quad i=1..m \tag{2.8}$$

where subscript j refers to the firm and subscript i refers to he sector. Thus, the firm j benefits from its sector externalities and from other sectors externalities. Substitution of (2.8) into

(2.7) yields

$$\frac{dY_{ij}}{Y_{ij}} = \gamma_i \frac{dX_{ij}}{X_{ij}} + a_i \frac{dY_i}{Y_i} + b \frac{dY}{Y} + \frac{dV}{V}, \tag{2.9}$$

where γ_i measures the ecinomies of scale of sector i. Equation (2.9) says that the firms benefits from possible economies of scale (γ_i), from the production of firms belonging to its sector (a_i), from other sectors output (b) and from technical progress. The problems to estimate the parameters of (2.9) arise when one wants to perform the regression at a higher level of aggregation. Assuming that the production shares are equal to the input shares, if we multiply both sides of (2.9) by δ_j, the share of

firm j in the output of sector i and integrate over j, we get

$$\frac{dY_i}{Y_i} = \gamma_i \frac{dX_i}{X_i} + a_i \frac{dY_i}{Y_i} + b \frac{dY}{Y} + \frac{dV}{V}, \tag{2.10}$$

and rearranging terms

$$\frac{dY_i}{Y_i} = \frac{\gamma}{1-a_i} \frac{dX_i}{X_i} + \frac{b}{1-a_i} \frac{dy}{Y} + \frac{1}{1-a_i} \frac{dV}{V}. \tag{2.11}$$

Therefore, the estimate of the parameter relating inputs to output will be biased, as well as those referring to the output of other sectors and technology. The higher is the aggregation level the larger is the bias. For example, when inputs raise they generate two effects on the output of the sector, a direct one derived from the use of more inputs and an indirect one derived from the intra-sector externalities caused by the increase in the output of firms. Yet, we attribute to inputs the total output growth such as to account for possible economies of scale what really should be accounted for intra-sector externalities. Additionally, in this example it is easy to see the problems mentioned above stemming from the interdependence of factors. When inputs raise so does output but we can no attribute total output growth to the increase in inputs because externalities contribute to output growth. But, in fact, if externalities come into play it is because inputs have previously increased, so, its contribution is not independent from the evolution of inputs.

To sum up, in order to test for externalities and economies of scale is more convenable to work at a low aggregation level. Caballero and Lyons found that if inputs increased 100% in an individual sector of US manufactures, the output only raised by 80%, while if all sectors raised their inputs by 100%, the output increased 130%. In other words, they found decreasing returns to scale at a sectoral level and increasing returns at a higher aggregation level, confirming, according to them, the presence of externalities in US manufactures. Yet, as pointed out by Amable and Guellec (1992), it is also possible to explain this result as a consequence of Keynesian mechanisms: changes in the aggregate demand and in the inputs utilization rate.

2.1 The catch-up bonus

The addition of a catch-up variable is a common practice in growth accounting studies, playing an important role in Denison (1962, 1967), Helliwell, Sturm and Salou (1985) and Maddison (1987).

Firs of all, it is important to stress the difference existing between the catching up argument and the neoclassical case of transitional dynamics. Both predict convergence across countries but due to different reasons. In the neoclassical theory of growth convergence occurs because capital productivity is higher in less developed countries than in industrialized countries while catching up approach explains convergence as a result of technology transfer from rich to poor countries. In both cases GDP per capita is supposed to be negatively correlated with growth rates but while in empirical works based on the neoclassical theory it serves as a proxy for capital-labour ratio, studies on catching up use it as a proxy for technological level.

The catch-up argument was developed by economic historians such as Gerschenkron (1962), Maddison (1979) and Abramovitz (1986). In a celebrated article, Baumol (1986) tested for catch-up across a sample of sixteen countries during the period 1870-1970. He found that a large part of differences in economic growth could be explained by means of a catch-up variable. In fact, this factor seemed to have such a high explanatory power as to make growth irrespective to the level of investment. As Baumol assessed, *whatever its behaviour, that nation was apparently fated to land close to its predestined position* (Baumol 1986 p. 1077). Moreover, not only among the market industrialized countries had convergence occurred but also among the centrally-planned economies.

De Long (1988) criticized strongly Baumol's work arguing that he used an ex-post sample of countries and therefore convergence was guaranteed. In other words, Baumol's regression was forced to show convergence because any nation relatively rich in 1870 that had not converged was excluded from the sample; for instance, Norway is included but not Spain. Furthermore, the estimation technique used by Baumol (OLS) was not satisfactory because of errors in measuring 1870 incomes. Such errors generate opposite errors in the magnitudes of growth, biasing the regression slope towards one. De Long carries out a regression using an ex-ante sample, countries that were likely to converge in 1870, and he finds that convergence had not occurred. A relative high income in 1870 was not a sufficient condition to exploit the potentials of catching up.

This idea was already present in most part of historians who initiated this work. They emphasized the important role played by economic, social and institutional factors in the catching up process. Abramovitz (1986) coined the concept social capabilities which is referred to the necessary conditions to assimilate modern technology. Following an approach influenced by Schumpeter, Justman and Tebal (1991) argue that a structural change in the economy is necessary in order to generate and assimilate technology and this change is not guaranteed by the market. Quite to the contrary, structural change is conditioned to experience, technological capabilities, specific infrastructure, an adequate supply of entrepreneurs and a large and sophisticated local market. To some extent, a country may enter a vicious circle, since technological progress is related to new capabilities and these are related to functioning routine. This last argument was introduced in the literature by Young (1928) and it refers to some kind of dynamic economies of scale. According to him, both, the division of labour and the extension of the market are interdependent. This means that present growth, related to a market enlargement, generates a greater division of labour, which raise its productivity, thus, creating new opportunities to extend the market. Some years later Myrdal (1957) following this idea coined the concept *cumulative causation*, according to which, success brings success and failure brings failure. Technological innovation and diffusion depends positively on the development level of the country and on its rate of growth. Therefore, convergence is far from being guaranteed.

The difficulties to model social capabilities explain the scarcity of attempts to test them. Additionally, one runs the risk of misunderstanding the results. De Long himself finds that, according to statistical tests, being or not being a protestant country is crucial for economic growth. Obviously he takes this result only as a rough demonstration of the relevance of social conditions. However, most studies tackle the problem by using education and investment as proxies for human capital and efforts to close the gap, respectively[6]. Generally speaking, both variables seem to have a significant influence on growth,

[6]See Cornwall (1976), Barro (1989) and Lindbeck (1983).

although it must be noted that they are highly correlated to each other.

A very different theoretical framework has been followed by the so called "technological gap approach." According to it, technology must be introduced in the model so as to permit not only convergence but also divergence. Following Schumpeter, growth is regarded as the result of two conflicting forces, both of them related to technology. On one hand, innovation, which tends to increase the differences in income per head across countries. On the other hand, imitation, which tends to close the income gap. Therefore, an innovation variable should be included in the models explaining growth. Fagerberg (1991) builds a model including potential for imitation, efforts to close the gap and innovation activity as explanatory variables. It explains a large part of the differences in growth among the sample of countries, although innovation activity (proxied by patents) does not seem to affect growth for the OECD area after 1973 and for the medium sized developed countries included in the sample it has not any effect all over the period. Similar models have been developed by Verspagen (1991) and Amable (1993).

However, most of these studies test for convergence at a high level of aggregation and, as noted by Dollar and Wolf (1988), this may be inappropriate. A regression restricted to GDP level may explain convergence as the result of catch-up while the true explanation may be something else; for instance, structural change[7]. Besides, the potential for catching up may vary across sectors since they have different rates of technical progress. Furthermore, if the diffusion of technology is related to trade it may follow different patterns across sectors since their degree of international tradability differs. Dowrick and Gemmel (1991) carried out a study across a sample of countries during the period 1960-1985 and they did not find any evidence for catching up in agriculture while it existed in non agricultural sectors. Hansson and Henrekson (1994) suggest that in the OECD area during the period 1979-1985, catch-up only occurred for non tradables because the diffusion of technology in tradables was almost depleted in the early 1970s.

Another important nuance has been pointed out by Dowrick and Nguyen (1989) and Hansson and Herekson (1994). They assert that there is a crucial difference between convergence in income per capita or labour productivity and any tendency for catching up in levels of total factor productivity (TFP). Thus, in order to test for catching up, Dowrick and Nguyen use a regression of the form

$$q_{it}= \gamma k_{it}+ \beta l_{it}-\lambda LnY*_{i,t-1}, \qquad (2.12)$$

where q ,k and l are, respectively, the rates of growth of output,

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[7]If the composition of output changes as it grows and branches growing in relative terms face a relative low productivity growth, then, present growth implies a future slowdown. In this case, convergence occurs thanks to this composition effect and not to catching up. (See next section).

capital and labour; Y* is the ratio of labour productivity in country i to labour productivity in the leader country and subscripts i and t refer to country and time, respectively. The results support catching up in the OECD area as well as in other countries, exception made of nations with a low investment ratio or high growing populations.

We can conclude this section by saying that catching up is not only a controversial topic but also a very important one. If it exists, it must be taken into account when comparing across countries the effects of economic policies on growth.

2.3 Structural Change

Structural change has accompanied economic growth in all countries. It is well known that some sectors and branches have increased their share in national output while others have experienced a relative decline. This process is the result both from changes in demand and from the evolution of productivity.

The different income elasticities for particular products tend to raise the share of some sectors and branches. Other things equal, structural change would have no effect upon growth. Yet, since the productivity of labour varies across sectors, changes in the sectoral composition of employment have deep consequences on growth. Historically, agriculture has been a low-productivity sector in relation to industry. Therefore, the flow of workers from the former to the latter has fostered growth. Subsequently, the increase in income occurred during the last decades together with the high income elasticity of services have diverted resources to this sector, hindering growth given its low productivity in comparison with industry.

As we mentioned in the previous section, this composition effect may to some extent explain why growth rates differ across countries, allowing, in principle, for both, convergence and divergence. Additionally, we must stress a crucial implication of this effect: it questions the validity of the traditional one sector models. To understand the forces governing growth may be inappropriate to rely on models that really only describe the path followed by one sector. If different sectors follow different paths and growth implies structural change, then, the growth path followed by the economy as a whole is not unique. To take this into account would help us to understand why in some periods and/or countries economic growth speeds up while in others a slowdown occurs.

The structural change effect is present in most growth accounting exercises. It is usually measured by calculating the presumed increase in output had not employment structure changed[8]. In other words, first we compute the growth of output per worker in each sector, then, using this figures we calculate the sectoral output growth would have occurred had employment distribution

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[8]See, for example, Denison (1967), Kendrick (1981) or Maddison (1987).

among sectors been constant, and, finally, we estimate the total output growth would have been had sectoral output grown at the previously computed rate and not at its actual rate. The difference between these two figures is supposed to be due to the structural change effect, which can be either positive or negative.

Some other explanatory variables, like foreign trade effect, costs of governmental regulation or discovery of natural resources, have been included in growth accounting exercises. However, they neither play an important role nor are present in all works. Hence, we shall not deal with them.

3. TECHNOLOGY

In Solow's model technology is assumed to grow at a constant exogenous rate and to be a free good from which any country can benefit. This approach was criticized because it does not take into account the relation existing between capital accumulation and technology. Investment in new machines is a necessary condition for technical progress to take place since technology is usually embodied in capital goods. However, Phelps (1962) showed that the introduction of embodied technical progress in Solow's model did not change its main characteristics: the steady state growth depends on the total rate of technical progress but it is independent of the fraction of embodiment of technology. This is not the case for the speed of adjustment, which does depend on the fraction of embodied progress. Therefore, to distinguish between embodied and disembodied technical progress seems to be irrelevant when dealing with long run issues but it is important when studying short run dynamics.

Endogenous versus exogenous productivity growth

Indeed, a radical departure from Solow's model forced to drop at least one of its two main assumptions about technology: its "public" character and its exogenous character. This is what Kaldor and Mirlees (1962), Kaldor (1957) and Arrow (1962) did. They tried to endogenize technical progress by relating productivity to experience.

In an attempt to explain the low growth rates of the United Kingdom in comparison to other countries, Kaldor (1966) introduced some ideas in the literature of growth, which eventually became to be known as Kaldor's laws. The first of them asserts that the higher is the rate of growth of industry the higher is the rate of growth of the whole economy. It is important to note that this relation is not due to the large weight of this sector in total output but to the fact that the growth of industry induces other sectors to grow, so industry generates some kind of externalities, which do not exist from, let us say, services to the rest of the economy. Kaldor tested GNP growth on manufactures growth using a sample of twelve developed countries over the period 1952-1964 and he found a value of the parameter of 0,614, i.e. an increase in manufactures generated a more than proportionally to its weight increase in total output. This relation was rejected for agriculture or mining[9]. Therefore, conversely to the traditional approach, the first of Kaldor's laws showed that it is not irrelevant where growth takes place.

The second law was originally introduced in the literature by Verdoorn (1949). Leaving Solow's approach, technical progress is to a certain extent considered a consequence of growth itself so as to exist a cumulative process: growth generates future growth. According to Kaldor, knowledge increases as output raises because of a learning by doing process, which role had already been confirmed in some learning function studies at a firm level (Alchian (1963), Hirsh(1952) and Rapping (1965)). This second law was tested among others by Verdoorn (1949), Kaldor (1966), Kennedy (1971), Cripps and Tarling (1973) and Cornwall (1976), mainly by using a regression of the form

$$\frac{dp}{p} = a + b\frac{dy}{y} \tag{3.1}$$

where dp/p stands for the rate of growth of productivity and dy/y is the rate of growth of output. In all of these works the coefficient linking production to productivity was found significant and ranking between zero and one, thus, supporting

[9]The law was also supported in subsequent studies. See, for example, Cripps and Tarling (1973) or Thirlwall (1980).

Kaldor-Verdoorn's law and avoiding explosive paths[10].

However, the law was severely criticised because of two main problems. The first one refers to the instability of the value of the parameter *b* across countries and over time. Rowthorn, using a different specification, (1975) found that if Japan was excluded from the sample in the mentioned works *b* was not statistically different from zero. Additionally, its value turned out to be very sensitive to the sample period; see, for example, Boyer and Petit (1891). The second problems deals with the direction of causality. According to Salter (1960), it is an autonomous increase in productivity that causes the output growth rather than the opposite case. Kaldor himself argued that the fact that productivity growth in a particular industry varies across countries in the same period supports the idea that it depends on the activity level of the country, reinforcing the causality from output growth to productivity growth. Some empirical studies have confirmed Kaldor's opinion[11].

As pointed out by Boyer and Petit (1981), the Kaldor-Verdoorn's law seems the reduced form of a structural equation,

[10]If the coefficient b is greater than one the economy will follow a explosive path. As output grows in period t it generates a new amount of knowledge which will drive output to grow in t+1 at a higher rate than in t. Therefore, the rate of growth will tend to infinity, which does not seem to be a very realistic path.

[11]See Parikh (1978) and McCombie and de Ridder (1983). It is also interesting to mention the study carried out by Griliches (1957) about the diffusion of the hybrid corn in the US. He concludes that an increase in demand implies a greater diffusion of new technology, which, to some extent, could explain Kaldor-Verdoon's Law.

which needs to be made explicit. An increase in labour productivity as output raises may be the consequence of an increase in capital, so no total factor productivity effect occurs. Bearing in mind this remark, Michl (1985) regressed the increase in labour productivity on output growth and capital growth, adding a variable for catching up. He found that all three were significative, so output growth had a separate effect on labour productivity. Another interesting result was that the intercept was not significatively different from zero, which means that no autonomous technological progress occurred.

An important implication of Kaldor's approach was the role given to demand, absent in the traditional approach. As demand increases (Kaldor himself stressed the relevance of exports as a part of total demand) it affects positively not only output but also productivity. Parikh (1978) suggested a four equations model in which productivity depends on growth, which, in turn, depends on exports. According to him, the results confirmed the idea that growth is not labour constrained, as it is in the neoclassical approach, but exports constrained[12].

Recently, within the framework of endogenous growth literature, some models conceiving knowledge as a by-product of economic activity have been developed. See, for example, Grossman and Helpman (1990), Romer (1986) and Lucas (1988). Despite of all, this view of technical progress has in common with Solow's model

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[12]See Thirlwall and McCombie (1994) for an exposition of balance of payment constraint growth models.

the idea that nothing can be done by the firm to increase its level of technology. In Solow's model, firms just wait for an increase in its technical level, which occurs periodically and at the same rate. In Kaldor-Verdoorn's approach technical progress is in fact a by-product of growth. When output increases every industry and firm can in principle benefit from this side effect but no resources are expressly devoted to make better the techniques in use.

Research and development investment

Yet, we have seen when we dealt with catching up that the free technology diffusion assumed in Solow's model is far from being guaranteed. Therefore, if there is some degree of appropiability of technology, there is no reason to expect firms not to devote resources to increase it. In fact, the main conclusion emerging from studies relating R&D and productivity is that both variables are positively related[13], although, as in other topics on growth accounting, we face some methodological problems when trying to estimate the contribution of R&D to growth. In this sense, we have already noted that the definition of final output is crucial. Griliches (1979) has pointed out that one of the main obstacles to measure the contribution of R&D to growth is the fact that much of it is performed in industries whose product is badly measured, like defense or health. The problem is more complex with new and improved products sold directly to consumers, since advances in quality are not included

[13]For a survey see Griliches (1991).

in price indices. He mentions the case of computers whose "real price" fell by about 20% in the seventies. Since this decline was not reflected in price indices, the estimates of output and productivity growth were seriously biased.

The special feature that distinguishes technology from other inputs is its non rival character: its use by one firm in no way limits its use by other firms. This fact makes difficult for firms to appropriate technology, generating two opposite forces for its increase. If appropriability is too high, there may be redundant resources devoted to R&D and it is more expensive for the firm to conduct R&D investment for it only counts with its own technology stock. Therefore appropriability hinders R&D investment. But, on the other hand, if appropriability is too low, firms may have no incentives to invest because of *free rider* problems. However, as pointed out by Rosenberg (1974) and Nelson (1982), the trade off between incentives (high appropiability) and spillovers (free technological diffusion) may be overstated. They argue that in order to benefit from spillovers is necessary to invest in R&D. Hence, spillovers may incentive rather than disincentive R&D investment. Mansfield, Schmartz and Wagner (1981) found that for US electronics, machinery and drugs industry there is a clear trade off between imitation time and imitation cost. They also found that patent system only was effective as a protection mechanism for a 25% of patented inventions. Therefore, the study support the idea that spillovers and own R&D investment are, to some extent, complementary.

To combine R&D expenditures with spillovers rises the possibilities to get endogenous growth. As firms invest in R&D, they increase the stock of knowledge, which, in turn and thanks to spillovers, reduces the cost of investment in R&D. This is the approach followed by Grossman and Helpman (1989a,b and 1991). In these models R&D has a public component (spillovers) as well as a private component. While the latter fosters R&D projects, the former facilitates subsequent research. However, sustained growth is guaranteed in these models because there are constant returns to investing to R&D. Englander, Evenson and Hanazaki (1988) follow a different approach. Using a Schumpeterian framework, in the sense that opportunities to innovate are not constant over time, they relate R&D potency to the stock and growth of knowledge and techniques available to conduct R&D. If this stock is fixed, R&D will face decreasing returns but if new inventions are developed, the stock increases and invention potential is replenished. In other words, if the rate of exhaustion of the stock exceeds its rate of replenishment, potency is said to decline. In their empirical research they use ratios of inventions per unit of R&D expenditure and per unit of R&D personnel. They find that the efficiency of R&D is not constant over time. Moreover, they also find strong divergences across sectors, which, according to them, could explain the uneven evolution of inflation in manufacturing and service industries. Since other studies (Schankerman and Pakes (1985)) have argued that the average quality of patents has increased over time and hence it is not possible to assert that R&D potency has declined, they proceed to estimate the effect of R&D on total factor productivity. First they calculate the flows of technology across industries by computing the proportion of patent inventions originated in one industry but used in others. Then, they estimate the stock of technology in each industry by accumulating those flows and assuming a constant obsolescence rate. Finally, they analyze the relation between the TFP and the stock of R&D within each industry. The conclusions do not differ much from those previously mentioned.

Nevertheless, if spillovers are important, the private rate of return of R&D investment will differ from its social rate of return and, therefore, its efficiency should be measured taking into account the impact on the whole economy and not only on the firm or sector conducting the investment. In this sense, two main approaches can be found in the literature. The so called technology flow approach uses technology flow matrices based on patent data or on input-output coefficients to measure spillovers. The stock of borrowed R&D of an industry is computed as the addition of R&D stock of other industries weighted by the purchases of materials and capital from these industries. Subsequently, TFP of the industry is regressed on its own R&D stock and on the borrowed R&D stock. Using this framework Terleckyj (1974), Rosenberg and Frischtak (1984) and Jaffe (1989) found a positive relation between TFP and borrowed R&D stock.

The second approach to measure spillovers is the cost function approach. The idea is to formulate a cost function, and in some cases also an inverse demand function, which depends on output, relative price factors and quasi-fixed inputs such as physical capital, own R&D capital and other firms and industries

R&D capital. Within this framework several studies (Bernstein (1988), Bernstein and Nadiri (1988, 1989 and 1991)) found significant spillover effects in some industries, creating a dichotomy between the private and social rates of return of R&D investment. However, following Griliches (1991), it must be stressed the crucial difference exixting between monetary and technological spillovers. The first type derives from the fact that prices do not capture completely advances in the quality of goods, so firms benefit from other firms R&D by buying inputs at a price below its marginal productivity. On the contrary, the main feature of technological spillovers, the only true spillovers according to Griliches, is that they transmit knowledge, which is used by other firms to expand the technological frontier. Monetary spilllovers stem from trade relations while pure spillovers are the result of technical relations.

In conclusion, despite the problems of measurement there is a consensus among researchers about the important role played by R&D investment as an engine of economic growth and about the existence of technological spillovers. Additionally, from the empirical research some other conclusions can be extracted. First, the efficiency of R&D investment seems to vary across industries. Secondly, not all industries have the same ability to generate spillovers. Thirdly, not all industries have the same capacity to absorb spillovers. Fourthly, given the existing dichotomy between the social and private rate of return of R&D investment, there is a room for public intervention in the technology field[14], but its efficiency will depend on the structure of the economy since as we have noted not all industries have the same capacity to absorb and propagate technology.

4. CONCLUDING REMARKS

One of the major points of this paper is to stress the lack of consensus defining many fields of growth accounting. Its methodology has been severely criticized and every single factor added to the group of explanatory variables generates a strong debate. But, could it be other way?. An account of growth is such a huge task that it is unavoidable not to be a controversial topic. In fact, many fields of economics underlie these studies.

First, it is necessary to deal with the production function and we all know how problematic this issue is. Besides, the income distribution and the set of prices will depend upon the form of this function. Another question that must be resolved is if long run growth in addition to the supply side is also related to the demand side and, if so, how?. These are only a few examples of the problems faced by growth accounting but they serve to illustrate the controversial nature of the topic.

Therefore, since growth accounting seems to rest on a weak basis, we may wonder if it is useful to carry out such tedious

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[14]Not only promoting innovation but also promoting diffusion. In this sense, see, for example, Geroski (1991).

exercises. We think it is useful. Growth accounting has fruitfully influenced our understanding of economic growth, although we must emphasize that it does not explain it. The pioneering studies showed the importance of the residual, which as it is said in growth accounting literature measures the size of our ignorance. A very large part of growth needs to be explained. The aggregate production function, providing it exists, does not seem to be as simple as that of Solow's model but many other factors should be taken into account. Moreover, as growth accounting studies suggest, these factors are not necessarily the same for all countries and some ad-hoc factors must be included. They also suggest that it is important to consider social capabilities and the institutional framework in order to explain growth.

However, the persisting large share of the residual has forced to deal with the most powerful explanatory variable, technology, whose role has been emphasized in last years and which can shed some light on our knowledge of economic growth. In this sense, let us conclude by stressing two basic ideas which we think can be very useful to understand long run growth. The first of them is that the creation and diffusion of knowledge seems to be very sensitive to the economic structure of the country (not only the composition of output but also the degree of economic and social development). This being true, the traditional approach of one sector may be not very accurate to specify the determinants of growth. Moreover, since the economic structure is not constant, the structural change would help us to understand why growth rates differ across countries and epochs. The second idea refers to the role of demand as a determinant of growth. All growth accounting exercises have been based on a supply approach, according to which the increase in output is constrained by the increase in inputs. Yet, most of modern economies seem not to be supply constrained. Quite to the contrary, during long periods of time there is not full employment of resources. This being so, industrial economies seems to be demand constrained rather than supply constrained, which forces to deal with the role of demand in order to explain growth. As pointed out by Kaldor, an increase in demand may induce not only to a greater utilization of resources but also to an improvement of productivity. In other words, if demand affects the level of knowledge, its role is of the utmost importance to explain growth.

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1) Lunes 26 de febrero (11,30 h.): EL CIUDADANO DE LA UNION Y EL COMITE ECONOMICO Y SOCIAL (Candelas Sánchez, Miembro del Comité Económico y Social de la Unión Europea).

2) Lunes 26 de febrero (12,30 h.): LA NUEVA POLITICA MEDITERRANEA DE LA UNION EUROPEA (Josep M. Jordán Galduf, Catedrático de Economía Aplicada, Universidad de Valencia)

3) Lunes 26 de febrero 17 h: COMPETITIVIDAD DE LA EMPRESA ESPAÑOLA EN EL MERCADO UNICO (Vicente Donoso, Catedrático de Economía Aplicada, UCM)

4) Lunes 26 de febrero 18 h.: AMERICA LATINA Y LA POLITICA EXTERIOR EUROPEA (José A. Nieto, Profesor Titular de Economía Aplicada, UCM). (y a las 19 h.) SEMINARIO: LAS POLITICAS EXTERIOR DE LA UE (José A. Nieto y Eugenio Tardón, UCM)

5) Lunes 4 de marzo 11,30 h.: EL FUTURO DE LA SEGURIDAD SOCIAL EN ESPAÑA (María Teresa López, Profesora Titular de Economía Aplicada, UCM)

6) Lunes 4 de marzo 12,30 h.: PERSPECTIVAS DEL SECTOR TURISTICO EN LA UNION EUROPEA (Agueda Esteban, Profesora Titular de Comercialización e Investigación de Mercados, UCM)

7) Lunes 4 de marzo 17 h.: IMPLICACIONES INTERNAS Y EXTERNAS DE LA POLITICA AGRICOLA COMUN (Rafael Bonete, Profesor Titular de Economía, Universidad de Salamanca).

8) SEMINARIO SOBRE EL PRESUPUESTO Y LAS POLITICAS COMUNES (Coordinado por Alfonso Utrilla y Eugenio Tardón, UCM).

9) Lunes 11 de marzo 11,30 h.: LA POLITICA DE INFORMACION Y DOCUMENTACION DE LA UNION EUROPEA (Pepa Michel, Representación en España de la Comisión Europea).

10) Lunes 11 de marzo 12,30 h.: CONVERGENCIA Y PERSPECTIVAS DE LA ECONOMIA EUROPEA (Carlos Berzosa, Decano de la Facultad de Ciencias Económicas y Empresariales, UCM).

11) Lunes 11 de marzo 18 h.: FEDERALISMO FISCAL Y POLITICA FISCAL EN EUROPA (Alfonso Utrilla, Profesor Titular de Economía Aplicada, UCM).

12) SEMINARIO SOBRE EL SECTOR PUBLICO DE LOS ESTADOS MIEMBROS (Coordinado por Alfonso Utrilla y Eugenio Tardón, UCM).