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**A Quasi-Cobb Douglas Production Function with Sectoral
Progress: Theory and Application to the New Economy**

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Summary: A new approach for analyzing technological progress is presented in the context of a quasi-Cobb-Douglas production function which offers within a simple and consistent equation interesting options for identifying different types of technological progress. In particular the approach suggested allows us to shed new light on the New Economy debate and to indeed focus more adequately on process innovation dynamics – this includes a distinction between Harrod neutrality and Solow neutrality of technological progress.

Zusammenfassung: Präsentiert wird ein neuer Ansatz zur Analyse des technischen Fortschritts im Kontext mit einer Quasi-Cobb-Douglas-Produktionsfunktion die einen konsistenten und einfachen Ansatz bietet, um verschiedene Arten von technischem Fortschritt zu unterscheiden. In der Tat erlaubt der neue Ansatz eine genauere Ausleuchtung einiger wichtiger Aspekte der New Economy Debatte bzw. eine angemessene Untersuchung von Prozessinnovationen – mit Unterscheidung von Solow-neutralem Fortschritt und Harrod-neutralem Fortschritt auch in empirischen Untersuchungen

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1. Introduction

Explaining economic growth has been a standard challenge for economists. Growth rates differ across countries and time so that it is important to understand which elements determine output growth. For example, in the context of EU integration, which raises the issue of economic convergence and the question as to which mechanisms are relevant for relatively backward and leading countries, trade and technological specialization play an important role in Europe as shown in recent empirical analysis (JUNGMITTAG, 2004). In a broader perspective one also would like to understand why there have been periods of growth acceleration or growth deceleration in various countries. The role of information and communication technology apparently has played an important role for faster growth in the US and some other OECD countries, including some eastern European countries (e.g. VAN ARK/PIATKOWSKI, 2004; OLINER/SICHEL, 2002). In the following essay, we will disregard the so-called new growth theory and rather focus on the more traditional neoclassical growth theory. However, we will show that adequate modification can be useful for better understanding technological progress of various types.

The standard neoclassical approach to growth is to assume that output in each firm is based on a production function with inputs such as labor, capital and knowledge. Aggregating across firms of a given sector gives a sectoral output function and further aggregating across sectors results in a macroeconomic production function. The aggregation of production functions can be quite cumbersome from an analytical point of view. From an economic perspective one faces the problem that factor shares should add up to unity. So in an economy which has only labor and capital as input the wage-income ratio plus the profit income ratio must add up to unity. With a linear-homogeneous production function – such as the Cobb-Douglas function $Y=K^{\beta}L^{\alpha}$ (Y is output, K capital and L labor, β and α are in the interval 0.1) – we indeed have the implication that $\alpha=1-\beta$ and that β is the income share of capital owners who obtain rK . Under profit maximization and competition r is the real interest rate which is equal to the marginal product of capital Y_K .

2. Aspects of Process Innovations and Market Dynamics

The Cobb-Douglas production function has been a useful workhorse in theoretical and empirical economic analysis, and this includes simple approaches to technological progress (i.e., a Harrod-neutral progress which is labor augmenting – see the parameter A and the following refined production function).

$$(1) Y = K^{\beta} [AL]^{1-\beta}$$

Alternatively, one might assume Solow neutral progress which is capital augmenting (see the parameter B as well as the new production function):

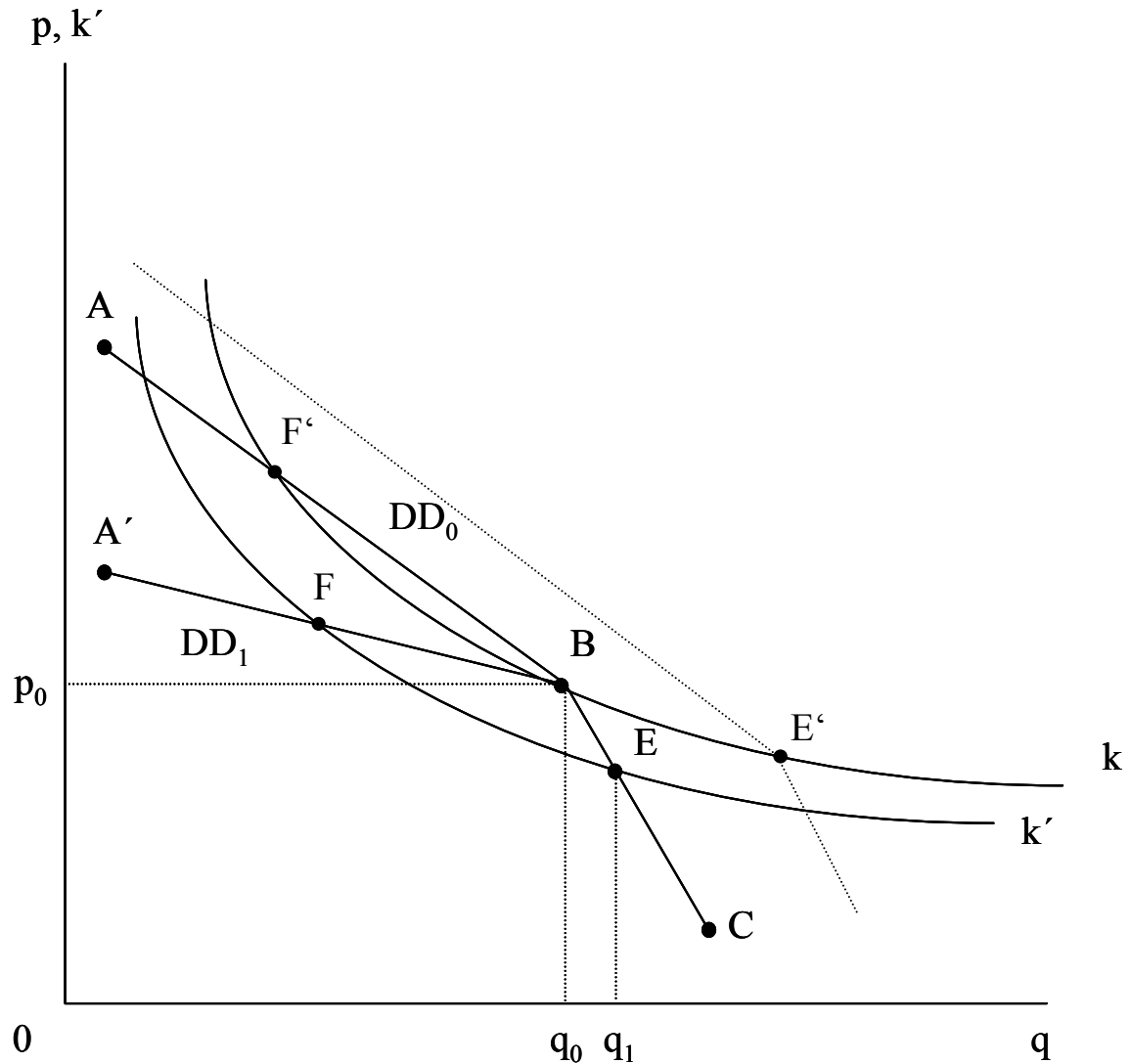
$$(2) Y = [BK]^{\beta} L^{1-\beta}$$

At first sight the (linear-homogeneous) Cobb-Douglas production function has a clear disadvantage since it does not allow for the identification of the nature of technological progress, e.g. Hicks neutral progress (K and L effectively are raised by equal percentages) vs. Harrod neutral vs. Solow neutral. From the perspective of analytical consistency the

advantage of the Cobb-Douglas function is that partial output elasticities add up to unity if we follow the standard restrictions imposed which are indeed consistent with competition in goods markets and factor markets. There is also a caveat related to the implicit assumption of full employment and the efficient use of input factors. In the late 1990s the opening up of telecommunications markets in the EU obviously has contributed to efficiency gains in the telecommunications sector. Among OECD countries, Germany has achieved the highest contribution of ICT-producing services to aggregate productivity growth (PILAT et al., 2002). This top result, however, might partly be reflected by previous strong X-inefficiencies in the former (state-owned) monopoly operator. Nevertheless, in a medium and long term perspective growth accounting can be quite useful.

With innovations and technological progress one might raise some objections against the traditional assumptions with respect to competition since a temporary deviation from a perfect competition model can be expected in economies with Schumpeterian dynamics. Moreover, the existence of research efforts might even imply falling average and marginal costs. However, we argue here that one may approximate the standard neoclassical textbook world through a specific oligopoly structure in all or some industries. We assume a setting with oligoplistic markets and a Hitch-Sweezy price setting where there is asymmetric oligopolistic interdependency. We thus introduce Schumpeterian innovation dynamics in the standard Hitch-Sweezy approach. Firms follow the innovation leader when the price is reduced which implies a relatively steep effective demand curve below the equilibrium price (see the arch BC). If the leader raises the price above the equilibrium price, other firms in the sector will not follow so that the demand curve is relatively elastic at high prices, that is we have a kinked demand curve (arch A'B; if there is consolidation in industry and hence tighter interdependency which causes some firms to follow the leader in price increase we have arch AB instead of AB'). In such a setup the intersection of the demand curve with the average cost curve (k) determines an output volume which is close to the neoclassical optimum characterized by the equality of price and marginal costs: the difference between q_1 and q_0 indeed is very small. Shifts in the demand curve will bring about a new equilibrium, but again the Schumpeterian equilibrium point and the neoclassical situation would not differ much. This rather radical approximation of reality basically implies that a world with oligopolistic Schumpeterian competition can be modelled on the basis of a rather simple macroeconomic production function.

Fig. 1: Schumpeterian Hitch-Sweezy Model of Oligopoly



How can a simple neoclassical growth accounting approach shed light on the issue of technological progress? We will suggest a modification of the traditional approach which allows us to get a better understanding of technological dynamics.

3. A Quasi-Linear Homogeneous Production Function and Technological Progress

While many countries obviously recorded a much higher technological progress – dubbed multifactor productivity or total factor productivity – in the 1990s than in the 1980s, it is unclear as to what the reasons behind this acceleration in technological progress really are. According to OECD (2003, p. 52; for basic methodology see SCARPETTA et al. 2000), there was an acceleration in Ireland, Finland, Norway, Denmark, Sweden, Australia, Canada, United States and New Zealand, but there was a deceleration in the 1990s in the

Netherlands, Austria, Belgium, Italy, Japan, France, Germany and Spain. A key factor for the acceleration of technological progress might be the increasing use of information and communication technology (ICT), but there could be other factors as well. Furthermore, there is indeed a broad debate about the potential dynamics of productivity, innovation and growth in the literature (see e.g. AUDRETSCH/WELFENS, 2002; BARFIELD/HEIDUK/WELFENS, 2003; WELFENS, 2003; WELFENS, 2005). In 2001 ICT capital accounted for roughly 30% of the capital stocks in certain sectors in OECD countries, the share of ICT capital in the private business sector reached an average of 11% (OECD, 2003). ICT capital accumulation might go along with considerable capital-saving progress in some sectors, but there also is labor saving progress in other sectors (WELFENS, 2003). Let us take a closer look at a simple Cobb Douglas function to see which analytical problem we are facing here (β is the output elasticity of capital, $1-\beta$ is the output elasticity of labor; B and A are parameters representing Solow neutral progress and Harrod neutral progress, respectively):

$$(3) Y = [BK]^\beta [AL]^{1-\beta}$$

Taking logarithms leads to

$$(4) \ln Y = \beta \ln B + \beta \ln K + (1-\beta) \ln A + (1-\beta) \ln L = \\ \beta \ln K + (1-\beta) \ln L + \{\beta \ln B + (1-\beta) \ln A\}$$

Based on this equation we can apply “growth accounting” in a simple way: the output is decomposed into capital, labor and a residual $R' := \{\beta \ln B + (1-\beta) \ln A\}$. Thus empirical analysis based on time series or panel data analysis will deliver estimated elasticities – that is the elasticity β and $(1-\beta)$ – plus a residual R' , where the latter cannot be split in a meaningful way. Indeed, the residual is a rather opaque variable. It is called total factor productivity but to which extent it is linked to capital or labor remains unclear which in turn leaves many ambiguities for policymakers and thus could lead to many pitfalls. One cannot rule out that during part of the sample period we have only Solow-type progress, while in a later period we have only Harrod neutral progress. The relative role of Solow-type progress and Harrod neutral progress in a given period naturally will determine the relative price of capital and labor, respectively; if the New Economy should be characterized by a relatively strong role of Solow-neutral progress a relative fall of the real interest rate could be expected.

However, one may indeed use a linear-homogeneous production function while identifying the nature of progress to some extent; the assumption will be made that Solow-type capital augmenting technological progress is associated only with the use of ICT capital. Moreover, we develop our approach in the context of an implicit two sector production function (with K' denoting ICT-capital and K'' non-ICT capital; overall input of capital is K and of labor is L) that the sectoral Solow progress factor depends on the “hybrid sectoral capital intensity” which is defined as K'/L . Thus we assume that sectoral Solow progress B in the sector using ICT capital depends on K'/L – the higher K'/L the higher is B and hence:

$$(5) Y = [B(K'/L)K']^\beta [K'']^{\beta''} [AL]^{1-\beta'-\beta''}$$

This production function basically says that output is higher, the higher the input of labor, ICT capital and non-ICT capital are and the higher the progress parameters A and B are, respectively – with B depending on the ratio of ICT capital to overall labor input. Once a steady state is reached B will be constant and thus this production function effectively is asymptotically a linear-homogeneous production function. The parameter $B(K'/L)$ basically says that the ICT sector is characterized by capital-saving technological progress which indeed is found in various cases, e.g. the case of computer chips (Moore’s law says

that computing power of a chip will double within 3 – or more recently 2 – years) or in the case of fibre optical cables. Taking logarithms and differentiating with respect to time (with g denoting growth rate and E' the elasticity of B with respect to K'/L), we get:

$$(6) \quad g_Y = \beta' [E' g_{K'/L} + g_{K'}] + \beta'' g_{K''/L} + (1 - \beta' - \beta'') g_A$$

Thus the growth rate of output is equal to the output elasticity of ICT capital per capita times $\beta'[E'+1]$ plus the weighted (see β'') growth rate of K''/L plus the growth rate of labor plus the weighted (weight is $1-\beta'-\beta''$) growth rate of Harrod neutral progress.

$$(7) \quad g_Y = \beta' [E'+1] g_{K'/L} + \beta'' g_{K''/L} + g_L + (1 - \beta' - \beta'') g_A$$

4. Implications for Empirical Analysis

The implication thus is that with respect to the sum of elasticities for K' , K'' and L empirical studies to be conducted should reveal that they do not add up to unity. Rather, they will exceed unity. In particular one should expect that the elasticity of output with respect to K'/L exceeds unity. In the approach presented one can indeed distinguish between Harrod neutral progress and Solow neutral progress. With the new specification suggested here we have an implicit endogenous growth approach. It still leaves open many issues, in particular we have no explanation for the Harrod progress rate which in an extended model might depend on such variables as the wage-interest ratio or the share of R&D in overall output.

We have developed a rather simple approach in which one can study different types of technological progress. Thus one may analyze a rather important unsolved issue of the 1990s, namely whether technological progress is both labor augmenting and capital augmenting. Indeed, at the bottom line we can identify the type of technological progress prevailing, and in empirical studies the choice of adequate subperiods can help to control for regime changes in technological progress. Moreover, one should apply such testing before embarking upon international panel data analyses.

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