

# Unwrapping Some Euro Area Growth Puzzles: Factor Substitution, Productivity and Unemployment<sup>\*,†</sup>

Rainer Klump  
(*Johann Wolfgang Goethe University*)

Peter McAdam and Alpo Willman  
(*Research Department, European Central Bank*)

Submitted to a Special Issue of the  
*Journal of Macroeconomics*  
“CES Production Functions: Theory, Empirics and Applications”

**Abstract:** In this paper, we estimate a long-run supply-side system incorporating a CES production function with time-varying factor-augmenting technical progress for the euro area over the period 1970-2005. We find that the elasticity of substitution lies below unity at 0.7, that labor-augmenting technical progress is dominant in the long-run while capital-augmenting technical progress plays an important role in the interim period. Importantly, we also find evidence of a structural break in the pattern of biased technical progress towards the end of the 1990s. Our results help to solve two puzzles in Europe’s recent growth experience which differ markedly from the US experience. The first is related to the effects of the IT boom in the 1990s on productivity growth in Europe. The second puzzle concerns the changes in the “Okun’s law” relationship, linking growth to the reduction of unemployment, which are observable in Europe since the late 1990s.

**Keywords:** CES Production Function, Elasticity of Substitution, Factor-Augmenting Technical Progress, IT Revolution, Okun’s Law, US, Euro Area.

**Total Word Count:** 9,194.

---

\* Correspondence: *Department of Economics, Johann Wolfgang Goethe University, Frankfurt am Main. Email: [klump@wiwi.uni-frankfurt.de](mailto:klump@wiwi.uni-frankfurt.de); Research Department, European Central Bank. Emails: [peter.mcadam@ecb.int](mailto:peter.mcadam@ecb.int), [alpo.willman@ecb.int](mailto:alpo.willman@ecb.int)*

† We thank participants at the Conference “A bright future at the age of 50 - The CES production function in the theory and empirics of economic growth” in Eltville, October 2006, and especially our discussant Chris Papageorgiou; the session “75<sup>th</sup> Anniversary of Hicks’ Introduction of the Elasticity of Substitution between Labor and Capital”, at the AEA in Chicago, January 2007, and especially our discussant Nils Gottfries; and to Uwe Hassler, Alberto Musso, Willi Semmler and Luca Zamparelli for helpful comments and discussions. The opinions expressed are not necessarily those of the ECB. McAdam is also an Honorary Reader at the University of Kent.

*Productivity is not everything, but in the long run it is almost everything.*

Paul Krugman (1994)

## **1. Introduction**

The economies of continental Europe, in particular those which in the late 1990s became members of the euro area, have attracted considerable interest because of the puzzling manner in which they eschewed standard, balanced-growth features. Examples of this include non-stationary factor income shares, fragile growth, stagnant labor productivity and intractably high unemployment. In this paper, however, we wish to draw special attention to two quite recent puzzles in euro area growth. The first relates to the effects of the IT boom in the 1990s on productivity growth, whilst the second concerns developments in the “Okun’s law” relationship linking growth to unemployment. Resolving and reconciling these puzzles through the lens of a supply-side system estimation is the purpose of this paper.

As is well known, the traditional workhorse of growth theory is the Cobb-Douglas production function whose elasticity of substitution is unity. This property meets the essential condition for a neoclassical steady state and accords with presumed stylized facts of long-term economic development: the approximate constancy of factor income shares during a steady increase in capital intensity and per-capita income. It also follows that the direction of technical change is irrelevant for income distribution. In contrast, non-stationarities of factor income distribution support the more general CES function and make biases of technical progress a central issue. In the CES world, a steady state with constant factor income shares is only possible, if exogenous technical progress is purely labor augmenting. In a series of influential articles Acemoglu (2002, 2003), however, suggested that while technical progress is strictly labor augmenting along the long-term balanced growth path, it may become capital-biased in periods of transition.

Accordingly, in our estimates for the euro area, we make use of a general CES production technology and model technical progress as factor-augmenting and time-varying. This allows us to capture underlying supply not only in a relatively data-driven manner but also to use the results for an in-depth diagnosis of some interesting patterns of growth. Putting a high emphasis on data consistency, we obtain robust results not only for the elasticity of substitution but also for the parameters and dynamics of technical change. We find for the euro area for the period 1970-2005 an aggregate elasticity of substitution below unity (about 0.7) and a pattern of factor-augmenting technical growth rates where labor-augmenting technical progress growth dominates in the long-run while capital-augmenting technical progress plays a significant role in the interim period. We also importantly find evidence for a structural break in this pattern of biased technical progress at the end of the 1990s with an upward shift in capital augmenting technical progress and a downward shift in labor augmenting progress.

Our results thus help solve two puzzles in Europe’s recent growth experience which differ markedly from the US experience. The first is related to the effects of the IT boom in the 1990s on productivity growth in Europe (Gordon, 2004). While in the US the IT revolution of the 1990s resulted in an increase in aggregate labor

productivity, we find a declining labor productivity in Europe for the same time period which even decelerated further in the most recent years. The second puzzle concerns developments in the “Okun’s law” relationship, linking growth to unemployment. While the US experienced high, but almost jobless growth, in Europe, contrary to public opinion, a much lower output growth led to a significant reduction in unemployment (Khemraj et. al., 2006). We suggest that both puzzles can be solved and reconciled in our supply side framework, if factor substitution, the specific pattern of biased technical progress and its possible shifts (i.e., flexible structural breaks) are taken into account.

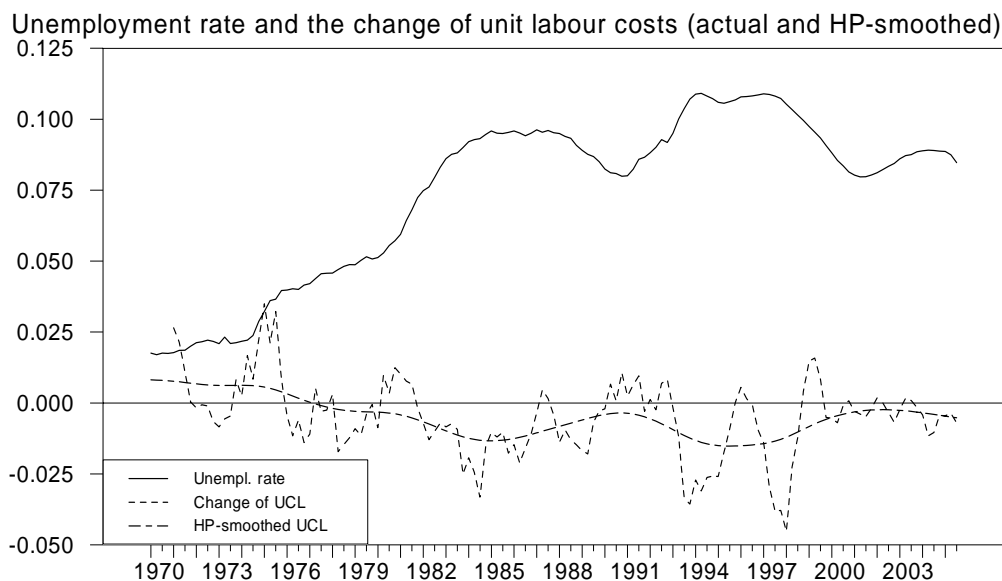
The paper is organized as follows. The next section offers background on the characteristics and puzzles of growth in the euro area during the last three decades, focusing on the non-stationary in factor incomes shares, the secular deceleration of labor productivity, the breakdown in “Okun’s Law” and the conjecture of a structural break in the late 1990s. Section 3 outlines our supply-side framework which is build around a “normalized” production function and supply side (de La Grandville, 1989; Klump and de La Grandville, 2000) with time-varying, factor-augmenting technical progress (Klump, McAdam and Willman, 2007). After touching upon the aggregate euro area data for 1970-2005 in section 4, section 5 presents our empirical results and relates them to our underlying growth diagnosis. In section 6 we conclude.

## **2. Growth in the Euro Area: Patterns and Puzzles**

### *2.1 Factor income shares, unemployment and factor substitution*

Compared to the US where labor income share remained relatively stable over decades (Klump, McAdam and Willman, 2007), the labor income shares in the countries that later formed the euro area have shown a high degree of volatility since the 1970s. Blanchard (1997) and Caballero and Hammour (1988) were among the first to pay attention to the fact that after a hump in the mid 1970’s the GDP-share of labor income has continuously decelerated in the euro area or, in difference form, after in early 1970’s real wage growth exceeding the growth rate of labor productivity it has, thereafter, quite persistently gone under productivity growth, i.e. unit labor costs have decreased (see Figure 1).

**Figure 1: Unemployment Rate and the Change of United Labor Costs in the Euro Area**



We see that after the first oil shock the real wage correction was quite modest and unable to eliminate the negative employment effects of the supply shocks of the 1970's. However, coupled with continued and strengthened downward adjustments in unit labor costs in early 1980's the growth of the unemployment rate leveled off in the mid 1980's and, thereafter, it has fluctuated around close to 10 % level.

Moreover, developments in the euro area fundamentally cast doubt on the Cobb-Douglas function as well as the CES function with Harrod-neutral technical progress, which are commonly used to model aggregate production, since these functions entail stationary factor income shares and zero factor biases. In contrast, pronounced trends in factor income distribution, visible in many countries, not only support the more general CES function but also, as we will explain, make possible biases in technical progress central issues.

Regarding factor substitutability, Caballero and Hammour (1998), Blanchard (1997) and Berthold et al. (2002) used models assuming purely labor-augmenting technical progress and a relatively high substitution elasticity (above unity in the long run, with short-run putty-clay characteristics). Consequently, for example, a cost-push shock with sticky real wages would lead at first to only a small decline in employment and an increase in the labor-income share. In the long run, however, labor is replaced over-proportionally by capital and, with rising capital intensity, the labor share will fall again. Besides being unable to explain persistent (continuous) decrease in the labor income share, critics of this explanation argued that Europe also experienced a decline in capital formation since the 1970's. Declining capital intensity, however, can cause a rise in the capital income share only if the substitution elasticity does not exceed unity, Rowthorn (1999).<sup>1</sup> Acemoglu (2002, 2003), moreover, assuming an elasticity below

<sup>1</sup> We can briefly mention some other contributions in this area. Bentolila and Saint-Paul (2003) introduced changes in the relative price of imported materials, in the skill mix, in union bargaining power or in current and expected adjustment costs as possible factors affecting the labour income share. Alcalá and Sancho (2000) find similar time profiles of European inflation and labour income share and suggest inflation as a proxy for uncertainty in explaining the mark-up. de Serres *et al.* (2000) studied the possible role of aggregation bias due to sectorally differentiated

unity, suggests oil crises, coupled with rigid labor markets induced persistent (albeit transient) capital-augmenting technical progress; attractive features of such a framework is that it coincidences asymptotically with the steady-state condition of purely labor-augmenting technical progress.

## 2.2 Labor productivity and the IT revolution

If European data did support a non-unitary elasticity, we would not only be in a position to better account for (non-stationary) factor income shares, but also to explain the puzzling behavior of average labor productivity growth in the euro area. Along a balanced growth path one would expect a constant growth of labor productivity at about, say, 2% per year. But what we find empirically in Table 1 is a decelerating time profile of average euro-area labor productivity which only in the middle of the sample period showed some stationarity. The most puzzling aspect is the last 10 years, when the growth of the average labor productivity is about half of that over the previous 15 year period. What makes this especially puzzling is that during the very same period in the US economy the average labor productivity has markedly accelerated. Many observers relate this productivity and growth boom in the US to the effects of the IT revolution (Schrader, 2000; Cohen et al., 2006). But then one wonders why the IT revolution should have been coupled in the euro area with a deceleration of labor productivity and output growth?

**Table 1: Euro Area/US Productivity Growth and Output Growth.**

	1971-1980	1981-1990	1991-1995	1996-2005
Euro Area				
Growth of Average Labor Productivity, %	2.9	1.8	1.8	0.9
Average per capita <sup>(1)</sup> Output Growth, %	2.5	1.5	1.2	1.1
US				
Growth of Average Labor Productivity, %	1.1	1.4	1.4	2.1
Average per capita <sup>(1)</sup> Output Growth, %	0.9	1.6	1.4	2.1

Source: Authors' own calculations from AWM database, and from NIPA sources.

Notes: (1) In terms of labor force.

A solution to this puzzle should start with the observation that purely labor-augmenting technical change is not a uniform pattern of development across all countries (Acemoglu, 2003, Marquetti, 2003). And the continuing decline in the

---

wage shares and conclude that in many countries aggregation bias explains at least part of the decline in labour income share.

relative prices of new IT capital goods, such as computers and semiconductors, is suggestive of strong (possibly even dominant) capital-augmenting technical change (Jalava et al., 2006). But why should capital-augmenting technical change caused by the IT revolution become dominant?

Evidence for the profitability of capital-augmenting technical progress comes from an inspection of the growth rate of real wages, which since about 1976, as Figure 1 shows, have remained continuously under the growth rate of labor productivity. The cumulative decrease of unit labor costs may have made, in line with Acemoglu's (2003) analysis, capital augmenting technical progress a profitable alternative to that of labor augmenting.<sup>2</sup> Further, given the high average unemployment rate, labor could not be regarded as constraining factor for growth, at least, over business cycle frequencies.

**Table 2: Some Recent Growth Accounting in the euro area and US.**

	EU-15				
	$\Delta k$ (ICT)	TFP Growth Accounting			
		$\Delta y$	$\Delta k$	$\Delta n$	$\Delta tfp$
1986 - 1995	8.4	2.4	3.0	0.1	1.4
1996 - 2004	10.6	2.1	2.3	0.7	0.9
	US				
1986 - 1995	8.1	2.9	2.5	1.6	1.0
1996 - 2004	11.9	3.4	2.9	0.9	1.9

Sources: Calculations based on data from the Groningen Growth and Development Centre Database (using  $\beta^{EU} = 0.32$ ;  $\beta^{US} = 0.29$ )

The data shown in Table 2 support this interpretation. An interesting feature of the GGDC data is that contains information on the development of the capital stock split into the ITC and the non-ICT component. If we approve the hypothesis that the adoption of the ITC technology is closely related to the development of ICT-capital stock, then in this regard, developments in the EU and the US have been quite similar. Since the mid-80s the average growth rates of the ICT-capital stock have been close to 10% per annum (the first column of Table 2), which is above 4-fold of the output growth in the EU area and about 3-fold in the US. Hence, in the light of these figures the ITC boom has been at least as strong in Europe as in the US. However, when a simple Solovian (1957) growth accounting framework with the Cobb-Douglas production function is applied on GDP, the capital stock, hours worked, and TFP, developments in both areas begin to look quite different. As in Table 1, the growth of average labor productivity decelerates in Europe while it accelerates in the US in the sub-period of 1996-2004 compared to the preceding 10-year sub-period. According to this standard growth accounting framework the slowing of the average labor productivity growth is contributed by the deceleration of the growth of capital deepening (i.e.  $\Delta k - \Delta n$ ) and TFP growth in the EU-15.<sup>3</sup>

<sup>2</sup> If the elasticity of substitution less than 1, then in Acemoglu's (2003) model capital augmenting technical change is an additional channel, through which the income distribution is restored back to equilibrium and the economy is pushed back towards the balanced growth path. It is quite evident that the importance of this channel is the larger the less flexible real wages are.

<sup>3</sup> Data for ICT Capital were unavailable for the EU12, but we would not expect the conclusions from Table 2 to be sensitive to that.

How might we interpret these developments in the light of underlying ICT boom? A reasonable answer can be given in terms of augmented technical progress. By denoting by  $\beta$  the capital income share; and by  $g_K$ ,  $g_N$  and  $TFP$  as respectively the logs of capital and labor augmenting technical progress and total factor productivity, the growth of average labor productivity can be written as follows:

$$\Delta \log\left(\frac{Y}{N}\right) = \Delta TFP + \beta \Delta \log\left(\frac{K}{N}\right)$$

where

$$\Delta TFP = \beta \Delta g_K + (1 - \beta) \Delta g_N$$

This relationship shows that, if there is acceleration in capital augmenting technical progress, which replaces a certain part of labor-augmenting technical progress, i.e.  $\beta/(1-\beta) = 0.5$  (with  $\beta \approx 0.33$ ) or more, then TFP growth decelerates. An acceleration in the capital augmenting technical progress may have a negative impact on the growth of average labor productivity even in the case where capital augmenting technical compensates the effect of the deceleration of labor augmenting technical progress on TFP because the shift in the augmentation of technical progress anyway slows down the change of capital intensity. This story looks quite plausible for the EU as shown in Table 2. The US data, in turn, is well in line with the acceleration of labor augmenting technical progress. In the US the acceleration of the acceleration of labor augmenting technical progress has increased both growth of TFP, capital intensity and the average labor productivity.

Whilst this analysis is necessarily limited – being, for example, based on Cobb-Douglas accounting (where factor augmentation is not directly identified) – it does nevertheless intimate that differences in factor augmented technical progress, given the smaller income share of capital than labor in total income, is going to play a large role in explaining different developments in the euro-area and in the US.

To summarize, if the IT revolution in Europe led to an increase in capital-augmenting technical progress and the elasticity of factor substitution was unitary or below unity this would have substituted for labor-augmenting technical progress. Given the smaller share of capital in total income, this would induce a slowdown in TFP growth, as will be discussed more closely later in the context of CES production function, and in output growth. And at the same time, the relatively slow increase in real wages compared to labor productivity growth should have helped to stabilize unemployment, although on a high level, before it contributed to its reduction.

### 2.3 Growth, Unemployment and “Okun’s Ratio”

Aligned with the puzzling decline in labor productivity is another issue in the growth pattern of the euro area, which has gained attention only recently (Khemraj et. al., 2006): the dramatic drop in the “Okun’s law” relation, i.e. the per capita (measured in terms of labor force) output growth required to keep the unemployment rate unchanged. This again is puzzling from an intertemporal as well as from an

international perspective. For a long time it had hardly been disputed among economists (Blinder, 1997; Solow, 1997) that changes in unemployment were linked to changes in output by a stable linear relationship. Lee (2000), however, already reports structural breaks in this relationship for a number of countries, which are mostly visible when the US is compared to the euro area (Semmler and Zhang, 2004). While Europe with small growth rates experienced a pronounced reduction in unemployment since the mid 1990s, the US which grew at a much higher rate saw almost “jobless growth”. Evidence for a structural break in the aggregate employment and productivity dynamics of the euro area in the second half of the 1990s is also provided by Mourre (2006).

Explanations relate the jobless growth in the US to higher structural unemployment caused by stronger international competition (Groshen and Potter, 2003) and the increase in European employment to the beneficial effects on ongoing labor market reforms (Mourre, 2006). Both causes may be important but, as we wish to stress, in a macroeconomic setting they will finally influence the “Okun’s law” relationship via changes in productivity. In order to illustrate this point let us recall, that in Okun’s (1962) seminal work, the (empirical) relation between the change of the unemployment rate (U) and the change of real GDP (Y) takes the form:

$$\Delta U_t = a - b\Delta \log Y_t \quad (1)$$

where parameter  $a$  is related to the growth rate of real GDP necessary to keep the unemployment unchanged. Parameter  $b$  is the inverse of the so-called Okun coefficient, i.e. the change in the unemployment rate corresponding to one percent change in output. Unlike the bulk of Okun’s Law literature, however, our focus is not in parameter  $b$  but in the ratio  $a/b$ . This ratio in fact corresponds to the “threshold growth rate” which, furthermore, on a balanced growth path with no unemployment would equal the sum of growth of the labor force  $\Delta \log N_t^F$  and of the (potentially time-varying) labor-augmenting technical progress  $\gamma_t^N$  (i.e., when  $\Delta U_t = 0 \Rightarrow \Delta \log Y_t = \frac{a}{b} \equiv \Delta \log N_t^F + \gamma_t^N$ ), then the Okun relationship can be rewritten as:

$$\Delta U_t = -b(\Delta \log Y_t - \Delta \log N_t^F - \gamma_t^N) \quad (2)$$

As it turns out from equation (2) a downward trend in the average labor productivity, as found in the euro area over the period 1970-2005, would imply that the threshold output growth needed to keep the unemployment rate unchanged should also decrease. To account for this possibility we estimated the following specification, where  $\Delta$  refers to the difference over four quarters and the fourth-order time polynomial allows a quite flexible specification for the threshold growth rate, if it is time varying.<sup>4</sup>

$$\Delta U_t = -\sum_{j=0}^2 b_j \Delta \log(Y_{t-i}/N_{t-i}^F) + \sum_{i=0}^4 a_i t^i \quad (3)^5$$

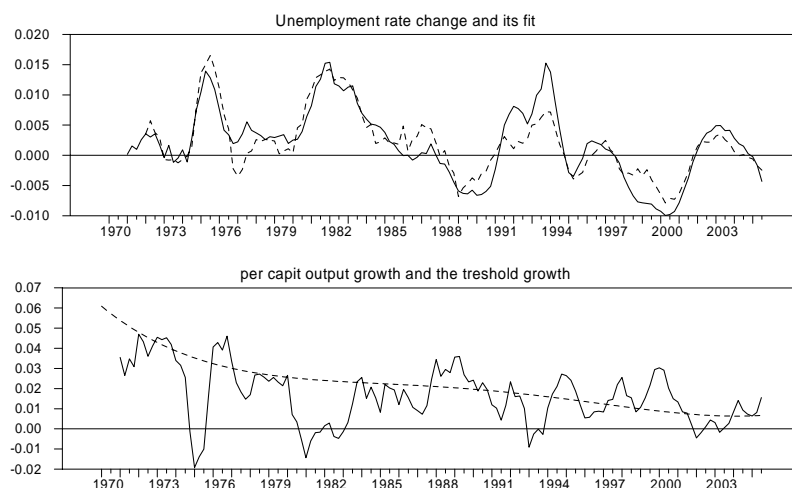
<sup>4</sup> We know from the Weierstrass Theorem that a polynomial expansion with a progressively larger power is capable of approximating to a given degree of precision any unknown but continuous function.

<sup>5</sup> In this estimation all parameters are highly significant and  $\sum \hat{b} = 0.5$ .



The upper panel of Figure 2 presents the change of the actual unemployment rate and its fit (which, as one might expect from polynomial-based equation (4), appears very close). The lower panel presents the observed per capita (in terms of labor force) output growth rates and the implied (also per-capita) threshold growth rate (i.e.,  $\sum a_i t^i / \sum b_j$ ). We observe that the threshold growth rate decelerates over the sample period from 3-5% (in the 1970s), to 3-2% in the 1980s, to around 1% thereafter. In the 1970s until the mid 1980s actual growth is most of time below the threshold rate. This corresponds to the period when unemployment continuously increased (or the change in the unemployment rate was persistently positive). From the mid 1980s to the early 1990s the decrease of the threshold output growth almost halted resuming to decelerating since around mid 1995. We see that on both sides of the year 2000 actual output growth exceeds the threshold growth which is reflected in a decrease in the unemployment rate. Looking at the US experience over the last decade, we would see a similar, though mirrored picture. High labor productivity growth resulted in high employment threshold growth so that even high actual output growth rates did not lower unemployment (Khemraj et. al., 2006).

**Figure 2: Change of Unemployment and Threshold Growth in the Euro Area**



We can thus conclude two things. First, technical progress in the euro area is clearly both time-varying and downward trending. Any model of long-run supply in the euro area which does not somehow embrace that entails a specification bias of some order. Second, interpreting “Okun’s Ratio” in terms of a balanced growth path (as we have done) evidently only takes us only so far: the IT Boom should logically lead to a rise in euro area productivity and TFP growth, but does not. This begs the question of where the increasing use of IT-intensive goods shows up in the productivity-TFP nexus. Our speculation would be that there has been a break in the development of TFP which represents, in effect, directed technical change in favor of capital. Indeed, following the Acemoglu hypothesis the time profile of technical change need not be constant or dominant, at least in the short run, if the elasticity of factor substitution is below unity. And if it could be shown that over the 1990s technical progress in Europe had strong

capital bias and factor substitution remained low enough (i.e., at or below unity), then the observed changes in the Okun's Law relationship need not be puzzling at all.

### 3. The Supply Side Model and the Normalized CES Production Function

In the following sub-sections we outline the theoretical model which is simply the representation of the simultaneous supply side (both factor input equations and the production function) transformed to eliminate the mark-up (Section 3.1). We then motivate and implement the Normalized CES Production function (Section 3.2). Thereafter, we explain how we calculate TFP growth in the context of factor-augmenting CES functions by applying the Kmenta Approximation (Section 3.3). Finally, we illustrate our choice of specific functional forms to capture time-varying technological progress. (Section 3.4)

#### 3.1 The Theoretical Model

The supply-side system that we estimate for the euro area is a standard classical, three-equation system. It assumes that factors are paid their marginal product (subject to a mark-up) and that there exists some aggregate production function and mark-up:

$$\frac{\partial F}{\partial N_t} = (1 + \mu) \frac{W_t}{P_t} \quad (4)$$

$$\frac{\partial F}{\partial K_t} = (1 + \mu) \frac{r_t + \delta}{P_t(1 + r_t)} \quad (5)$$

$$Y_t = F(K_t, N_t, t) \quad (6)$$

where  $N$  and  $K$  denotes the labor and capital input,  $W$  denotes real wages,  $P$  the price level,  $r$  the real interest rate,  $\delta$  the fixed depreciation rate,  $Y$  final output, with the mark-up,  $1 + \mu = \left(1 + \frac{\partial P / \partial Y}{P/Y}\right)^{-1}$ .

Thus equation (4) assumes that the marginal product of labor (capital) is equal to a mark-up on the real wage (real user cost of capital). Finally, equation (6) defines the production function.

Despite this standard system, there are some particular points of note. First, in line with our previous discussions, we take a *CES* production function to the data (rather than presupposing Cobb-Douglas technology). Second, we estimate using a more robust and technically more correct "normalized" supply-side system (normalization is discussed in the following section). Third, we assume a very general time-varying evolution for factor-augmenting technical progress. Finally, we undertake a rigorous examination of the euro area data to ensure feasible estimation of the supply-side system (4)-(6).

Moreover, this system would be a reasonable base for estimation, but as the treatment of the aggregate mark-up is no trivial issue in the euro area (e.g., Willman, 2001) we multiply both sides of (4) and (5) by  $N/Y$  and  $N/K$ , respectively, and utilize

the relation  $\frac{PY_t}{(1+\mu)} = W_t N_t + q_t K_t$  to end up with the transformed but equivalent system:

$$\frac{W_t N_t}{W_t N_t + q_t K_t} = \frac{N_t}{Y_t} \frac{\partial F}{\partial N_t} \quad (4')$$

$$\frac{q_t K_t}{W_t N_t + q_t K_t} = \frac{K_t}{Y_t} \frac{\partial F}{\partial K_t} \quad (5')$$

$$Y_t = F(K_t, N_t, t) \quad (6')$$

where  $q_t = r_t + \delta$  is the real user cost. The advantage of (4')-(6') over (4)-(6) is that the possible problems associated with estimating time-varying aggregate mark-up (e.g., Willman, 2001) are not mixed with the estimation of production function parameters.

### 3.2. The Normalized CES Production Function

In estimating system (4'-6'), our technology assumption is the “normalized” CES production function allowing for time-varying factor-augmenting technical progress. The importance of explicitly normalizing CES functions was discovered by de La Grandville (1989), further explored by Klump and de La Grandville (2000), Klump and Preißler (2000), and de La Grandville and Solow (2005), and first implemented empirically by Klump, McAdam and Willman (2007). Normalization starts from the observation that a family of CES functions whose members are distinguished only by different elasticities of substitution needs a common benchmark point. Since the elasticity of substitution is defined as point elasticity, one needs to fix benchmark values for the level of production, the inputs of capital and labor and for the marginal rate of substitution, or equivalently for per-capita production, capital intensity and factor income shares.

Normalization is crucial in several respects when dealing with CES functions: (a) It is necessary for identifying in an economically meaningful way the constants of integration which appear in the solution to the differential equation from which the CES production function is derived. (b) It helps to distinguish among the various functional forms, which have been developed in the CES literature, namely those which are identical and those which are not, (c) it is necessary for securing the basic property of CES production in the context of growth theory, which is the strictly positive relationship between the elasticity of substitution and the level of output, (d) it is (implicitly or explicitly) employed in all empirical studies of CES functions, (e) and finally it is convenient when biases in the direction of technical progress are to be empirically determined.

To elaborate:

(a) The construction of the CES production function starts from the definition of the elasticity of substitution,  $\sigma$ , as being equal to the elasticity of income per capita with

respect to the wage rate according to Allen's theorem. This leads to a second-order differential equation whose solution implies two constants of integration. Introducing  $K_0$ ,  $N_0$  and  $Y_0$  as the baseline values for capital, labor and output, respectively, and  $\eta_0 = \frac{\partial Y_0 / \partial N_0}{\partial Y_0 / \partial K_0}$  as the baseline value for the marginal rate of substitution, one can identify those constants of integration in an economically meaningful way and arrives at the normalized CES production function at a given point of time  $t$  (de La Grandville and Solow, 2005):

$$Y_t = C(\sigma) \{ [1 - \alpha(\sigma)] N_t^{-\rho} + \alpha(\sigma) K_t^{-\rho} \}^{-\frac{1}{\rho}} = Y_0 \left[ (1 - \beta) \left( \frac{N_t}{N_0} \right)^{-\rho} + \beta \left( \frac{K_t}{K_0} \right)^{-\rho} \right]^{-\frac{1}{\rho}} \quad (7)$$

where

$$\alpha(\sigma) = K_0^{\rho-1} / (K_0^{\rho-1} + \eta_0 N_0^{\rho-1})$$

$$C(\sigma) = Y_0 [(K_0^{\rho-1} + \eta_0 N_0^{\rho-1}) / (K_0 + \eta_0 N_0)]^{-\frac{1}{\rho}}$$

$$\beta = K_0 / (K_0 + \eta_0 N_0) \quad \text{and} \quad \rho = (1 - \sigma) / \sigma$$

(b) The “intra-family” relations between different functional forms of the CES production function were analyzed by Klump and Preißler (2000, p.43 f.). In particular, it could be shown that the CES variants proposed by Arrow et al. (1961) and David and van de Klundert (1965) could all be traced back to a common ancestor which is given by the normalized production function (1). Also the CES variants used by Solow (1956) or Acemoglu (2002) can be traced back under certain special assumptions concerning the baseline values to the general normalized CES function (7), but not the functional form which, for example, was proposed by Barro and Sala-i-Martin (1995).<sup>6</sup>

The baselines values for capital, labor, output and the marginal rate of substitution are the same for all functions belonging to one particular CES family. This implies automatically, that under imperfect competition, two members of one family also share the same baseline values for the distribution parameter  $\pi_0 = \frac{q_0 K_0}{w_0 N_0 + q_0 K_0} = (1 + \mu) \frac{q_0 K_0}{P_0 Y_0}$ , where  $w$ ,  $q$ , and  $P$  refer to the wage rate, the rental price of capital and to the price of output, respectively, and  $\mu$  is the mark-up.<sup>7</sup>

(c) The general form (7) and all its admissible variants share the property of being a General Mean of the order of  $\rho$ . General means, however, are strictly increasing functions of their order (see de La Grandville and Solow, 2005). Hence, it becomes easy to prove that everywhere (except in the benchmark point) an increase in the elasticity of substitution will lead to a higher level of output. Within the context of a

<sup>6</sup> See Klump and Preissler (2000) and Klump (2001).

<sup>7</sup> Under perfect competition, this distribution parameter is equal to the capital income share but, under imperfect competition with non-zero mark-up, it equals the share of capital income over total factor income.

standard neoclassical growth model one can then show (Klump and de La Grandville, 2000) that a higher elasticity of substitution induces a higher steady level of capital-intensity and per-capita production. The degree of factor substitution can thus be regarded as a determinant of the steady state just as important as the savings rate or the growth rate of the labor force.

(d) As stressed by Rutherford (2003) empirical work on CES functions very often uses calibrated functional forms which can be traced back to the normalized CES function (1). The benchmark values which show up in these calibrations are needed to convert observations for output levels, capital stock and numbers of workers (or hours worked), all measured in different units, into consistent index numbers. In many empirical studies one finds an implicit normalization where the benchmark values for output, capital and labor are set equal to one.<sup>8</sup> In other studies these benchmark values correspond to the values of the respective variables in a particular base year.

(e) Finally, it should be noted, that normalization also fixes a benchmark value for the factor income shares. This is important when it comes to an empirical evaluation of changes in the income distribution which are the result of technical progress. If technical progress is biased in the sense that factor income shares change over time the nature of this bias can only be classified with regard to a given baseline value (Kamien and Schwartz, 1968). As has been pointed out by Acemoglu (2002, 2003), the neoclassical theory of induced technical change regards such biases as necessary market reactions to endogenous or exogenous changes in factor income distribution. In this view the interaction of factor substitution and biased technical change is crucially responsible for the relative stability of long term factor income share in market economies despite a steadily growing capital intensity, whereas non-market economies are not able to develop a comparable allocation mechanism (Easterly and Fischer, 1995). We will make use of this particular property of normalized CES functions for our own estimation approach.

Following Klump and Preißler (2000), any two CES functions with different elasticity of substitution belong to the same “family”, if at a fixed point of time ( $t=t_0$ ) with the amounts of inputs  $K_0$  and  $N_0$ , they give the same output  $Y_0$  and the same marginal rate of substitution. We call this point  $(t_0, K_0, N_0, Y_0)$  the “point of normalization”. The normalized factor-augmenting production function, which fulfils that definition, can be written as,

$$Y_t = Y_0 \left\{ (1 - \pi_0) \left[ \frac{N_t}{N_0} \cdot e^{g_N(\cdot)} \right]^{-\rho} + \pi_0 \left[ \frac{K_t}{K_0} \cdot e^{g_K(\cdot)} \right]^{-\rho} \right\}^{\frac{1}{\rho}} \quad (8)$$

where  $\pi_0 = q_0 K_0 / (W_0 N_0 + q_0 K_0)$  is the capital share evaluated at the normalization point and  $g_i(\cdot)$  define the level of technical progress from factor  $i$ .

---

<sup>8</sup> This implicit normalization can e.g. be found already in Arrow et al. (1961, p230), when the “efficiency parameter” is set equal to one “by appropriate choice of output units”. In the light of the normalized CES function, the parameter C is exactly equal to one, when  $K_0 = N_0 = Y_0 = 1$  is assumed.

### 3.3 Kmenta Approximation of the Total Factor Productivity (TFP)

It is well known that the log of the TFP is separable from the rest of the production function, only under Hicks neutrality, i.e. in (8)  $g_N = g_K$ . However, it would also be useful to calculate an estimate of the TFP in the context of augmented technical change. By applying the Kmenta (1967) approximation, equation (8) can be presented as:

$$\begin{aligned} \log(Y_t/Y_0) = & -\frac{1}{\rho} \log\left\{(1-\pi_0)(N_t/N_0)^{-\rho} + \pi_0(K_t/K_0)^{-\rho}\right\} \\ & + \pi_0 \left[1 - \rho(1-\pi_0) \log\left(\frac{K_t/K_0}{N_t/N_0}\right)\right] g_K(\cdot) + (1-\pi_0) \left[1 + \rho\pi_0 \log\left(\frac{K_t/K_0}{N_t/N_0}\right)\right] g_N(\cdot) \quad (8') \\ & - \frac{\rho\pi_0(1-\pi_0)}{2} [g_N(\cdot) - g_K(\cdot)]^2 \end{aligned}$$

In the neighborhood of  $K_t = K_0$  and  $N_t = N_0$  the TFP component is simplified further and (8) can thus be approximated by relation:

$$\begin{aligned} \log(Y_t/Y_0) = & -\frac{1}{\rho} \log\left\{(1-\pi_0)(N_t/N_0)^{-\rho} + \pi_0(K_t/K_0)^{-\rho}\right\} \quad (8'') \\ & + \pi_0 g_K(\cdot) + (1-\pi_0) g_N(\cdot) - \frac{\rho\pi_0(1-\pi_0)}{2} [g_N(\cdot) - g_K(\cdot)]^2 \end{aligned}$$

### 3.4 Flexible Modeling of Technical Progress

Neo-classical growth theory suggests that, for an economy to possess a steady state with positive growth and constant factor income shares, the elasticity of substitution must be unitary (i.e., Cobb-Douglas) or technical change must exhibit Harrod Neutrality (i.e., labor-augmentation). The intuition for this reflects the feature that whilst capital can be accumulated, labor cannot; thus, labor is the constraining factor, and firms, in order to avoid an explosion of wage income (or labor share), bias and concentrate technical improvements towards labor.

Under Cobb-Douglas, however, the direction of technical change is irrelevant for income distribution since it is not possible to determine any biases in the direction of technical change. In contrast, pronounced trends in factor-income distribution witnessed in many industrialized countries support the more general CES function and make possible biases of technical progress a central issue. For CES, though, a steady state with constant factor income shares is only possible if technical progress is purely labor augmenting. Acemoglu (2003) was able to derive this same result in a model with endogenous innovative activities but also demonstrated that, over quite significant periods of transition, growth of capital-augmenting progress can be expected resulting from endogenous changes in the direction of innovations. Indeed, abstracting from theory, it would be surprising if the decline in the price (and rise in usage) of goods

such as computers and semi-conductors since the 1970s – alongside rigid labor markets in Europe – had not induced some capital-augmenting technical change.

Earlier work on CES functions, moreover, tended to assume constant technical growth. However, following recent debates about biases in technical progress, it is not obvious that growth rates should always be constant; accordingly, we follow an agnostic approach and model factor-augmenting technical progress using a well-known

flexible, functional form (Box and Cox, 1964):  $g_i(t, t_0, \gamma_i, \lambda_i) = \frac{\gamma_i t_0}{\lambda_i} \left[ \left( \frac{t}{t_0} \right)^{\lambda_i} - 1 \right]$ ,  $t > 0$ <sup>9</sup>.

Technical progress,  $g(\cdot)$  is, thus, a function of time,  $t$  (around its point of normalization) and a curvature parameter,  $\lambda$ . When  $\lambda=1$  ( $=0$ ) [ $<0$ ], technical progress displays linear (log-linear) [hyperbolic] transitional dynamics. The level and growth of technical progress for these different  $\lambda_i$  are, respectively,

$$g_i(\cdot) \Rightarrow \begin{cases} \lim_{t \rightarrow \infty} g_i(\cdot) = \infty & \text{if } \lambda_i \geq 0 \\ \lim_{t \rightarrow \infty} g_i(\cdot) = -\frac{\gamma_i t_0}{\lambda_i} > 0 & \text{if } \lambda_i < 0 \end{cases} ; \quad \frac{\partial g_i(\cdot)}{\partial t} = \gamma_i \left( \frac{t}{t_0} \right)^{\lambda_i - 1} \Rightarrow \begin{cases} \frac{\partial g_i(\cdot)}{\partial t} = \gamma_i, \forall t & \text{if } \lambda_i = 1 \\ \lim_{t \rightarrow \infty} \frac{\partial g_i(\cdot)}{\partial t} = 0, & \text{if } \lambda_i < 1 \end{cases} \quad (9)$$

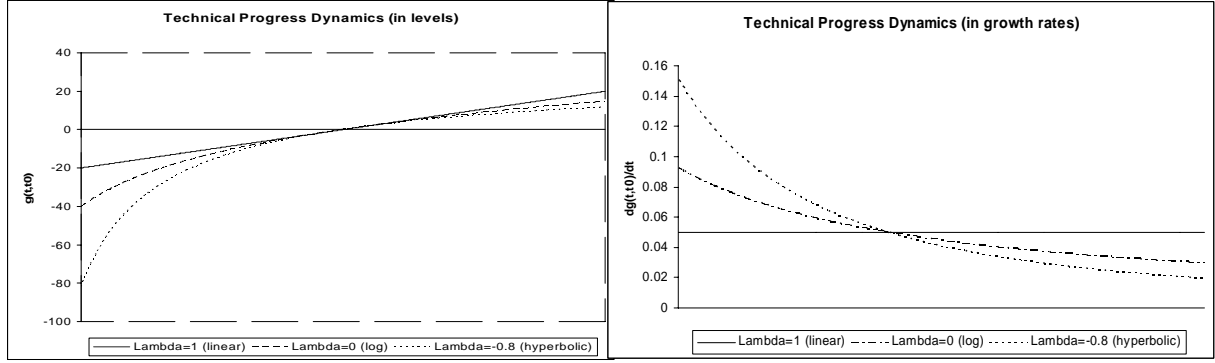
Thus, if  $\lambda_i \geq 0$ , the *level* of technical progress obtained from factor  $i$  tends to infinity but is bounded otherwise. If  $\lambda_i = 1$  the *growth* of technical progress is constant (i.e., the textbook case) but tends to zero for any  $\lambda_i < 1$  (these cases are illustrated in Figure 3).

The main advantage of this flexible (Box-Cox) modeling of technical progress is that it allows the data to decide on the presence and dynamics of factor-augmenting technical progress.<sup>10</sup> If, for example, the data supports an asymptotic steady state, this will arise *naturally* from the dynamics of these curvature functions (i.e., labor-augmenting technical progress becoming dominant, that of capital decaying) rather than being imposed a priori.

<sup>9</sup> Note we scaled the Box-Cox specification by  $t_0$  to interpret  $\gamma_N$  and  $\gamma_K$  directly as the rates of labour- and capital-augmenting technical change at the fix point period.

<sup>10</sup> Assuming a specific, albeit flexible, function form for technical progress, has the added advantage of circumventing problems related to Diamond et al.'s (1978) non-identification theorem.

**Figures 3: Illustrative Level and Growth Effects of Technical Progress**



**Note:** The level of technical progress function  $g_i(\cdot)$  equals zero when  $t=t_0$ , as is clear from our specification of the Box-Cox function.

Accordingly, the final system that we estimate is given by:

$$\log\left(\frac{w_t N_t}{w_t N_t + q_t K_t}\right) - \log(1 - \bar{\pi}) + \frac{1 - \sigma}{\sigma} \left[ \log\left(\frac{Y_t / \bar{Y}}{N_t / \bar{N}}\right) - \log \zeta - \frac{\bar{t} \gamma_N}{\lambda_N} \left( \left( \frac{t}{\bar{t}} \right)^{\lambda_N} - 1 \right) \right] = 0 \quad (10)$$

$$\log\left(\frac{q_t K_t}{w_t N_t + p_t k_t}\right) - \log(\bar{\pi}) + \frac{1 - \sigma}{\sigma} \left[ \log\left(\frac{Y_t / \bar{Y}}{K_t / \bar{K}}\right) - \log \zeta - \frac{\bar{t} \gamma_K}{\lambda_K} \left( \left( \frac{t}{\bar{t}} \right)^{\lambda_K} - 1 \right) \right] = 0 \quad (11)$$

$$\log\left(\frac{Y_t / \bar{Y}}{N_t / \bar{N}}\right) - \log(\zeta) - \frac{\bar{t} \gamma_N}{\lambda_N} \left( \left( \frac{t}{\bar{t}} \right)^{\lambda_N} - 1 \right) + \frac{\sigma}{1 - \sigma} \log \left[ \bar{\pi} e^{\frac{1 - \sigma}{\sigma} \left[ \frac{\bar{t} \gamma_N}{\lambda_N} \left( \left( \frac{t}{\bar{t}} \right)^{\lambda_N} - 1 \right) - \frac{\bar{t} \gamma_K}{\lambda_K} \left( \left( \frac{t}{\bar{t}} \right)^{\lambda_K} - 1 \right) \right]} \left( \frac{K_t / \bar{K}}{N_t / \bar{N}} \right)^{\frac{\sigma - 1}{\sigma}} + (1 - \bar{\pi}) \right] = 0 \quad (12)$$

where  $\bar{\pi} = \frac{\bar{q} \bar{K}}{\bar{w} \bar{N} + \bar{q} \bar{K}}$  is the capital share evaluated at the fixed point (sample mean).

#### 4. The Data and its properties

Following Coenen and Wieland (2005), Galí et al. (2001), Smets and Wouters (2003), etc, we model interactions in continental Europe, using aggregate euro-area data from 1970q1-2005q3 from the (updated) Area Wide Model (AWM) database of Fagan et al. (2001).<sup>11</sup> However, our capital stock for the euro area is based on Eurostat harmonised net capital stock data for the European Union, which is substantially more reliable. Due to the different base year and minor difference in aggregation practices, gross investment in the Eurostat data and the AWM-data were not identical. Therefore, using

<sup>11</sup> Though we use aggregate data, pronounced labour income share declines apply equally well to constituent countries (e.g., Germany, France, Italy). Our analysis, subject to the relevant data availability, could therefore be mechanically performed at the country level. We leave this for possible future research.



the depreciation rates of the Eurostat data as benchmarks the Eurostat capital stock data was calibrated to be consistent with the AWM gross investment data.<sup>12</sup>

Likewise some additional information is needed to calculate factor incomes. Regarding labor income the problem is that, at the area-wide level, no data on the income of self-employed workers are available. Therefore as e.g. Blanchard (1997), Gollin (2002) and McAdam and Willman (2004) we used the aggregate wage rate as a shadow wage rate also for the labor income component of self-employed workers. We also accounted for the fact that a part of the self-employed was unpaid family workers, whose share has continuously decreased.<sup>13</sup> Hence, the calculation of labor income was based on the formula:

$$\text{Compens. to Employees} + \left( \frac{\text{Self Empl} - \text{Unpaid}}{\text{Total Employment}} \right) (\text{Wage and Salary Income})$$

Capital income is calculated as the product of nominal user cost and the volume of the capital stock. The interest rate measure is the long term nominal interest rate of the AWM data. To retain compatibility with the National accounting practices, which assumes no net operating surplus in government sector, the rate of return requirement on government sector capital was assumed to equal the depreciation rate. Accordingly, in calculating capital income we used the following formula:

$$\text{Invest. Deflator} \cdot \left[ \frac{\text{Private Capital Stock}}{\text{Total Capital Stock}} \cdot (\text{Interest Rate} - \text{Infl. Rate}) + \delta \right] \cdot \text{Total Capital Stock}$$

Figure 4 presents some salient data features of the data. The top panel presents the development of output (GDP), the total capital stock and total employment in indexed form over the sample period. We see that inconsistently with the balanced growth hypothesis, in our sample period the capital stock has grown faster than output.

The second panel shows the development of the capital income share on total factor income. It is straightforward to see that its development has not been stationary.<sup>14</sup> Essentially, we can observe two regimes in the capital factor income share: a low level covering most of 1970s and a shift in the late 1970s/early 1980s to a markedly higher level thereafter.

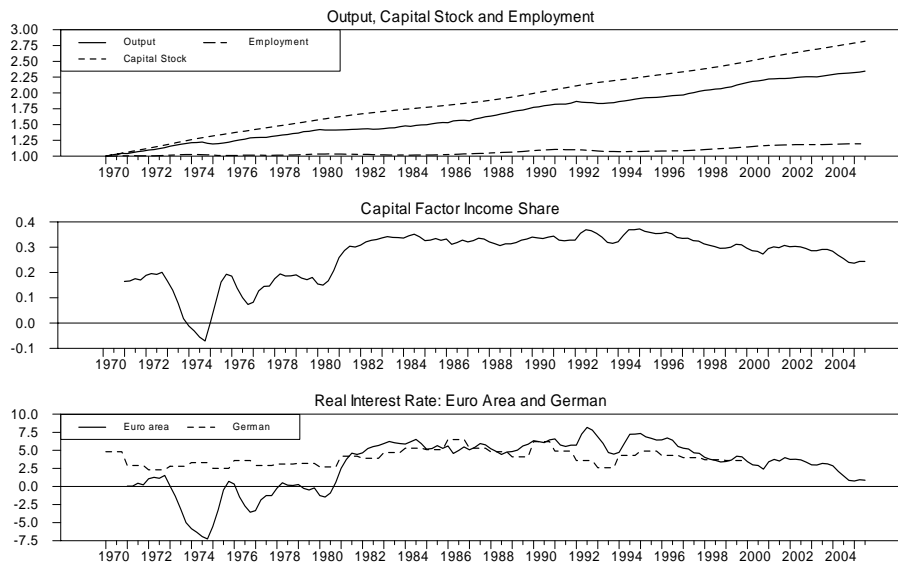
---

<sup>12</sup> Eurostat capital stock data ended in 1999. Therefore, since 1999q4 the capital stock was accumulated by assuming the depreciation rate remain on the level observed in 1999.

<sup>13</sup> As the information of on unpaid family workers (Source: OECD Labour Force Statistics) did not cover the full sample we used backward extrapolation in evaluating the labour share development in 1970:1-1976:4.

<sup>14</sup> Non-stationarity is confirmed by the ADF test.

**Figure 4: Key features of euro area data**



How might we explain these developments? This must be linked to the way capital income is constructed. Our capital income is an imputed concept and thus sensitive to variations in the measured user cost and, in turn, to variations in the real interest rate. Notably, the variation in the capital factor income share, including the regime shift, essentially matches that of the real interest rate (the bottom panel of Figure 5). Although there is nothing to prevent the ex-post real interest rate from being temporarily negative, a precarious feature is that it was negative for most of the 1970s. The use of a persistently negative real rate as an operational counterpart for the expected real rate used in the optimization framework seems contradictory (since it implies infinite profit opportunities), and, at the very least, worth investigating.

One possible explanation for the negative character of the measured real interest rate in the 1970s and of the upward level shift in the late 1970s and early 1980s might be that financial markets were highly regulated in Europe during the most of 1970s. In the late 1970s and early 1980s, this regulated system broke down, at first perhaps partly due to leakage caused by financial innovations, and later to the formal removal of regulations.<sup>15</sup> Under this explanation, measuring the regulated interest rate, does not measure the marginal cost of financing correctly. The development of the German real interest rate in the bottom panel further encourages this interpretation. The real euro-area interest rate was strongly negative throughout most of the 1970s, whilst the German rate was positive (from the mid 1980s onwards, though, the two series are quite similar). The German case is interesting since Germany took the lead in financial liberalization and all direct controls had been removed before 1974, i.e. by the point of time at which real interest rates in other euro-area countries turned negative (e.g., Issing, 1997).<sup>16</sup>

<sup>15</sup> The level-shift in the real interest rate seems somewhat to precede the formal removal of financial regulations in many countries. It is quite possible, however, that financial innovations caused the regulated system to start to leak long before the formal removal of regulations.

<sup>16</sup> The real interest rate in France and, especially, Italy was strongly negative throughout most of the 1970s. The real interest rate in France mimics the euro-area real interest rate relatively well (see Willman, 2002).

To account for the possibility that the euro-area real interest rate does not correctly measure the marginal cost of financing in the 1970s, a freely-determined level-shift dummy was constructed to correct the interest rate (upwards) during this period.<sup>17</sup> This corrected interest rate could be interpreted as a shadow rate,  $i''$ , measuring the marginal cost of financing<sup>18</sup>,  $i'' = i + h \cdot DUM$ , where  $DUM$  is a smooth, hyperbolic level-shift dummy calibrated to unity in the early 1970s, starting gradually to deviate from unity around 1976 and converging to zero around 1983, after which  $i''$  in practice equals the observable interest rate  $i$ .

## 5. Estimation Results

Table 3 shows the parameter estimates for the supply-side system, (4'-6'). The rows list the technical parameters ( $\zeta; \gamma_N; \gamma_K; \sigma$ ), curvature parameters ( $\lambda_N; \lambda_K$ ), and the interest-rate financing dummy ( $h$ ).<sup>19</sup> Thereafter, we report individual and total factor productivity (TFP) evaluated at the fixed point; residual stationarity tests; and the system metric (the log determinant).

The first column shows the full-sample supply-side estimation. Taken at face value they suggest Solow Neutrality.<sup>20</sup> Solow Neutrality, though contrary to balanced growth, is not without its attractions: with historically high unemployment in euro-area economies, it may be un-reasonable to assume that labor is the scarce, fixed factor. Looking at other metrics, however, we see that the production-function residual exhibits non-stationarity (the ADF t-test statistic equals -2.7).

Further examination, moreover, proves that this full-sample estimation does not fulfill stability requirements either. Strongly capital augmenting technical progress seems to be coupled with development in the relatively recent past. When gradually dropping years from the sample end-point (results suppressed for brevity) the curvature

<sup>17</sup> This accords with Coenen and Wieland (2005) who found a strong, significant negative dependence of euro-area aggregated demand on the German real interest rate, whilst the dependency of the weighted average of the euro area real interest rate was markedly weaker and statistically insignificant. Following Coenen and Wieland (2000), we also could have used the German real interest as a proxy for the real interest rate of the euro area. However, the drawback would be that we lose the information contained by the euro area real interest rate in the latter part of the sample, when we believe that the euro area real interest rate measures reasonably well the real marginal cost of financing in the euro area. Moreover, the size of the correction to the real interest rate implied by estimated parameter for the dummy may also serve as evidence (or counter-evidence) of our hypothesis.

<sup>18</sup> This would presuppose the existence of a rather well functioning "grey" financial market. Then, when regulation is binding, the marginal cost of financing can be markedly above the average cost of financing, which the interest rate measures. After deregulation, under the *Modigliani-Miller* theorem, as our user cost definition assumes, the marginal and average costs of financing are equal.

<sup>19</sup> We suggest normalization points should be calculated from sample averages (denoted by a bar), because over a longer time period cyclical variations have netted out and even longer-term fluctuations have compensated. However, due to the non-linearity of the CES functional form, sample averages (arithmetic or geometric) need not exactly coincide with the implied fixed point of the underlying CES function. That would be the case only if the functional form is log-linear i.e. Cobb-Douglas with constant technical growth. Therefore, we capture and measure the possible emergence of such a problem by introducing an additional parameter,  $\zeta$ , which should be close to unity. This allows us to express the fixed point in terms of the geometric sample averages of output and inputs,  $Y_0 = \zeta \cdot \bar{Y}, K_0 = \bar{K}, N_0 = \bar{N}$ , and the arithmetic sample averages of capital income share and time:  $\pi_0 = \bar{\pi}, t_0 = \bar{t}$ . Distribution parameter  $\bar{\pi}$  can be calculated directly, pre-recursively, from the data or it can be estimated jointly with the other parameters of the model. We apply the former approach, however, modified so that the implied factor income share is conditional on the estimated level correction on the real marginal cost of financing (the parameter  $h$ ).

<sup>20</sup> Note, by definition, when  $\lambda_N = 0$ , its curvature parameter,  $\lambda_N$ , cannot be identified.

parameter of the capital augmenting technical progress ( $\lambda_K$ ) decreased and turned statistically insignificant in 1997:4 (second column in Table 3). Correspondingly, the role of labor-augmenting technical progress was strengthened with, in fact, the curvature parameter,  $\lambda_N$ , exceeding one. Moreover, the residual and likelihood results of the system are also satisfactory. This pattern of technical progress with labor augmentation dominating was repeated, when additional years are dropped from the estimation sample (not reported here). The estimate for the elasticity of substitution remained uniformly around 0.7. Hence, we find that until the end of 1997 technical progress was quite consistent with Acemoglu-type technological progress i.e. technical progress is asymptotically labor augmenting with the contribution of capital augmenting progress gradually fading out. Thereafter there is a break in the nature of factor augmenting technical progress. This is also consistent with the findings of Mourre (2006) for raw labor productivity and consistent with our earlier discussion of structural breaks, Sections 2.2-2.3.<sup>21</sup>

Therefore, we proceed to re-estimate allowing for a very general form of structural break (affecting both the curvature and growth rate of factor augmentation). We can see in column 3 of Table 3, that the parameters of technical progress and curvature in the pre-break sample (i.e.,  $\gamma_{N1}, \lambda_{N1}; \gamma_{K1}, \lambda_{K1}$ ) essentially remain unchanged (relative to column 2) with labor being the dominant contributor to overall productivity. As might be expected, however, estimation of factor curvature after 1997:4 is severely limited by the available observations. Accordingly, we calibrated them on the basis of economically reasonable priors (at midpoint on the unit interval:  $\lambda_{N2} = \lambda_{K2} = 0.5$ ); to have the curvature parameters exceeding unity would not only be incompatible with a balanced-growth prior (which, after all, is our natural prior) but would also imply that the detected productivity slowdown and technical-progress break would be permanent in nature (which is an extremely strong assumption and largely at odds with the relevant time-series literature). Likewise, setting them marginally below unity (e.g., 0.99) would imply an exceptionally persistent dynamics following the break in factor augmentation.<sup>22</sup>

What can we conclude? We find that the elasticity of substitution between labor and capital is well below unity and that until 1997 labor-augmenting technical progress occurs at a slightly accelerating rate whereas the rate of capital-augmenting technical progress is declining. In 1997/98 there is a break in technical progress with an upward shift in capital augmenting technical progress and a downward shift in labor augmenting progress. Although the upward shift in capital augmenting is somewhat higher than the drop in labor augmenting progress, the growth of total factor productivity decelerates – due to the relatively lower income share of capital in total factor productivity. Estimated factor augmented technical progress also explains in a reasonable way, why the output growth required to keep unemployment rate unchanged (Okun’s Law) was so much higher in the 1970’s than presently and why the average labor productivity simultaneously with the IT revolution over during about last ten years has decelerated while, for instance in the U.S. it has accelerated. In the euro area, due to the high unemployment rate, the availability of labor force does not set constraints to the medium-run growth and, hence, technical progress coupled with the

<sup>21</sup> We also confirmed a break in labour productivity using the well-known Bai-Perron (2003) battery of structural break tests (details available). Likewise, the statistical fit of the non-linear system is uniformly optimized using a break in 1997:4.

<sup>22</sup> Full results with these break parameter values imposed are available on request.

IT revolution has taken the capital augmenting form. Given a below-unitary elasticity of substitution, this pattern of technical growth rates helps explain the dynamics and development of factor income shares in the euro area. This combination of labor and capital augmenting technical progress mimics eventual convergence to path balanced growth with constant factor shares (in line with economic theory). Our results are therefore supportive of Acemoglu's view on biased technical change where labor efficiency is dominant in the long run while capital efficiency growth tends to fade away.

## **6 Conclusions**

We tried to demonstrate in our supply side framework how different aspects of the patterns of growth in the euro are since 1970 can be related in a meaningful way. Our empirical results confirm that the aggregate factor elasticity in Europe is below unity (at about 0.7) and that technical progress is essentially labor-augmenting in the long run, but capital-augmenting progress can have significant effects in the interim period. We also find evidence for a structural break in the factor biases of technological change at the end of 1997.

Taken together our result can help to explain two keenly-debated features of the European growth pattern, which seemed to puzzle many observers because they were in a sharp contrast to corresponding developments in the US. The first puzzle refers to the (almost missing) impact of the IT revolution on European productivity and growth figures. The second puzzle concerns the shift in the Okun's Law relation which led to a higher decline in unemployment in Europe during the last decade despite relatively low actual growth rates. Both features are related and can be explained by the dominance of capital-augmenting technical change, in particular after the structural break in 1997.

**Table 3: Supply-Side Estimates**

Case	1970:1-2005:3	1970:1-1997:4	1970:1-2005:3
$\zeta$	1.0098 (0.0014)	1.0000 (0.0015)	1.0078 (0.0013)
$\gamma_{N1}$	0.0000 (0.0000)	0.0031 (0.0002)	0.0036 (0.0001)
$\lambda_{N1}$	-5.9057 (0.4044)	1.4579 (0.0995)	1.3634 (0.0776)
$\gamma_{N2}$	–	–	-0.0080 (0.0006)
$\lambda_{N2}$	–	–	0.5000 (–)
$\gamma_{K1}$	0.0082 (0.0001)	0.0020 (0.0004)	0.0014 (0.0003)
$\lambda_{K1}$	0.9723 (0.0317)	0.1649 (0.1614)	0.0348 (0.1467)
$\gamma_{K2}$	–	–	0.0103 (0.0011)
$\lambda_{K2}$	–	–	0.5000 (–)
$\sigma$	0.7889 (0.0060)	0.6804 (0.0095)	0.6538 (0.0108)
$h$	0.0281 (0.0004)	0.0302 (0.0004)	0.0281 (0.0004)
<i>TFP Growth</i>	0.0026	0.0028	0.0029
$\bar{\pi}$	0.3200	0.3410	0.3200
	<b>Stationarity</b>		
ADF <sub>p</sub>	-4.3188	-5.2848	-5.46050
ADF <sub>ck/wn</sub>	-4.2458	-5.0000	-5.14973
ADF <sub>y/N</sub>	-2.7139	-3.4229	-3.88592
<b>Log Determinant</b>	-24.2739	-25.4409	-25.0526

## References

- Acemoglu, D., 2002. Directed technical change, *Review of Economic Studies*, 69, 781-809.
- Acemoglu, D., 2003. Labor- and capital-augmenting technical change, *Journal of the European Economic Association*, 1, 1-37.
- Alcalá, F and I. Sancho, 2000. Inflation and factor shares, mimeo, Univeridad de Murcia, May.
- Arrow, K. J., H. B. Chenery, B. S. Minhas, and R. M. Solow, 1961. Capital-labor substitution and economic efficiency. *Review of Economics and Statistics*, 43, 225-250.
- Bai, J. and P. Peron, 2003. Computation and analysis of multiple structural change models, *Journal of Applied Economics*, 18, 1-22.
- Barro, R. J., and X. Sala-i-Martin, 1995. *Economic growth*, First Edition, MIT Press.
- Bentolila, S. and G. Saint-Paul, 2003. Explaining movements in the labor share, *Contributions to Macroeconomics*, 3, 1, Article 9.
- Berthold, N., R. Fehn, and E. Thode, 2002. Falling labor share and rising unemployment: Long-run consequences of institutional shocks?, *German Economic Review*, 3, 431-459.
- Blanchard, O. J., 1997. The medium Run, *Brookings Papers on Economic Activity*, 2, 89-158.
- Blinder, A. S., 1997. A core of macroeconomic beliefs?, *Challenge*, 40, 36-44,
- Box, G. and D. Cox, 1964. An analysis of transformations, *Journal of the Royal Statistical Society*, 26, Series B, 211-243.
- Caballero, R. J. and M. Hammour, 1998. Jobless growth: Appropriability, factor substitution and unemployment, *Carnegie-Rochester Conference Series on Public Policy*, 48, 51-94.
- Coenen, G. and V. Wieland, 2005. A small estimated euro area model with rational expectations and nominal rigidities, *European Economic Review*, 49(5), 1081-1104.
- Cohen, D., Garibaldi, P. and S. Scarpetta, 2004. (Eds.), *The ICT revolution*. Oxford University Press.
- David, P. A. and T. van de Klundert, 1965. Biased efficiency growth and capital-labor substitution in the US, 1899-1960, *American Economic Review*, 55, 357-394.
- de La Grandville, O., 1989. In quest of the Slutsky diamond, *American Economic Review*, 79, 468-481.
- de La Grandville, O., and R. M. Solow, 2005. Capital-labor substitution and economic growth, Working Paper, University of Geneva.
- de Serres, A., S. Scarpetta, and C. de la Maisonneuve, 2000. Falling wage shares in Europe and the United States: How important is aggregation bias? Presented at the conference Flexibility and adaptability of EU Labor Markets, December, Frankfurt, ECB.
- Diamond, P., D. Mc Fadden, and M. Rodriguez, 1978. Measurement of the elasticity of factor substitution and bias of technical change, in M. Fuss and D. McFadden (Eds.) *Production economics 2*, Amsterdam and New York, 125-147.
- Easterly, W. and S. Fischer, 1995. The soviet economic decline, *World Bank Economic Review*, 9, 341-371.

- Fagan G., J. Henry, and R. Mestre, 2001. An area wide model (AWM) for the euro area, Working Paper No. 42, European Central Bank, Frankfurt, also *Economic Modelling*, 2004, 22, 1, 39-60.
- Groshen, E. L. and S. Potter, 2003. Has structural change contributed to a jobless recovery?, *Current Issues in Economics and Finance*, Federal Reserve Bank of New York, 9, 8 (August), 1-7.
- Gordon, R. J., 2004. Why was Europe left at the station when America's productivity locomotive departed? NBER Working Paper 10661.
- Issing, O., 1997. Monetary targeting in Germany: The stability of monetary policy and of the monetary system, *Journal of Monetary Economics*, 39, 67-79.
- Jalava, J., Pohjola, M., Ripatti, A. and J. Vilmounen, 2006. Biased technical change and capital-labor substitution in Finland, 1902-2003, *Topics in Macroeconomics*, 6, 1, Article 8.
- Kamien, M. I. and N. L. Schwartz, 1968, Optimal 'induced' technical change, *Econometrica*, 36, 1-17.
- Khemraj, T., Maddrick, J. and W. Semmler, 2006. Okun's law and jobless growth, Schwartz Center for Economic Policy Analysis, Policy Note No. 3, New York.
- Klump, R. and H. Preißler, 2000. CES production functions and economic growth, *Scandinavian Journal of Economics*, 102, 41-56.
- Klump, R. and O. de La Grandville, 2000. Economic growth and the elasticity of substitution, *American Economic Review*, 90, 282-291.
- Klump, R., P. McAdam and A. Willman, 2007. Factor substitution and factor augmenting technical progress in the US, *Review of Economics and Statistics*, forthcoming. (ECB Working Paper, No. 367).
- Kmenta, J., 1967. On estimation of the CES production function, *International Economic Review*, 8, 180-189.
- Krugman, P., 1994. *The Age of Diminished Expectations*, MIT Press.
- Lee, J., 2000. The Robustness of Okun's law: Evidence from OECD countries, *Journal of Macroeconomics*, 22, 331-356.
- Okun, A., 1962. Potential output: Its measurement and significance, *Proceedings of the Business and Economic Statistics Section of the American Statistical Society*.
- Marquetti, A.A., 2003. Analyzing historical and regional patterns of technical change from a classical-Marxian perspective, *Journal of Economic Behavior and Organization* 52, 191-200.
- McAdam, P. and A. Willman, 2004. Supply, factor shares and inflation persistence, *Oxford Bulletin of Economics and Statistics*, 66, 637-670.
- Mourre, G., 2006. Did the pattern of aggregate employment growth change in the euro area in the late 1990s?, *Applied Economics*, 38, 15, 1783-1807.
- Rowthorn, R., 1999. Unemployment, wage bargaining and capital-labor substitution, *Cambridge Journal of Economics*, 23, 413-425.
- Rutherford, T., 2003. Lecture notes on constant elasticity functions, University of Colorado.
- Schrader, P., 2000. The contribution of information and communication technology to output growth, *OECD Science, Technology and Industry Working Papers*, 2000/2, OECD Publishing.
- Schwerdt, G. and Turunen, J., 2006. Growth in euro area labor quality, Working Paper No. 575, European Central Bank.
- Semmler, W. and W. Zhang, 2005. The impact of output growth, labor market institutions, and macro policies on unemployment, Working paper, SCEPA



- Smets, F. and R. Wouters, 2003. An estimated stochastic dynamic general equilibrium model of the euro area, *Journal of the European Economic Association*, 1, 5, 1123-1175.
- Solow, R. M., 1956. A contribution to the theory of economic growth, *Quarterly Journal of Economics*, 70, 65-94.
- Solow, R.M., 1957. Technical Change and the Aggregate Production Function, *Review of Economics and Statistics*, 39, 312-320.
- Solow, R. M., 1997. Is there a core of usable macroeconomics we should all believe in?, *American Economic Review*, 87, 230-232,
- Uzawa, H., 1961. Neutral inventions and the stability of growth equilibrium, *Review of Economic Studies*, 28, 117-124.
- Willman, A., 2002. Estimation of the area-wide production function and potential output, Working Paper No. 153, European Central Bank.