

# **A Supply-Side Diagnosis of Growth in the Euro Area: Factor Substitution, Productivity and Unemployment**

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**Abstract:** We estimate a long-run supply-side system incorporating a CES 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 labour-augmenting technical progress is dominant in the long-run while capital-augmenting technical progress plays an important role in the interim. We also find evidence for a structural break in the pattern of biased technical progress at the end of the 1990s. Our results help to solve two puzzles in Europe’s recent growth experience which differ extremely from the US experience. The first puzzle 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, Income Distribution, IT Revolution, Okun’s Law, Euro Area.

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## 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, declining labour productivity and 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 the changes in the “Okun’s law” relationship linking growth to the reduction of unemployment. Resolving and reconciling these puzzles through the lens of supply-side system estimation is the purpose of this paper.

Of course, the traditional workhorse of long-run growth theory and supply estimation 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 labour augmenting. In a series of influential articles, however, Acemoglu (2002, 2003), however, suggested that while technical progress is strictly labour augmenting along the long-term balanced growth path, it may become capital-biased in periods of transition.

Accordingly, 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 labour-augmenting technical progress growth dominates in the long-run while capital-augmenting technical progress plays a significant role in the interim. We also 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 labour augmenting progress.

Our results help solve two puzzles in Europe’s recent growth experience which differ markedly from the US experience. The first puzzle 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 labour productivity, we find a declining labour productivity in Europe for the same time period which even accelerated in the most recent years. The second puzzle concerns the changes in the “Okun’s law” relationship, linking growth to the reduction of 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 shift 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 labour productivity, the

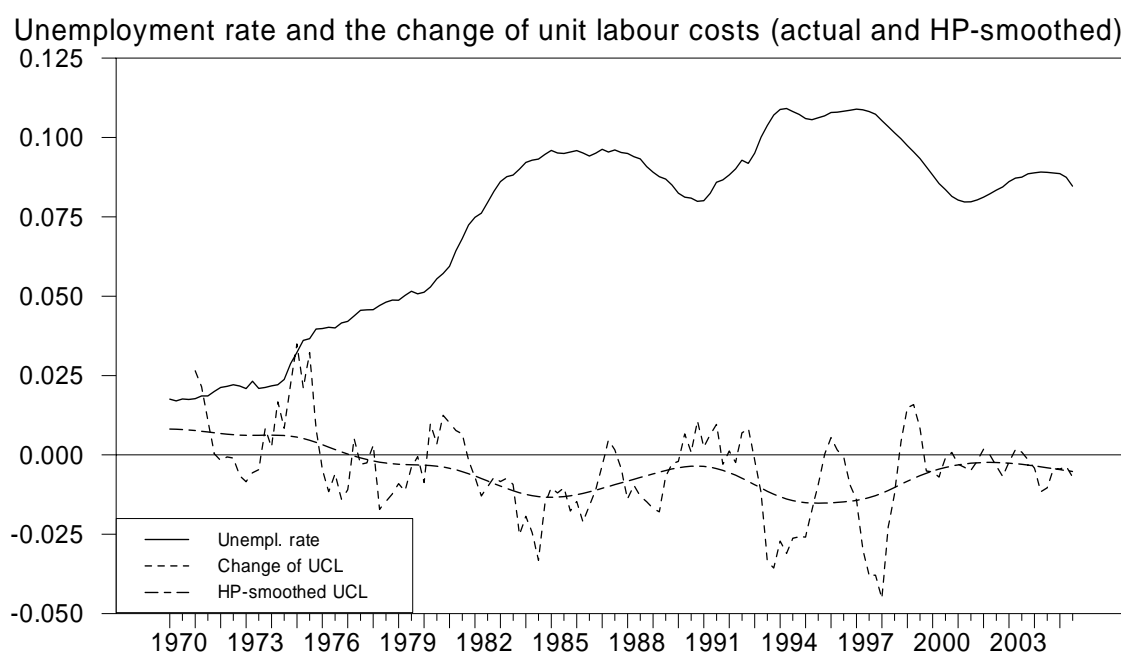
breakdown in “Okun’s Law” and the conjecture of a structural break in the late 1990s. Section 3 outlines our supply-side framework which is build around a normalized production function (de LaGrandville, 1989; Klump and de LaGrandville, 2000) with time-varying, factor-augmenting technical progress (Klump et al., 2004). 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 factor income shares remained relatively stable over decades (Klump et al., 2004), the factor income distribution in the countries that later formed the euro area has 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 labour income has continuously decelerated or, in difference form, real wage growth in the euro area has remained continuously under the growth rate of labour productivity, i.e. unit labour costs (ULC) have decreased (see Figure 1).

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



We see that after the first oil shock the real wage correction was quite modest and not able to eliminate negative employment effects of the supply shocks of the 1970’s. However, coupled with continued and strengthened downward adjustments in unit labour costs in early 1980’s the growth of the unemployment rate levelled off in mid 1980’s and, thereafter, it has fluctuated around close to 10 % level.

Moreover, developments in the euro area 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. 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 labour-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 labour-income share. In the long run, however, labour is replaced over-proportionally by capital and, with rising capital intensity, the labour share will fall again. Besides being unable to explain persistent (continuous) decrease in the labour 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 unity, suggests oil crises, coupled with rigid labour 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 labour-augmenting technical progress.

## 2.2 *Labour 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 behaviour of average labour productivity growth in the euro area. Along a balanced growth path one would expect a constant growth of labour productivity at about 2% per year. But what we find empirically in Table 1 is a decelerating time profile of average euro-area labour 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 labour 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 labour productivity has markedly accelerated. Most observers relate this productivity and growth boom in the US, 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 labour productivity and output growth?

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

**Table 1: Growth of Labour Productivity and Output in the Euro Area**

	1971 – 1980	1981 – 1990	1991 – 1995	1996 - 2005
Growth of Average Labour Productivity, %	2.9	1.8	1.8	0.9
Average per capita Output Growth, %	2.5	1.5	1.2	1.1

A solution to this puzzle should start with the simple empirical evidence that purely labour-augmenting technical change is not a uniform pattern of development across all countries and all periods (Acemoglu, 2003 and Marquetti, 2003). And the ongoing decline in the relative prices of new IT capital goods, such as computers and semiconductors, can be taken as current evidence for strong capital-augmenting technical change (Jalava et al., 2005). But why should capital-augmenting technical change caused by the IT revolution become dominant? One answer would certainly be that IT capital is relatively scarce. As Schrader (2000) reports, the contribution of IT capital to output growth has been significant and rising in relative terms in all G7-countries although interesting differences are observable. In the US, the growth contribution of IT equipment amounts to about half of the entire growth contribution of fixed capital, and in Canada and the UK it is not much less. In continental Europe, however (Germany, France, Italy), it is much smaller. This is mainly due to a lower income share of IT capital goods. The lower income share, in turn, reflects the smaller share of IT assets in the total capital stock.

Evidence for the relative scarcity of capital which then induced capital-augmenting technical progress also 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 labour productivity. The cumulative decrease of unit labour costs may have done, compatibly with Acemoglu's (2003) analysis, capital augmenting technical progress a profitable alternative to that of labour augmenting.<sup>2</sup> Further, given the high average unemployment rate, labour could not be regarded as constraining factor for growth, at least, in the medium run.

To summarise, if the IT revolution in Europe led to an increase in capital-augmenting technical progress and the elasticity of factor substitution was below unity this would have substituted labour-augmenting technical progress. Given the smaller share of capital in total income, this would induce a decrease in total factor productivity, as will be discussed more closely later, and in output growth. And at the same time, the relatively slow increase in real wages compared to labour 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 Law*

Aligned with the puzzling decline in labour 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 labour 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

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<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.

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 are 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 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 (Groschen and Potter, 2003) and the increase in European employment to the beneficial effects on ongoing labour 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:

$$\Delta U_t = \alpha - \beta \Delta \log Y_t \quad (1)$$

where the parameter  $\alpha$  is related to the growth rate of real GDP necessary to keep the unemployment unchanged. Parameter  $\beta$  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, our focus is not in parameter  $\beta$  but in the ratio  $\alpha/\beta$ . This ratio corresponds to the threshold growth rate which, on a balanced growth path with no unemployment would equal the sum of growth of the labour force  $\Delta \log N_t^F$  and of (potentially time-varying) labour augmenting technical progress  $\gamma_t^N$  then the Okun equation can be rewritten as:

$$\Delta U_t = -\beta \left( \Delta \log \left( \frac{Y_t}{N_t^F} \right) - \gamma_t^N \right) \quad (2)$$

As it turns out from equation (2) a downward trend in the average labour 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>3</sup>

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

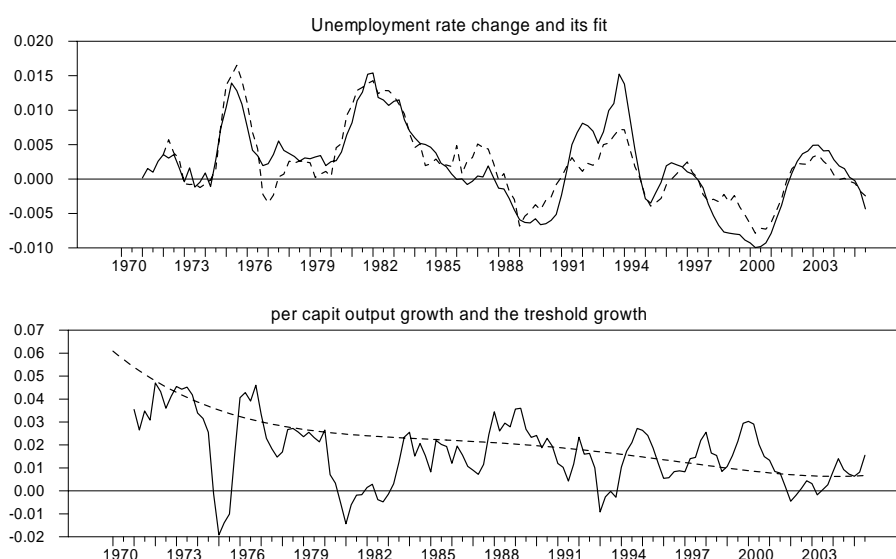
The upper panel of Figure 2 presents the change of the actual unemployment rate and its fit. The lower panel, in turn, presents the observed per capita (in terms of labour force) output

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<sup>3</sup> In this estimation all parameters are highly significant and  $\sum \hat{\beta} = 0.5$ .

growth rates and the implied threshold growth rate. We observe that the threshold growth rate decelerates over the sample period from above 5% to below 1%. In the 1970s until the mid 1980s actual growth is most of time below the threshold rate. This corresponds to the period when the level of unemployment rate continuously increased (or the change of unemployment rate was persistently positive). From the mid 1980s to the early 1990s the decrease of the threshold output growth almost halted resuming to decelerate 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 labour 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 that the threshold growth rate in the Okun's Law relationship should coincide with the time profile of labour augmenting technical progress. Following the Acemoglu hypothesis this time profile need not be constant nor dominant, at least in the short turn, if the elasticity of factor substitution is below unity. If be could show that over the 1990s technical progress in Europe had strong capital bias and factor substitution remained low enough, 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

#### 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 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 labour 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 labour (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 LaGrandville and Solow (2005), and first implemented empirically by Klump, McAdam and Willman (2004). 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 a point elasticity, one needs to fix benchmark values for the level of production, the inputs of capital and labour 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 factor 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.

(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, labour 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 LaGrandville and Solow, 2005):

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

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>4</sup>

The baseline values for capital, labour, 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>5</sup>

(c) The general form (7) and all its admissible variants share the property of being a general mean of the order of  $\frac{1}{\rho}$ . General means, however, are strictly increasing functions of their order (see De LaGrandville 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 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 as important as the savings rate or the growth rate of the labour 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 labour are set equal to one.<sup>6</sup> In other studies these benchmark values correspond to the values of the respective variables in a particular base year.

<sup>4</sup> See Klump and Preissler (2000) and Klump (2001).

<sup>5</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.

<sup>6</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.

(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,

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

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  $i$ .

### 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)  $g_N(\cdot) = g_K(\cdot)$ . However, already simply for descriptive purposes it would be useful to calculate an estimate of the TFP also 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 neighbourhood of  $K_t = K_0$  and  $N_t = N_0$  the TFP component is simplified further and (8) can be approximated by relation:

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

### 3.4 Flexible Modelling 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., labour-augmentation). The intuition for this reflects the feature that whilst capital can be accumulated, labour cannot; thus, labour is the constraining factor, and firms, in order to avoid an explosion of wage income (or labour share), bias and concentrate technical improvements towards labour.

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 labour 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 labour 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>7</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 different  $\lambda_i$  are, respectively,

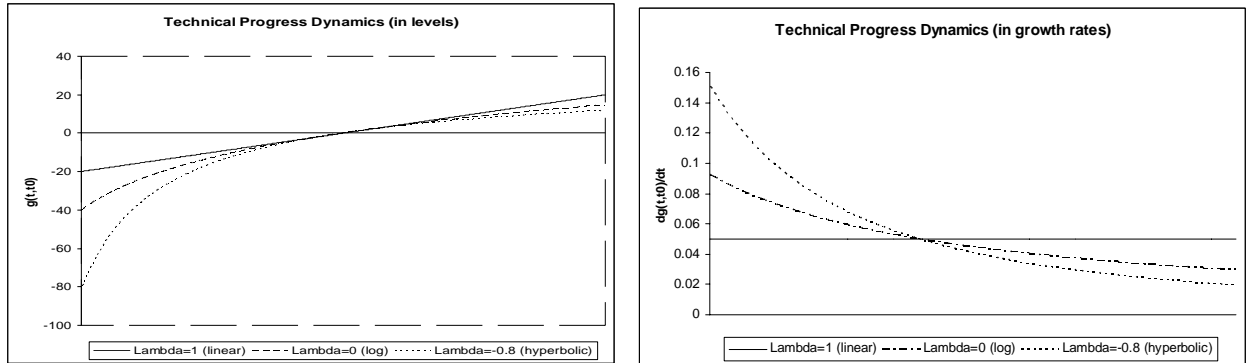
$$g_i(\cdot) \Rightarrow \begin{cases} \lim_{t \rightarrow \infty} g_i(\cdot) = \infty & \text{if } \lambda_i \geq 0 \\ \lim_{t \rightarrow \infty} g_i(\cdot) = -\frac{\gamma_i t_0}{\lambda_i} > 0 & \text{if } \lambda_i < 0 \end{cases} ; \frac{\partial g_i(\cdot)}{\partial t} = \gamma_i \left( \frac{t}{t_0}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

Thus, if  $\lambda \geq 0$ , the *level* of technical progress obtained from factor  $i$  accruing tends to infinity but is bounded otherwise. If  $\lambda = 1$  the *growth* of technical progress is constant but tends to zero for

<sup>7</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.

any  $\lambda < 1$  (illustrated in Figure 3). The main advantage of this flexible (Box-Cox) modelling of technical progress is that it allows the data to decide on the presence and dynamics of factor-augmenting technical progress.<sup>8</sup> If, for example, the data supports an asymptotic steady state, this will arise *naturally* from the dynamics of these curvature functions (i.e., labour-augmenting technical progress becoming dominant, that of capital decaying) rather than being imposed a priori.

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



<sup>8</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.

#### 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>9</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 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>10</sup>

Likewise some additional information is needed to calculate factor incomes. Regarding labour 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 labour 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>11</sup> Hence, the calculation of labour 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:

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

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>12</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.

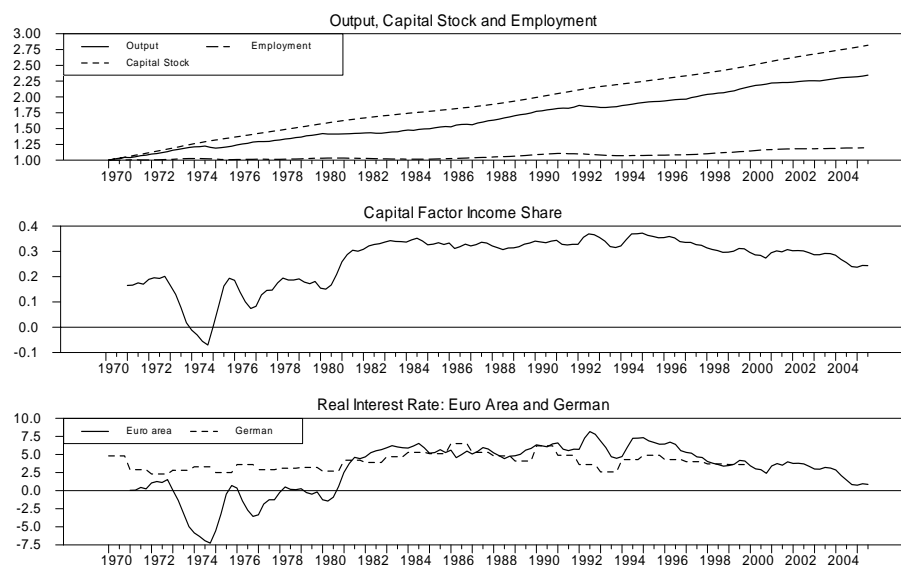
<sup>9</sup> Though we use aggregate data, pronounced labour income share declines apply equally well to constituent countries (e.g., Germany, France, Italy). Our analysis, subject to the relevant data availability, could therefore be mechanically performed at the country level. We leave this for possible future research.

<sup>10</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>11</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>12</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>13</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>14</sup>

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

<sup>13</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>14</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).

constructed to correct the interest rate (upwards) during this period.<sup>15</sup> This corrected interest rate could be interpreted as a shadow rate,  $i^n$ , measuring the marginal cost of financing<sup>16</sup>,  $i^n = i + h \cdot DUM$ , 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  $i^n$  in practice equals the observable interest rate  $i$ .

## 5. Estimation Results

Table 2 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>17</sup> Thereafter, we report individual and total factor productivity (TFP) evaluated at the fixed point; residual stationarity tests; the system metric (the log determinant); and, where applicable, tests for conventional technical neutrality.

The first column shows the full-sample supply-side estimation. Taken at face value they suggest Solow Neutrality. Solow Neutrality, though contrary to balanced growth, is not without its attractions: with historically high unemployment in euro-area economies, it may be unreasonable to assume that labour is the scarce, fixed factor. Indeed, the attractive feature of our framework is that the data (rather than the researcher) selects the appropriate form of technical progress; our flexible modelling of augmentation, while it nests the balanced growth case, need not select it. 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, however, proves that this full-sample estimation does not fulfil stability requirements. Strongly capital augmenting technical progress seems to be coupled with the development in relatively recent past. When gradually dropping years from the sample end-point (results suppressed for brevity) the curvature parameter of the capital augmenting technical progress ( $\lambda_K$ ) decreased and turned statistically insignificant in 1997:4 (second column in Table 2). Correspondingly, the role of labour-augmenting technical progress was strengthened with, in fact, the curvature parameter,  $\lambda_N$ , exceeding one. Likewise, the residual and likelihood results of the system are also satisfactory. This pattern of technical progress with labour augmentation

<sup>15</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 loose 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>16</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>17</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  $h$ ).



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 labour 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) and the references therein.<sup>18</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 the third column of Table 2, 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 with labour 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>19</sup>

What can we conclude? Our paper is concerned with the medium-run economic performance of the euro area and formalising the concept of the medium run in general. This is analyzed within the framework of a long-run supply system using a CES production function with time-varying, factor-augmenting technical progress. We find that the elasticity of substitution between labour and capital is well below unity and that until 1997 labour-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 labour augmenting progress. Although upward shift in capital augmenting is somewhat higher than the drop in labour augmenting progress, the growth of total factor productivity decelerates – due to lower income share of capital than labour the weight of capital augmenting technical progress in total factor productivity than that of labour. 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 labour 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 labour force does not set constraints to the medium-run growth and, hence, technical progress coupled with the 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 labour and capital augmenting technical progress mimics eventual convergence to path balanced growth with constant factor shares (in line with economic theory) but, in line with our “medium-run” emphasis, only approximately so. Our results are therefore supportive of Acemoglu’s view on biased technical change where labour efficiency is dominant in the long run while capital efficiency growth must fade away.

<sup>18</sup> We also confirmed a break in labour productivity using a number of well-known structural break tests (details available). The statistical fit of the non-linear system is uniformly optimized using a break in 1997:4.

<sup>19</sup> Results with these break parameter values imposed are available on request.

## 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 the (weak) Acemoglu hypothesis that aggregate factor elasticity in Europe is below unity (at about 0.7) and that technical progress is purely labour-augmenting in the long run, but capital-augmenting progress can have significant effects in the short run. 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 the development in the US during the same period of time. 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.

The supply side diagnosis means neither a causal explanation nor an obvious therapy but it should improve both. As to the causes of the particular European pattern of growth compared to the US one should start with a look at the basic differences in factor intensities. In the US, labour has always been a relatively scarce factor of production while it had historically been relatively abundant in Europe. More rigid labour market regulations since the 1970s had increased the scarcity of labour in Europe and had thus contributed to the dominance of labour augmenting technical change in the first part of our sample period. Continuous labour market reforms over the 1980s and early 1990s in most European countries induced, however, a change which made capital become the relatively more scarce factor of production. Given this constellation the immediate effects of the IT revolution when they swept over to Europe, had a significant capital-augmenting technology bias which led to a reduction in total factor productivity but an increase in employment despite relatively low growth rates. Regarding a possible therapy to the low productivity and growth performance in the euro area our supply side framework stresses, that the ongoing labour market reforms should be combined with incentives for higher saving and capital investment. Such a growth strategy would be able to achieve higher productivity and output growth without increasing the employment threshold over proportionally.

**Table 2—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)	0.4579 (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)
<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

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