Estimation and Analysis of Euro Area Potential Output Growth

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Work in progress. Preliminary and incomplete. Please do not quote

Comments and suggestions more than welcome

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Abstract

In this paper an extended model-based approach is proposed to estimate and analyse euro area potential output and its components. More precisely, a statistical model combining the production function approach and a Phillips type relationship is developed and fitted to the case of the euro area. The paper extends the production function based model of Proietti, Musso and Westermann (Estimating Potential Output and the Output Gap for the Euro Area: a Model-Based Production Function Approach, 2006, forthcoming in Empirical Economics), by including a series for hours worked as labour input in the production function. The generalised framework is then used to carry out an analysis of the sources of potential output growth in the euro area since 1970 using growth accounting perspective. Finally, the model is extended to allow for a formal analysis of the degree of smoothness of estimates of potential output and its components. In this respect, we propose and evaluate a model–based approach to the extraction of the low–pass component of potential output growth. This framework is also used to the estimation of the optimal degree of smoothness consistent with the definition of potential output as the level of output that is consistent with stable inflation. A major advantage of the approach proposed is that it allows also to assess how the uncertainty characterising estimates changes along with the different degrees of smoothness.

Keywords: Potential output, Output gap, Euro Area, Unobserved components, Production function approach, Low-pass filters.

1 Introduction

Estimates of potential output, typically defined - as proposed by Okun (1962) - as the maximum level of output the economy can produce without inflationary pressures, can play a useful role in macroeconomic analysis. In the European context, estimates of potential output and the deviations of actual output from potential, known as the output gap, represent an important input into the economic policy process. From the monetary policy perspective, estimates of potential output growth are one of the factors from which a reference value for monetary growth are derived (see ECB, 2004). As regards fiscal policy, these estimates are instrumental in deriving measures of structural budget deficits, which play a key role in the context of the Stability and Growth Pact. Moreover, from a structural policy perspective, estimates of potential output and its components can provide indications on the sustainability of growth developments as well as the need for further reforms in the labour and product market, also against the background of the targets of the Lisbon strategy.

This paper proposes a model-based approach to estimate and analyse euro area potential output growth. Starting from the production function based model of Proietti, Musso and Westermann (2006) (henceforth referred to as PMW (2006)), this paper aims at making three main contributions. First, the model of PMW (2006) is extended and includes a series for hours worked as labour input in the production function (as opposed to employment, like several previous studies have done). Second, the paper develops the growth accounting analysis that can be implemented within this approach, allowing for a discussion of sustainable developments in a single coherent framework. Finally, it provides a discussion of the question of the desirable level of smoothness of potential output estimates in a formal way.

PMW (2006) propose a multivariate model which, from an economic point of view, combines a production function and a Phillips-type of relationship and, from a statistical perspective, is formally represented as a multivariate unobserved components model. Among the various alternative specifications considered by PMW (2006) which appear to perform relatively well in terms of validity (assessed from a predictive content point of view, through an extensive rolling forecast experiment), reliability (evaluated on the basis of the final estimation error of the unobserved components) and consistency (judged from the fit within the sample, with an emphasis on the capability of providing an exhaustive representation of the individual series dynamics), in this paper we adopt as reference point the so-called pseudo-integrated cycles model. The key aspect of this specification is that it is assumed that the cyclical component of each variable (productivity, capital and labour) is driven by both the economy-wide business cycle and an idiosyncratic cycle. This choice appears to be particularly important in modelling euro area labour market variables, which tend to follow a more persistent cycle compared to other variables. Moreover, this specification encompasses several other cases of interest and is therefore relatively general. While PMW (2006) model the labour input via employment, given the lack of a quarterly series for hours worked for the euro area covering a sufficient sample period, the model is extended to include hours worked as a proxy for labour. This choice is more line with traditional production function analysis, and allows to obtain more reliable estimates of total factor productivity growth.

In this paper we also fully exploit the proposed framework as regards the growth accounting analysis. Previous similar production function approaches hint at the possibility of using this framework for such an analysis but rarely undertake a detailed model-based growth accounting investigation, a gap which this paper aims to fill for the euro area. Thus, we provide a detailed empirical assessment of the source of potential output growth in the euro area from 1970 to 2005. We approach the problem by first investigating the role played by the three main sources of potential growth, namely improvements in labour productivity, increases in labour utilisation and demographic forces (i.e. changes in the working age population). Second, we also assess the contribution of various components of the main sources of growth, including total factor productivity, capital deepening, average hours worked, the employment rate, the participation rate, total population and the dependency ratio.

Discussions of the appropriate or desirable degree of smoothness of potential output estimates most often are undertaken in an informal way. Several studies, for example, follow the approach of Gordon (1998) (with reference to the NAIRU) and apply a smoothness prior without a formal analysis to justify it. In this paper we show how it is possible to extend the statistical framework adopted to allow for a formal discussion of the degree of smoothness of potential output and its components as well as for an estimation of the optimal degree of smoothness (based on the information content of the data). However, such an extension also allows to link formally the choice of smoothness degree to economic considerations, such as the stylised facts of the business cycle. A major advantage of the approach proposed is that it allows also to assess how the uncertainty characterising estimates changes along with the different degrees of smoothness.

The paper is structured as follows. Section 2 provides an overview of the main framework of analysis, namely the extended production function approach. Section 3 reports the empirical analysis, including the growth accounting investigation. Section 4 illustrates the extension of the framework which allows for a formal discussion of the smoothness issue. Finally, section 5 summarises the conclusions that can be drawn from the analysis and highlights the main planned extensions of the approach.

2 The model

2.1 The production function approach

Let y_t denote the logarithms of output, and consider its decomposition $y_t = \mu_t + \psi_t$, where potential output, μ_t, is the expression of the long run behaviour of the series and ψ_t, denoting the output gap, is a stationary component, usually displaying cyclical features. Potential output is the level of output consistent with stable inflation, whereas the the output gap is an indicator of inflationary pressure.

The production function approach is a multivariate method that obtains potential output from the "non-inflationary" levels of its structural determinants, such as productivity and factor inputs.

Assuming a Cobb-Douglas technology exhibiting constant returns to scale, the aggregate production function takes the form:

$$y_t = f_t + \alpha h_t + (1 - \alpha) k_t. \tag{1}$$

where f_t is the Solow residual, h_t is hours worked (in logarithms), k_t is the capital stock, and α is the elasticity of output with respect to labour $(0 < \alpha < 1)$.

In setting up the measurement model, the variables on the right hand side of equation (1) are decomposed additively into their permanent (P) and transitory (T) components:

$$f_t = f_t^{(P)} + f_t^{(T)}, \quad h_t = h_t^{(P)} + h_t^{(T)}, \quad k_t = k_t^{(P)}; \tag{2}$$

this breakdown is useful to measure the contribution of production factors and their constituent series

Hence, we achieve the required decomposition of output into potential and gap:

$$\begin{aligned} y_t &= \mu_t + \psi_t \\ \mu_t &= f_t^{(P)} + \alpha h_t^{(P)} + (1-\alpha) k_t \\ \psi_t &= f_t^{(T)} + \alpha h_t^{(T)} \end{aligned} \tag{3}$$

where potential output is the value corresponding to the permanent values of factor inputs and f_t, while the output gap is a linear combination of the transitory components. Under perfect competition α is coincident with the labour share of output. For the euro area the average labour share obtained from the national accounts (adjusted for the number of self-employed) is 0.65.[1]

Hours worked can be further decomposed into four determinants, as can be seen from the identity $h_t = n_t + pr_t + er_t + hl_t$, where n_t is the logarithm of working age population, pr_t is the logarithm of the labour force participation rate, er_t is that of the employment rate, and hl_t is the logarithm of labour intensity. The determinants are in turn decomposed into their permanent and transitory components in order to obtain the decomposition:

$$h_t^{(P)} = n_t + pr_t^{(P)} + er_t^{(P)} + hl_t^{(P)}, \quad h_t^{(T)} = pr_t^{(T)} + er_t^{(T)} + hl_t^{(T)}. \tag{4}$$

The idea is that population dynamics are fully permanent, whereas labour force participation, employment and hours are also cyclical. Moreover, since the employment rate can be restated in terms of the unemployment rate, we can relate the output gap to cyclical unemployment and potential output to structural unemployment.

2.2 The Multivariate Model

The multivariate unobserved components model for the estimation of potential output and the output gap, implementing the production function approach (PFA) outlined in the previous sub-

[1] Although the choice of a Cobb-Douglas production function with constant factor income shares is to some extent controversial and the evidence for the euro area in this respect is scarce, Willman (2002) provides some evidence in favour of such a production function for the euro area. See Musso and Westermann (2005) for adjusted estimates of the euro area labour share.

section, is formulated in terms of the six variables

$$[f_t,\ hl_t,\ pr_t,\ cur_t,\ c_t,\ p_t]' = [\mathbf{y}_t', \quad p_t]'.$$

The variables divided into two blocks. The first block defines the permanent-transitory decomposition of $\mathbf{y}_t = [f_t, \quad hl_t, \quad pr_t, \quad cur_t, \quad c_t]'$, and yields PO and OG according to the PFA. The second block is the price equation, which relates underlying inflation to the output gap.

For $\mathbf{y}_t$, we specify the following system of time series equations:

$$\mathbf{y}_t = \boldsymbol{\mu}_t + \boldsymbol{\psi}_t + \boldsymbol{\Gamma}\mathbf{X}_t, t = 1, \ldots, T, \tag{5}$$

where $\boldsymbol{\mu}_t = \{\mu_{it}, i = 1, \ldots, 5\}$ is the 5×1 vector containing the permanent levels of f_t, hl_t,pr_t, cur_t, and c_t, $\boldsymbol{\psi}_t = \{\psi_{it}, i = 1, \ldots, 5\}$ denotes the transitory component in the same series, and $\boldsymbol{\Gamma}\mathbf{X}_t$ are fixed effects.

The permanent component is specified as a multivariate integrated random walk:

$$\Delta^2\boldsymbol{\mu}_t = \boldsymbol{\zeta}_t, \quad \boldsymbol{\zeta}_t \sim \text{NID}(\mathbf{0}, \boldsymbol{\Sigma}_\zeta). \tag{6}$$

Here $\Delta = 1 - L$ denotes the difference operator, and L is the lag operator, such that $L\mathbf{y}_t = \mathbf{y}_{t-1}$; NID stands for normally and independently distributed. It is assumed that the disturbance covariance matrix has rank 4. This restriction enforces the stationarity of c_t around a deterministic trend, possibly with a slope change, and amounts to zeroing out the elements of $\boldsymbol{\Sigma}_\zeta$ referring to c_t, and introducing a slope change variable in $\mathbf{X}_t$. For more details about the trend in capacity see PMW (2006).

The matrix $\mathbf{X}_t$ contains interventions that account for a level shift both in pr_t and cur_t in 1992.4, an additive outlier (1984.4) and a slope change in capacity utilisation, c_t; $\boldsymbol{\Gamma}$ is the matrix containing their effects.

As far as the specification of the cyclical component $\boldsymbol{\psi}_t$ is concerned, we adopt the pseudo-integrated cycles specification (PMW, 2006). In particular, we take the cycle in capacity as the reference cycle, writing $\psi_{5t} = \bar{\psi}_t$,

$$\bar{\psi}_t = \phi_1\bar{\psi}_{t-1} + \phi_2\bar{\psi}_{t-2} + \kappa_t, \ \ \kappa_t \sim \text{NID}(0, \sigma^2_\kappa), \tag{7}$$

a stationary second order autoregressive process. The roots of the autoregressive polynomial are a pair of complex conjugates. This restriction is imposed by the following reparameterisation:

$\phi_1 = 2\rho\cos\lambda_c$, $\phi_2 = -\rho^2$, with $\rho \in (0,1)$ and $\lambda_c \in [0,\pi]$. For the cycle in the i-th variable $(i = 1,2,3,4)$, where i indexes f_t, hl_t, pr_t, cur_t,

$$\psi_{it} \quad = \quad \rho_i\psi_{i,t-1} + \theta_i(L)\bar{\psi}_t + \kappa_{it}, \quad \kappa_{it} \sim \text{NID}(0, \sigma^2_{\kappa,i}) \tag{8}$$

where κ_{it} is an idiosyncratic disturbance, ρ_i is a damping factor. We refer to (8) as a *pseudo-integrated cycle.* It encompasses several leading cases of interest:

1. If $\theta_i(L) = 0$, it defines a fully idiosyncratic AR(1) cycle with autoregressive coefficient ρ_i and disturbance variance $\sigma^2_{\kappa,i}$.
2. If $\rho_i = 0$ the i-th cycle has a common component and a white noise idiosyncratic one, that is $\psi_{it} = \theta_i(L)\psi_t + \kappa_t$.
3. If $\rho_i = 0$ and $\sigma^2_{\kappa,i} = 0$ the i-th cycle reduces to a model with a common cycle, that is $\psi_{it} = \theta_i(L)\psi_t$.

The rationale of (8) is that the cycle in the i-th series is driven by a combination of autonomous forces and by a common cycle; cyclical shocks, represented by $\bar{\psi}_t$ are propagated to other variables according to some transmission mechanism, which acts as a filter on the driving cycle. As a result, the cycle ψ_{it} is more persistent, albeit still stationary, than $\bar{\psi}_t$. This framwork is relevant for extracting the cycle from the labour variables.

Potential output and the output gap are defined as linear combinations of the cycles and trends in (5):

$$\mu_t = [1, \;\; \alpha, \;\; \alpha, \;\; -\alpha, \;\; 0]'\boldsymbol{\mu}_t + \alpha n_t + (1-\alpha)k_t; \qquad \psi_t = [1, \;\; \alpha, \;\; \alpha, \;\; -\alpha, \;\; 0]'\boldsymbol{\psi}_t,$$

the latter affects the changes in underlying inflation.

The specification of the model is completed by the price equation, which is a generalisation of the Gordon triangle model of inflation (Gordon, 1997):

$$\begin{array}{rcll} p_t & = & \tau_t + \delta_C(L)compr_t + \gamma_t + \delta_N(L)neer_t & \\ \tau_t & = & \tau_{t-1} + \pi^*_{t-1} + \eta_{\pi t} & \eta_{\pi t} \sim \text{NID}(0, \sigma^2_{\eta\pi}), \\ \pi^*_t & = & \pi^*_{t-1} + \theta_\pi(L)\psi_t + \zeta_{\pi t} & \zeta_{\pi t} \sim \text{NID}(0, \sigma^2_{\zeta\pi}); \end{array} \tag{9}$$

where γ_t is a seasonal component. It is assumed that the disturbances are mutually independent and independent of any other disturbance in the output equation, so that the only link between the prices and output equations is due to the presence of ψ_t as a determinant of inflation, π_t^*; the order of the lag polynomial $\theta_\pi(L)$ is one, and we write $\theta_\pi(L) = \theta_{\pi 0} + \theta_{\pi 1} L$.

The reduced form of equation (9) is:

$$\Delta^2 p_t = \theta_\pi(L)\psi_{t-1} + \mathsf{DS}_t + \delta_C(L)\Delta^2 compr_t + \delta_N(L)\Delta^2 neer_t + \theta(L)\epsilon_t,$$

where DS_t is a deterministic seasonal kernel. The term $\theta(L)\epsilon_t$ is the MA(1) representation of the process $\zeta_{\pi,t-1}+\Delta\eta_{\pi,t}$. Gordon (1997) stresses the importance of entering more than one lag of the output gap in the triangle model, which allows to distinguish between level and change effects; this follows from the decomposition $\theta_\pi(L) = \theta_\pi(1) + \Delta\theta_\pi^*(L)$. In our case $\theta^*(L) = -\theta_{\pi 1}$; $\theta_\pi(1) = \theta_{\pi 0} + \theta_{\pi 1} = 0$ would imply that the output gap has only transitory effects on inflation.

The price equation features the three essential ingredients of Gordon's triangle model: an exogenous component driven by the nominal effective exchange rate of the euro and commodity prices, which enter with a first order lag polynomial, inflation *inertia* associated with the unit root in inflation and an MA(1) feature, the presence of demand shocks: π_t^* depends dynamically on the current and past values of the output gap, via the lag polynomial $\theta_\pi(L)$.

3 The empirical analysis

3.1 Database description

The time series used in this paper, listed below, are quarterly data for the euro area covering the period from the first quarter of 1970 to the second quarter of 2005. As far as possible euro area wide data are drawn from official sources such as Eurostat or the European Commission. Historical data for euro area-wide aggregates were largely taken from the Area-Wide Model (AWM) database (see Fagan, Henry and Mestre, 2001).

Series	Description	Transformation
y_t	Gross Domestic Product at constant prices	Log
k_t	Capital Stock at constant prices	Log
h_t	Hours worked, Total	Log
l_t	Employment, Total	Log
hl_t	Hours per worker	$(h_t - l_t)$
f_t	Total Factor Productivity	$(y_t - 0.65h_t - 0.35k_t)$
pr_t	Labour Force Participation Rate	Log
er_t	Employment rate	Log
cur_t	Contribution of Unemployment Rate	$(-er_t)$
n_t	Population	Log
c_t	Capacity Utilisation (Survey based)	Log
p_t	Consumer prices index	Log
$compr_t$	Commodity prices index (both oil and non-oil)	Log
$neer_t$	Nominal effective exchange rate of the euro	Log

The plot of the series is available from figure 1. All the series are seasonally adjusted except for p_t and $compr_t$. Residual seasonal effects were detected for the labour market series, especially cur_t; pr_t and cur_t are subject to a downward level shift in the fourth quarter of 1992, consequent to a major revision in the definition of unemployment.

The series on hours worked, h_t, results from the interpolation of the euro area aggregate annual time series derived from the country data of the Total Economy Database of The Conference Board and Groningen Growth and Development Centre (January 2006 vintage; for Germany, data before 1991 were approximated on the basis of the growth rates of data for West Germany). The quarterly series was estimated using the Fernandez method (postulating a random walk for the and using employment as an indicator variable. See Proietti (2004) for further details.

The capital stock at constant prices is constructed from euro area wide data on seasonally adjusted fixed capital formation by means of the perpetual inventory method. As in Rünstler (2002) and PMW (2006), we define the contribution of the unemployment rate (cur_t) as minus the

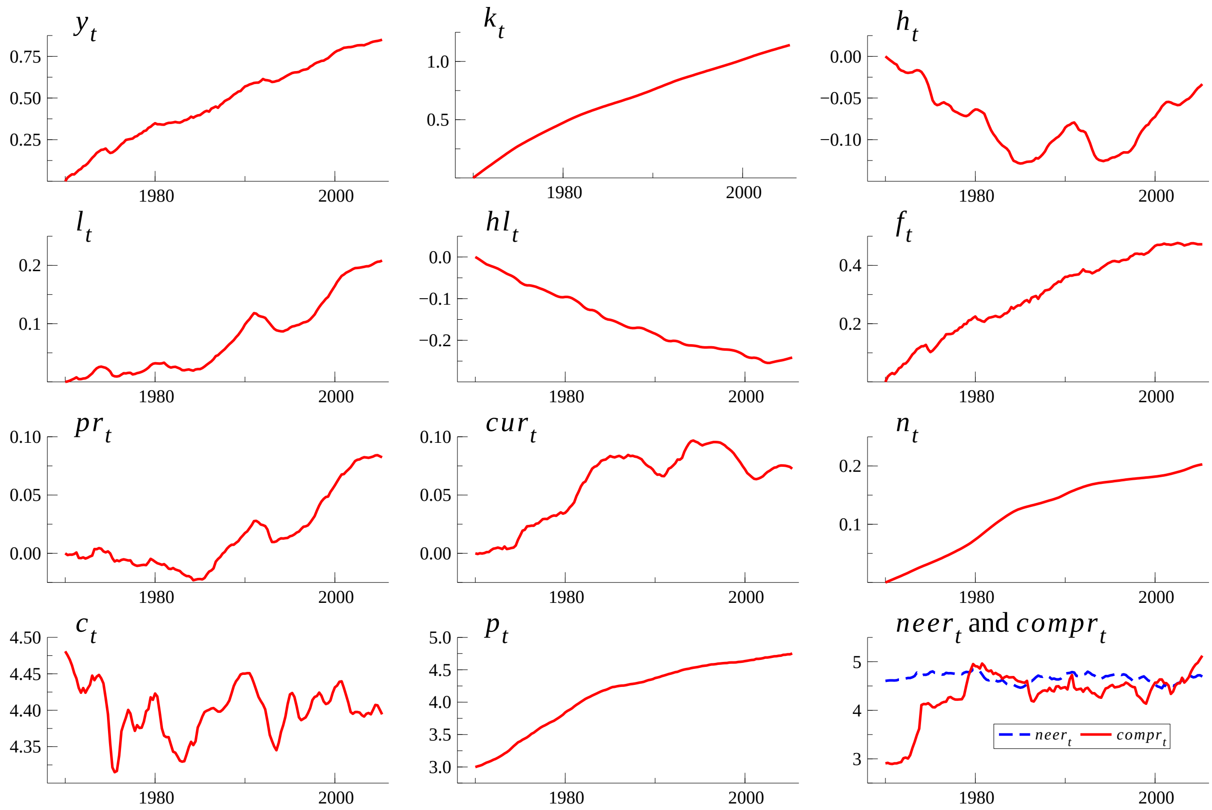

Figure 1: Plot of the available time series.

logarithm of the employment rate (er_t). cur_t enables modelling the natural rate of unemployment without breaking the linearity of the model, the only consequence for the measurement model being a sign change in (4). In fact, denoting with U_t the unemployment rate, then $cur_t = -\ln(1-U_t) \approx U_t$ is the first order Taylor approximation of the unemployment rate.

Seasonally adjusted survey based rates of capacity utilisation in manufacturing were obtained from the European Commission starting from 1980.1 and self compiled (GDP-weighted average of available national indices) for previous years. The logarithm of capacity utilisation in the manufacturing sector, c_t, is slightly trending. The evidence arising from the Busetti and Harvey (2001) test is that we cannot reject stationarity when the trend is linear and subject to a level shift and slope break occurring in 1975.1.

3.2 Estimation results

The model is estimated by maximum likelihood using the support of the Kalman filter. Estimation and signal extraction were performed in Ox 3.3 (Doornik, 2001) using the Ssfpack library, version beta 3.2; see Koopman, Doornik and Shephard (1999). The maximum likelihood estimate of the covariance matrix of the trend disturbances resulted

$$10^7 \cdot \tilde{\mathbf{\Sigma}}_\zeta = \begin{bmatrix} 2.176 & -0.446 & -0.040 & -0.714 & 0.000 \\ -1.555 & 5.591 & -0.297 & -0.006 & 0.000 \\ -0.104 & -1.236 & 3.083 & 0.420 & 0.000 \\ -2.207 & -0.027 & 1.545 & 4.387 & 0.000 \\ 0.000 & 0.000 & 0.000 & 0.000 & 0.000 \end{bmatrix}$$

(the upper triangle reports correlations). The estimated cycle in capacity is

$$\begin{array}{lllll} \bar{\psi}_t = & 1.63 & \bar{\psi}_{t-1} - & 0.71 & \bar{\psi}_{t-2} + \kappa_t, \quad \kappa_t \sim \text{NID}(0, 422 \times 10^{-7}), \\ & (.02) & & (.04) & \end{array}$$

and implies a spectral peak at the frequency 0.28 corresponding to a period of about five to six years. The specific damping factors, ρ_i, are similar for pr_t and cur_t (0.93 and 0.89, respectively) and are closer to zero for f_t and hl_t (0.39 and 0.30, respectively).

Table 1 reports the parameter estimates of the loading and the pseudo–integrated cycles parameters. All the loadings parameters are significant, with the exception of those for hl_t, for which

Table 1: Parameter estimates and diagnostics for the multivariate PFA model with pseudo-integrated cycles

	θ_{i0}	θ_{i1}	ρ_i	$10^7 \cdot \sigma^2_{\kappa,i}$	$Q(4)$	N
f_t	0.341	-0.207	0.39	131	3.79	11.68
	(.044)	(.038)	(.11)			
hl_t	0.009	0.005	0.30	0	105.50	11.72
	(.008)	(.010)	(.62)			
pr_t	0.052	-0.026	0.94	13	15.69	4.68
	(0.016)	(.016)	(.08)			
cur_t	-0.048	0.022	0.68	0	4.68	4.76
	(0.012)	(0.013)	(.06)			
c_t	–	–	–	–	4.23	3.78
	$\theta_{\pi 0}$	$\theta_{\pi 1}$	$10^7 \cdot \sigma^2_{\eta\pi}$	$10^7 \cdot \sigma^2_{\zeta\pi}$	$Q(4)$	N
p_t	0.160	-0.145	64	13		
	(.039)	(.040)			2.70	3.58
Log Lik.			3899.45			

the cyclical component has a very small amplitude. The price equation provides an excellent fit. The Wald test of the restriction $\theta_{\pi 0} + \theta_{\pi 1} = 0$ (long run neutrality of inflation to the output gap) is not significant. As a result, the change effect is the only relevant effect of the gap on inflation. The table also reports the LjungBox test statistic, using four autocorrelations, computed on the standardised Kalman filter innovations, and the Bowman and Shenton (1975) normality test. Significant residual autocorrelation is detected for hl_t. It must however be remarked that the residual display a highly significant lag 4 autocorrelation, which arises as a consequence of the temporal disaggregation of hours worked.

The individual components and the corresponding output gap estimates are plotted in figure 2, along with the decomposition of potential output quarterly growth ($\Delta\tilde{\mu}_t$) into its three sources (growth accounting).

The plot reveals that smoothness is indeed an issue here since potential output growth estimates suffer from excess cyclicality. The next section illustrates how to extract a low–pass component from the trend and how the reliability of this component can be assessed.

3.3 Stylised facts on potential output growth in the euro area

Although growth accounting exercises can provide very useful information, it is important to keep in mind that they can only represent a starting point in any comprehensive analysis of growth ad its sources. As a matter of fact, a growth accounting perspective can only provide information on the proximate, or immediate, sources of growth (such as TFP growth, capital and labour), while being silent on the fundamental, or ultimate, sources (such as institutions or preferences). Moreover, a policy analysis cannot disregard the important interactions between the different sources of growth, on which a growth accounting perspective cannot provide much information. Nevertheless, keeping these caveat in mind, it is widely recognised that useful insights can be gleaned from decompositions of potential growth into its main components.

Potential output can be decomposed in alternative ways. From an accounting point of view, for example, it can be decomposed into labour productivity (output per hour worked), labour utilisation (hour worked per head of the working age population) and working age (defined as persons aged 15 to 64) population growth. From a production function perspective potential

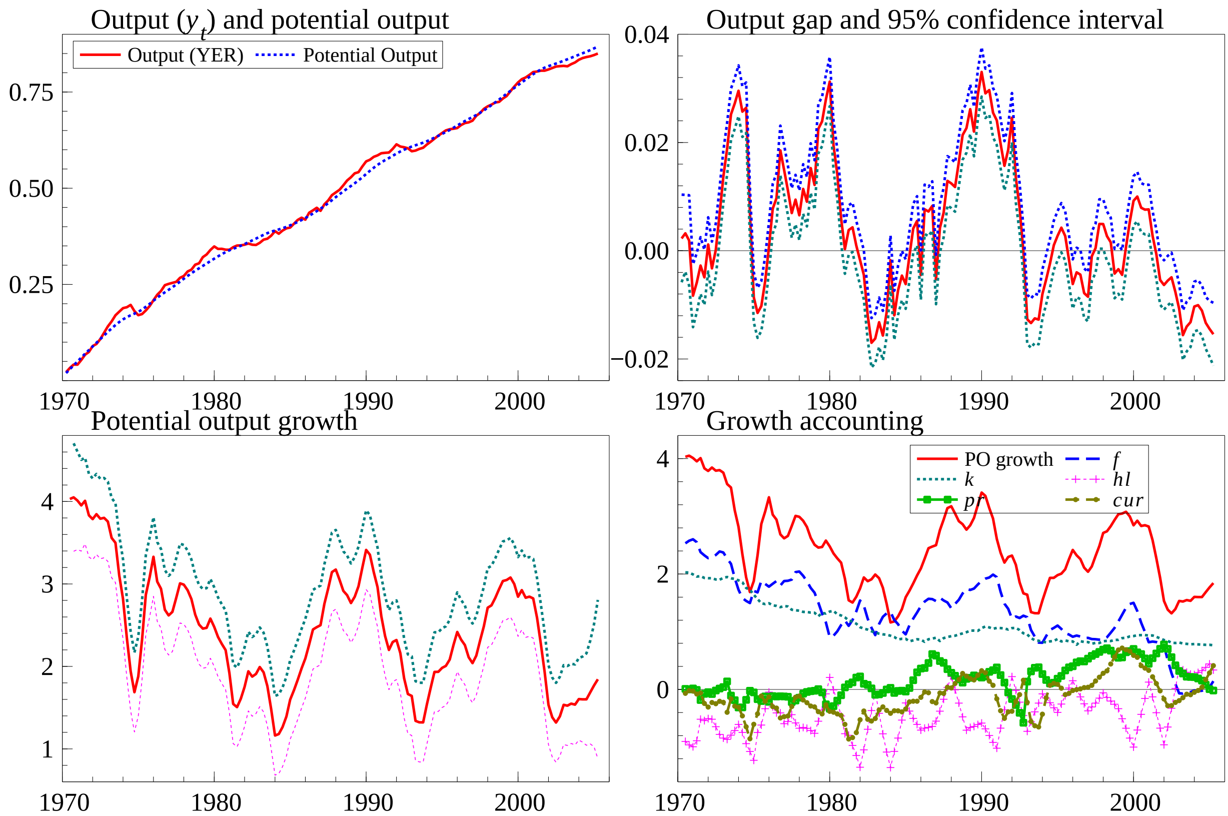

Figure 2: Multivariate PFA model with IRW trends and pseudo-integrated cycles. Smoothed components of potential output, output gap estimates (with 95% confidence bounds) and decomposition of potential output growth.

output can be seen as resulting from total factor productivity (TFP) growth, the contribution from capital deepening (the change in capital intensity) and the labour input (hours worked). From both perspectives, the estimates of the components provide a similar picture. More precisely, the evolution of euro area potential output growth since 1970 would appear to have resulted from the combination of two forces working in opposite direction: the contributions to potential growth of the growth in labour productivity and working age population have been gradually decreasing, while the opposite pattern can be observed for labour utilisation growth (see Tables A and B and Charts A to D in the annex). In order to abstract from cyclical developments (which are still present given the residual ciclycality in the estimates, an aspect addressed more in detail in the next section), it is useful to observed the average developments over the past three (trough-to-trough) business cycles. For example, although labour productivity growth remains the main factor of potential output growth, over the past three cycles its contribution has declined from an average of 3.1 percent during the 75-82 cycle to an average of 2.4 percent during the 82-93 cycle and to an average of 1.5 percent during the 93-03 cycle1. The growth rate of working age population has been gradually declining by about 0.3 percentage point across cycles. Finally, the contribution from labour utilisation growth increased significantly from the 1970s onwards, and became positive on average in the latest cycle. The latter factor largely compensated for the decreasing contributions from productivity and demographic forces.

The estimates of the more detailed components of the main factors of growth are shown in Table C and Charts E to L of the annex. Starting from demographic factors, the negative trend in working age population growth in Europe since 1970 has mainly reflected adverse changes in the age structure. Although total population growth has slightly declined on average across decades, the change has been minor. More important has been the declining contribution to growth from changes in the overall dependency ratio, largely as a result of the gradually increasing old age dependency ratio (while the young age dependency ratio has been declining).

The gradual increase in labour utilisation since the mid-1990s, reversing a steady deterioration over the preceding two decades, was undeniably in support of higher potential output growth. These more positive developments can at least partially be associated with successful labour market policies towards higher participation and a protracted period of wage moderation which gradually raised the rate of employment in the euro area. The contribution from labour utilisation however continued to be negatively affected by the trend decline in average hours worked per person employed. From a longer perspective, focusing on average developments over the past three economic cycles, the contribution to growth from labour utilisation reflected similar trends in the contributions from more specific factors, average hours worked, the employment rate (or the contribution from the unemployment rate) and the participation rate. Average hours worked continued to decline throughout the three periods, but the rate of decline gradually decreased on average and in the most recent years the trend level of average hours worked remained broadly unchanged or even increased slightly. However, these developments over the past three cycles were partially compensated for by a stronger average increase in the trend participation rate (mainly driven by increases in the trend participation rate for women) and, during the most recent cycle, a stabilisation of the trend unemployment rate (NAIRU). As a result, during the most recent cycle the contribution of labour utilisation growth to potential growth became positive on average.

Over the last decade hourly labour productivity decelerated significantly, representing a major force causing a tendency towards lower potential output growth. A possible interpretation of developments is that the labour productivity growth slowdown over the last decade could largely be attributed to more robust job creation, supported by a sustained period of wage moderation and the impact of labour market reforms. In this respect, the slowdown in productivity growth could have resulted to some extent from a trade-off with increased labour utilisation, as the latter mechanically induced a slower pace of capital deepening. Beyond the higher "job-intensity" of growth, however, other factors may have played a role in the slowdown of labour productivity growth. This view appears to be confirmed by analysis of estimates of the trends of the main components of labour productivity growth, discussed below. Despite favourable economic conditions, hourly labour productivity growth declined in the second half of 1990s as well as during the first half of the first decade of the new millennium (2001-2005). Developments over the last decade represent not only a downward shift from the first half of the 1990s, but also compared to average developments in the previous three decades. These developments stand in stark contrast to the corresponding ones for the US economy, which experienced a turning point in labour productivity growth trend, often associated with the widespread adoption of the advances in Information and Communication Technology (ICT). Not only didn't the euro area experience such positive turning point, but the gradual declining trend continued during the last decade, and possibly accelerated during the recent five years. Labour productivity growth can usefully be decomposed into contributions from TFP (defined as real output per unit of all -combined- inputs) and capital deepening (i.e., the increase in capital per unit of labour). It is often assumed that TFP, sometimes called equivalently multi-factor productivity (MFP), is a measure closer to capturing technological progress. However, TFP is a catch-all term that captures the impact of several factors, such that it is not immediate to associate its evolution to technological advances. Measurement problems imply that estimates of TFP growth and capital deepening are surrounded by significant uncertainty. For example, the lack of measures of euro area capital and labour quality for a prolonged period of time implies that available estimates of TFP would also capture changes in factor quality. Nevertheless, available estimates suggest that the trend decline in labour productivity growth resulted from both lower trend capital deepening and lower trend TFP growth. As regards the more recent decade, the former can partly be associated with the robust pace of job creation since the mid-1990s, while the latter might be partly explained by higher utilisation of lower skilled workers. However, these declining trends can be observed since at least the 1970s. Moreover, available estimates of trend TFP growth do not point to a change in the underlying pattern in the most recent years.

4 To smooth or not to smooth? That's an issue

Frequently, estimates of potential output and its components display a significant degree of volatility or cyclicality which may seem at odd with the implicit idea that these factors should change slowly over time or even change rarely, if at all. Thus, often the variance of some of these components is restricted somewhat arbitrarily. In this section we propose an extension of our approach which allows for a formal analysis of the degree of smoothness of estimates of potential output and its components. A major advantage of the approach proposed is that it allows also to assess how the uncertainty characterising estimates changes along with the different degrees of smoothness.

4.1 Model-based low-pass filtering of potential output

This section defines a class of low-pass filters for the separation of the long run movements in potential output growth. In particular, we propose a model-based decomposition that enables to extract a smoothed potential output series, and the corresponding decomposition into the sources of growth, and allows to measure its uncertainty. Our result is based on an exact and parametric decomposition of the process $\boldsymbol{\mu}_t$ and it is a multivariate generalisation of the results in Proietti (2004).

The starting point is the following decomposition of the multivariate white noise disturbance $\boldsymbol{\zeta}_t$:

$$\boldsymbol{\zeta}_t = \frac{(1+L)^n \boldsymbol{\zeta}_t^{\dagger} + (1-L)^m \boldsymbol{\kappa}_t^{\dagger}}{\varphi(L)}, \tag{10}$$

where $\boldsymbol{\zeta}_t^{\dagger}$ and $\boldsymbol{\kappa}_t^{\dagger}$ are two mutually and serially independent Gaussian disturbances, $\boldsymbol{\zeta}_t^{\dagger} \sim \text{NID}(\mathbf{0}, \boldsymbol{\Sigma}_{\zeta})$, $\boldsymbol{\kappa}_t^{\dagger} \sim \text{NID}(\mathbf{0}, \lambda\boldsymbol{\Sigma}_{\zeta})$, and the scalar polynomial $\varphi(L)$ is such that:

$$|\varphi(L)|^2 = \varphi(L)\varphi(L^{-1}) = |1+L|^{2n} + \lambda|1-L|^{2m}. \tag{11}$$

The existence of the polynomial $\varphi(L) = \varphi_0 + \varphi_1 L + \cdots + \varphi_{q^*} L^{q^*}$, of degree $q^* = \max(m, n)$, satisfying (11), is guaranteed by the fact that the Fourier transform of the rhs is never zero over the entire frequency range; see Sayed and Kailath (2001).

In the light of (10)-(11), the process $\boldsymbol{\mu}_t$ can be decomposed into orthogonal low-pass and high-pass components:

$$\boldsymbol{\mu}_t = \boldsymbol{\mu}_t^{\dagger} + \boldsymbol{\psi}_t^{\dagger},$$

where the components have the following representation:

$$\begin{array}{rcll} \varphi(L)\Delta^2 \boldsymbol{\mu}_t^{\dagger} & = & (1+L)^n \boldsymbol{\zeta}_t^{\dagger}, & \boldsymbol{\zeta}_t \sim \text{NID}(\mathbf{0}, \boldsymbol{\Sigma}_{\zeta}) \\ \varphi(L)\boldsymbol{\psi}_t^{\dagger} & = & \Delta^{m-2}\boldsymbol{\kappa}_t^{\dagger}, & \boldsymbol{\kappa}_t^{\dagger} \sim \text{NID}(\mathbf{0}, \lambda\boldsymbol{\Sigma}_{\zeta}). \end{array} \tag{12}$$

The low-pass component, $\boldsymbol{\mu}_t^{\dagger}$, has the same order of integration as $\boldsymbol{\mu}_t$ (regardless of m) and the cycle is stationary provided that $m \geq 2$. Moreover, if $m \geq 2$ the high–pass component $\boldsymbol{\psi}_t^{\dagger}$ has a stationary representation. In particular, if $m = 2$ $\boldsymbol{\psi}_t^{\dagger}$ has a second order vector autoregressive representation with scalar AR polynomial, $\varphi(L)$, whereas if m is strictly greater than 2, it will feature unit $m-2$ unit roots in the moving average representation. It should also be noticed that the covariance matrices of the low-pass and high-pass disturbances, $\boldsymbol{\zeta}_t^\dagger$ and $\boldsymbol{\kappa}_t^\dagger$, are proportional, $\lambda \geq 0$ being the proportionality factor. Obviously, if $\lambda = 0$, $\boldsymbol{\mu}_t = \boldsymbol{\mu}_t^\dagger$. As λ increases, the smoothness of the low–pass component also increases.

The role of the smoothness parameter λ is better understood if we relate it to the notion of a cut–off frequency. For this purpose, it is useful to derive the analytic expression of the Wiener-Kolmogorov signal extraction filter for the low–pass component (Whittle, 1983) . Assuming a doubly infinite sample, and denoting by $\tilde{\boldsymbol{\mu}}_t$ the minimum mean square estimators (MMSE) of $\boldsymbol{\mu}_t$, the MMSE estimator of the low-pass component is

$$\tilde{\boldsymbol{\mu}}_t^\dagger = \mathrm{w}_\mu(L)\tilde{\boldsymbol{\mu}}_t, \quad \mathrm{w}_\mu(L) = \frac{|1+L|^{2n}}{|1+L|^{2n} + \lambda|1-L|^{2m}}. \tag{13}$$

Hence, the estimator results from the application of a linear filter to the final estimates of the permanent components. It should be noticed that this is different from applying a low-pass filter to the original time series.

Let $\mathrm{w}_\mu(\omega)$ denote the gain of the signal extraction filter in (13), where ω is the angular frequency in radians takes values in the interval $[0, \pi]$. The gain is a monotonically decreasing function of ω, with unit value at the zero frequency (being a low–pass filter it preserves the long run frequencies) and with a minimum (zero, if $m \geq 0$) at the π frequency. Let us then define the cut-off frequency of the filter as that particular value ω_c in correspondence of which the gain halves. The parameter λ is related to the cut-off frequency of the corresponding signal extraction filter: solving the equation $\mathrm{w}_\mu(\omega_c) = 1/2$, we obtain:

$$\lambda = 2^{n-m}\left[\frac{(1+\cos\omega_c)^n}{(1-\cos\omega_c)^m}\right], \tag{14}$$

which expresses the parameter λ as a function of ω_c and the orders m and n. For interpretative purposes the cut–off frequency can be translated into a cut–off period, $p = 2\pi/\omega_c$, e.g. $\omega_c = \pi/2$ implies that the filter selects those fluctuations with periodicity equal or greater than 4 observations (1 year of quarterly data).

In the sequel we concentrate on the case $m = n = 2$, i.e. on the class of Butterworth filters of order 2. The case $m = 2, n = 1$, produces Hodrick and Prescott (1997) type filters, although we recall that the low–pass filters is not applied to the series. Increasing λ we obtain smoother estimates, as, for given values of m and n, the cut–off frequency of the filter decreases, and the amplitude of higher frequency fluctuations is further reduced.

The decomposition 10 is illustrated by figure 3. The rectangle with height 1 and base $[0, \pi]$ can be though of as the spectral density of a univariate white noise shock that drives the potential output dynamics. According to our representation, the shock would be doubly integrated in the level of potential output. For a white noise process, the contribution of fluctuations defined at the different frequencies is constant. Thus, high frequency components play the same role as low frequency ones. Assuming $m = n = 2$ and for a given cut–off frequency, the decomposition (12) defines a new trend shock that uses only the low frequencies whereas the remainder will contribute to the high–pass component. The spectral density of the disturbances of the low–pass component has two poles at the frequency π; on the contrary, the spectral density of the high–pass component has two poles at the zero frequency. The solid and dotted lines of the first panel also represent the gain of the corresponding two–sided filter, $\mathrm{w}_\mu(\omega)$, for two different cut–offs; the first is $\pi/2$, which corresponds to a period of 4 observations (one year of quarterly data) and the second is $\pi/20$, corresponding to 10 years of quarterly data.

The second panel illustrates the role of different values of $m = n$; for higher values we have a sharper transition from 1 to zero. However, as it is argued in Proietti (2004), the flexibility of the filter is at odds with the reliability of its estimates.

The weighting function expresses the central weights; at the extremes of the sample the sample weights depend on the features of the series, i.e. are adapted to it and are computed by the KFS for the state space representation of the model $\mathbf{y}_t = \boldsymbol{\mu}_t^\dagger + \boldsymbol{\psi}_t^\dagger + \boldsymbol{\psi}_t + \mathbf{\Gamma X}_t$, augmented by the price equation. The MMSE of the components will be provided by the Kalman filter and smoother (if $l \leq 0$) associated to the model (12), whose state space representation can be constructed using the results in Proietti (2004).

Applying the same univariate filter (i.e. the BF using the same value of λ) to the capital stock and population series, the low-pass component of potential output can be defined as follows:

$$\tilde{\mu}_t^\dagger = [1, \;\; \alpha, \;\; \alpha, \;\; -\alpha, \;\; 0]'\tilde{\boldsymbol{\mu}}_t^\dagger + \alpha n_t^\dagger + (1-\alpha)k_t^\dagger;$$

Figure 4 displays the estimates of the low-pass component of PO growth, also decomposed according to its sources, for three values of the smoothness parameter corresponding to a cut-off

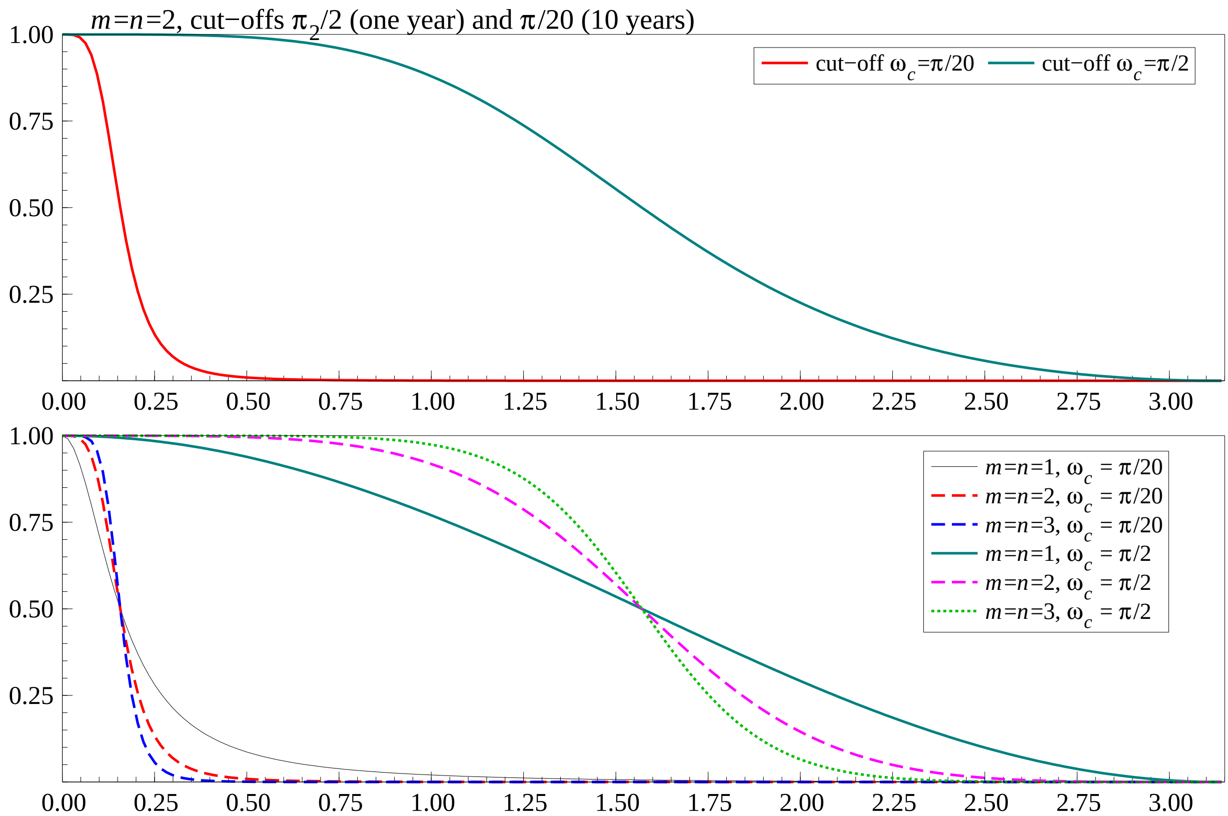

Figure 3: Gain of model–based low–pass filters for different cut–off frequencies and different values of n and m.

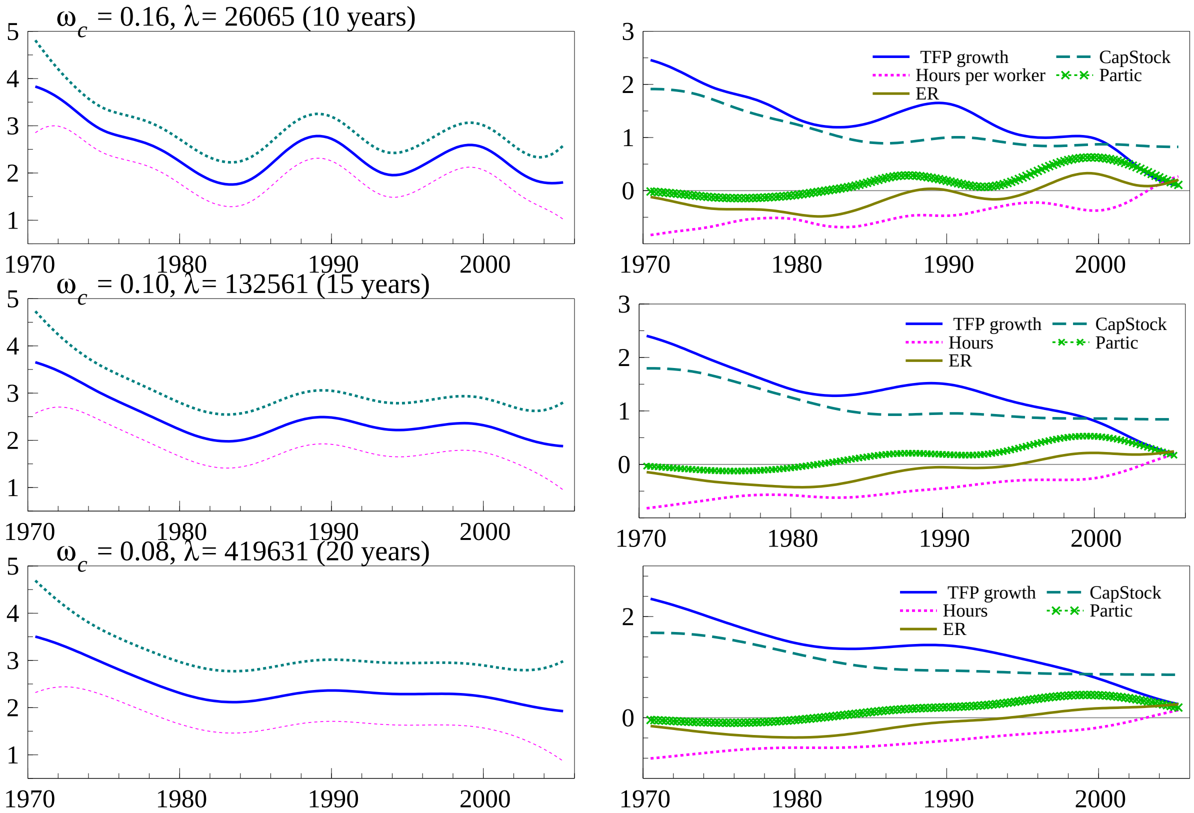

Figure 4: Low-pass estimates of potential output growth and growth accounting for various values of the smoothness parameter.

period of 10, 15 and 20 years, respectively. It is worthwhile to remark that the confidence intervals become wider as λ increases. Thus, the reliability of potential output growth estimates decreases as the smoothness increases.

4.2 Is there an optimal level of smoothness?

In the previous section potential output was decomposed into two parts: a low–pass component and a high–pass one. The intent was descriptive and aimed at extracting the component of potential output growth prevailing at a purposively chosen horizon. The horizon depends on a smoothness parameter, λ, or equivalently on a cut-off frequency that is fixed outside the model. For given

$m = n = 2$ and λ, and conditional on the maximum likelihood parameter estimates presented in section 3.2, the Kalman filter and smoother for the relevant state space model produces the MMSE of the components.

This section takes a different perspective and addresses the issue of the smoothness of potential output from an inferential standpoint. In particular, the high-pass component arising from the combination of the levels of $\psi_t^\dagger$ will be supposed to contribute to the output gap and thus will enter the inflation equation. The output gap will depend on the smoothness parameter λ and within this framwork we can address the issue of how smooth potential output can be to be consistent with stable inflation.

The multivariate model implementing the PFA is now formulated as follows. The time series equations for $\mathbf{y}_t$ are

$$\begin{array}{rcll} \mathbf{y}_t & = & \boldsymbol{\mu}_t^\dagger + \boldsymbol{\psi}_t^\dagger + \boldsymbol{\psi}_t, & \\ \varphi(L)\Delta^2\boldsymbol{\mu}_t^\dagger & = & (1+L)^2\boldsymbol{\zeta}_t^\dagger, & \boldsymbol{\zeta}_t \sim \mathrm{NID}(\mathbf{0}, \boldsymbol{\Sigma}_\zeta) \\ \varphi(L)\boldsymbol{\psi}_t^\dagger & = & \boldsymbol{\kappa}_t^\dagger, & \boldsymbol{\kappa}_t^\dagger \sim \mathrm{NID}(\mathbf{0}, \lambda\boldsymbol{\Sigma}_\zeta). \end{array} \tag{15}$$

The transitory component $\boldsymbol{\psi}_t$ has the pseudo-integrated cycles specification discussed in section 2.2.

Potential output is defined as

$$\mu_t = [1, \ \ \alpha, \ \ \alpha, \ \ -\alpha, \ \ 0]'\boldsymbol{\mu}_t^d ag + \alpha n_t^\dagger + (1-\alpha)k_t^\dagger,$$

whereas the output gap results from the linear combination:

$$\psi_t = [1, \ \ \alpha, \ \ \alpha, \ \ -\alpha, \ \ 0]'(\boldsymbol{\psi}_t + \boldsymbol{\psi}_t^\dagger) + \alpha(n_t - n_t^\dagger) + (1-\alpha)(k_t - k_t^\dagger),$$

where it should be noticed that capital and population are no longer considered as entirely permanent. As a result, their high–pass components contribute to the output gap. Recall that in our case, $m = 2$ implies that the high–pass component $\boldsymbol{\psi}_t^\dagger$ has a stationary VAR(2) representation with scalar AR polynomial, $\varphi(L)$. The model is completed by the price equation, which is specified as in section 2.2, with the output gap defined as in the above equation.

The new measurement framework the decomposition of output into potential and output gap depends on the parameter λ. The latter is identifiable and it can be estimated by maximum like-

Table 2: Profile likelihood for the smoothness parameter.

λ	0.00	0.11	1.00	3.59	9.00	33.97	193.99
ω_c	3.14	2.09	1.57	1.26	1.05	0.79	0.52
$p = 2\pi/\omega_c$	2.00	3.00	4.00	5.00	6.00	8.00	12.00
log lik	3899.36	3909.45	3912.12	3912.55	3912.05	3910.02	3904.81

lihood; the inflation equation will indicate what value is most likely, and what smoothness is required of potential output to be consistent with stable inflation.

Table 2 reports the value of the likelihood as a function of the smoothness parameter (or, equivalently, of the corresponding cut-off frequency and period, reported in the second and third line), maximised with respect to the remaining parameters. Figure 5 plots the profile likelihood against the the cut-off frequency ω_c, and complements the evidence resulting from the table. The value of λ maximising the likelihood is 3.59, corresponding to a cut-off frequency of 1.26. With respect to the case discussed in section 2.2, corresponding to $\lambda = 0$, potential output will be smoother, since fluctuations with periodicity less than 5 quarters were assigned to the output gap.

The likelihood ratio test of the hypothesis $H_0 : \lambda = 0$ is clearly significant at the 1% level. Since the null hypothesis is that this parameter is on the boundary of the parameter space, the distribution of the likelihood ratio test statistic is the mixture $LR = \frac{1}{2}\chi_0 + \frac{1}{2}\chi_1$, where χ_0 takes the value zero with probability 1 and χ_1 is a chisquare random variable with one degree of freedom. The test with size a has critical region $LR > c$, where $P(X > c) = 2a$, and $X \sim \chi_1$. See Gourieroux *et al.* (1982) for details. For $a = 0.01$, $c = 5.41$.

The estimates of potential output and the output gap are displayed in the first two panels of Figure 6. Compared to the estimates arising in the case $\lambda = 0$, the output gap has greater amplitude during the seventies. Correspondingly, potential output growth is smoother during the same period.

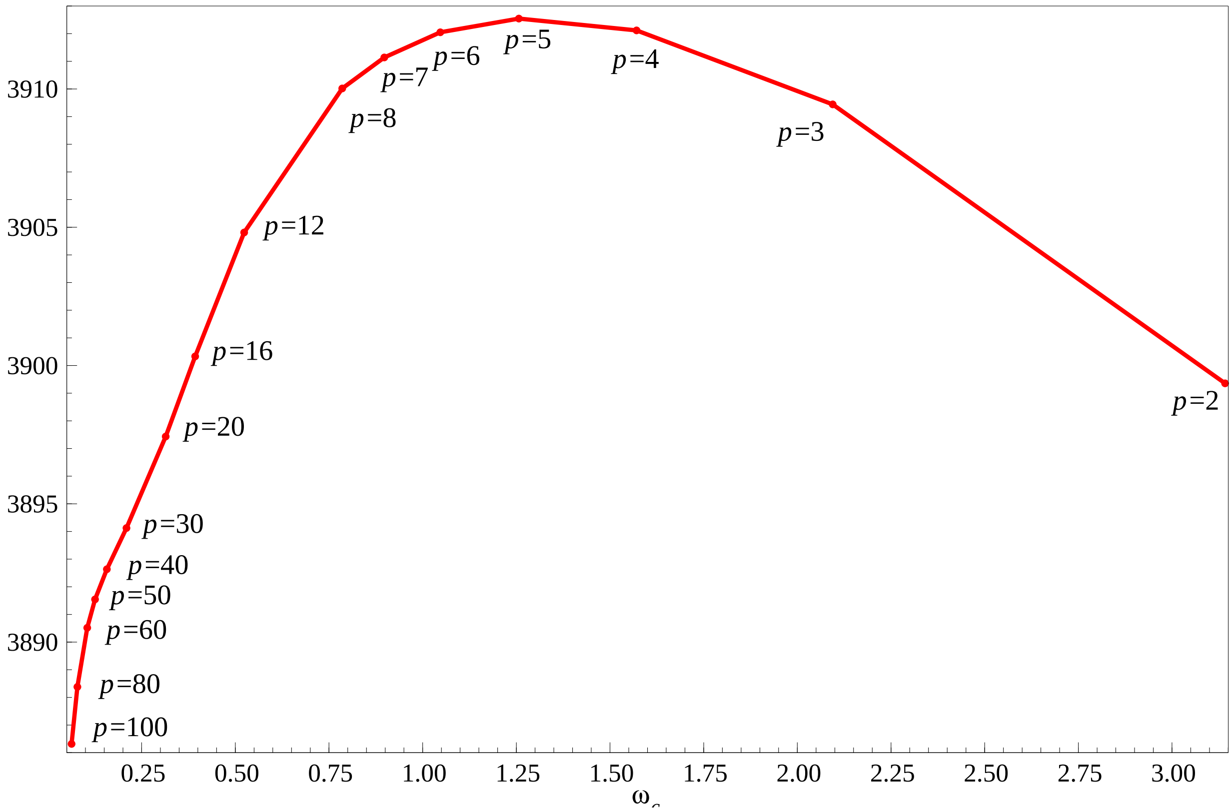

Figure 5: Profile likelihood for cut–off parameter ω_c.

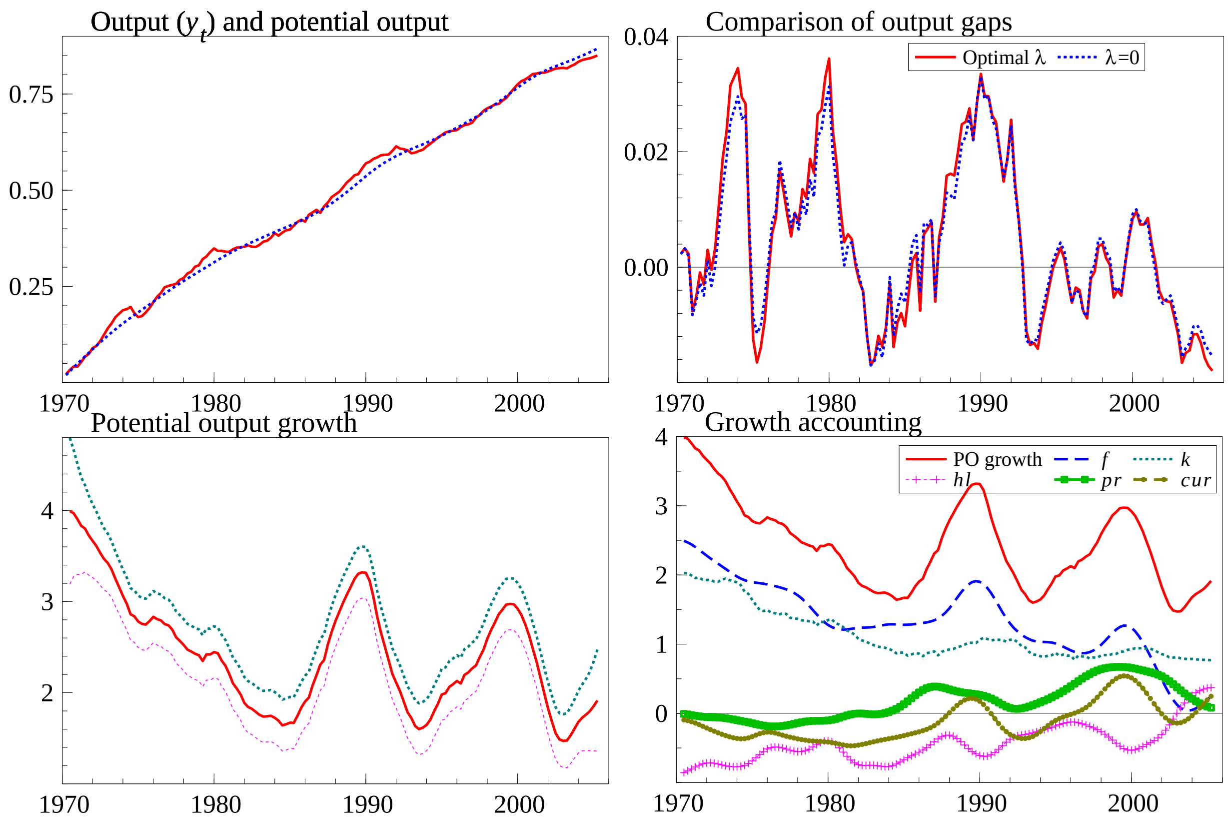

Figure 6: Multivariate PFA model with estimated smoothness parameter ($\lambda = 3.59$). Smoothed components of potential output, comparison of output gap estimates and composition of potential output growth.

5 Conclusions

In this paper we have extended the production function approach proposed by PMT (2006) to include data for hours worked and used this generalised framework to explore in detail the sources of potential growth in the euro area since 1970. Moreover, we have proposed an extension which allows to formally analyse the degree of smoothness of estimates of potential output and its components. This approach requires further analysis to fully exploit its potentials, including a closer formal link between smoothness and economic and policy considerations, which is one of the priorities in our future research agenda.

The model-based approach we propose has several advantages, but further extensions are warranted. Among the extensions we plan to consider are the inclusion of a wages-NAIRU block. Moreover, a sectoral perspective is another extension which can potentially provide very interesting insights and is therefore a venue that is being investigated.

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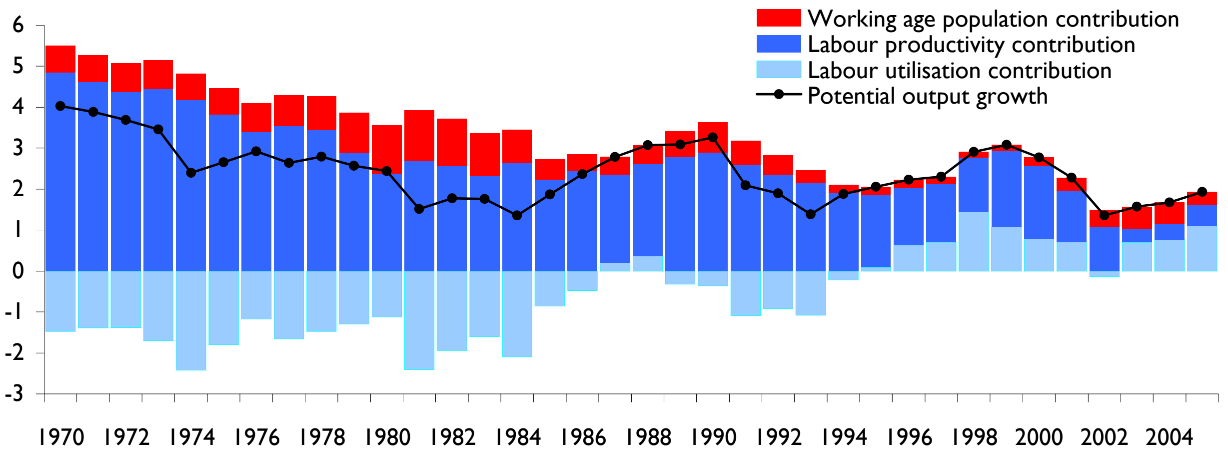
Annex – Growth accounting for the euro area (1970-2005)

Table A – Contributions to euro area potential output growth (accounting decomposition)
(averages of annual percentage changes)

	average annual contribution to potential growth from change in			average annual growth in
	Accounting decomposition			
	Working age population	**Labour utilisation**	**Labour productivity**	**Potential output**
	(a)	(b)	(c)	sum(a-c)
by decade				
1971-1980	0.8	-1.5	3.7	2.9
1981-1990	0.7	-0.9	2.5	2.3
1991-2000	0.3	0.1	1.9	2.3
past three cycles				
1975-1982	0.9	-1.6	3.1	2.4
1982-1993	0.6	-0.8	2.4	2.2
1993-2003	0.3	0.4	1.5	2.2
recent periods				
1991-1995	0.4	-0.6	2.1	1.9
1996-2000	0.2	0.9	1.6	2.7
2001-2005	0.4	0.6	0.7	1.8
longer periods				
1970-2005	0.6	-0.6	2.5	2.4
1980-2005	0.5	-0.2	1.9	2.2
1995-2005	0.3	0.7	1.2	2.2

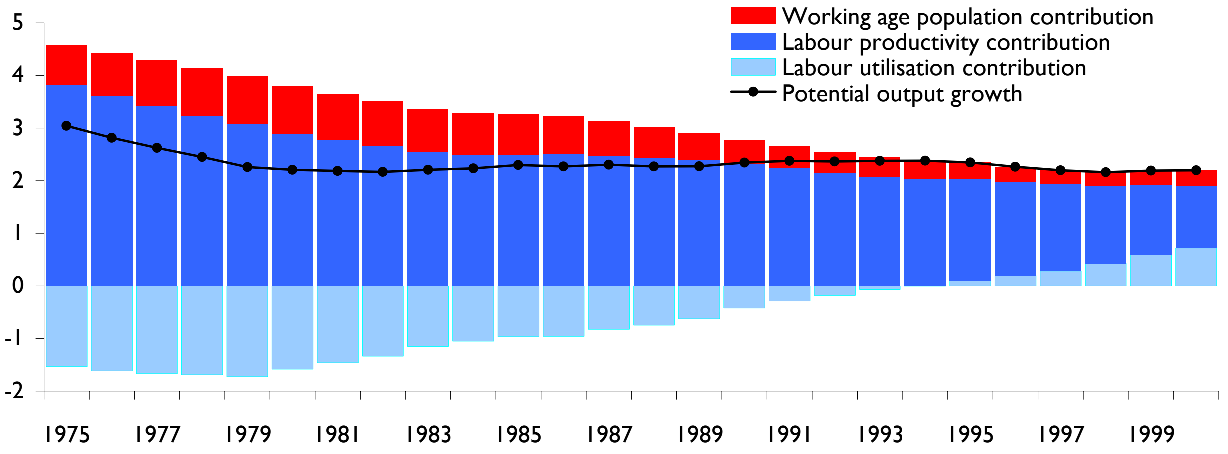
Sources: ECB calculations.
Note: Labour productivity is defined as output per worker. Labour utilisation is defined as person employed per head of the working age population. Turning points are based on the chronology published by the CEPR Euro Area Business Cycle Dating Committee, except for the last peak (in 2001) and trough (in 2003), which are selected on the basis of real GDP growth developments.

Chart A: Contributions to euro area potential output growth (accounting decomposition)
(annual percentage changes)



Sources: ECB calculations.
Note: Labour productivity is defined as output per worker. Labour utilisation is defined as person employed per head of the working age population.

Chart B: Contributions to euro area potential output growth (accounting decomposition)
(annual percentage changes, centred 10 years moving averages)



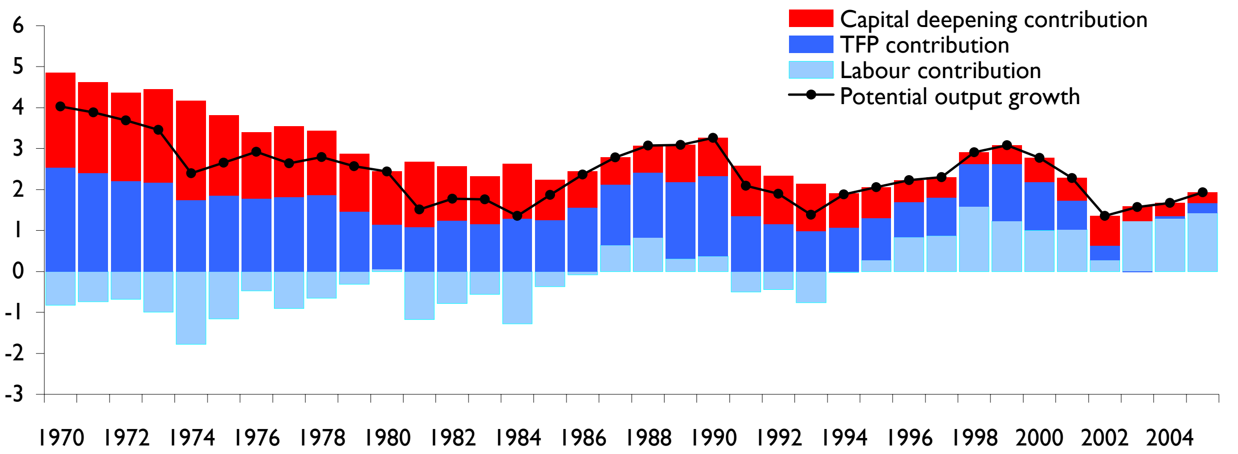
Sources: ECB calculations.
Note: Labour productivity is defined as output per worker. Labour utilisation is defined as person employed per head of the working age population.

Table B – Contributions to euro area potential output growth (production function decomposition)
(averages of annual percentage changes)

	average annual contribution to potential growth from change in			average annual growth in
	Production function decomposition			
	TFP	**Capital Intensity**	**Labour**	**Potential output**
	(a)	(b)	(c)	sum(a-c)
by decade				
1971-1980	1.8	1.9	-0.8	2.9
1981-1990	1.4	1.0	-0.2	2.3
1991-2000	1.1	0.8	0.4	2.3
past three cycles				
1975-1982	1.5	1.6	-0.7	2.4
1982-1993	1.4	1.0	-0.2	2.2
1993-2003	0.9	0.6	0.7	2.2
recent periods				
1991-1995	1.1	1.0	-0.3	1.9
1996-2000	1.1	0.5	1.1	2.7
2001-2005	0.3	0.5	1.1	1.8
longer periods				
1970-2005	1.3	1.1	0.0	2.4
1980-2005	1.1	0.8	0.3	2.2
1995-2005	0.7	0.5	1.0	2.2

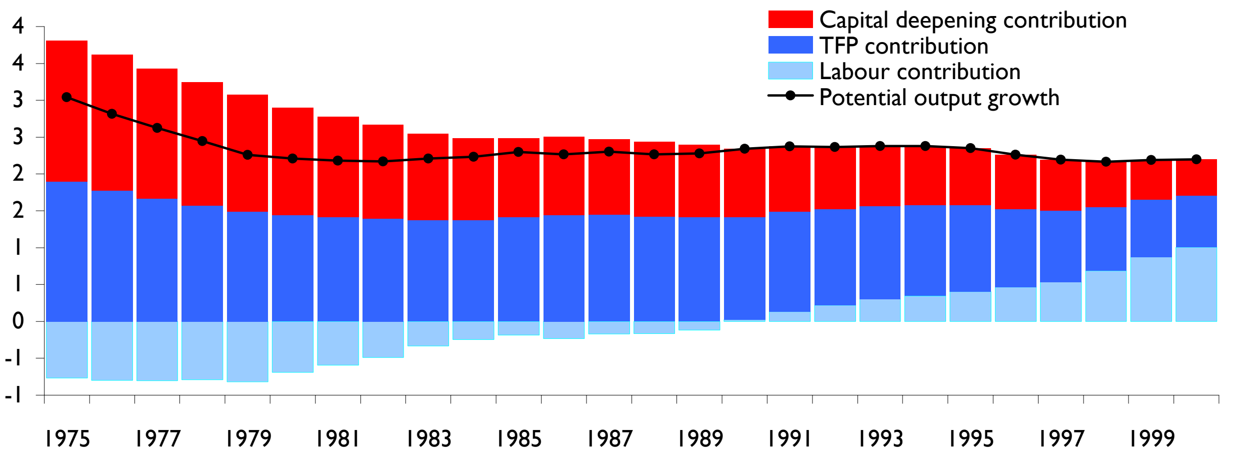
Sources: ECB calculations.
Note: Decomposition based on a Cobb-Douglas production function with constant labour share equal to 0.65. Capital intensity is defined as the ratio of the capital stock to total hours worked and its contribution is the product of the capital share times its growth rate. Labour contribution is defined as the growth rate in total hours worked. TFP estimated as Solow residual.

Chart C: Contributions to euro area potential output growth (production function decomposition)
(annual percentage changes)



Sources: ECB calculations.
Note: Decomposition based on a Cobb-Douglas production function with constant labour share equal to 0.65. Capital deepening contribution is defined as the product of the capital share and the difference between capital stock growth and hours worked growth. Labour contribution is defined as the growth rate in total hours worked. TFP estimated as Solow residual.

Chart D: Contributions to euro area potential output growth (production function decomposition)
(annual percentage changes, centred 10 years moving averages)



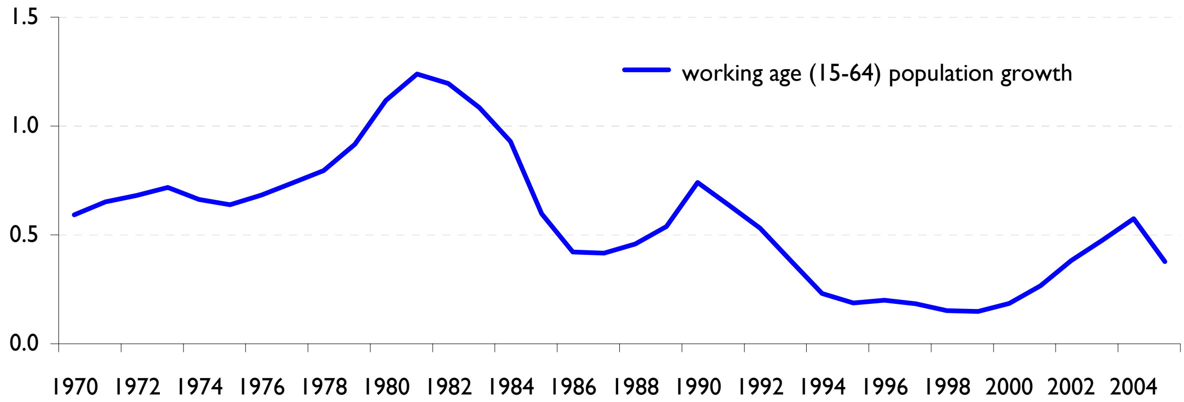
Sources: ECB calculations.
Note: Decomposition based on a Cobb-Douglas production function with constant labour share equal to 0.65. Capital deepening contribution is defined as the product of the capital share and the difference between capital stock growth and hours worked growth. Labour contribution is defined as the growth rate in total hours worked. TFP estimated as Solow residual.

Table C – Detailed decomposition of euro area potential output growth
(averages of annual percentage changes)

	average (annual) contribution to growth from change in										average (annual) growth in
	Total population	Age structure	**Working age population**	TFP	Capital Intensity	**Labour productivity**	Participation rate	Unemployment rate	Hours worked per person	**Labour utilisation**	**Potential output**
	(a)	(b)	(a)+(b)	(c)	(d)	(c)+(d)	(e)	(f)	(g)	sum(e to g)	sum(a to g)
by decade											
1971-1980	0.5	0.2	0.8	1.8	1.9	3.7	-0.2	-0.5	-0.9	-1.5	2.9
1981-1990	0.3	0.4	0.7	1.4	1.0	2.5	0.3	-0.3	-1.0	-0.9	2.3
1991-2000	0.3	-0.1	0.3	1.1	0.8	1.9	0.5	0.1	-0.5	0.1	2.3
past three cycles											
1975-1982	0.4	0.5	0.9	1.5	1.6	3.1	-0.1	-0.6	-0.9	-1.6	2.4
1982-1993	0.3	0.3	0.6	1.4	1.0	2.4	0.2	-0.3	-0.8	-0.8	2.2
1993-2003	0.3	-0.1	0.3	0.9	0.6	1.5	0.7	0.1	-0.4	0.4	2.2
recent periods											
1991-1995	0.4	-0.1	0.4	1.1	1.0	2.1	0.2	-0.3	-0.5	-0.6	1.9
1996-2000	0.3	-0.1	0.2	1.1	0.5	1.6	0.9	0.5	-0.5	0.9	2.7
2001-2005	0.5	-0.1	0.4	0.3	0.5	0.7	0.5	0.1	0.1	0.6	1.8
longer periods											
1970-2005	0.4	0.2	0.6	1.3	1.1	2.5	0.3	-0.2	-0.7	-0.6	2.4
1980-2005	0.4	0.2	0.5	1.1	0.8	1.9	0.4	-0.1	-0.5	-0.2	2.2
1995-2005	0.4	-0.1	0.3	0.7	0.5	1.2	0.7	0.3	-0.2	0.7	2.2

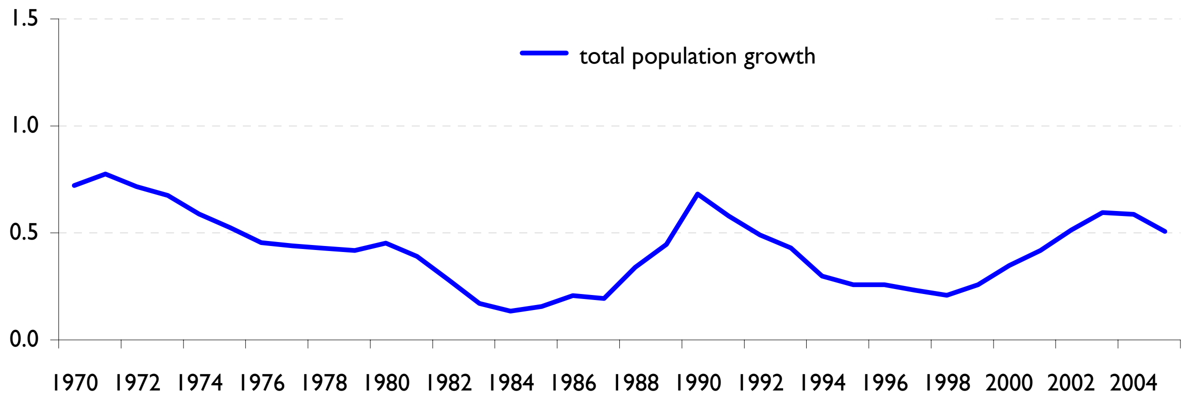
Sources: ECB calculations based on data from Eurostat and the Groningen Growth and Development Center (GGDC).
Note: The contribution from the unemployment rate is inversely related to the unemployment rate. The contribution of capital deepening is obtained as the difference between labour productivity growth and TFP growth.

Chart E: Working age population growth in the euro area
(annual percentage changes)



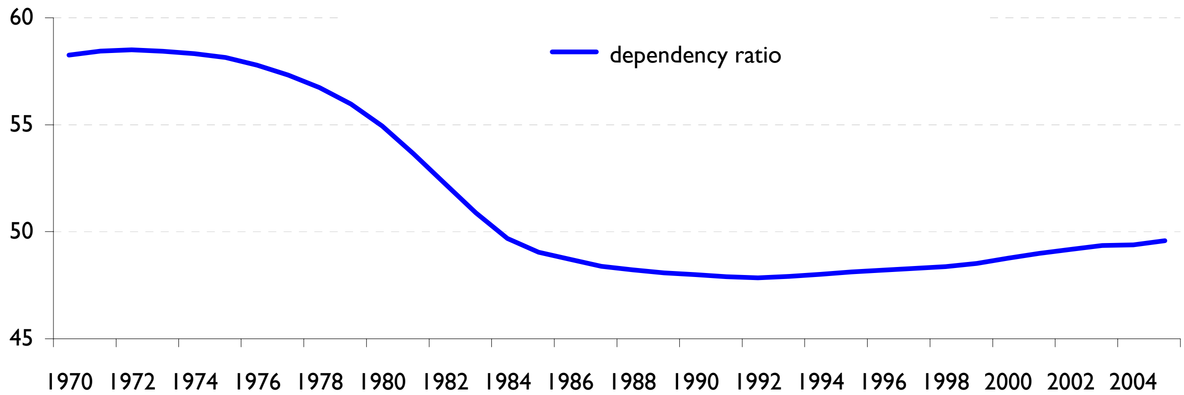
Source: ECB calculations based on data from Eurostat and the Groningen Growth and Development Center (GGDC).
Note: Working age population defined as 15-64 population.

Chart F: Total population growth in the euro area
(annual percentage changes)



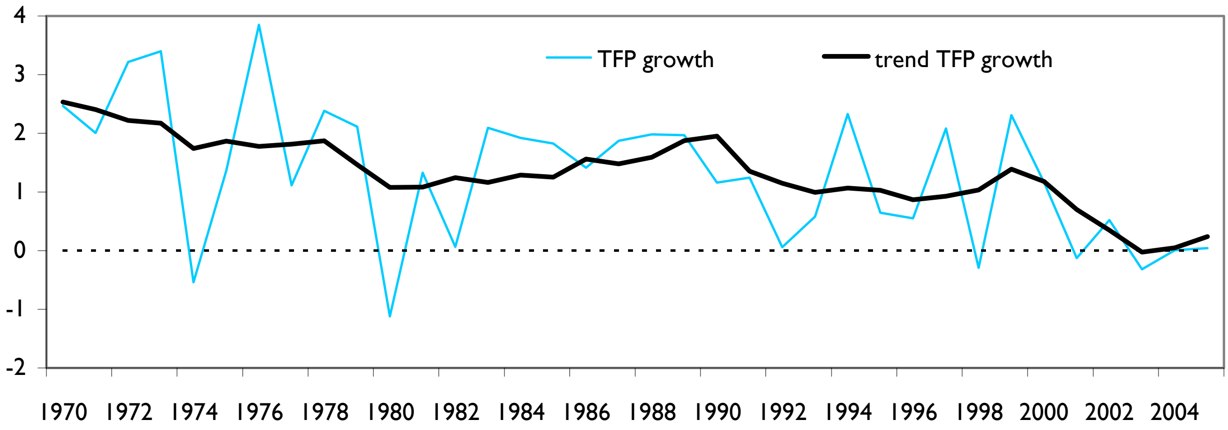
Source: ECB calculations based on data from Eurostat and the Groningen Growth and Development Center (GGDC).
Note: Total population.

Chart G: dependency ratio in the euro area
(percentages)



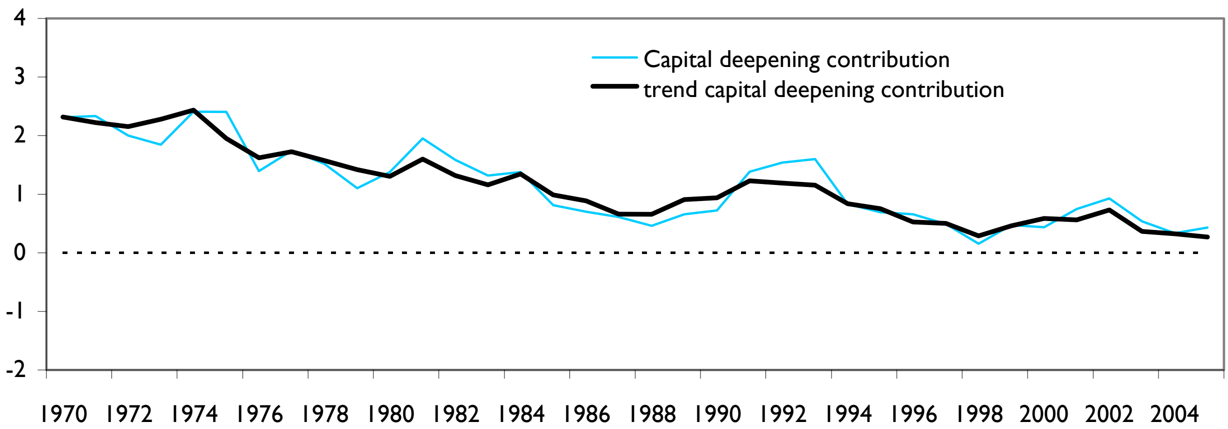
Source: ECB calculations based on data from Eurostat and the Groningen Growth and Development Center (GGDC).
Note: persons above 64 and below 15 as % of working age population.

Chart H: TFP growth in the euro area: actual and trend
(annual percentage changes)



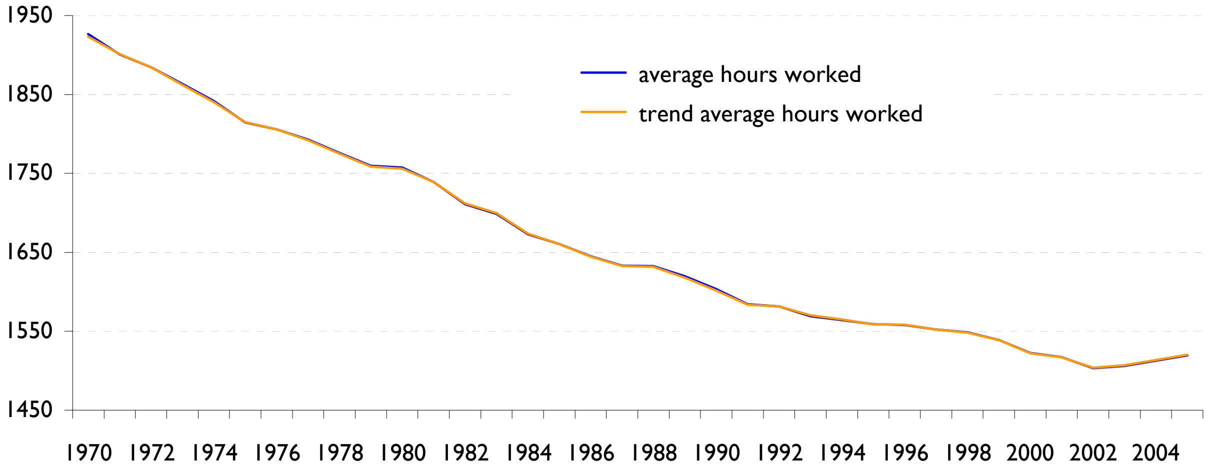
Source: ECB calculations based on data from Eurostat and the Groningen Growth and Development Center (GGDC).
Note: TFP estimated as Solow residual.

Chart I: Capital deepening contribution in the euro area: actual and trend
(annual percentage changes)



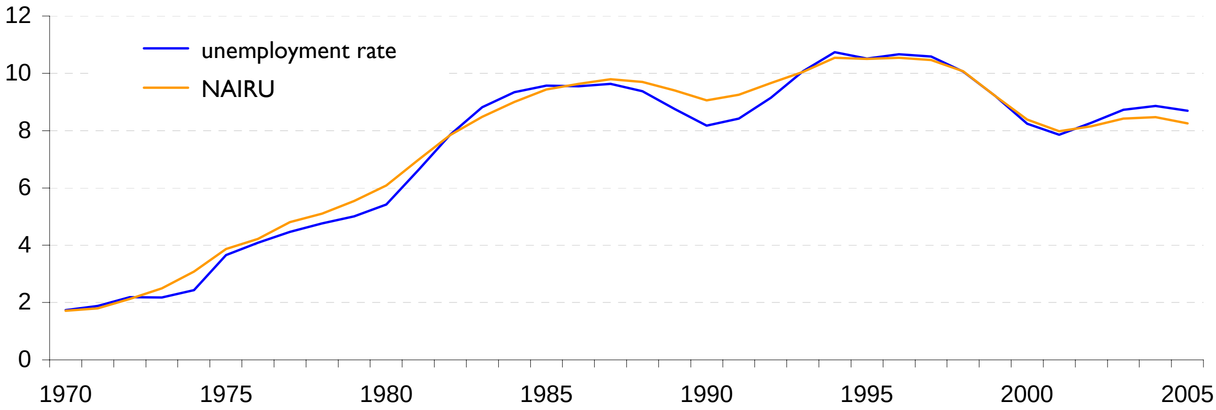
Source: ECB calculations based on data from Eurostat and the Groningen Growth and Development Center (GGDC).
Note: TFP estimated as Solow residual.

Chart J: Average hours worked developments in the euro area: actual and trend
(annual percentage changes)



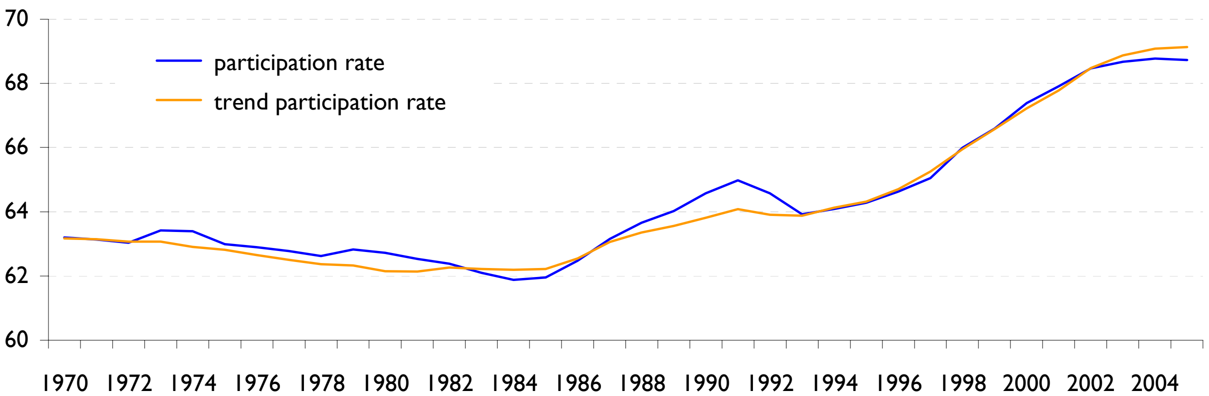
Source: ECB calculations based on data from Eurostat and the Groningen Growth and Development Center (GGDC).
Note: Average hours worked per year.

Chart K: Unemployment rate developments in the euro area: actual and trend (NAIRU)
(annual percentage changes)



Source: ECB calculations based on data from Eurostat and the Groningen Growth and Development Center (GGDC).
Note: Eurostat definition of the unemployment rate, consistent with the ILO definition.

Chart L: Participation rate developments in the euro area: actual and trend
(annual percentage changes)



Source: ECB calculations based on data from Eurostat and the Groningen Growth and Development Center (GGDC).
Note: Participation rate defined as labour force to working age population ratio.