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ABSTRACT

This paper examines shifts in labour productivity growth in the United States and in Europe between 1970 and 2007 based on econometric tests of structural breaks. Additionally, it makes use of time-series-based projections of labour productivity growth up to 2009 in order to detect breaks depending on confidence intervals of the projections. The identification of structural breaks in US labour productivity growth is far from obvious. A statistically significant break is found in the late 1990s only if at least the 97.5th percentile of forecasts materialises in the future, which means that despite a clear pick-up in productivity growth in the second half of the 1990s, the size of the hump is not large enough compared with past variations to make this change a statistically significant break. However, a significant breakpoint is detected in the mid-1990s for the difference in labour productivity growth between the United States and the EU15, even when controlling for the convergence of Europe towards US productivity levels that has contributed to higher European performance in the early catch-up phase. Finally, within Europe, the accumulation of ICT capital seems to be related to differences in the shifts in structural labour productivity growth across countries.

JEL classification codes: E30; O47; O51; O52

Key words: labour productivity growth; structural break tests; ICT

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RECENT TRENDS AND STRUCTURAL BREAKS IN US AND EU15 LABOUR

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1. Introduction

The gap in hourly labour productivity growth between the United States and the EU15 was nearly closed by the second half of the 1990s. Since then, there has been a sharp turnaround, with labour productivity growing faster in the United States than in Europe. However, productivity growth in the United States has slowed since 2003, to reach 1.4% in 2007. In contrast, in conjunction with the cyclical recovery, a small acceleration in labour productivity occurred in the EU15 between 2004 and 2006, before decelerating to a growth rate of 1.2% in 2007.²

This paper aims at assessing the extent to which the recent changes in labour productivity growth in the United States and in Europe are structural as opposed to cyclical. First, for descriptive purposes, filtering techniques are employed on observed data to calculate the underlying trends in labour productivity growth between 1970 and 2007. Then, time series modelling is used to get forecasts of labour productivity growth up to 2009 as well as a high and a low scenario. Identifying the trends of those scenarios gives an insight on the conditions under which structural changes might have recently taken place. Finally, the statistical significance of the breaks in labour productivity growth is assessed. Throughout the paper, “breaks” should be understood as induced by sudden shifts rather than by gradual changes or drifts.

2. Since the analysis was carried out, the published data has been extended by almost one year. However, it has been checked that growth rate trends have been little affected, such that the results are not altered by the extension of the available data.

The paper takes into account the heterogeneity between European countries. The paper investigates whether this heterogeneity in recent performance is due to different propensities of being intensive in Information and Communication Technology (ICT).

Well-known stylised facts are highlighted by the descriptive analysis:

- a. Until the second half of the 1990s, the EU15 outperformed the United States in terms of labour productivity growth.³ As from then, the United States experienced an increase in productivity growth, whereas EU15 labour productivity growth kept on decreasing. The trend in the productivity growth gap between the United States and the EU15 reached a peak in the early years of the 2000s, and has decreased since then.
- b. Over 2000-2007, the United Kingdom, Ireland, Finland and Sweden were in the upper range of labour productivity growth performance in Europe, whereas Italy, Spain, Portugal and the Netherlands were in the lower range (Table 1).
- c. During the 1996-2007 decade, European countries with high intensity of Information and Communication Technology (ICT) have been performing better in terms of structural labour productivity growth than the others.

This paper contributes to the literature that both identifies and dates breaks in labour productivity growth in the United States and in Europe, using statistic and econometric techniques, as in Benati (2007), European Commission (2007), Gomez-Salvador (2006), Hansen (2001) and Stiroh (2001). It also brings in new elements. First, it extends data time coverage and makes use of various scenarios of labour productivity growth forecasts up to

3. EU15 is defined as a weighted average based on each country's GDP at PPP. Throughout the paper EU15 is without Austria because of the lack of data on hours worked before 1990 for this country.

2009 based on confidence intervals.⁴ Second, whereas few studies have concerned individual European countries, the current paper estimates the structural breaks in labour productivity growth on a country-by-country basis. It also provides the test and dating of structural breaks in the *difference* between US and EU15 labour productivity growth rates. Finally, it sheds some light on the contrasted patterns of labour productivity growth developments of the countries with high, medium and low intensity of ICT.

The main findings of the paper are the following:

- a. Identification of structural break in US labour productivity growth is far from obvious at conventional test sizes. The tests for structural change over 1970-2007 fail to identify a break, with the exception of the manufacturing sector around 1993.
- b. It is only if high growth rates of labour productivity are reached in the future – consistent with the 97.5th percentile of forecasts - that a statistically significant break date is found around 1998 in the United States and the structural break, presumably due to ICT, is confirmed.
- c. In Europe, statistically significant downward shifts in structural labour productivity growth are found in 1979 and at the end of 2000. However, the 2000 break is not robust to likely projections of future productivity growth, while the 1979 break is not identified any longer when controlling for difference in productivity levels *vis-à-vis* the United States, suggesting that it is related to the convergence process.
- d. A clear breakpoint is found in 1995 for the *difference* in labour productivity growth between the EU15 and the United States, the estimated difference in annual growth rates slowing down from 1.6 percentage points over 1970-1995 to -0.6 percentage

4. As described in the Annex 1, the data coverage is 1970-2007. The forecasts are based on time-series analysis and on OECD Economic Outlook 84 projections.

point over 1996-2007. This breakpoint holds when controlling for the difference in lagged productivity levels. The latter finding suggests that the 1995 breakpoint is due both to the catch-up of Europe, which has stopped since the mid-1990s, and to different ICT performances.

- e. European countries that have similar timing of the structural shifts in their labour productivity growth are devoting comparable effort to ICT. This suggests that in Europe the accumulation of ICT capital is correlated to structural shifts in labour productivity.
- f. In the United States, a structural increase of growth in ICT capital services is estimated to have taken place after 1995, followed by a strong fall after 2001. These breaks do not translate into breaks at the total economy level.

The paper is organised as follows. The next section presents a brief review of the literature. Section 3 deals with the nature — cyclical or structural — of the recent evolution of labour productivity growth in the United States and in Europe, as well as across European countries and across groups of countries based on their ICT intensity. Different scenarios based on forecast analysis are presented. The fourth section assesses the statistical significance of breaks in labour productivity growth. Results are provided for the United States and Europe, individual European countries, and high, medium and low ICT country groups in Europe. The data are described in the Annex 1.

2. Overview of the literature

The focus of this paper is the timing and extent of breaks in labour productivity growth rather than the identification of the determinants of labour productivity growth. An initial literature predominantly made use of growth decomposition techniques to document the sources of the

shifts in labour productivity growth with specific attention placed on the role of ICT.⁵ These studies have two shortcomings concerning the identification of the structural trends in productivity. First, they presume a breakpoint in 1995 in US labour productivity growth. While the average annual labour productivity growth has strongly increased after 1995, an *a priori* selection of the break date is not satisfactory from a statistical point of view. The break date should be estimated as the one for which the shift in trend is statistically significant. Secondly, as Hansen (2001) underlines, structural change has a meaning only in the context of a model, and occurs when the model's parameters change over time at some breakpoints.

The current paper overcomes these issues by relying on the econometrics of structural change, which allows for both the identification of multiple structural shifts in series and their dating with confidence intervals. The amount of work in this field is voluminous and surveyed by Perron (2006). In particular, substantial advances have been made by Bai and Perron (1998, 2003) to cover models at a high level of generality. Their methodology, used in the current paper, is now widely implemented in applied studies covering a wide range of domains. For example, it is used to test for changes in the pattern of different series, such as aggregate employment growth in the euro area in the late 1990s (Mourre, 2006).⁶ The break tests are adequate for detecting sudden shifts. Conversely, such tests might have a low power to identify drifts when the underlying series is driven by too gradual changes (Benati, 2007).

For the United States, the results obtained in this literature depend upon the sectoral coverage (non-farm business, manufacturing, total economy) and the period under study (Table 2). For

5. Gordon (2000, 2004), Jorgenson and Stiroh (2000), Jorgenson, Ho and Stiroh (2002, 2006, 2007), and Oliner and Sichel (2000, 2002). See Jorgenson, Ho and Stiroh (2007) for a comprehensive survey of this literature for the United States, as well as Gordon and Dew-Becker (2005) for a complementary analysis; see also Gust and Marquez (2000) for the other main industrialised countries.

6. It has also been applied in such domains as budget deficits (Bajo-Rubio, Díaz-Roldán and Esteve, 2008), export performance (Rodríguez and Samy, 2003) and inflation (Santos and Oliveira, 2008).

the non-farm business sector, Benati (2007) investigates changes in the growth of labour productivity using data from the Bureau of Labor Statistics (BLS) over 1947:1-2005:4. The Bai and Perron (1998, 2003) test for structural change fails to identify any statistical break for growth in output per hour. In an earlier paper, Stiroh (2001) uses one of the methodologies that served as a basis for the Bai and Perron (1998, 2003) test, which allows to estimate just one unknown break point and then test for the significance of the change. The data used in this study are from the Bureau of Economic Analysis (BEA) and cover 1974:1 to 2000:3. The result for the non-farm business sector fails to detect any statistically significant breakpoint. However, for the manufacturing sector, Stiroh (2001) estimates a breakpoint in 1993:3 which is statistically significant. Hansen (2001) also finds a breakpoint in 1997 in the manufacturing/durables sector with the Bai and Perron (1998, 2003) methodology. For the total economy, using the Groningen Growth and Development Center (GGDC) Total Economy Database over 1950-2006 and the same methodology, Gomez-Salvador *et al.* (2006) find two break dates in the United States labour productivity growth in 1973 and in 1995.

The case of Europe's labour productivity growth is documented by Benati (2007), Gomez-Salvador *et al.* (2006) and the European Commission (2007), as shown also in Table 2. Benati (2007) uses quarterly series of the euro-zone real GDP per worker from the European Central Bank Area Wide Model Database over 1970:1 – 2006:2. One breakdate is found in 2001:1 that leads to a period of lower labour productivity. Using the GGDC Total Economy Database over 1950-2006, Gomez-Salvador *et al.* (2006) find three break dates in the Euro Area annual growth of labour productivity per hour. The break dates reported are 1973, 1979 and 1995. All the structural changes identified give rise to a period of lower labour productivity growth. The European Commission (2007) studies structural breaks in labour productivity growth in

Europe using the private business sector Eurostat data over 1980:1 – 2006:4.⁷ According to this estimation, one break is found for the euro area in 1998:1 (the mean of labour productivity growth that follows the break date is lower). With respect to individual EU countries, the European Commission (2007) finds that Germany shows a break in 1987:1 (downwards) and France in 1998:2 (downwards). Italy shows two breaks, in 1983:2 (upwards) and 1997:2 (downwards), and Spain three breaks in 1985:1 (downwards), 1991:1 (upwards) and 1994:4 (downwards).

3. Standard Hodrick-Prescott filtering of the trends

The 2004-2007 acceleration of labour productivity in Europe from a low growth rate and the deceleration in the United States seem to be closely related to the economic cycle. EU15 annual labour productivity growth next fell from 1.6% in 2006 to 1.2% in 2007. First, for descriptive purposes, Hodrick-Prescott (HP) filtering has been employed to disentangle the trend and the cyclical components of labour productivity growth. Second, more sophisticated statistical techniques are used to determine whether labour productivity growth has been subject to shifts.

Figures 1A and 1B show the inversion in labour productivity growth trends that occurred in the second half of the 1990s between Europe and the United States based on HP filters. Since then, the United States have outperformed the EU15. The trend gap between the United States and the EU15 reached a peak in the early years of the 2000s, but has decreased since then.

7. The methodology differs in that the series are first filtered before the Bai and Perron (1998, 2003) test for structural breaks are run on the extracted trend. Moreover, the criteria employed to select the number of breaks is the Bayesian information criteria (BIC) which is weaker than the sequential procedure of Bai and Perron (see simulation analysis in Bai and Perron, 2006). Model selection procedure based on information criteria cannot take into account potential heterogeneity across time segments unlike the sequential method and shows limits when serial correlation is present.

However, it can be noted from Table 3 that much of the decrease in US labour productivity growth over 2004-2007 could be cyclical.

To gain further insight into possible shifts in labour productivity growth in recent years, both in the United States and in Europe, a forecast for US and EU15 labour productivity growth up to 2009:Q4 is made using time series analysis methods, as well as a confidence interval for the forecast consisting of an upper and a lower scenario at the 95% confidence level. That is, the upper scenario is defined by the 97.5th percentile of the forecasts and the lower scenario by the 2.5th percentile. This gives three series of labour productivity growth consisting of the observed data supplemented by the forecasts, namely the central, the upper and the lower scenarios. All scenarios are then decomposed into structural and cyclical parts, in order to compute three alternatives in labour productivity growth. Figure 2A and 2B show the central, upper and lower trend scenarios obtained for the EU15 and United States.^{8,9}

The robustness of the identified trends is subjected to two limitations that the tests reported in Section 4 partly overcome.

- One of the well documented drawbacks of the HP filter is that at the end of the sample, the filter becomes one-sided and the contemporaneous data are given a weight that is much greater than in the middle of the sample. This effect can be seen on Figures 2A and B: the upper and lower scenarios are diverging from the central

8. These scenarios are based on ARIMA forecasts of the labour productivity series. The model that fits the EU15 is an ARIMA with differentiation parameter $d=1$, AR parameters $p=9, 10, 11, 21, 22, 23$ and MA parameter $q=0$, whereas the model for the USA is an ARIMA where $d=1, p=9, 12$ and $q=0$. The trends are robust to various specifications.

9. The HP trends based on the OECD Economic Outlook 84 projections for the US and EU15 labour productivity growth up to 2009:4 are shown in Figure 2 as well. The trend based on these projections is close to the central scenario based on ARIMA forecasts, albeit slightly below. The purpose of using time-series-based forecasts is to get the upper and the lower scenarios.

scenario as soon as 2003:Q4, even though all scenarios are based on the same observed data covering four additional years.

- Trends are to some extent sensitive to the filtering parameter.¹⁰ When using the $\lambda=1600$ filter, the central prediction is that the post-1995 gap between US and EU15 labour productivity growth is shrinking quicker and reaching a lower level in 2009 than when using the $\lambda=7000$ filter (Figure 3).

The aggregate European labour productivity growth trend masks some heterogeneity between countries. Over 1996-2007, Spain and Italy have been driving down EU15 labour productivity growth trend, whereas Ireland, Finland, Sweden and the United Kingdom have been pushing it upwards (Table 1).

Productivity developments differ systematically across European countries depending on their propensity of being more or less ICT intensive over the recent past. Looking at the average growth in total capital services over 1996-2005 in the ICT sector, three groups of countries can be distinguished (see Figure in Annex 2). An ICT high-intensive group that includes Sweden, United Kingdom and Ireland; an ICT low-intensive group consisting of Germany, Italy and Greece; an intermediary group including France, Finland, Belgium, Denmark, the Netherlands, Spain and Portugal.¹¹ It appears that the high-intensive group performed better since the mid-

10. A filter should include around 90% of the short cycles amplitude in the cyclical component, and under this constraint, the percentage of the long cycles amplitude included in the cyclical component should be as low as possible. On this basis, HP filtering on annual data requires $\lambda=30$ (Bouthevillain, 2002). $\lambda=30$ leads to a value of 91% of the short cycles amplitude included in the cyclical component and 41% of the long cycles amplitude included in the cyclical component. $\lambda=100$ – the value suggested by Hodrick and Prescott – leads to a value of 97% of the short cycles amplitude included in the cyclical component but to 70% of the long cycles amplitude included in the cyclical component. On quarterly data, $\lambda=7000$ corresponds to $\lambda=30$ on annual data. However, the usual value for international comparisons is $\lambda=1600$ (which would correspond to $\lambda=7$ on annual data). The different parameter specifications $\lambda=30$ and $\lambda=100$ have been studied on annual data as well as $\lambda=7000$ and $\lambda=1600$ on quarterly data.

11. No data on capital services in the ICT sector being available for Luxembourg, it is excluded from this country classification.

1990s, recording a growth rate of both observed and trend labour productivity that is twice as large as that of the EU15.

4. An econometric assessment of structural breaks in labour productivity growth

This section investigates the existence and importance of multiple breaks in labour productivity growth since 1970 using the segmented trend approach developed in the context of the econometrics of structural change and more specifically the Bai and Perron (1998, 2003) test. This section is organised as follows. The next subsection describes briefly the methodology. Subsection 4.2 presents the results from the Bai and Perron sequential procedure for the EU15. Subsection 4.3 focuses on the United States, and subsection 4.4 gives the results for the difference between the United States and EU15. The last subsection deals with the European countries and groups of countries based on their ICT intensity.

4.1 Methodology

The econometrics of structural change provides statistical answers to the questions of the existence, number and dates of structural shifts in labour productivity growth. Compared with HP filtering, this method has the critical advantage of dating the breaks without any *a priori* hypothesis about the length of the economic cycles. It also indicates how statistically significant the shifts are. Therefore it overcomes these two limits of HP filtering.

The estimation focuses on the identification of breaks in the mean of the labour productivity growth between different periods. The model used for testing structural change and estimating the number of break dates is the following, for m breaks at dates T_m :

$$\Delta y_t = \beta_1 + \sum_{k=1}^m \beta_{k+1} I(t > T_k) + v_t$$

where Δy_t is labour productivity growth, $(\beta_1, \dots, \beta_m)$ the parameters, and v_t the error term.

The Bai and Perron (1998, 2003) method of estimation of the candidate break dates is based on the least-squares principle and uses grid-search.¹² The methodology covers models at a level of generality that permits numerous practical applications. In particular, it allows for autocorrelation and heteroskedasticity in the residuals and different distribution for the data and for the errors across segments. The results of the test are reported at conventional test sizes of 5% or 10%.

4.2 Results for the EU15

Testing for structural change on quarterly data for the EU15 gives two break dates in 1979:Q2, and in 2000:Q2 in the central scenario (Table 4).¹³ After each break, the estimated average annual labour productivity growth rate is lower, decreasing from 4.1% to 1.3% over the whole period. These results are in line with the literature reviewed above. The breaks, however, could be due to a convergence effect towards the steady state having fostered growth in the catch-up phase. Indeed, Figure 4 displays the strong EU15 labour productivity growth until the mid-1990s, while the United States evolved on a more steady growth path at higher labour productivity levels.¹⁴ To investigate whether such breaks might be explained by convergence, the difference between the EU15 and US productivity levels is added as a control variable.

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12. For each m -partition (T_1, \dots, T_m) , the associated least squares estimates of the parameters $(\beta_1, \dots, \beta_m)$ are obtained by minimising the sum of squared residuals. Substituting the resulting estimates in the objective function and denoting the resulting sum of squared residuals $S(T_1, \dots, T_m)$, the estimated break points $(\hat{T}_1, \dots, \hat{T}_m)$ are the solution of the minimisation of $S(T_1, \dots, T_m)$ over all partitions. Then, the stability tests are implemented. The procedure is sequential. First, stability of the trend is tested against the hypothesis of one break. If stability is rejected, then one break date is imposed on the model, and the hypothesis of one break is tested against the hypothesis of two breaks. The second break date is obtained by testing all the possible models with two breaks knowing the first break date against the one break model. The procedure is repeated until the number of breaks and the corresponding break dates are determined. A maximum of 5 breaks have been allowed for this study. In the remaining of the text, the results of the sequential procedure are reported at the 5% or 10% significance level.
13. Results limited to observed data, i.e. without the forecasts up to 2009:Q4 give the same results.
14. Convergence has remained incomplete though as the catch-up stopped in the mid-1990s.

Estimates indeed point to convergence towards the US level at an annual pace of 7.8%. When this convergence effect is taken into account, the break in 2000:Q2 is still identified, but the one in 1979:Q2 disappears, suggesting that it actually reflects the convergence process. Sub-section 4.4 comes back on the convergence effect in greater detail whereby additional tests are applied to the difference in the US and EU15 series.

It is interesting to investigate the extent to which the departure from the central scenario affects the results. Testing multiple structural breaks in the lower scenario (2.5th percentile), as defined in Section 3, does not modify the results, whereas it does in the upper scenario (97.5th percentile). More precisely, a break is always found in 1979. Another break is found at the end of 2000 in the lower scenario, as in the central one. However, if future productivity growth were consistent with the upper scenario, the slowdown after 2000 would not be identified as a structural break. A less stringent characterisation of the upper scenario, the 75th percentile, rejects also the structural break in 2000, such that the 2000 break cannot be considered as being robust to possible future productivity developments.

In sum, the only robust break for EU15 labour productivity growth is in 1979 and disappears once convergence towards US productivity levels is controlled for, as convergence explains the faster growth in the (incomplete) catch-up phase.

4.3 *Results for the United States*

For the US non-farm business sector (Table 5), the test on data covering 1970-2007 as well as in the central or lower scenario up to 2009:Q4 gives no statistically significant break dates in US labour productivity growth even at the 10% level. It is only if high growth rates of labour productivity were reached in the future, *i.e.* consistent with the upper scenario, that the structural break of the mid-1990s, presumably due to ICT, would be confirmed. With the upper scenario, a statistically significant break date is found in 1998:Q3. However, with a less

stringent definition of the upper scenario, the 95th percentile instead of the 97.5th percentile, the break is not identified. Despite the clear pick-up in productivity growth in the second half of the 1990s, the size of the hump is not large enough compared with past variations to make this change a statistically significant break.

In order to gain more insight on the structural evolution of labour productivity in the United States, breaks in some of the series related to labour productivity growth – capital deepening growth, multifactor productivity growth, labour quality growth and ICT capital accumulation – have been studied between 1970 and 2006. The results are reported in Annex 3. The main finding is a structural increase in the growth rate of ICT capital services after 1995, followed by a sharp fall after 2001. This analysis implies that these breaks do not translate into breaks at the total economy level. Finally, for the manufacturing sector over 1987:2 to 2007:4, a break is found in 1993:3 at the test significance level of 10%, but not at the 5% level.¹⁵

4.4 Results for the difference in the US and EU15 growth rates

One advantage of looking at the difference between the US and EU15 series of labour productivity growth is to control for the effect of global shocks affecting both zones. Studying the difference in the US and EU15 series of labour productivity growth over 1970:Q1-2007:Q4

15. As discussed earlier, for the total economy, using the Groningen Growth and Development Centre (GGDC) Total Economy Database over 1950-2006, Gomez-Salvador *et al.* (2006) finds two break dates in the United States labour productivity growth in 1973 and in 1995. Those breaks are not found using the BLS data at the non-farm business sector level over the same period. In order to understand the result of Gomez-Salvador *et al.* (2006), the structural change test was ran for the same sectoral coverage of data, *i.e.* the total economy, using the OECD Economic Outlook 84 database. The period covered could only start in 1960 due to data availability. The result of the test gives a break date in 1968. Over the same period of 1960-2006, the GGDC data also support a similar unique break date in 1966. This means that the results of Gomez-Salvador *et al.* (2006) depend both on the sectoral coverage (total economy versus non-farm business) and the starting date (1950 versus 1960).

leads to the identification of a structural shift in the gap in labour productivity growth between the two areas after 1995:Q2 (Table 6). Until 1995, the structural EU15 labour productivity growth rate is estimated to exceed the US one by 1.6 percentage points annually (significant at the 99% confidence level), while EU15 is estimated to underperform the United States by 0.6 percentage point per annum after 1995 (this difference after 1995 is not significant).¹⁶ This result is robust to whether the central, upper or lower scenario is considered.

One weakness of the above analysis is the lack of a structural model for the productivity growth rates. The over-performance of Europe in terms of labour productivity growth before 1995 might be due to a convergence effect towards the US level as discussed above. In order to explore this hypothesis further, the test for structural change is run controlling for the difference in the levels of labour productivity (in logarithms). Within the Bai and Perron (1998, 2003) framework, the model used is the following:

$$\Delta(y_t^{EU} - y_t^{US}) = \beta_t + \sum_{k=1}^m \beta_{k+1} I(t > T_k) + \alpha (y_{t-1}^{EU} - y_{t-1}^{US}) + v_t$$

where y_t^{US} and y_t^{EU} are US and EU15 labour productivity levels (in logarithms), $(\beta_1, \dots, \beta_m)$ the usual parameters, α the convergence effect, and v_t the error term.

When controlling for the difference in levels, the sequential test confirms the break in 1995:Q2 with a significant change in the growth-rate difference from +0.8 before 1995 to -1.1 percentage points after 1995, and an annual speed of convergence of 3.1%. In order to discriminate between a break in the steady-state growth rate (the β 's) and a break in the convergence process (the α 's) regressions conditional on the 1995:Q2 break date were made.

16. The identified structural break means that the difference between the two sub-periods of the growth rate differential (from +1.6 to -0.6) across the two areas is significant at the 95% confidence level.

Results are reported in Table 7. According the first regression (first column) which does not distinguish between the two sub-periods (before and after 1995:Q2), the difference in growth rates between the two areas is partly explained by convergence at an annual pace of 7.8%. Column (2) allows for different speeds of convergence between sub-periods.¹⁷ The speed of convergence is estimated to have diminished from an annual rate of 6.8% before 1995 to no convergence afterwards. Column (3) controls for overall convergence, but allows for different levels of growth rate differentials (the β 's): it is therefore entirely consistent with the results of the sequential Bai and Perron's testing procedure reported above. Column (4) is the most general as it replicates column (3) while allowing for different speeds of convergence. Both cases are consistent with the break in growth rates and with a non-significant convergence parameter. However, multicollinearity might be problematic, and the last two columns replicate (3) and (4), respectively, but drop the non significant growth-rate difference in the first sub-period. These last estimates suggest that there was a break in both the speed of convergence from 5.7% to zero, and the structural growth rate differential after 1995:Q2, the latter being favourable to the United States by 0.6 percentage point annually after the break.

4.5 Results for the European countries and the ICT groups of countries

Finally, heterogeneity in Europe across countries and across ICT groups of countries has been taken into account. The results are summarised in Tables 8 and 9. The European countries that have similar timing of the structural shifts in their labour productivity growth are also part of the same ICT group. This suggests that in Europe the accumulation of ICT capital is correlated to structural shifts in labour productivity.

17. Given possible collinearity issues, to be consistent with the idea of convergence, the convergence parameters (the α 's) have been constrained to be no greater than zero.

- a. As for the United States, no significant break is found for the United Kingdom, Sweden, and Ireland. Those countries are all ICT- intensive.
- b. Italy and Germany experienced a structural change (downwards) in the labour productivity growth around the end of 1979 according to the tests. Both countries have a low intensity of ICT.
- c. The break (downwards) in France and Spain is estimated to have occurred around the late 1980s. Both countries are part of the intermediary ICT group.

The study of the *difference* in labour productivity growth between Europe high ICT and Europe medium-low ICT over 1970:1-2007:4 gives a break point at the end of 1990, indicating that labour productivity has structurally grown faster in Europe high ICT than in Europe medium-low ICT after this point.

5 Conclusion

This paper aimed at assessing the existence and extent of structural shifts in US and EU15 labour productivity growth since 1970. Four main conclusions emerge from the econometric tests. First, the analysis of the EU15 series points to a structural slowdown in productivity growth around 1979 and again around 2000. However, the 2000 break is not robust to likely scenarios of future productivity growth, while the 1979 break disappears when convergence towards US levels is controlled for. Second, the pick-up in United States labour productivity growth, presumably due to ICT, would be statistically measured as a break only if high growth rates of labour productivity, consistent with the 97.5th percentile of forecasts, were reached in the future. Third, a clear breakpoint is found in 1995 for the *difference* in labour productivity growth between the United States and the EU15. This breakpoint holds when controlling for a convergence effect of Europe towards United States levels, suggesting further that there has been a structural change in both the speed of convergence and the structural growth rate

differential after 1995:Q2, the latter becoming favourable to the United States after the break. Fourth, looking at individual European countries, the paper shows that ICT-intensive countries have been structurally performing better in terms of labour productivity growth since the nineties.

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ANNEX 1: DATA

Labour productivity is defined as GDP per hour. Annual data for the European countries come from the OECD Productivity Database and cover 1970 to 2007. Quarterly data come from the OECD Economic Outlook 84 database and cover 1970:1 to 2007:4. The data are available at the aggregate country level. They cover the total economy.

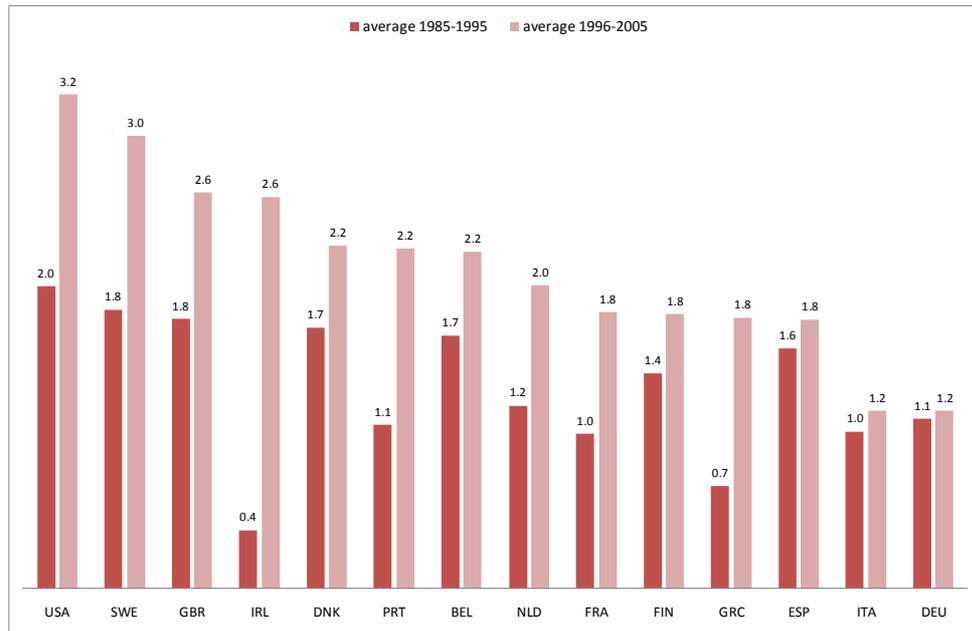
For the United States, the data sources are the OECD Economic Outlook 84 database and the Bureau of Labour Statistics (BLS) databases. The non-farm business sector is the one studied. However, the BLS also provides historical series of annual labour productivity growth for the non-farm business sector from 1948 as well as a quarterly series for manufacturing from 1987. Section 4 makes use of those data in order to allow comparison of results with the existing literature.

Also, in Section 4, in order to gain more insight about the structural evolution of labour productivity in the United States, capital deepening, multifactor productivity growth and labour quality have been studied, as well as ICT capital trends. The data on capital deepening (capital services divided by hours) are the annual data of the BLS between 1970 and 2006, and the quarterly data of the OECD Economic Outlook 84 database on capital stock in volume divided by hours between 1970:1 and 2006:4. Multifactor productivity growth is provided by the BLS on an annual basis between 1970 and 2006. Finally, the BLS provides annual data on labour composition between 1970 and 2006. Labour composition measures the effect of shifts in the experience, education, and gender composition of the work force. It is the ratio of labour input to hours of all persons, where labour input is a Tornquist aggregate of hours of all persons (classified by education, work experience and gender) using hourly compensation to

determine weights. Two series of data were used to study the ICT capital trends over 1970-2006. Jorgenson and Stiroh (2007) have built a dataset which contains IT capital services' values and prices from 1948 to 2006. The ratio of these series, which approximate the quantity of IT capital services, is taken as the first series. The second data series considered is the BLS calculation of the contribution of IT capital intensity to aggregate productivity growth (growth rate of information processing equipment and software capital services per hour times its share in total costs) available also from 1948 to 2006.

ANNEXE 2 : ANNUAL GROWTH RATE OF TOTAL CAPITAL SERVICES IN THE ICT SECTOR, IN THE UNITED STATES AND EUROPE

Figure. Annual growth rate of total capital services (in %), ICT sector, United States and Europe, 1985-2005



Source: OECD Capital-Services Database. No data are available for Luxembourg.

**ANNEX 3: BREAKS IN SOME COMPONENTS OF US LABOUR PRODUCTIVITY
GROWTH**

Periods identified by the BP test	Estimates
Capital deepening growth, 1970 – 2006	
1970 – 2006	2.9 ¹
Multifactor productivity growth, 1970 – 2006	
1970 – 2006	0.9 ¹
Labour composition, 1970 – 2006	
1970 – 1979	0.0***
1980 – 2006	0.5***
ICT capital services growth, 1970-2006	
1970 – 1995	15.6***
1996 – 2001	21.4***
2002 – 2006	9.3***

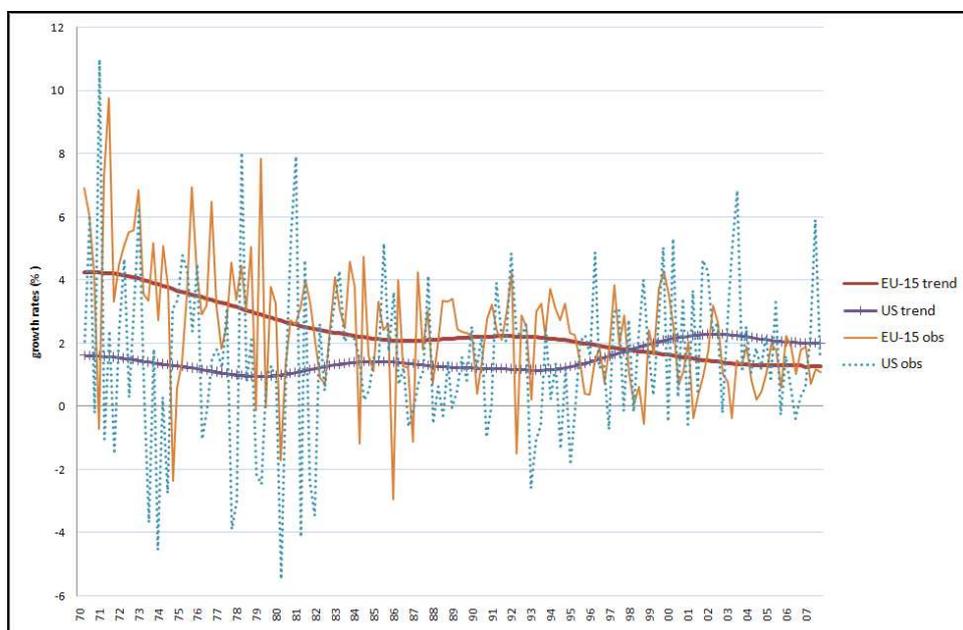
*** indicates estimates at significant at the 1% level

Labour composition measures the effect of shifts in the experience, education, and gender composition of the work force. It is the ratio of labour input to hours of all persons, where labour input is a Tornquist aggregate of hours of all persons (classified by education, work experience and gender) using hourly compensation to determine weights.

The results reported for the ICT capital services growth rely on Jorgenson and Stiroh (2007) dataset. They were confirmed using the BLS dataset.

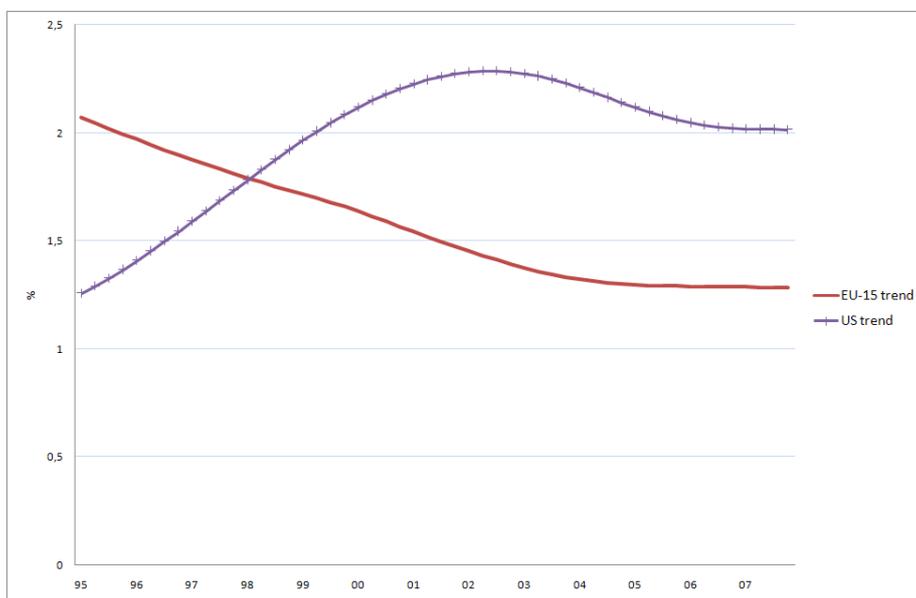
1. No break date is found. This figure is the average over 1970-2006.

Figure 1A. US and EU15 labour productivity growth rates, observations and trends, quarterly data, 1970:1 - 2007:4



Source: OECD Economic Outlook 84 Database, and BLS for 2007 US labour productivity growth rates in the non-farm business sector. Hodrick-Prescott filtering ($\lambda=7000$).

Figure 1B. Zoom on US and EU15 labour productivity growth rate trends, quarterly data, 1995:1 - 2007:4



Source: OECD Economic Outlook 84 Database, and BLS for 2007 US labour productivity growth rates in the non-farm business sector. Hodrick-Prescott filtering ($\lambda=7000$).

Figure 2A. EU15 growth rate trends in labour productivity, quarterly data 1970:1 - 2007:4, and arima forecast to 2009:4

Central, upper and lower projected trends in labour productivity growth

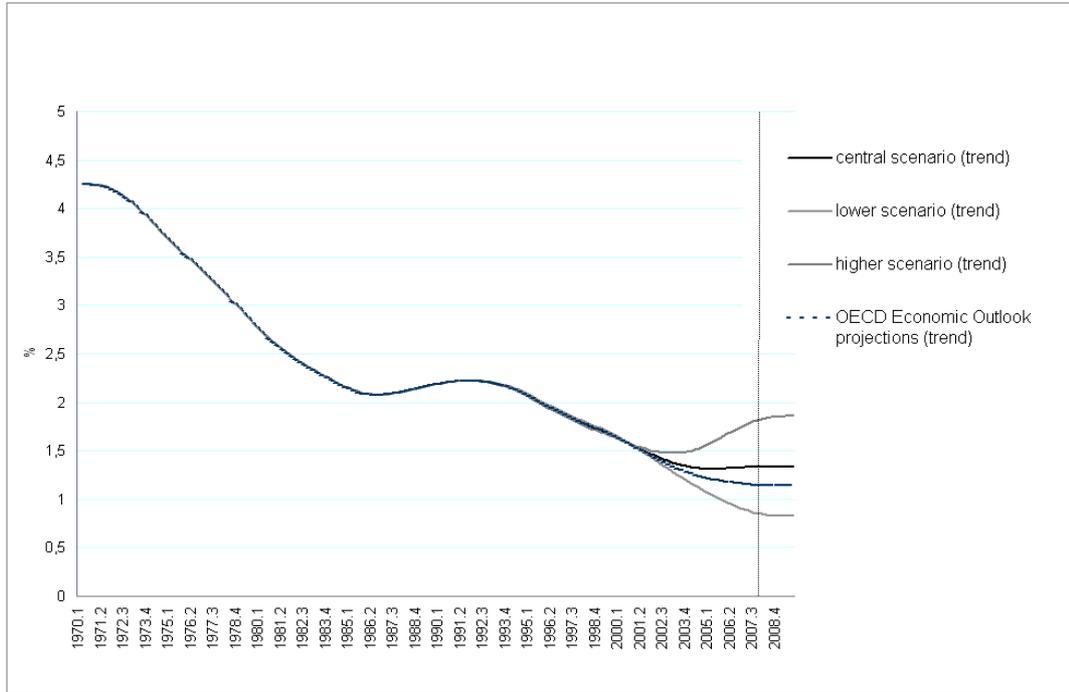
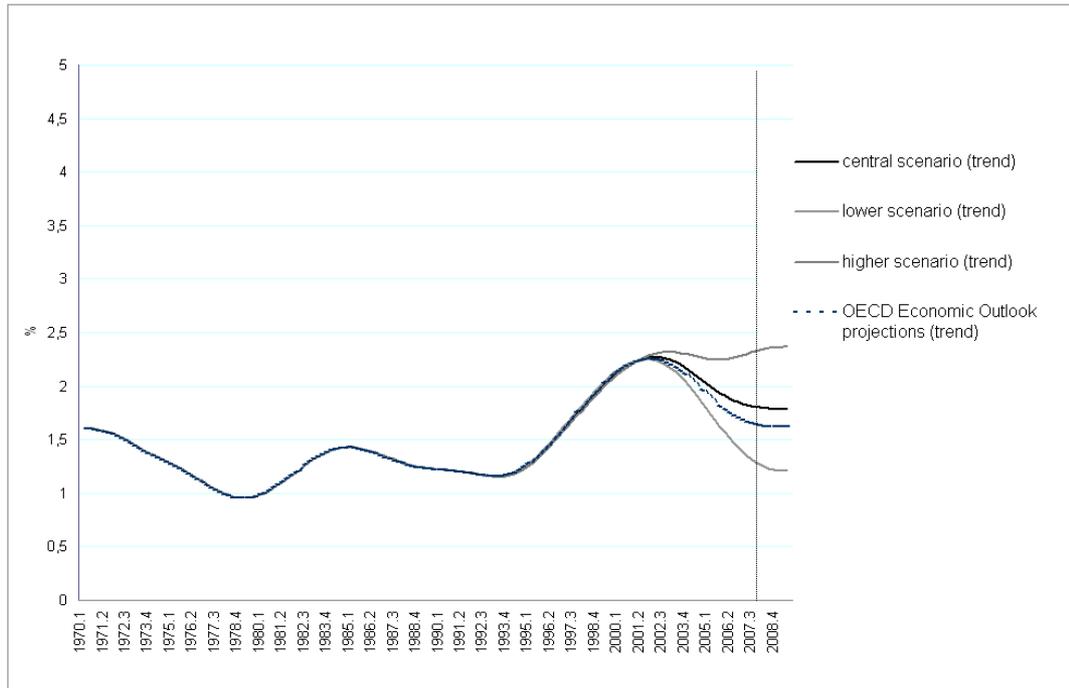
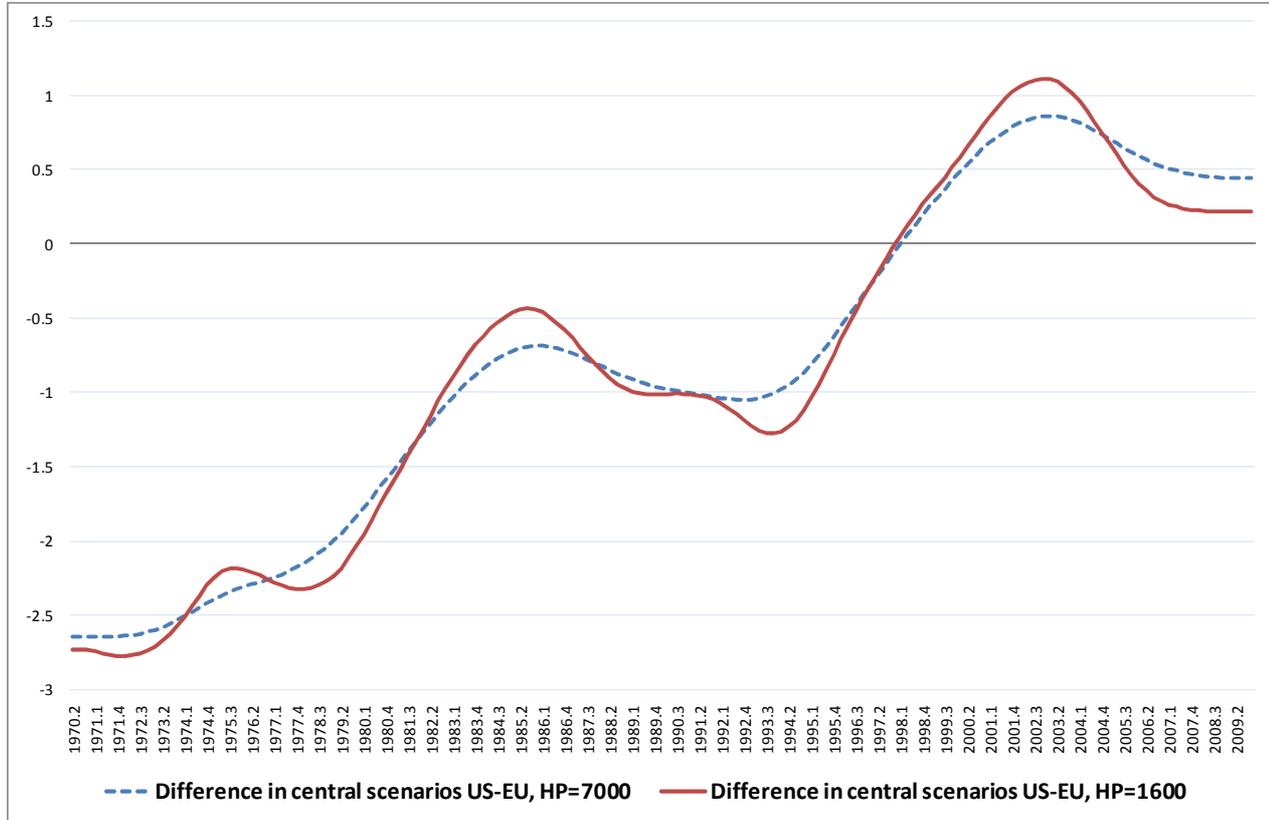


Figure 2B. US growth rate trends in labour productivity, quarterly data 1970:1 - 2007:4, and arima forecast to 2009:4



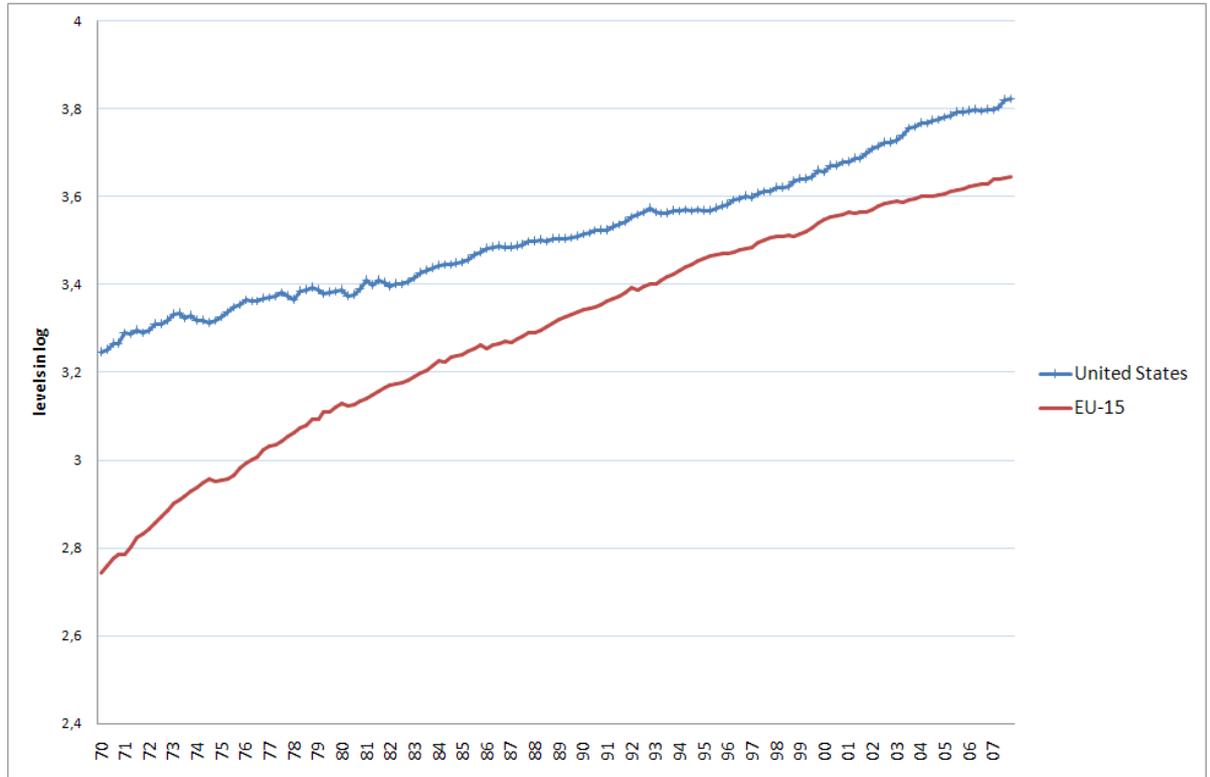
Source: OECD Economic Outlook 84 Database, and BLS for 2007 US labour productivity growth rates in the non-farm business sector. Hodrick-Prescott filtering ($\lambda=7000$). Scenarios are based on ARIMA projection (see Section 3).

Figure 3. Differences between US and EU15 labour productivity growth trends in the central scenario, 1970:Q1 - 2009:Q4 according to the HP filtering parameter



Source: OECD Economic Outlook 84 Database, and BLS for 2007 US labour productivity growth rates in the non-farm business sector. Arima forecasts to 2009:4.

Figure 4. Labour productivity levels in the United States and in Europe, 1970:1 - 2007:4 at 2000 PPP, USD



Source: OECD Economic Outlook 84 Database.

Table 1. Average growth rate of labour productivity (quarterly annualised)

	1985-1995			1996-2007			2000-2007		
	LP	Trend	Cycle	LP	Trend	Cycle	LP	Trend	Cycle
BEL	2.2	2.2	0.0	1.4	1.4	0.0	1.1	1.2	-0.1
DEU	2.7	2.7	0.0	1.6	1.6	0.0	1.5	1.4	0.1
DNK	2.6	2.3	0.3	1.0	1.1	-0.1	1.0	1.0	0.0
ESP	1.8	1.8	-0.1	0.5	0.6	-0.1	0.7	0.5	0.2
FIN	3.2	3.2	0.1	2.5	2.4	0.1	2.5	2.3	0.2
FRA	2.4	2.4	0.0	1.6	1.6	0.0	1.6	1.5	0.1
GBR	2.0	1.9	0.1	2.2	2.5	-0.3	2.0	2.7	-0.7
GRC	1.7	1.0	0.7	3.1	3.2	-0.1	3.7	3.4	0.3
IRL	3.6	4.0	-0.4	4.2	4.0	0.2	3.1	3.4	-0.3
ITA	2.2	1.9	0.3	0.6	0.7	-0.1	0.5	0.4	0.1
LUX	3.0	3.0	0.0	1.9	1.7	0.2	1.7	1.7	0.0
NLD	1.5	1.7	-0.2	1.3	1.4	-0.1	0.9	1.0	-0.1
PRT	3.0	2.6	0.4	1.9	1.7	0.2	1.2	0.8	0.3
SWE	1.6	1.6	0.0	2.3	2.3	0.0	2.2	2.0	0.2
EU15	2.1	2.1	0.0	1.5	1.5	0.0	1.2	1.4	-0.1
ICT high-intensive countries	2.4	2.5	-0.1	2.9	2.9	0.0	2.4	2.7	-0.3

Source: OECD Economic Outlook 84 Database. Hodrick-Prescott filtering ($\lambda=7000$).

Reading note: the ICT high-intensive group of countries includes Sweden, United Kingdom, and Ireland. It was defined considering the countries' average growth in total capital services over 1996-2005 in the ICT sector (see section 3)

Table 2. Overview of the previous results

Paper	Data source and scope	Data period	Data frequency	Statistical approach	Break(s) identified
UNITED STATES					
Benati (2007)	USA Non-farm business, BLS	1947:1-2005:4	quarterly	Bai and Perron (1998, 2003)	No break
Stiroh (2001)	USA Non-farm business, BEA	1974:1-2000:3	quarterly	estimation of one break date	No break
Stiroh (2001)	USA, Manufacturing, BEA	1974:1-2000:3	quarterly	estimation of one break date	1993:3
Hansen (2001)	USA Manufacturing/durables, BLS	1947:1-2000:4	quarterly	Bai and Perron (1998) among others	1997
Gomez-Salvador et al. (2006)	USA, Total Economy, GGDC Database	1950-2006	annual	Bai and Perron (1998, 2003)	1973, 1995
EUROPE					
Benati (2007)	Euro-zone, Total Economy, European Central Bank Area Wide Model Database	1970:1 – 2006:2	quarterly	Bai and Perron (1998, 2003)	2001:1
Gomez-Salvador et al. (2006)	Euro-zone, Total Economy, GGDC Database	1950-2006	annual	Bai and Perron (1998, 2003)	1973, 1979, 1995
EC (2007)	Euro-zone, Total Economy, Eurostat	1980:1 – 2006:4	quarterly	Bai and Perron (1998, 2003) on trend extracted by filter. BIC criteria.	1998:1

Table 3. Trend/cycle breakdown of labour productivity growth
(annual data, Hodrick-Prescott filtering with $\lambda=30$)

EU15			
	Labour productivity growth	Trend	Cycle
1985-1995	2.1	2.1	0.0
1996-2006	1.5	1.5	0.0
2000-2006	1.2	1.4	-0.1
2000-2003	1.2	1.5	-0.2
2004-2007	1.3	1.3	0.0

United States			
	Labour productivity growth	Trend	Cycle
1985-1995	1.2	1.4	-0.2
1996-2006	2.1	2.1	0.0
2000-2006	2.2	2.2	-0.1
2000-2003	2.7	2.3	0.3
2004-2007	1.3	2.1	-0.8

Source: OECD Productivity Database and BLS for 2007 US labour productivity growth rates in the non-farm business sector. Hodrick-Prescott filtering ($\lambda=30$).

Table 4. Breaks in EU15 labour productivity growth

Results of the Bai-Perron sequential test at significance level of 5%

Central scenario		Lower scenario		Higher scenario	
Periods identified by the BP test	Estimated average growth rate of labour productivity	Periods identified by the BP test	Estimated average growth rate of labour productivity	Periods identified by the BP test	Estimated average growth rate of labour productivity
70q1-79q2	4.1***	70q1-79q2	4.1***	70q1-79q2	4.1***
79q3-00q2	2.1***	79q3-00q2	2.1***	79q3-09q4	2.0***
00q3-09q4	1.3***	00q3-09q4	1.0***		

*** indicates that estimates are significant at the 1% level

Reading note: Identification of a break means that the difference in growth rates before and after the break date is significantly different from zero at the 5% level. For example, in the central scenario, the Bai-Perron sequential test identifies 2 breaks in EU15 labour productivity growth, dividing the whole period into 3 sub-periods: from 1970 Q1 to the first break in 1979 Q2, the average annual growth rate is 4.1%, while it is 2.1% between 1979 Q3 and the second break date in 2000: Q2, and 1.3% between 2000 Q3 and 2009 Q4.

Table 5. Breaks in US labour productivity growth

Results of the Bai-Perron sequential test at significance level of 5%

Central scenario		Lower scenario		Higher scenario	
Periods identified by the BP test	Estimated average growth rate of labour productivity	Periods identified by the BP test	Estimated average growth rate of labour productivity	Periods identified by the BP test	Estimated average growth rate of labour productivity
Test non significant	no break	Test non significant	no break	70q1-98q3	1.3***
				98q4-09q4	2.4***

*** indicates that estimates are significant at the 1% level

Reading note: see Table 4.

Table 6. Breaks in the difference between EU15 and US labour productivity growth rates

Results of the Bai-Perron sequential test at significance level of 5%

Central scenario		Lower scenario		Higher scenario	
Periods identified by the BP test	Estimated difference in growth rates	Periods identified by the BP test	Estimated difference in growth rates	Periods identified by the BP test	Estimated difference in growth rates
70q1-95q2	1.6***	70q1-95q2	1.6***	70q1-95q2	1.6***
95q3-09q4	-0.6	95q3-09q4	-0.5	95q3-09q4	-0.6

*** indicates that estimates are significant at the 1% level

Reading note: see Table 4.

Table 7. Assessment of the 1995:Q2 break in the difference between EU15 and US labour productivity growth rates and in the speed of convergence

Dependent variable: $\Delta(y_t^{EU} - y_t^{US})$

	(1)	(2)	(3)	(4)	(5)	(6)
difference in the levels of labour productivity (in logarithms) $y_t^{EU} - y_t^{US}$	-0.078** (0.034)		-0.031 (0.040)		-0.056*** (0.014)	
difference in the levels of labour productivity (in logarithms), up to 1995:Q2		-0.068*** (0.021)		-0.035 (0.041)		-0.057*** (0.014)
difference in the levels of labour productivity (in logarithms), from 1995:Q2		0.000 bound		0.000 bound		0.000 bound
Dummy (=1 up to 1995:Q2)			0.008 (0.010)	0.007 (0.010)		
Dummy (=1 from 1995:Q2)			-0.011* (0.006)	-0.006** (0.003)	-0.014*** (0.004)	-0.006** (0.003)
Constant	-0.009 (0.007)	-0.004 (0.003)				

Note. To be consistent with convergence, the parameter for the difference in levels (first three rows in the table) is restricted to be negative. The constraint is binding for the difference in levels after 1995:Q2. Standard errors in parenthesis are robust to heteroskedasticity and autocorrelation.

Table 8. Results of the Bai-Perron sequential test at significance level of 5% for selected countries

Countries	Periods identified by the BP test	Estimated average growth rate of labour productivity
FRA	1970:Q1- 1989:Q4	3.5***
	1990:Q1- 2007:Q4	1.7***
ESP	1970:Q1- 1986:Q2	4.4***
	1986:Q3- 2007:Q4	0.9***
DEU	1970:Q1- 1979:Q2	4.6***
	1979:Q3- 2007:Q4	2.0***
ITA	1970:Q1- 1979:Q4	4.3***
	1980:Q1- 2007:Q4	1.2***
GBR	non significant	—
SWE	non significant	—
IRL	non significant	—

*** indicates that estimates are significant at the 1% level

Reading note: see Table 4.

Table 9. Results of the Bai-Perron sequential test at significance level of 5 % - Difference between high ICT Europe and medium-low ICT Europe

Periods identified by the BP test	Estimated difference in growth rates
1970q1-1990q4	-0.5*
1991q1-2006q4	1.0**

** indicates that estimates are significant at the 5% level, * at the 10% level.

“Europe high ICT” and “Europe medium-low ICT” labour productivities are unweighted averages. The ICT groups of countries are defined looking at the average growth in total capital services over 1996-2005 in the ICT sector (see section 3).

Reading note: see table 4.