ICT and Productivity Growth in the 1990's: Panel Data Evidence on Europe*

Christian M. Dahl

Department of Economics, University of Aarhus, and CEBR

Hans Christian Kongsted

Department of Economics, University of Copenhagen, CAM and CEBR

Anders Sørensen

Department of Economics, Copenhagen Business School, and CEBR

July 2009

Abstract

What has been the quantitative effect on productivity growth of information and communication technology (ICT) in Europe after 1995? Based on a multi-country sectoral panel data set, we provide econometric evidence of positive and significant productivity effects of ICT in Europe, mainly due to advances in total factor productivity. In contrast to the US, this impact of ICT has happened against a negative macro economic shock not related to ICT. Our main result is in contrast to the established consensus in the growth accounting literature that there has been no acceleration of productivity growth in Europe, mainly due to the performance of ICT-using sectors. One important advantage of using econometric methods is that we can distinguish between growth effects from ICT and macro economic shocks; a feature that growth accounting methods cannot handle.

Keywords: Labor productivity, total factor productivity, information and communications technology, panel data methods

JEL Classification codes: E32, C23, O47

*This research is part of the EUKLEMS project on Growth and Productivity in the European Union. The project was supported by the European Commission, Research Directorate General as part of the 6th Framework Programme, Priority 8, "Policy Support and Anticipating Scientific and Technological Needs." Acknowledgements: Sørensen and Kongsted gratefully acknowledge financial support from the Tuborg Foundation. We are also grateful to Dale Jorgenson and to seminar participants at the 15th International Confererence on Panel Data, in particular Maurice Bun and Jacques Mairesse, for useful comments. The usual disclaimer applies. CAM: Centre for Applied Microeconometrics; CEBR: Centre for Economic and Business Research, Porcelaenshaven 16A, DK-2000 Frederiksberg, Denmark.

1 Introduction

This paper provides new econometric evidence on the relationship between information and communication technology (ICT) and productivity growth in Europe. We find that ICT-intensive industries went through a far less dramatic reduction in productivity growth after 1995 than industries which did not use ICT intensively in production. In effect, the overall slow-down in productivity growth that happened in Europe after 1995, would have been even more dramatic in the absence of any positive impact of ICT. This result is contrary to the general consensus reached in the growth accounting literature as recently summarized by Draca, Sadun, and Van Reenen (2006): "There has been no acceleration of productivity growth in the EU, mainly due to the performance of the ICT using sectors."[1] Whereas our econometric findings confirm the first part of this statement, we find significant effects of ICT, including a positive effect on productivity growth among ICT users.

Two important differences in terms of productivity developments between Europe and the United States stand out in the literature. First, a productivity gap between Europe and the United States developed over the second half of the 1990s because the *aggregate* productivity levels of the two regions diverged. For example, Van Ark, O'Mahony, and Timmer (2008) find that the US productivity growth rate *increased* from 1.5 per cent before 1995 to 3 per cent after 1995, whereas the productivity growth rate in Europe *declined* from 2.4 per cent to 1.5 per cent.

Second, O'Mahony and Van Ark (2003) found that although European ICT-*producing* sectors experienced a productivity acceleration similar to that of US ICT-producers, ICT-*using* sectors failed to achieve a similar development in Europe. However, the fact that ICT-using industries in Europe showed stagnant productivity does not in itself preclude a positive differential impact of ICT. In order to identify the impact of ICT use, the performance of ICT users will have to be compared to the aggregate scenario of declining productivity growth in Europe during the 1990s.

Our main hypothesis is based on these observations. We test if ICT had a positive differential impact on productivity growth in the sense that ICT–intensive industries had significantly higher productivity growth rates than non-ICT-intensive industries after 1995. To properly address this question it is crucial to distinguish aggregate macro effects from sectoral effects generated by differences in the use of ICT. Therefore, we apply econometric methods that control separately for macro effects, sector-specific fixed effects, and the effects from ICT-use.

[1] This consensus has also found its way to the Economist in the feature "Europe: Use IT or lose it" of May 17, 2007, a feature based on Van Ark et al (2007).

The applied data source is the industry data from the EUKLEMS database.[2] This dataset comprises a large set of internationally comparable data on productivity developments at a disaggregated sectoral level. The database also contains detailed data on capital investments, including ICT related capital expenditures. We exploit the panel structure of the country and industry data to control for unobserved industry-specific and country-specific fixed effects as well as time effects. This allows us to identify the productivity effects of ICT *within* industries and, therefore, separately from productivity effects generated by changes in the business structure.

Our use of econometric methods has some advantages over the growth accounting framework usually employed in the literature on productivity growth determinants.[3] The econometric methods quantify the impact of ICT by exploiting the variation in industry-level data. Moreover, they allow statistical tests of significance of the economic impact of ICT. In contrast, the growth-accounting method basically assumes the result since factor shares are used as measures for output elasticities.

Moreover, the growth accounting methods decompose labor productivity growth into contributions from labor composition, capital deepening, and multifactor productivity. The latter component is a residual measure with multiple interpretations; it can be a measure of technological progress but could also pick up widespread macroeconomic shocks. In other words, it is not possible to distinguish between effects on productivity from new technology, e.g., ICT, and macro economic effects, e.g., effects of labor market reforms, changes in competition, regulation, etc.

Our main findings are that the decline in labor productivity growth after 1995 is a general phenomenon across European industries but sectoral productivity growth rates decreased the most in non-ICT-intensive industries. More specifically, the average decline in sectoral growth rates of non ICT-intensive industries was around 1 percentage point for labor productivity growth after 1995. This was partly countervailed by a positive effect of around 0.8 percentage points in industries that were ICT-intensive pre-1995. Our results weaken when ICT-producers are excluded although an economically significant differential effect of 0.5 percentage points remains for ICT-users versus remaining sectors. The result does not depend critically on the developments in financial intermediation (FIRE) industries nor the exact timing of the break.

In addition to providing results on labor productivity in a comparable multi-country setting, a main contribution of our paper is to extend the analysis to total factor productivity (TFP) growth. The extension is crucial in order to distinguish genuine effects of technological progress due to ICT

[2] See www.euklems.net or Van Ark *et al.* (2008).
[3] See below in Section 2 for a summary of this literature

from the capital-deepening effects of increasing the amounts of ICT capital used in production in different sectors.

Our results show that the average growth rate of total factor productivity (TFP) fell by 0.6-0.7 percentage points after 1995 in non ICT-intensive sectors. In ICT intensive industries, there was a countervailing positive growth effect of 0.6 percentage points. The result does not depend critically on developments in ICT-producing industries, FIRE industries, nor the exact timing of the break. Hence, we find evidence that that higher ICT intensity has contributed positively to TFP productivity growth in Europe, including an economically sizable and statistically significant TFP gain in intensively ICT-using industries. Moreover, a comparison of TFP and labor productivity impacts of ICT shows that the impact of ICT in Europe is predominantly due to gains in TFP rather than capital deepening.

The basic set-up of our analysis is closely related to Stiroh (2002). He analyzed the relationship between ICT intensity and labor productivity growth across industries for the United States. A comparison with Stiroh's results will thus enable us to quantitatively assess whether the US is ahead of Europe in terms of productive applications of ICT. This turns out to be the case since Stiroh found a larger differences in terms of post-1995 labor productivity growth between ICT-intensive and non-ICT-intensive industries. His point estimate suggests almost 2 percentage points higher growth rate of labor productivity compared to other industries for the US economy. The overall conclusion is that there has been significant effects of ICT in European economies but that the effects have been around half of the ICT effects experienced in the United States when looking at labor productivity growth.

The paper is laid out as follows. Section 2 is a brief review of the literature on ICT and productivity growth at the sectoral level. Section 3 documents the basic descriptive facts about the aggregate growth scenario, the development of certain sectors, and the timing of a break in productivity in Europe during the 1990's. Section 4 provides a detailed account of the EUKLEMS data on which our analysis is based while section 5 summarizes our econometric approach. Our empirical results are reported in Section 6, whereas Section 7 concludes.

2 Related Literature

The literature on the possible impact of ICT on productivity growth took off from the so-called Solow paradox, the observation by Solow (1987) that although enormous technological progress in

ICT production had been realized and gone along with strong investments in ICT, hardly any effect on economic growth could be observed. Subsequent studies on ICT and productivity growth in the macro literature have mostly been performed for the United States using the growth-accounting framework. For an introduction to the growth accounting methodology, see Jorgenson et al (1987). The studies find that productivity growth has accelerated after 1995 and a consensus has been established that this acceleration is linked to ICT.[4] This was stated by Dale Jorgenson in his presidential address to the American Economic Association meeting, see Jorgenson (2001):

> "The resurgence of the American economy since 1995 has outrun all but the most optimistic expectations. Economic forecasting models have been seriously off track and growth projections have been revised to reflect a more sanguine outlook only recently......Productivity growth in IT- producing industries has gradually risen in importance and a productivity revival is now under way in the rest of the economy. Despite differences in methodology and data sources, a consensus is building that the remarkable behavior of IT prices provides the key to the surge in economic growth."

An implication of these findings is that the Solow Paradox no longer applies. The paradox was simply a consequence of ICT constituting a small part of the capital stock.

The growth-accounting method decomposes labor productivity growth into growth in labor input, growth contributions by capital deepening, and growth in TFP. In order to assess the magnitude of the direct effects of ICT on growth, two additional steps are taken. First, to measure the contribution from the use of ICT capital, the growth in capital input is decomposed into two elements, one related to ICT capital and one related to other capital goods. Second, to single out the contribution from technological progress in the production of ICT capital, the private sector is decomposed into ICT-producing industries and ICT-using industries. The technological progress in the production of ICT is then measured by the TFP growth in the former industries. Using this method, Oliner and Sichel (2000) find that the growth rate in labor productivity increased by 1.04 percentage points from 1991-95 to 1996-99 for the US. Of this increase 43 per cent can be attributed to the accumulation of ICT capital in all industries, whereas 36 per cent can be attributed to TFP growth in ICT-producing sectors. The method also provides a measure of TFP growth, however, this measure cannot be linked directly to ICT, though it may reflect that ICT-using sectors have higher productivity partly as a result of higher ICT use.

[4] See for example, Oliner and Sichel (2000), Jorgenson, Ho, and Stiroh (2008), and Whelan (2002).

Using industry data, Stiroh (2002) produces econometric evidence that there was significant productivity growth in the ICT-using sectors, even after controlling for macro economic shocks. The analysis is performed for US industries for the periods 1987-95 and 1995-2000.[5] The main findings are that the acceleration in productivity is a broad phenomenon across US industries — not only in ICT-producing sectors — but that growth rates increased the most in ICT-intensive industries. More specifically, ICT-intensive industries experienced a productivity acceleration about 2 percentage points greater than other industries. The results are developed for labor productivity growth. It remains unclear whether effects from ICT are generated through capital deepening or TFP.[6]

Some growth-accounting studies have also appeared for European economies. Contrary to the United States, European productivity growth did not accelerate after 1995; instead aggregate labor productivity growth declined. In other words, the productivity gap betwen Europe and the United States widened, see Van Ark et al (2008).

O'Mahony and Van Ark (2003) perform a comparative study between the United States and a small number of European countries (EU-4). The authors find that European ICT-producing sectors had similar productivity acceleration as in the United States. Moreover, the authors find that productivity growth in the EU remained relatively stable across time in intensively ICT-using sectors, in contrast to a very large acceleration in the US. According to the authors, this is a clear indication that the US is ahead of Europe in terms of productive application of ICT outside the ICT producing sector itself. Also based on the growth accounting framework, Timmer and Van Ark (2005) find that the difference in ICT-capital deepening and from the contribution from TFP growth in ICT-goods production explain the major gap in growth rates between Europe and the United States after 1995. These conclusions are followed up in Van Ark et al (2008) who conclude that "the European productivity slowdown is attributable to the slower emergence of the knowledge economy in Europe compared to the United States".[7]

[5] O'Mahony and Vecchi (2005) perform an econometric comparison of the United Kingdom and the US. Estimates suggest a strong impact in the United States, whereas the results are less conclusive for the United Kingdom.

[6] Jorgenson et al (2008) argue that US productivity growth after 1995 and up to 2000 was driven by productivity growth in ICT producing sectors and ICT-capital-deepening effects. After 2000 productivity growth is driven by TFP growth in ICT-using industries.

[7] Van Ark et al (2008) evaluate the effect of structural changes on productivity growth. They find that reallocation of labor between industries has contributed negatively to labor productivity growth after 1995 in Europe. This can, however, not explain the low European growth rates, since the negative reallocation effect is numerically larger for the United States.

3 European productivity developments in the 1990s

Europe enjoyed a much less favourable productivity trend than the US after 1995. Table 1 details the labor productivity developments in eight European countries using the US for comparison. The table contains the unweighted average of labor productivity growth rates over industries for the pre- and post-1995 periods for the nonfarm business sector, and the nonfarm business sector excluding ICT producers or FIRE industries, respectively. The included European economies are Austria, Denmark, Finland, France, Germany, Italy, the Netherlands, and the United Kingdom.

[Table 1 about here]

It is evident that the average industry growth rates either decreased or increased only slightly in Europe post-1995 with the only exception of Austria that experienced an increasing growth rate of 0.7 percentage points. When excluding ICT production it is found that the average growth rates fell in all European economies except in Austria that experienced an increase of around half a percentage point. In contrast to the European economies, the average industry growth rate in the United States more than doubled post-1995.

While the rate of productivity growth was generally very modest in Europe compared to the US, there was also some degree of dispersion in productivity growth rates across European countries. In order to be able to measure any differential productivity impact in relatively ICT-intensive sectors, we will have to take into account that such differences happened against a much weaker general productivity trend than in the US.

When studying growth rates across subperiods, it is of course important to determine the break year. In the growth accounting literature the applied break year is 1995, see for example Jorgenson et al (2008). A break in productivity trends during 1995 is supported econometrically by Hansen (2001) and Stiroh (2002) who analyze quarterly data for the US business sector over the period from 1974 to 2001. This tradition has been passed on as the standard point of reference used in analyzing the aggregate European experience, e.g., in Van Ark, O'Mahony, and Timmer (2008). Although the dividing line of 1995 has been accepted for Europe as well, this tradition is not based on any statistical tests; according to our knowledge, no such statistical test of break year for European productivity exists. Empirically, the date of any break is less easily determined for individual European countries than for the US because the available data are annual. By having a set of comparable panel data, we can pool the data across countries. The cost that we have to cover when pooling is an assumption that the break happens simultaneously across all countries. The test presented in Figure 1 applies the Sup F test of Andrews (1993) to a pooled data set containing the nonfarm business sector industries across eight European countries.[8]

[Figure 1 about here]

Details on the applied model is presented in Section 5 below. The dotted curve shows the average for all eight countries of Sup F tests calculated for each potential break year. We also calculate the test excluding data for Austria (the dashed line). This country turns out to be non-poolable with the remaining countries, see Section 6 below.

Figure 1 shows that any trend break in productivity should be found during the second half of the 1990's. The test is not quite conclusive as to the exact timing of the break. When including all countries, the maximum test statistic is achieved in 1998. Also 1995 and 1999 are candidate break years. When excluding Austria from the test 1995 emerges as the main candidate for the break year. In any case, there is little evidence of a break year prior to 1995.

Overall, by pooling the evidence across countries, we find that the econometric evidence on the timing of the break is consistent with the ICT-induced break in the US during 1995 that was established by Stiroh (2002). In conclusion, we will follow existing literature in allowing for a break in productivity in 1995. We present further evidence on the robustness of our results as to the timing of the break in Section 6.

4 Data and Variables

The applied data source is the EUKLEMS Growth and Productivity Accounts.[9] This database include data on gross output, value added, ICT capital, other capital, hours worked, employment, and intermediate inputs at the industry level, implying that analyses of the relationship between productivity growth and ICT can be carried out for both labor productivity and total factor productivity. The database comprises data for the period 1970 to 2004. In the following we discuss key variables used in the empirical analysis below.

[8] We do not report any critical value since a panel data version of the Sup F test has not been worked out in the literature.

[9] See www.EUKLEMS.net.

4.1 Productivity growth

We apply two measures of productivity growth. The first measure is based on labor productivity that is simply defined as output divided by labor input, whereas total factor productivity relates output to a composite of primary factor inputs and intermediate inputs.

The applied measure of output is sectoral gross output. This measure is superior to sectoral value added because an output measure based on a real value-added function is justified only when the production function of gross output is separable in real value-added and intermediate inputs. Jorgenson, Fraumani, and Galop (1987) find that separability is heavily rejected.

We follow the standard in the literature and measure labor productivity as output in relation to the total hours worked. When estimating TFP we measure factor inputs as labor service where labor types with high relative wages weight more than labor types with low relative wages in a sectoral measure of labor input. Capital service is used as the measure of capital input. As for labor service, capital service is a measure where capital stocks of different asset types are weighted by relative compensations; in this case relative user costs. Finally, intermediate input origin from supply and use tables.

4.2 ICT intensity

The main measure of ICT-intensity is defined as ICT-capital service out of total capital service. Moreover, we apply two alternative measures of ICT-intensity; ICT-capital service per worked hour and ICT-capital service in relation to gross output. These definitions follows Stiroh (2002).

The main analysis is based on dummy variables defined using the main measure of ICT-intensity. If the ICT-intensity for an industry exceeds the country median value over industries, the dummy equals 1, whereas it equals 0 otherwise. In the robustness analysis, the empirical results are checked by using dummy variables based on two alternative measures of ICT-intensity. The regression analyses are also performed using the continuous measure of ICT intensity.

4.3 Countries and Industry Coverage

Data are provided for 31 industries in the EUKLEMS database. Of these we exclude agriculture, hunting, forestry and fishing as well as mining and quarrying. Moreover, we exclude 4 industries within non-market services and the personal service sector private households with employed persons. We are left with 24 industries within the nonfarm business sector on which the analysis is based.[10]

Throughout the analysis we distinguish between ICT-producing and -using industries. Stiroh (2002) found that although productivity growth in the US increased significantly in all ICT intensive industries, the effects were found to be stronger among ICT producers. We follow Van Ark et al. (2007) and define ICT producers as the ICT-producing manufacturing and service sectors.[11]

For the purpose of the present analysis, we use data for 8 European countries. These are Austria, Denmark, Finland, France, Germany, Italy, the Netherlands, and United Kingdom.[12]

5 Econometric Approach

We specify a difference-in-difference regression in terms of the log growth rate of labor productivity, $\Delta \ln A_{ijt} = \Delta \ln (Y_{ijt}/E_{ijt})$ measured in percentage terms. Here Y_{ijt} denotes real gross output of industry i in country j in year t and likewise for the number of hours worked, E_{ijt}.

$$\Delta \ln A_{ijt} = a_{ij} + \alpha_{0j} \Delta \ln A_{ijt-1} + \alpha_{1j} d_t + \alpha_{2j} it_{ij95} + \alpha_{3j} d_t \times it_{ij95} + \varepsilon_{ijt} \quad (1)$$

where ε_{ijt} is an error term and

$$d_t = 1 \quad \text{for } t \geq 1995 \text{ and } \quad d = 0 \text{ otherwise.}$$

ICT-intensity in the break year 1995 in industry j of country i is denoted it_{ij95}. We will consider two different specifications of this term: A binary term that equals one if the ICT intensity of a particular industry is above the median (and zero otherwise) and a continuous specification that simply includes the intensity variable itself. Using a binary classification based on the median provides robustness to outlying measurements.

We exploit the fact that we have a panel of consistent data across a number of European countries to approach the estimation of (1) at several different levels of generality. First, as a starting point to check the actual poolability of the data across countries, we consider country-by-country analyses that allow full flexibility in terms of all parameters, including the α slopes. Second, when pooling the data across countries we can allow for different fixed effects across countries

[10] The entering industries are 15t16, 17t19, 20, 21t22, 23, 24, 25, 26, 27t28, 29, 30t33, 34t35, 36t37, E, F, H, 50, 51, 52, 60t63, 64, J ,71t74, and O.

[11] The sectors denoted 30t33 and 64 in the EUKLEMS database.

[12] Belgium and Spain have been excluded from the analysis because the break-down ICT-data is not detailed enough.

and/or industries. Four cases are distinguished in terms the intercept a_{ij}: A fully pooled case of a common intercept ($a_{ij} = \delta$); a case of country-specific intercepts ($a_{ij} = \delta_j$) that do not vary across industries; a case of industry-specific intercepts ($a_{ij} = \delta_i$) that do not vary across countries; and finally, a general set of fixed effects that may vary both across countries and industries.

The regression (1) extends Stiroh's (2002) approach by including a term in lagged productivity growth, $\Delta \ln A_{ijt-1}$. We find ample evidence of the general significance of this extension. For consistent estimation of the dynamic panel data model we employ the generalized methods of moments approach of Arellano and Bond (1991).

A second main extension compared to Stiroh (2002) is the analysis of total factor productivity. For this we specify a diff-in-diff regression in terms of the growth rate of real output:

$$\begin{aligned} \Delta \ln Y_{ijt} &= b_{ij} + \beta_{0j} \Delta \ln Y_{ijt-1} + \beta_{1j} d_t + \beta_{2j} it_{ij95} + \beta_{3j} d \times it_{ij95} \\ &\quad + \beta_{4j} \Delta \ln X_{ijt} + \beta_{5j} \Delta \ln L_{ijt} + \beta_{6j} \Delta \ln K_{ijt} + u_{ijt}. \end{aligned} \qquad (2)$$

The TFP regression furthermore includes controls for the growth rates of intermediate inputs ($\Delta \ln X_{ijt}$), labor ($\Delta \ln L_{ijt}$) and capital ($\Delta \ln K_{ijt}$), and an error term (u_{ijt}).

6 Empirical Results

6.1 Labor productivity

This section reports our results based on (1) for labor productivity growth. For each country we divide industries into ICT-intensive and non-ICT-intensive industries depending on their ICT intensities in comparison to the median intensity. In Section 6.3 below, we provide results based on two alternative measures and a continuous specifications of ICT intensity.

[Table 2 about here]

Table 2 contains the individual country results for industries in the nonfarm business sector. The results reported in Panels A through C differ in terms of their treatment of lagged effects and industry heterogeneity. Panel A reports the results for a simplified difference-in-difference specification. Panel B adds a term in lagged productivity growth. Panel C additionally extends the model to include industry fixed effects.

The estimates of the coefficients related to the trend-break term, d, and its interaction term with ICT-intensity, $d \times it$, are of main interest. They remain fairly stable across specifications. The most general specification (panel C) is preferred because it encompasses the fact that lagged productivity growth enters very significantly in some countries and because we can control for any unobserved time-invariant level differences between industries by including industry fixed effects.

The point estimates suggest that seven out of eight countries experienced negative changes in productivity growth rates in 1995 for non-ICT-intensive industries (the coefficient of d). This is consistent with a decrease in the aggregate productivity growth rate in Europe after 1995 as found in the literature. Moreover, since the present analysis is carried out on industry data, it shows that productivity growth falls on average within industries meaning that the trend break cannot be (fully) attributed to changing business structure

With respect to the interaction term $d \times it$, six countries have positive point estimates. This pattern of effects is consistent with a positive impact of ICT after 1995 against an overall negative change in productivity growth. In this sense, the results suggest that ICT has affected productivity growth positively after all.

Comparing across European countries, there is an apparent dispersion of point estimates. Moreover, the standard errors of single country estimates are also fairly large and we find that many individual country estimates remain insignificant. In order to reduce the uncertainty of point estimates, we pool the data over European countries. The cost of doing this is that we have to assume that production functions are equal across countries and industries apart from country/industry fixed effects.

Results for Austria are seen to differ substantially from the overall pattern of a negative break and a positive interaction term. We conclude that Austria is too different to be included in an overall European panel data set.[13] Crucially, we note that our basic conclusion about the timing of the productivity trend break from Section 2 is left unaltered when Austria is excluded from the panel. This can be seen by comparison of the dotted and dashed curves in Figure 1. Therefore, we can still use 1995 as the break year when combining the data into a panel of seven European countries (EU-7).

The results of the EU-7 panel data regressions are reported in Table 3. Results under the heading "All industries" apply to the full set of 24 industries. They differ according to the type of fixed

[13] Averaging the interaction term across countries including Austria, the mean effect is 0.56 percentage points, whereas it becomes 0.80 percentage points when Austria is excluded.

effects allowed: “Pooled” excludes fixed effects altogether and imposes a common constant term across countries and industries; “FE Country” allows intercepts to vary across country (but not across industry); “FE Industry” allows intercepts to vary across industry (but not across country); and “FE General” allows a full set of industry/country specific intercepts. In the latter case, the coefficient of 1995-ICT intensity (it) is not identified due to its time-invariance.

[Table 3 about here]

There is evidence of an overall negative change of about one percentage point in the rate of labor productivity growth in non-ICT-intensive industries after 1995; a negative and significant coefficient of d. No significant difference can be recorded between ICT-intensive and non-ICT-intensive industries pre-1995; the coefficient of it. The overall negative trend break is to a large extent counterweighted by the positive and significant interaction term for the ICT-intensive industries; the coefficient of $d \times it$.

The results are consistent in terms of sign and magnitude both across methods and with the average results for individual countries in Table 2. In the panel results, we find that the coefficients to the break dummy equals -1.10 and .90 to the interaction term, whereas the single country regressions lead to average coefficients of -1.14 and .80, respectively.[14]The fact that our panel estimates remain very close to the average of country-specific results supports the poolability of the seven countries in the panel.

The remaining results in Table 3 are obtained by excluding certain industries from the panel.[15] Excluding the ICT-producing industries (ICT hardware production and telecommunications) we find that the interaction term becomes less significant.[16] The finding of a smaller effect when excluding ICT-producers is consistent with Stiroh’s results for the US. The marginal loss of significance is in keeping with the fact that overall effects for the European case are less significant. Looking into the importance of individual ICT-producing industries we find that the lower level of significance is primarily driven by the exclusion of telecommunications. The final set of results in Table 3 exclude FIRE industries. There is little change in the coefficient of the interaction term.

[14]The mean country results (excluding Austria) from Table 1 are .057 for the coefficient of ΔlnA_{-1}, -1.136 for d, and .801 for $d \times it$.

[15]As results have been found to remain very stable across methods, we report only the most general fixed effects specification.

[16]The coefficient estimate is borderline insignificant at the ten per cent level.

In qualitative terms, our main results remain unaltered by excluding FIRE. This is consistent with Stiroh's (2002) findings for the US.

In Figure 2 we address our initial choice of 1995 as the break year. The figure shows the estimated coefficient of the interaction term between break-year ICT-intensity, *it*, and the corresponding break dummy, *d*, when the potential break year is varied between 1990 and 1999. It also depicts the approximate 95 per cent confidence bands.[17] The magnitude of the break in the trend of labor productivity seems fairly robust to the choice of a different break year around the middle of the 1990s.

[Figure 2 about here]

In conclusion, we find that European industries, which are relatively ICT-intensive pre-1995 outperform remaining industries post-1995 in terms of labor productivity growth. In contrast to the US, the change happened against a bleak overall European productivity growth scenario. Our results become weaker when ICT-producers are excluded although an economically significant differential effect of 0.5 percentage points remains for ICT-users versus remaining sectors. The result does not depend critically on the developments in FIRE industries nor the exact timing of the break.

It is of interest to compare the magnitude of effects to existing results for the United States. Stiroh (2002) finds an interaction term of two per cent for the United States, implying that the interaction term for European economies is around half the size. This result is consistent with the single country regressions in the sense that the effect of ICT in Europe is less noticable that in the United States, which resulted in imprecise point estimates. Thus, ICT has an positive effect on productivity growth in Europe, however, it is only half the size of the United States. In this sense, the difference in the utilization of ICT between the two regions has partially lead the divergence in productivity levels, but it does not explain the fall in European productivity growth after 1995.

6.2 Total Factor Productivity

We next turn to total factor productivity growth. The importance of this analysis is that it enables us to study if the relationship between ICT and labor productivity growth is mainly due to capital-deepening or whether advances in ICT technology also influence productivity growth. We employ

[17] Note that this band has a pointwise interpretation only.

the extended difference-in-difference regression (2) in decomposing the growth rate of real output. Industries are divided into ICT-intensive and ICT-extensive sectors as above. The basic diff-in-diff regression is augmented by terms to capture the growth rates of input in terms of labor, capital, and intermediate inputs.

[Table 4 about here]

The importance of the post-1995 productivity slowdown in ICT-extensive sectors reduces to approximately .6 percentage points as compared to the fall of about one percentage point in the rate of growth of labor productivity. This suggests that part of the fall in labor productivity around 1995 is due to reduced accumulation of physical capital and intermediate inputs.

As for the case of labor productivity, the ICT-intensive sectors significantly outperform the remaining sectors post-1995. The size of the differential TFP gain in ICT-intensive industries (the coefficient of $d \times it$) is marginally reduced to .6 percentage points from the .8 percentage gain in labor productivity. Again, this reduction is due to the fact that we take factor accumulation into account. The negative overall TFP trend break is now completely counterweighted by the positive interaction term for the ICT-intensive industries.

We address the robustness of our main TFP results in the same directions as above. First, in Figure 3 we repeat the exercise of changing the break year. A very similar picture emerges although the overall level of significance is somewhat reduced compared to the results on labor productivity. Second, Table 4 shows that the total factor productivity differential does not depend on the presence of ICT-producing industries nor on developments in the FIRE industries. Significant effects remain when excluding either of these sectors.

[Figure 3 about here]

Overall, our TFP extension of the analysis yields three main conclusions. First, there are significant TFP gains from ICT in Europe post-1995. Secondly, a comparison of TFP and labor productivity impacts of ICT shows that most of the impact of ICT in Europe is indeed due to gains in TFP rather than capital deepening; a result that is different from the experience in the United States. Third, we find economically sizable and statistically significant TFP gains for intensively ICT-using industries.

An interesting observation of the analyses is the growth effect for intensively ICT-using industries. Under the study of labor productivity growth, a positive but statistically insignificant difference is found between ICT-intensive and non-ICT-intensive industries, whereas the effect is positive and statistically significant under TFP growth. Thus, there is a strong acceleration in TFP growth in ICT using sectors, whereas it is less pronounced for labor productivity growth. This suggests the European economies, in addition to increasing TFP growth, experienced a reduction in capital deepening which is especially pronounced for ICT-intensive industries.

6.3 Continuous and alternative ICT intensity measures

In this section we further address the robustness of our main results in dimensions related to the measurement of ICT intensity. First, instead of the binary classification of ICT intensity in relation to the median industry intensity, we include the underlying measurements directly in order to more fully utilize the information in this variable.[18] Second, we apply several different possible measurements of ICT intensity. Note that the estimates of the coefficient of the interaction term, $d \times it_{cont}$ are not directly comparable across definitions or with the main results based on the binary measure due to differences in the normalizations of these variables.

[Table 5 about here]

Table 5 presents the results for labor productivity and TFP growth. The first column under the two growth measures presents the specification of (1) and (2) with industry and country dummies, i.e., the FE general model. It is seen that the results established in Tables 3 and 4 are robust to using continuous measures of ICT-intensity. In the remaining columns under each growth measure, we present results for two alternative definitions of ICT intensity: ICT-capital service per worked hour and ICT-capital service in relation to gross output.

The results show that our basic conclusion holds: Both labor productivity and TFP experienced a significant differential post-1995 gain in ICT intensive industries irrespective of the measure applied.

[18] The continuous measures are normalized using country-specific means and standard deviations.

7 Discussion and Conclusion

We challenge the general consensus that states that there has been no acceleration of productivity growth in the EU, mainly due to lacking performance of the ICT using sectors during the second half of the 1990s. Instead we find significant productivity gains, especially in TFP, from ICT in Europe post-1995. This result is established by treating macro economic shocks and productivity effects from ICT separately in an econometric analysis.

We find that sectors which are relatively ICT-intensive pre-1995 outperform remaining sectors post-1995 in terms of labor productivity. Our results become weaker when ICT-producers are excluded although an economically significant differential effect of 0.5 percentage points remains for ICT-users versus remaining sectors. The result does not depend critically on the developments in FIRE industries nor the exact timing of the break. Our TFP extension of the analysis yields three main conclusions. First, there are significant TFP gains from ICT in Europe post-1995. Secondly, a comparison of TFP and labor productivity impacts of ICT shows that most of the impact of ICT in Europe is indeed due to gains in TFP rather than capital deepening. Third, we find economically sizable and statistically significant TFP gains for intensive ICT-users.

The flip side of the positive ICT-effects on productivity growth is that the overall European productivity growth is still bleak. Thus, aggregate as well as industry averages of productivity growth decreased in Europe after 1995. Our findings thus clear ICT-using industries from being the main cause of weak performance because of unexploited productivity gains from ICT. Rather, the aggregate economy experiences a negative macro economic shock that lead to deceleration of productivity growth.

There are two broader implications of the analysis presented in the present paper. First, why are effects on productivity growth in Europe not as large not as large as in the United States? This question can be divided into the study of why the ICT-capital-deepening effect has been more extensive in the United States and the study of why US industries have been better to realize technology advances to productivity growth. The two effects may of course be related.

Second, the underlying reason for the deceleration in European productivity development is still unresolved. Is the European slowdown generated by labor market reforms getting unskilled and possible less productive workers back into jobs? According to Bloom et al (2008) this may be part of the reason, but not all.[19] Other potential explanations should also be taken into consideration.

[19] Bloom et al (2008): "Although some part of the observed European slowdown is due to labor market reforms

References

[1] Andrews, D.W.K. (1993), "Tests for Parameter Instability and Structural Change with Unknown Change Point," Econometrica, 61, 821-856.

[2] Arellano, M. and S. Bond (1991), 'Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations', Review of Economic Studies, 58, 1991, 277-297.

[3] Bloom, N, Sadun, R. and J. Van Reenen (2008), "Americans do I.T. better: US multinationals and the productivity miracle," NBER WP 13085.

[4] Draca M., R. Sadun, and J. Van Reenen (2006) "Productivity and ICTs: A review of the evidence", in "The Oxford Handbook of Information and Communication Technologies" (edited by R. Mansell, C. Avgerou, D. Quah, and R. Silverstone), Oxford University Press.

[5] Hansen B.E. (2001) , 'The New Econometrics of Structural Change: Dating Breaks in U.S. Labor Productivity', Journal of Economic Perspectives, 15(4), 117-128

[6] Jorgenson, D. W. (2001), "Information Technology and the U.S. Economy," American Economic Review , Vol. 90, No. 1, March 2001, pp. 1-32.

[7] Jorgenson, D. W., F. M. Galop and B. Fraumeni (1987), Productivity and US Economic Growth, North-Holland, Amsterdam.

[8] Jorgenson, D.W., M.S. Ho, and K.J. Stiroh (2008), "A Retrospective Look at the U.S. Productivity Growth Resurgence," Journal of Economic Perspectives, 22(1), 3–24

[9] Oliner, S., and D. Sichel, 2000. "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?," Journal of Economic Perspectives, American Economic Association, vol. 14(4), pages 3-22, Fall.

[10] O'Mahony, M. and B. Van Ark, (eds.) (2003), EU Productivity and Competitiveness: An Industry Perspective Can Europe Resume the Catching-up Process? Office for Official Publications of the European Communities, Luxembourg.

[11] O'Mahony, M., and M. Vecchi (2005), "Quantifying the Impact of ICT Capital on Output Growth: A Heterogeneous Dynamic Panel Approach," *Economica*, 72(288), 615-633

getting less skilled workers back into jobs, most analysts agree there was still a gap in productivity growth between the US and EU of at least 0.8% over the course of a decade."

[12] Solow, R. M. (1987), "We'd Better Watch Out," New York Times Book Review, July 12, p. 36.

[13] Stiroh, K. (2002), "Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?", American Economic Review, 92(5), 1559-1576

[14] Timmer, M. and B. Van Ark (2005), 'Does information and communication technology drive EU-US productivity growth differentials?', Oxford Economic Papers, 57, 693-716.

[15] Van Ark, B., M. O'Mahony and M..P. Timmer (2008), "The Productivity Gap between Europe and the U.S.: Trends and Causes", Journal of Economic Perspectives, 22(1), pp. 25–44.

[16] Van Ark, B., M. O'Mahony, and Gerard Ypma (2007) "The EU KLEMS Productivity Report", www.euklems.net

[17] Whelan, K. (2002). "Computers, Obsolescence, And Productivity," The Review of Economics and Statistics, MIT Press, vol. 84(3), pages 445-461, August.

Table 1: Labor productivity growth (per cent per year): EU-8 and US

	AUT	DNK	FIN	FRA	GER	ITA	NLD	UK	US
Panel A: Nonfarm business sector.									
1980-1994	3.367	3.052	3.700	3.559	3.120	2.632	2.596	3.531	1.461
1995-2004	4.060	2.062	3.198	3.709	3.492	1.645	2.806	1.683	3.295
Panel B: Nonfarm business sector excluding ICT production.									
1980-1994	3.254	2.869	3.433	3.423	3.023	2.664	2.487	3.600	1.160
1995-2004	3.712	1.277	2.382	3.133	2.881	1.155	2.450	1.632	2.778
Panel C: Nonfarm business sector excluding FIRE.									
1980-1994	3.419	3.049	3.639	3.700	3.201	2.809	2.616	3.630	1.442
1995-2004	4.024	1.802	3.127	3.659	3.394	1.634	2.828	1.706	3.292

Table 2: Labor productivity: Individual country results

	AUT	DNK	FIN	FRA	GER	ITA	NLD	UK
Panel A: No lagged productivity growth rate, no industry fixed effects.								
d	1.689***	-1.122	-1.921***	-0.141	-0.206	-1.042**	-0.086	-2.415***
	(0.639)	(0.676)	(0.610)	(0.539)	(0.553)	(0.454)	(0.582)	(0.719)
it	0.154	-0.999**	-1.100**	-0.119	0.573	0.184	0.462	-1.562***
	(0.347)	(0.393)	(0.550)	(0.537)	(0.522)	(0.428)	(0.513)	(0.488)
$d \times it$	-1.699**	-0.354	2.354***	0.681	1.474	1.303	0.612	0.734
	(0.933)	(0.877)	(1.045)	(1.026)	(1.029)	(0.930)	(1.031)	(0.956)
Panel B: Lagged productivity growth rate, no industry fixed effects.								
$\Delta \ln A_{-1}$	-0.025	-0.114	0.189***	0.298***	-0.002	0.149**	0.227**	0.270***
	(0.069)	(0.056)	(0.050)	(0.061)	(0.120)	(0.060)	(0.073)	(0.064)
d	1.127	-1.293	-2.079***	-0.580	-0.642	-1.459***	-0.172	-1.329**
	(0.686)	(0.829)	(0.514)	(0.383)	(0.593)	(0.391)	(0.538)	(0.597)
it	-0.160	-0.693	-0.869	-0.247	0.491	0.038	0.505	-0.886*
	(0.449)	(0.526)	(0.558)	(0.412)	(0.490)	(0.460)	(0.670)	(0.457)
$d \times it$	-1.015	-0.712	1.821**	0.610	1.604	1.101	0.326	0.219
	(1.039)	(1.064)	(0.902)	(0.699)	(1.127)	(0.793)	(0.894)	(0.744)
Panel C: Lagged productivity growth rate, industry fixed effects.								
$\Delta \ln A_{-1}$	-0.107	-0.151***	0.063	0.148**	-0.086	0.056	0.182**	0.184**
	(0.065)	(0.055)	(0.040)	(0.070)	(0.109)	(0.047)	(0.075)	(0.048)
d	1.270**	-1.327*	-2.308***	-0.463	-0.629*	-1.492***	-0.130	-1.603***
	(0.594)	(0.683)	(0.484)	(0.340)	(0.372)	(0.3481)	(0.481)	(0.483)
it	—	—	—	—	—	—	—	—
$d \times it$	-1.134	-0.691	2.198***	0.613	1.718*	1.165	0.307	0.294
	(0.783)	(0.870)	(0.676)	(0.587)	(0.902)	(0.745)	(0.827)	(0.631)

'*','**', '***': Significant at the 10, 5, or 1 percent level, respectively.

Table 3: Labor productivity: Panel results (EU-7)

	All industries				W/o ICT prod.	W/o FIRE
	Pooled	FE Country	FE Industry	FE General	FE General	FE General
ΔlnA_{-1}	0.150***	0.144***	0.094***	0.054	0.022	0.050**
	(0.040)	(0.040)	(0.034)	(0.033)	(0.032)	(0.034)
d	-1.031***	-1.035***	-1.048***	-1.098***	-1.194***	-1.101***
	(0.178)	(0.181)	(0.189)	(0.199)	(0.194)	(0.200)
it	-0.286	-0.288	-0.117	—	—	—
	(0.228)	(0.223)	(0.229)			
$d \times it$	0.814***	0.819***	0.861***	0.901***	0.490	0.824**
	(0.298)	(0.301)	(0.318)	(0.332)	(0.306)	(0.349)

’*’,’**’, ’***’: Significant at the 10, 5, or 1 percent level, respectively.

Table 4: Total factor productivity: Panel results (EU-7)

	All industries				W/o ICT prod.	W/o FIRE
	Pooled	FE Country	FE Industry	FE General	FE General	FE General
$\Delta \ln Y_{-1}$	0.118***	0.114***	0.098***	0.061**	0.035	0.054*
	(0.035)	(0.034)	(0.032)	(0.028)	(0.027)	(0.028)
d	-0.653***	-0.644***	-0.677***	-0.623***	-0.643***	-0.622***
	(0.139)	(0.135)	(0.142)	(0.145)	(0.151)	(0.145)
it	-0.104	-0.112	-0.172	—	—	—
	(0.160)	(0.161)	(0.203)			
d × it	0.572**	0.582**	0.633**	0.619**	0.481*	0.660**
	(0.256)	(0.258)	(0.262)	(0.274)	(0.282)	(0.287)
$\Delta \ln X$	0.360***	0.359***	0.353***	0.351***	0.370***	0.360***
	(0.080)	(0.080)	(0.080)	(0.081)	(0.099)	(0.086)
$\Delta \ln L$	0.180***	0.181***	0.203***	0.210***	0.208***	0.210***
	(0.048)	(0.049)	(0.052)	(0.054)	(0.064)	(0.056)
$\Delta \ln K$	0.026	0.031	0.028	0.051**	0.053**	0.056**
	(0.022)	(0.022)	(0.022)	(0.025)	(0.026)	(0.025)

'*','**', '***': Significant at the 10, 5, or 1 percent level, respectively.

Table 5: Continuous and alternative measures of ICT intensity: Labor productivity and TFP, panel results (EU-7)

	Labor productivity			Total factor productivity		
	Standard	Altern. 1	Altern. 2	Standard	Altern. 1	Altern. 2
$\Delta \ln A_{-1}$	0.053	0.047	0.049	—	—	—
	(0.033)	(0.032)	(0.032)			
$\Delta \ln Y_{-1}$	—	—	—	0.061**	0.060**	0.061**
				(0.028)	(0.028)	(0.028)
d	-0.648***	-0.649***	-0.649***	-0.314***	-0.316***	-0.317***
	(0.160)	(0.148)	(0.155)	(0.113)	(0.110)	(0.112)
it_{cont}	—	—	—	—	—	—
$d \times it_{cont}$	0.647**	1.018***	0.829***	0.288***	0.402***	0.338***
	(0.224)	(0.240)	(0.265)	(0.171)	(0.193)	(0.171)
$\Delta \ln X$				0.351***	0.350***	0.351***
				(0.081)	(0.081)	(0.081)
$\Delta \ln L$				0.211***	0.214***	0.213***
				(0.054)	(0.055)	(0.054)
$\Delta \ln K$				0.050**	0.048**	0.049**
				(0.025)	(0.024)	(0.024)

’*’,’**’, ’***’: Significant at the 10, 5, or 1 percent level, respectively.

Figure 1 Break tests

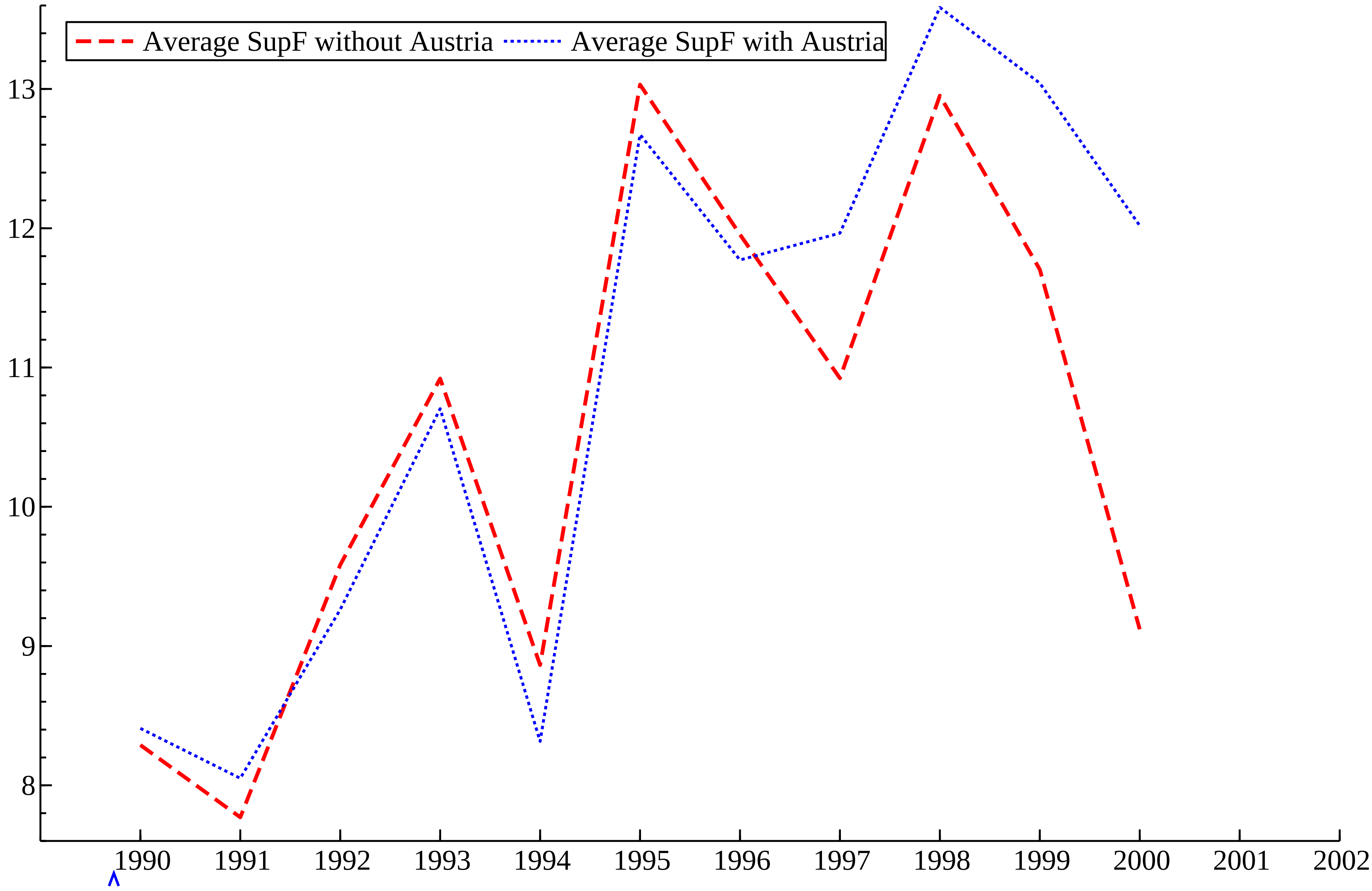

Figure 2: Labor productivity

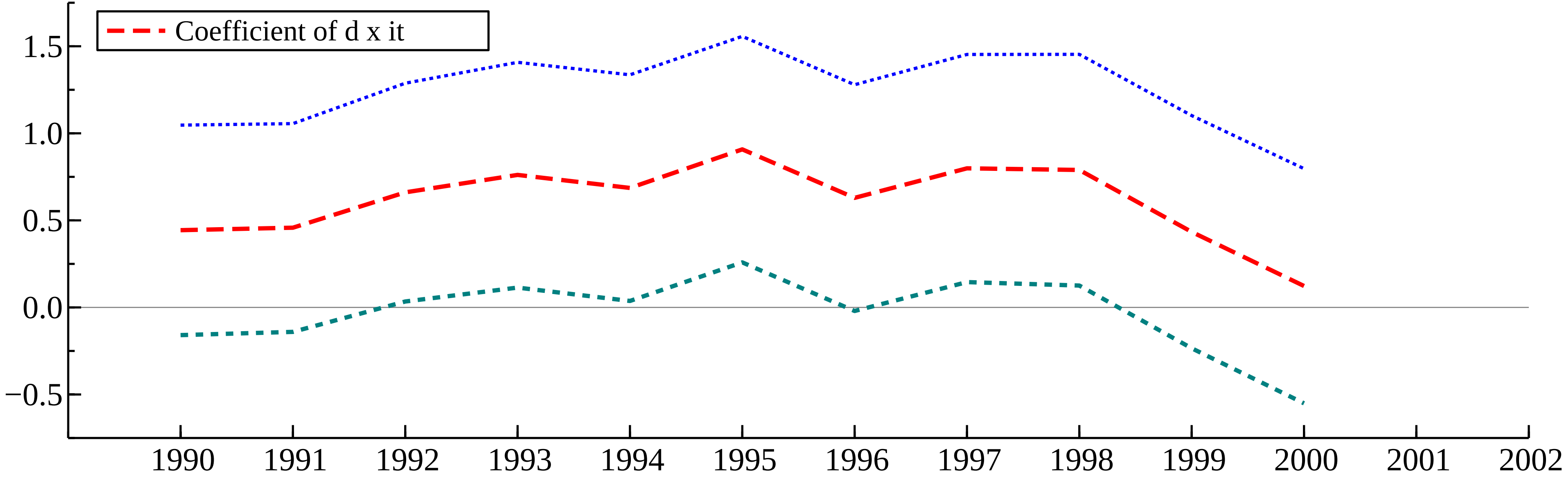

Figure 3: TFP