DISCUSSION PAPER SERIES

DP15011

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MACROECONOMICS AND GROWTH

ISSN 0265-8003

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Discussion Paper DP15011
Published 08 July 2020
Submitted 06 July 2020

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Abstract

We examine the role of the ICT revolution in driving productivity growth behavior for the United States and an aggregate of ten Western European nations (the EU-10) from 1977 to 2015. We find that the standard growth accounting approach is deficient when it separates sources of growth between ICT capital deepening and TFP growth, because much of the effect of the ICT revolution was channeled through spillovers to TFP growth rather than being limited to the capital deepening pathway. Using industry-level data from EU KLEMS, we find that most of the 1995-2005 U.S. productivity growth revival was driven by ICT-intensive industries producing market services and computer hardware. In contrast the EU-10 experienced a 1995-2005 growth slowdown due to a paucity of ICT investment, a failure to capture the efficiency benefits of ICT, and performance shortfalls in specific industries including ICT production, finance-insurance, retail-wholesale, and agriculture. After 2005 both the U.S. and the EU-10 suffered a growth slowdown, indicating that the benefits of the ICT revolution were temporary rather than providing a new permanent era of faster productivity growth. This joint transatlantic post-2005 slowdown is consistent with the broader view that ongoing innovation has been less potent in boosting productivity growth compared to earlier decades of the postwar era.

JEL Classification: E01, E24, O33, O47, O51, O52

Keywords: Information Technology, Computers, productivity slowdown, Industry Structure

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Acknowledgements
This research was supported by the Smith-Richardson Foundation. An earlier version of this paper was presented at the San Diego meetings of the American Economic Association in January, 2020. We are grateful to Marshall Reinsdorf for his contributions as the conference discussant.

1. Introduction

After a long slump between the 1970s and mid-1990s, when the annual rate of productivity growth in the United States languished, a distinct productivity growth revival occurred during the subsequent decade of 1995-2005. But that episode of renewed growth did not last, as in the subsequent decade of 2005-15 U.S. productivity growth slumped back to a rate even slower than that which had occurred prior to 1995. The trajectory of growth in Western Europe was quite different, starting off with a pre-1995 productivity growth rate faster than in the U.S. but then slumping in two stages, after 1995 and again after 2005, to a pace even slower than the mediocre post-2005 rate achieved by the U.S.

During the half decade between 1995 and 2000, the U.S. experienced a pronounced surge of investment in information and communication technology (ICT) equipment and software. The year 1995 marked the initial appearance of widely used web browsers, and the late 1990s witnessed an investment boom in hardware and software as business firms rushed to modify their business methods to take advantage of the newly invented internet and new business services such as Google, founded in 1998. Several articles published soon after this ICT investment boom credited it for most or all of the post-1995 revival in U.S. productivity growth (Jorgenson and Stiroh (2000), Oliner and Sichel (2000), and Stiroh (2002)).

However, the evolution of the U.S. data since the year 2000 raises a set of questions about the causal role of ICT. Since productivity growth continued to be strong from 2000 to 2005 yet ICT investment slumped after 2000, does ICT investment still play a causal role in explaining the productivity growth revival when the growth interval is extended? Furthermore, since U.S productivity growth slumped after 2005 to a rate lower than that before 1995, to what extent does lower ICT investment explain that post-2005 stalling of the growth process?

The failure of Europe to enjoy a productivity growth revival similar to the U.S. after 1995 and its lamentably slow performance after 2005 raises further questions about the role of ICT investment. Did the absence of a post-1995 growth revival occur because Europe invested substantially less in ICT equipment than did the U.S.? Or was it that the extent of ICT investment in Europe was similar to the U.S. but that same level of investment had a smaller payoff than in the U.S.? Given that the U.S. and Europe had similarly slow productivity growth rates after 2005, why was that growth performance so poor? To what extent did the same ICT-intensive industries that led the post-1995 revival also contribute to the post-2005 decline in growth?

The most common way of answering these questions is to conduct an exercise in growth accounting, crediting ICT and non-ICT capital growth as two distinct sources of growth by multiplying their growth rates by their income shares. A complementary approach is to use industry data to reveal the extent to which individual industries that produce ICT equipment or are relatively intensive users of ICT equipment account for periods of rapid or slow aggregate productivity growth. This article uses both approaches to investigate the role of ICT investment in the 1995-2005 and post-2005 behavior of growth in labor productivity and in total factor productivity (TFP) in the U.S. and in Western Europe.

Using KLEMS data on individual industries as in our previous transatlantic study (Gordon and Sayed (2019)), we have developed time series for an aggregate of 10 Western European nations, which we call the "EU-10."[1] We are able to examine output and input data for both the EU-10 and the U.S. for 16 industrial sectors as well as 11 subindustries within manufacturing. The creation of data for the EU-10 as a single European aggregate contrasts with previous studies that tend to examine a dizzying array of data for numerous individual European nations. The EU-10 aggregation greatly facilitates the task of isolating sources of differences in growth behavior between the U.S. and Europe. In our previous study (Gordon and Sayed, 2019) we divided up the sources of labor productivity growth for the 27 industries among capital deepening, changes in labor composition, and growth of TFP. There we highlighted individual industries that had performed particularly well or badly and examined the different time paths of capital deepening and TFP on each side of the Atlantic.

This study goes further by examining the role of ICT capital as a source of differences in labor productivity and TFP growth between the U.S. and EU-10 over three time periods extending from 1977 to 2015 and divided at 1995 and 2005.[2] We start by studying the evolution of labor productivity growth over the three time periods for the total economy and for two dimensions of disaggregation – industries producing commodities versus services, and industries that are relatively intensive or non-intensive users or producers of ICT equipment and software. We emphasize the distinction between industries producing commodities vs. services, since the usual explanation of the role of ICT-intensiveness in the productivity growth process emphasizes the role of ICT in revolutionizing office spaces as workers transitioned to desks with web-enabled personal computers, firms shifted their businesses to online platforms, and communication and collaboration occurred through the internet. This process should have boosted productivity growth in industries producing services more than in those producing commodities.

We then conduct a regression analysis to quantify the role of ICT intensiveness as a source of changes in productivity growth after 1995 and after 2005. We disentangle the relative roles of the *amount* of ICT intensiveness versus the *payoff* from a given extent of ICT

[1] "Western Europe" consists of the fifteen members of the European Union prior to its 2004 enlargement. Ten of these nations are included in our EU-10 data – Austria, Belgium, Denmark, France, Germany, Italy, the Netherlands, Spain, Sweden, and the United Kingdom. The five nations that are excluded – Finland, Greece, Ireland, Luxembourg, and Portugal – are all small and together account for only 7 percent of 2017 EU-15 GDP (Source: Conference Board Total Economy Database).

[2] This study starts in 1977 because that is the initial year of our ICT data. The previous paper extended back to 1972 for the EU-10 and to 1950 for the U.S.

intensiveness as sources of Europe's failure to experience a post-1995 productivity growth revival and as sources of the post-2005 slowdown on both sides of the Atlantic. We then ask whether ICT intensity contributed to productivity growth purely through its effect on capital deepening or, whether in addition ICT intensiveness spilled over to boost the growth of TFP.

We find that additional productivity growth in ICT intensive industries drove almost all of the post-1995 revival in U.S. productivity growth. However, this change in growth occurred almost entirely in services-producing industries rather than commodities-producing industries except for the electric machinery industry that produces computer hardware. This makes sense because the most intensive users of ICT were industries in the services sector. The EU-10 story is quite different. Productivity growth in producing computer hardware in the EU-10 actually slowed after 1995 in contrast to its explosive growth in the U.S. Further in the EU-10 there was little difference between the productivity growth slowdown after 1995 and after 2005 in industries that were intensive in ICT use versus the non-ICT industries. Europe not only invested less in ICT hardware but failed to reap its benefits even in industries that were heavy ICT users.

Plan of the Paper

The paper has seven main sections. Following this introduction, part 2 provides an overview of the literature on the relationship between ICT and productivity growth in the U.S. and Europe. Part 3 starts with a contrast of productivity growth rates over the three periods for the U.S. and EU-10. We present a decomposition of sources of growth that emphasizes the distinction between TFP growth and ICT capital deepening. In part 4 we introduce and display indicators of ICT intensity and examine the behavior of productivity growth in the ICT-intensive and ICT non-intensive industries. Part 5 provides the analytical framework for the regression analysis in which the observations are the evolution of labor productivity and TFP growth over the three periods for 27 industries. Part 6 carries out the regression analysis, emphasizes the similarity of results explaining growth in labor productivity versus TFP, distinguishes between the role of differing ICT intensity versus the payoff from ICT, and singles out individual industries as primarily responsible for the results. Part 7 summarizes the results and concludes.

2. Overview of the Related Literature

TFP takes a central role in the analysis of Jorgenson and Stiroh (2000). They attribute the acceleration between 1990-95 and 1995-98 in labor productivity growth roughly equally between TFP and capital deepening, with about two thirds of the increase in TFP due to non-ICT producing industries. They explicitly suggest inter-industry spillover effects, with the higher TFP growth of ICT-producing industries paving the way for other industries like wholesale and retail trade to invest in computers and electronic equipment.

Stiroh (2002) employs industry-level BEA data for 1977-2000 to examine the industry composition of growth prior to and after 1995. Stiroh flags a subset of his industries as ICT-intensive and examines the differential effect of ICT intensity on the post-1995 productivity growth acceleration. He estimates that ICT-intensive industries experienced a productivity growth revival of roughly 2 percentage points while non-ICT intensive industries experienced no revival, suggesting that the post-1995 productivity growth revival was *entirely* driven by industries that invested heavily in ICT. His emphasis on the stimulative role of these ICT-using industries shows that the productivity acceleration was not driven just by those industries producing computer hardware and software.

Jorgenson, Ho, and Stiroh (2005) emphasize spillover effects. These authors find that TFP accelerations of the late 1990s and early 2000s required investments in ICT capital. Thus ICT capital deepening *augments* TFP growth. A subsequent article by the same authors (2008) distinguishes between productivity growth from 1995-2000 that was driven by ICT-*producing* industries, as contrasted to the 2000-2005 interval that was driven by industries intensive in ICT *use.* They also point to the positive effects of structural market changes, such as reallocation effects, increases in competition, and the emergence of flexible labor markets. Bartelsman *et al*. (2007) suggest that while a productivity acceleration was led by the technology and wholesale/retail sectors in the late 1990s, additional growth in the finance and business services sectors during the early 2000s sustained an aggregate acceleration in growth until 2004, with TFP playing the primary role.

While there is a broad consensus that ICT-intensive industries drove the acceleration of U.S productivity growth in the late 1990s, the subsequent turnaround to much slower productivity growth after 2005 raises new questions. Did the ICT revolution of the late 1990s have a sustained positive impact on productivity growth, or was it only a one-time shock? In Fernald's (2015) interpretation, the ICT revolution had a temporary "level effect" that resulted in a marked but short-lived period of additional productivity growth that ran its course after about a decade. Extending Stiroh's (2002) result, Fernald suggests that both the rise and fall of labor productivity growth resulted from a temporary boost to productivity growth in both ICT-producing and ICT-using industries. Cette *et al.* (2016) likewise claim that the ICT revolution had run its course by 2004. In their view, the ability of ICT investment to foster TFP growth through channels like electronic inventory management or role-reorganization in services industries was exhausted by 2004-2005.

Byrne *et al*. (2016) maintain that while ICT-innovations continued into the late-2000s, they were not potent enough to prevent a broad post-2004 slowdown in U.S. productivity growth. They also suggest that the subsequent post-2005 wave of communications innovation associated with smartphones and social networks has enhanced consumer surplus without appreciably raising business-sector productivity. On the other hand, Byrne and Corrado (2017) suggest that ICT price-indices have been mis-measured and that the ICT services sector could have been contributing about 1.4 points to total economy productivity growth after 2014. About a quarter of this 1.4 points is concentrated in investment in cloud-based computing and online services, the use of which has been steadily rising in the economy through the late 2010s.

The dominant role of ICT investment in the U.S. productivity growth acceleration of the late 1990s is not universally accepted. Acemoglu *et al*. (2014) in a study of U.S. manufacturing show little difference in the degree of growth resurgence between ICT-using and non-ICT-using industries. While these authors do find a positive impact on labor productivity for manufacturing industries that utilize high-tech equipment, they cast doubt on the proposition that ICT intensity can explain the entire post-1995 revival. In our subsequent study of productivity growth differences across industries, we are careful to distinguish between the quite different behavior of industries producing commodities (including manufacturing) from those producing services.

In an early comparative study of ICT-related investment, Colecchia and Schreyer (2002) show that nine OECD countries[3] ramped up investment in ICT in the 1990s. In the late 1990s, ICT investment contributed between 0.3 and 0.9 points to economic growth, although the U.S. benefited much more than any of the other countries in their data set. In contrasting the U.S. mid-90s acceleration with the deceleration in Europe, O'Mahony *et al*. (2008) survey a variety of causes, including lower total factor productivity (TFP) growth and the lower importance of ICT-producing industries in Europe. They attribute the absence of a post-1995 productivity growth revival in Europe to the slower emergence of a knowledge economy in Europe, particularly in the services sector, and argue that particular labor market structures and regulatory laws may have played a role in dampening productivity growth.

Timmer and van Ark (2005) describe how Europe lagged behind the U.S. in ICT investment after 1980, implying that the region was not as prepared as the U.S. to reap the benefits of the post-1995 ICT revolution. TFP gains from ICT-producing sectors and additional capital deepening from ICT-capital investment explain almost all the U.S.-Europe productivity differential during 1995-2001. Their framework uses a European Union aggregate with a growth decomposition of labor productivity into its components of capital deepening, labor quality, and TFP.

Some authors have argued that Europe simply needed to play catch up to the U.S again, as it had done in the early postwar years. For example, Inklaar *et al.* (2007) argue that the main differences between U.S. and EU growth were due to a shortfall in TFP growth in the European services sector, and that over the next few years following their 2007 publication date we would see increased ICT investment and a subsequent growth revival in the European economy. But as we have seen that growth revival did not occur. In fact, Dabla-Norris *et al.* (2015) argue that while the services sector drove the gap between U.S. and European productivity growth, the time to tap into the full potential of ICT may have already passed for Europe. Cette *et al*. (2016) argue that the U.S. established a technological frontier to which Southern European countries

[3] Australia, Canada, Finland, France, Germany, Italy, Japan, the U.K., and the U.S.

like Italy and Spain needed to catch up. But this explanation fails to explain the lack of an ICT-driven growth revival in the EU countries outside of Southern Europe.

Inklaar *et al*. (2011) suggest that the significant decline in European labor force participation and hours worked per person between 1973 and 1995 may have meant that, when the ICT revolution finally came, European industries may not have been ready to reap the benefits of new technologies. Bloom *et al.* (2012) show that U.S.-owned multinational companies that had operations in Europe were able to reap the benefits of the ICT revolution while European firms were not, suggesting that differences in management structure between the two regions may have helped drive this transatlantic productivity gap. Adding further evidence of the reorganization role of ICT investment in the U.S. resurgence. Castellani *et al*. (2016) find that European countries performed worse at both investing in research and development and in transforming that R&D expenditure into a significant productivity growth response. Moreover, these authors contend that while the U.S. shifted its economy to "high-tech" sectors, much of the European economy remained in "medium-tech" and "low-tech" sectors, where capital deepening is the main channel driving productivity growth.

3. Transatlantic Productivity Growth, 1977-2015

We begin with a straightforward comparison between the U.S. and EU-10 in the growth rate of labor productivity during three eras spanning 1977 to 2015. Data limitations require that 1977 is the starting date in this paper, as contrasted with 1972 for the EU-10 and 1948 for the U.S. in our previous study (Gordon and Sayed, 2019).[4] After the initial labor productivity growth comparison, we proceed to a Solow-type decomposition of the sources of growth, including ICT and non-ICT capital deepening, changes in labor composition, and changes in TFP growth.

Table 1. Labor Productivity Growth Rates for the U.S. and EU-10

	United States			EU-10		
	1977-1995	1995-2005	2005-2015	1977-1995	1995-2005	2005-2015
Total Economy	1.11	2.17	0.87	2.21	1.26	0.63
Market Economy	1.54	2.89	0.86	2.41	1.61	0.72
Commodities	2.12	3.59	1.29	3.22	2.19	0.85
Market Services	1.41	2.61	0.65	1.71	1.21	0.63

Source: All cells are computed from the merged KLEMS database as described in the Data Appendix of Gordon and Sayed (2019).

Productivity Growth Across Time for the Major Sectors

[4] Our KLEMS data are missing observations on several inputs including ICT capital for the "Professional and Administrative" industry prior to 1977.

We look first at growth rates of labor productivity in Table 1, where the first two rows cover the total economy and the market economy (which excludes public services, education, health, and real estate). The bottom two lines divide up the market economy into industries producing commodities (agriculture, mining, manufacturing, construction, and utilities) and the remaining industries producing market services.

The top row of Table 1 for the total economy contrasts the 1995-2005 revival of U.S. productivity growth from 1.11 to 2.17 per cent per year with the post-1995 slowdown of EU-10 growth from 2.21 to 1.26 per cent per year. Both entities share in common a post-2005 growth slowdown, from 2.17 to 0.87 per cent per year for the U.S. and from 1.26 to 0.63 per cent per year for the EU-10. The second line for the market economy shows a sharper 1.35 per cent post-1995 increase in U.S. growth as compared to a smaller 1.06 per cent post-1995 increase for the total economy. The U.S. market economy also exhibits a more pronounced post-2005 slowdown of 2.03 percent per year as contrasted to the slowdown of 1.30 per cent per year for the total economy. The greater post-1995 revival and post-2005 slowdown in the market economy than the total economy reflects the relative stagnation of growth during all three periods in the four industries within the non-market economy. There are smaller differences between the total and market economies for the EU-10, where the overall slowdown from the first to the third period is 1.58 per cent per year for the total economy and a similar 1.69 per cent for the market economy.

The bottom two rows of Table 1 divide up the market economy into commodities-producing and services-producing industries and show that productivity growth has been faster in all three periods on both sides of the Atlantic in the production of commodities than in the production of services. In the U.S., the post-1995 growth revival and post-2005 growth slowdown were of roughly the same order of magnitude in commodities as in services, as the margin by which commodities growth exceeded services growth was relatively stable across the three periods (0.71, 0.98, and 0.64 percentage points respectively). From the first to last period the growth slowdown in commodities of 0.83 percentage points was almost the same as the 0.76 percentage-points slowdown in services.

The story for commodities versus services in the EU-10 is different, as the margin by which commodities growth exceeded services growth shrank from 1.51 percentage points in the first period to a mere 0.22 percentage points in the last period. The extent of the early-to-late productivity growth slowdown was 2.37 percentage points for commodities and a smaller 1.08 per cent for services. Thus in studying the behavior at the industry level we can anticipate finding that the problem of diminished growth in the EU-10 is disproportionately an issue of performance in the commodities sector, whereas in the U.S. responsibility for the post-1995 revival and post-2005 slowdown is shared roughly equally between commodities and services.

Was productivity growth in the EU-10 held back because its industry mix reflected a smaller role for hi-tech industries and a larger role for low-tech industries? This suggestion can be tested by calculating an alternative aggregate EU-10 productivity growth rate when the U.S.

industry mix is applied to the EU growth rate of productivity in each industry. We multiply each European industry's labor productivity growth rate by the U.S. value-added share of that industry for each year from 1977 through 2015 and then sum up the industry terms to calculate a hypothetical counterfactual aggregate for EU-10 labor productivity growth. We find that, were the EU-10 to have shared the same industry composition as the U.S., its alternative aggregate productivity growth would have been 1.69 per cent for 1977-95, 1.28 for 1995-05, and 0.76 for 2005-15.

Compared with the actual growth rates of 2.21, 1.26, and 0.63 for the same time periods, we see that the U.S. industry mix substantially *lowers* EU productivity growth in the first period, makes no difference in the second period, and slightly raises growth in the third period. The big change in the 1977-95 period occurs because the U.S. had a substantially lower share of total output devoted to commodities production, and since EU commodity growth was almost double growth in the services sector, imposing U.S. share weights reduces counterfactual EU 1977-95 growth. The counterfactual early-to-late slowdown for the EU is reduced from 1.58 percentage points in the actual data to 0.93 points in the counterfactual experiment which imposes U.S. weights. This exercise is another way of drawing attention to the predominant role of the commodities sector in driving the early-to-late slowdown in EU-10 productivity growth.

Sources of Growth Decomposition

Now we take the productivity growth rates from Table 1 and apply a standard decomposition of sources of growth in Table 2. The U.S. decomposition appears in the left half of the table and the EU-10 version in the right half. The growth rate of labor productivity ("LP") from Table 1 is listed in the left column and is decomposed in the remaining columns into the contributions of TFP, changes in labor quality ("LQ"), ICT capital deepening ("ICT KD") and non-ICT capital deepening ("NICT KD"). Here we ignore the LQ column, as the numbers are small and vary little across time intervals. Since ICT capital deepening contributions are not available in the U.S. KLEMS data prior to 1999, Table 2 backcasts the U.S. series using nominal ICT KLEMS data (which *is* available through the 1970s) deflated using total economy BEA data. The specifics of this backcasting process are described at the bottom of Table 2.[5]

[5] We note that the BEA deflators we utilize refer to the total economy and involve using data from outside the KLEMS database. Hence, while use of this backcasting method may be appropriate for the larger U.S. aggregates of the total economy, market economy, commodities, and services, it may not be suitable method of backcasting for the 27 individual industries that make up these aggregates.

Table 2. U.S. vs EU-10 Labor Productivity (LP) Growth Decomposition into Contributions of Total Factor Productivity (TFP), Labor Quality (LQ), ICT Capital Deepening (ICT KD), and non-ICT Capital Deepening (NICT KD), 1977-2015										
	LP	**TFP**	**LQ**	**ICT KD**	**NICT KD**	**LP**	**TFP**	**LQ**	**ICT KD**	**NICT KD**
	United States					**EU-10**				
Total Economy										
1977-1995	1.11	0.53	0.17	0.19	0.22	2.21	0.83	0.14	0.31	0.93
1995-2005	2.17	0.77	0.22	0.51	0.66	1.26	0.27	0.29	0.30	0.40
2005-2015	0.87	0.57	0.19	0.17	-0.06	0.63	-0.02	0.19	0.13	0.33
Market Industries										
1977-1995	1.54	0.59	0.19	0.46	0.31	2.41	1.18	-0.04	0.25	1.02
1995-2005	2.89	1.46	0.25	0.80	0.38	1.61	0.48	0.30	0.37	0.47
2005-2015	0.86	-0.17	0.18	0.25	0.60	0.72	0.02	0.19	0.18	0.34
Commodities										
1977-1995	2.12	1.34	0.29	0.30	0.20	3.22	1.70	-0.18	0.23	1.48
1995-2005	3.59	2.57	0.30	0.20	0.52	2.19	1.01	0.11	0.22	0.85
2005-2015	1.29	-0.20	0.24	0.06	1.19	0.85	-0.08	0.05	0.12	0.76
Services										
1977-1995	1.41	0.22	0.13	0.63	0.44	1.71	0.31	0.25	0.41	0.75
1995-2005	2.61	0.89	0.26	1.23	0.24	1.21	0.08	0.41	0.43	0.29
2005-2015	0.65	-0.11	0.21	0.31	0.25	0.63	0.04	0.26	0.19	0.14

Source : EU-10 data and U.S. labor productivity and labor quality data are from the KLEMS Database. Real ICT and non-ICT capital deepening series for the U.S. are backcast by deflating nominal KLEMS investment data by weighting price deflators in BEA NIPA Table 5.3.4 with nominal investment values in Table 5.3.5. ICT investment is deflated using rows 10, 17, and 18, with non-ICT investment using the remaining rows. U.S. TFP is subsequently calculated as a residual.

The question addressed by this exercise is the extent to which the rise and fall of U.S. productivity growth, as well as the two-phase decline in EU productivity growth, were associated with changes in TFP as contrasted with ICT and non-ICT capital deepening. In the top left row for the U.S. total economy, only a small portion of the post-1995 LP growth acceleration of 1.06 percentage points is due to the contribution of TFP (0.24 points), and much more to the two components of capital deepening (ICT 0.32 points and non-ICT 0.44 points). The story is similar for the 1.30 point productivity slowdown after 2005, with a minor TFP contribution of 0.20 points contrasted with ICT and non-ICT capital deepening contributions of 0.34 and 0.72 points, respectively. Stated another way, the contribution of ICT capital deepening accounted for less than one-third of either the post-1995 or post-2005 changes in U.S. labor productivity growth.

Moving down to the next U.S. sector describing the market economy the up and down movement of productivity growth is greater (1.35 and -2.03 points), and the contribution to these movements of TFP growth is considerably larger than for the total economy. The contribution of non-ICT capital deepening is negligible for post-1995 and goes in the wrong direction as an explanation for the post-2005 productivity growth slowdown. But we still retain the finding that less than one-third of the overall change can be attributed to ICT capital deepening (0.34 and -0.55 points respectively). Thus our initial look at the U.S. economy appears to contradict the finding in much of the literature reviewed above that the post-1995 acceleration of U.S. productivity growth was primarily driven by ICT investment.

The next sections for the U.S. provide the growth decomposition for commodities-producing industries and for market services. In commodities, a 1.23 point post-1995 acceleration in TFP growth explains almost all of the 1.47 point post-1995 rise in labor productivity growth. On the way down after 2005, the TFP contribution of 2.77 points more than explains the 2.30 point slowdown in labor productivity growth. ICT capital deepening plays virtually no role in explaining these movements for commodities. For market services the story is quite different, as TFP growth (0.69 points) and ICT capital deepening (0.60 points) divide the explanation of the 1.20 point post-1995 speedup in labor productivity growth. Similarly, their respective contributions of 1.00 and 0.92 points neatly divide the recorded post-2005 productivity growth slowdown of 1.96 points. We shall return in subsequent sections to explore this apparent bifurcation of roles for ICT capital deepening as making an important contribution in services while having little to no importance in the commodities sector.

The right half of Table 2 provides the same decomposition for the EU-10. In the top section on the total economy, we see that the initial post-1995 slowdown in labor productivity growth of 0.95 points was explained by TFP growth (0.56 points) and non-ICT capital deepening (0.53 points), with no role for ICT capital deepening. The subsequent post-2005 productivity growth slowdown of 0.63 had as its counterpart a 0.29 point deceleration in TFP growth together with very small contributions of ICT and non-ICT capital deepening (0.17 and 0.07 points, respectively). The balance of contributions was essentially the same in the EU market economy as in the total economy.

Since we are interested in why the EU did not match the post-1995 speedup in productivity growth enjoyed by the U.S., we can look from left to right across the market industries section of Table 2 to note that ICT capital deepening in the U.S. during 1995-2005 of 0.80 points greatly exceeded the 0.37 point ICT contribution for the EU-10. But that is not the whole story, as the contrast in TFP growth between the U.S. (1.46 points) and the EU-10 (only 0.48 points) was a bigger part of the explanation of U.S. success in this period. We will investigate in a subsequent section whether U.S. industries that were ICT intensive disproportionately enjoyed faster TFP growth during this interval.

As noted above, EU-10 labor productivity growth slowed down between the early (1977-95) period and the late (200515) interval much more in the commodities sector than in market services. The early-to-late productivity growth slowdown for commodities of 2.37 points was largely explained by a decline in TFP growth (1.78 points), with virtually no role of ICT capital deepening. Thus the EU experience of commodities was similar to that of the U.S. in that ICT capital deepening played little to no role on either side of the Atlantic. In the EU market services sector, the early-to-late labor productivity slowdown of 1.08 points is attributed most importantly to non-ICT capital deepening (0.61 points) with smaller roles for TFP growth (0.27 points) and ICT capital deepening (0.22 points). It thus appears that the industries in the market services sector are those in which the U.S. ICT advantage occurred.

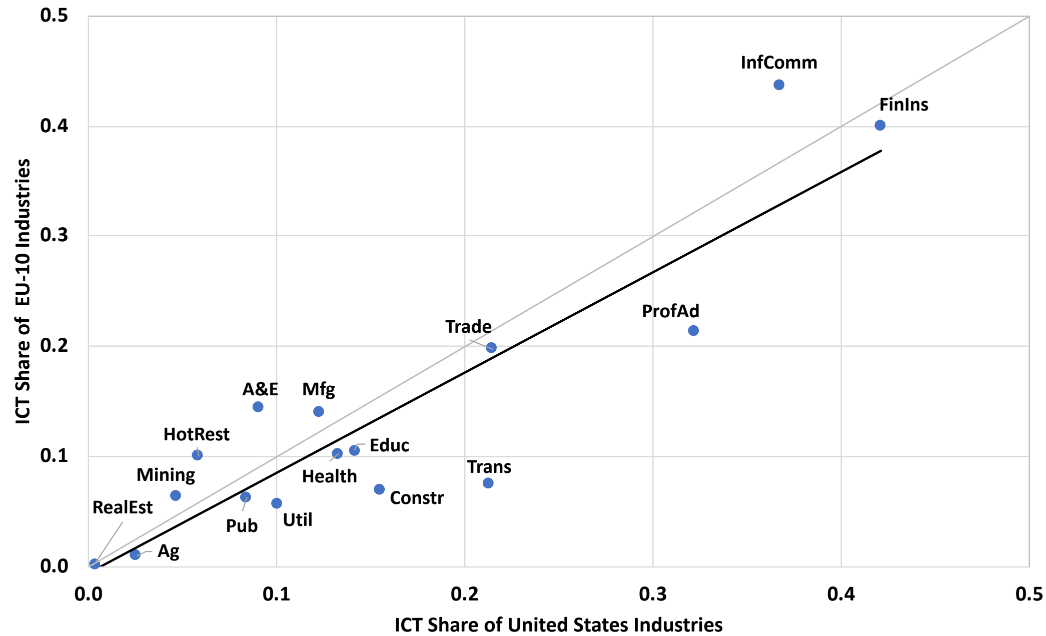
4. Measures of ICT Intensity and Their Industry Distribution

The relationship between labor productivity growth and ICT intensity is a central issue in this paper. Did U.S. industries that were relatively heavy users of ICT experience a relatively large post-1995 productivity growth acceleration and/or a relatively large post-2005 growth slowdown? Did EU-10 ICT-intensive industries have relatively large or small productivity growth slowdowns after 1995 and again after 2005? Can slower productivity growth during 1995-2005 in the EU-10 than in the U.S. be explained by lower values of ICT indicators in the EU-10?

Two alternative ICT-intensity variables are available in the KLEMS data for both the U.S. and EU-10 and for all 27 of the available industries, including the 16 industrial sectors into which the total economy is divided, as well as the 11 sub-industries within manufacturing. The first of these is the ICT "share indicator," which is formulated as in Stiroh (2002). We compute the average ICT share of investment, which is the annual nominal expenditure on computing equipment, communications equipment and computer software and databases, all divided by the annual nominal expenditure on total capital investment. Initially we examine the actual values of this ratio for individual industries and subsequently in the regressions we convert the share indicator into a share dummy variable equal to unity for industries which are ranked above the median value in the 1991-95 period and zero otherwise.

The other KLEMS ICT variable is the "contribution indicator," equal to the contribution of ICT capital to real value-added growth. This is available at the industry level only beginning in 1999. As with the share indicator, we initially display numerical values of the contribution indicator but for the regression analysis convert it into a dummy variable equal to unity for industries which are ranked above the median value in the 1999-2005 period and zero otherwise. For the regression analysis we also distinguish ICT use from ICT production by creating dummy variables for the "Electric machinery" industry that produces ICT hardware and the "Information and Communications" industry that produces ICT software and data.

Figure 1. Correlation Between Share of ICT Investment in Total Investment, 1991-1995, United States vs. EU-10



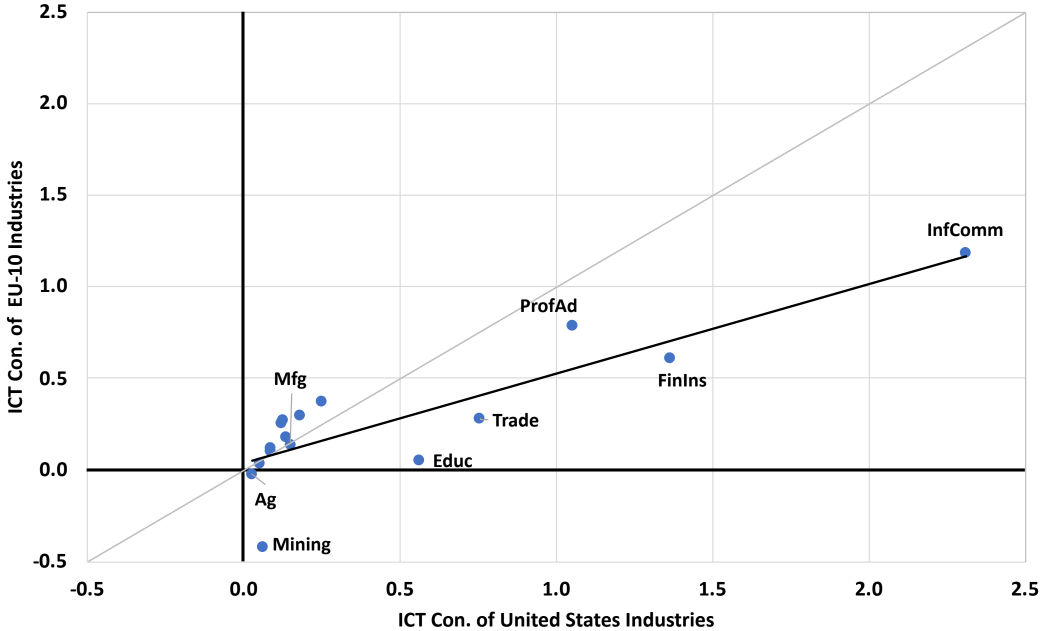
Source: KLEMS Database. Datapoints can be found in the first column of Appendix Table A1

The values of the share indicator for 1991-95 are displayed in Figure 1, where the EU value is plotted on the vertical axis and the U.S. value of the indicator for the same industry is plotted on the horizontal axis. Only the 16 industrial sectors are shown, as there is insufficient space to display clearly the 11 additional manufacturing sub-industries. The thin diagonal 45-degree line indicates equal values for the EU and U.S.; six industries are above that line indicating a higher EU-10 than U.S. value, while 10 are below that line, indicating a lower EU-10 than U.S. value.

The thick diagonal regression line in Figure 1 has a coefficient of 0.91, indicating that the average value of the share indicator for a given industry in the EU-10 is 91 per cent of its value in the U.S. Notice that all of the industries with the highest values of the share indicator are in the market services sector – finance/insurance, information/communications, professional/administrative, and trade. The fact that the regression line lies so close to unity suggests that on average a low EU value of the ICT share indicator is not an important explanation of why the EU-10 registered slower productivity growth than the U.S. during 1995-2005.

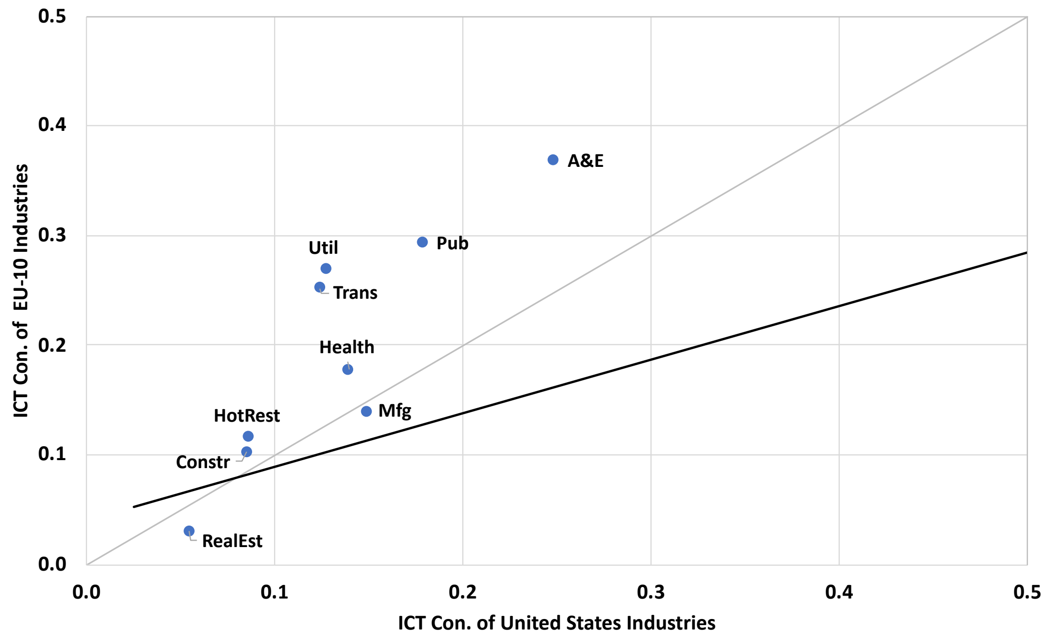
Panel A in Figure 2 displays the EU-10 and U.S. values of the alternative contribution ICT indicator for 1999-2005 in the same format as Figure 1. Note that, in contrast to the share indicator, the contribution indicator is less "spread out," with only five of the U.S. industries and only three of the EU-10 industries having a contribution indicator above 0.5. Because of the cluster of dots near the origin in Panel A, we supplement it with Panel B which shows a "zoomed in" version of the same information in the region of 0 to 0.5 on the two axes.

Figure 2a. Correlation Between Contributions of ICT Capital to Value-Added Growth, 1999-2005, United States vs. EU-10



Source: KLEMS Database. Datapoints can be found in the second column of Appendix Table A1

Figure 2b. Correlation Between Contributions of ICT Capital to Value-Added Growth, 1999-2005, United States vs. EU-10



Source: KLEMS Database. Datapoints can be found in the second column of Appendix Table A1

For the contribution indicator the values for the EU-10 are considerably lower on average than in the U.S., as summarized by the regression coefficient of 0.49. This indicates that on average the value of the contribution indicator for a given industry in the EU-10 is roughly half of its value for the counterpart industry in the U.S. Since the contribution indicator equals capital's income share times the growth rate of ICT capital[6], a factor holding back EU-10 labor productivity growth during 1995-2005 was slower growth of ICT capital. Notice that the four service-sector industries that are highest ranked in the U.S. by the criterion of the contribution indicator are the same as those when ranked by the share indicator.

Appendix Table A1 lists the actual and dummy values for all U.S. and EU-10 industries of both the share indicator (1991-95) and contribution indicator (1999-2005). Table A1 includes not just the 16 industrial sectors shown in the Figures 1 and 2 but also the 11 sub-industries within manufacturing. Also shown for ease of reference in Table A1 are the growth rates of labor productivity and of TFP in the three sub-intervals between 1977 and 2015 as well as the average 1977-2015 value-added share of each industry and sub-industry to provide a measure of its relative importance.

We have now examined productivity growth rates in Tables 1 and 2 and ICT intensity indicators in the two figures. The effect of ICT intensity on productivity growth is illustrated in Table 3, where we define industries that are intensive in ICT use as those ranked above the median in a ranking of the share indicator. This ranking is carried out separately for the U.S. and EU-10. By dividing up the industries into these two groups we are able to ask whether industries that are intensive in ICT use had higher growth rates in the U.S. 1995-2005 rapid growth period and whether the decline in productivity growth after 2005 in the U.S. and after 1995 in the EU-10 was concentrated in ICT-use-intensive industries. In addition to separating industries by their intensity of ICT use, we also single out two ICT-producing industries, electric machinery in the commodities sector and information/communications in the market services sector.

Because we obtain roughly the same decomposition using either the share or contribution version of the intensity of ICT use measure, we simplify Table 3 by exhibiting results only for the share version. The top section of the table for the total economy singles out the ICT-producing industries as having much faster productivity growth than the other industry groups in both the U.S. and EU for all three time periods. This breakdown also highlights the ICT-producing industries as the only group having a post-1995 growth acceleration in the EU, in contrast to the other two groups that experienced a post-1995 growth slowdown. All three industry groups in the EU as well as the U.S. registered slower productivity growth after 2005.

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[6] For example, if the growth rate of ICT capital over a given year is 0.5 and its income share is 0.4, the contribution of ICT capital to productivity growth is 0.2.

How do the industries intensive in ICT use compare to the non-ICT industries? For the U.S. the ICT-use group has faster growth than the non-ICT group by a margin of 2.23 to 1.20 per cent in the middle period but, surprisingly, somewhat slower growth in the first and third time intervals. This means that the ICT-use industries had a much greater 1995-2005 productivity acceleration than the non-ICT industries (1.45 vs. 0.29 points) as well as a much larger post-2005 slowdown (1.77 vs. 0.39 points). For the EU the ICT-use group registers faster growth than the non-ICT industries in all three periods by a modest margin of 0.78, 0.52, and 0.58 percentage points respectively. This means that the EU early-to-late productivity slowdown was similar in both groups (slowdowns of 1.70 and 1.50 points, respectively).

Table 3. Comparison of Productivity Growth Between U.S. And EU-10

	United States			EU-10		
	1977-1995	1995-2005	2005-2015	1977-1995	1995-2005	2005-2015
Total Economy	1.11	2.17	0.87	2.21	1.26	0.63
Total Economy ICT Use	0.78	2.23	0.46	2.52	1.34	0.82
Total Economy ICT Prod	4.90	8.04	4.04	3.40	4.08	2.43
Total Economy non-ICT	0.91	1.20	0.81	1.74	0.82	0.24
Commodities	2.12	3.59	1.29	3.22	2.19	0.85
Commodities ICT Use	0.20	0.58	-0.23	3.27	2.64	1.63
Commodities ICT Prod	10.01	17.57	7.07	5.49	4.78	2.95
Commodities non-ICT	1.93	2.88	1.25	2.84	1.52	0.02
Market Services	1.41	2.61	0.65	1.71	1.21	0.63
Market Services ICT Use	1.47	2.86	0.52	1.50	0.77	0.52
Market Services ICT Prod	2.22	4.04	3.05	1.98	3.84	2.26
Market Services non-ICT	0.53	0.59	-0.27	2.32	1.34	0.05

Source : KLEMS Database.

The bottom two sections of Table 3 divide up the market economy into commodities and market services. Again we see for the U.S. and EU-10 that the ICT-producing industries in the commodities sector (electric machinery) and in the services sector (information/communications) experienced growth accelerations in 1995-2005 and slowdowns in 2005-2015. For the other industries in the U.S. the commodities and services sectors exhibit very different impacts of ICT use. In the commodities sector the post-1995 acceleration was concentrated in the non-ICT industries with relatively slow productivity growth in the ICT-use group. The opposite was true for market services where the post-1995 acceleration and post-2005 slowdown were much more evident in the ICT-use-intensive industries than in the non-ICT group.

We can gain an understanding of these patterns for the U.S. by referring back to Figure 1, which displays the value of the ICT share indicator that is used to divide up industries into the ICT-use and non-ICT components for the decomposition of Table 3. Within the commodities sector the construction industry has a relatively high value of the ICT-use indicator but exhibits productivity growth of about -1.0 per cent per year in all three time intervals. This is sufficient to hold down overall U.S. productivity growth in the ICT-use segment of the commodities sector. In contrast in the market services sector all the post-1995 acceleration and post-2005 slowdown in productivity growth occurs in the ICT-use industries, four of which are the highest ranked in terms of the ICT-use indicator. These are the industries where we would expect the digital revolution to have its major impact on business efficiency – not only information/communications (which is shown separately on the services "ICT Prod" line in Table 3), but also finance/insurance, professional/administrative, and wholesale/retail trade.

For the EU there is much less difference between commodities and services and between ICT-use-intensive and non-ICT industries. In all these EU-10 industry groups productivity growth slowed down after 1995 and again after 2005. Surprisingly the ICT-producing electric machinery industry in the EU-10 actually experienced slower productivity growth after 1995 despite all the innovation that was driving faster productivity in that industry for the U.S. The extent of the EU-10 early-to-late slowdown was greatest in the non-ICT industries (2.82 percentage points in commodities and 2.27 percentage points in services) where productivity growth was zero after 2005. The early-to-late slowdown was somewhat less in the ICT-use-intensive industries (1.64 percentage points in commodities and 0.98 percentage points in services). To this extent intensity of ICT use helped the EU by avoiding the post-2005 productivity paralysis experienced by the EU's non-ICT-intensive industries.

Comparing the EU with the U.S. for the middle 1995-2005 period, the main sources of EU-10 weakness were in commodities ICT production (i.e., electrical machinery) with 12.79 percentage points slower labor productivity growth relative to the U.S. (4.78 per cent versus 17.87 per cent), non-ICT commodities 1.36 percentage points slower growth (2.88 per cent versus 1.52 per cent), and ICT-use market services 2.09 percentage points slower growth (2.86 per cent versus 0.77 per cent). We return in Table 7 to look more closely at the 1995-2005 performance of particular industries in both the U.S. and EU-10 that were intensive in ICT use.

5. Cross-Industry Regression Framework

We have now examined in Table 3 average rates of productivity growth for groups of industries that have a relatively high or low value of our share-based ICT-use-intensity indicator. Now we turn to regressions in which productivity growth in our 27 industry sectors and manufacturing sub-industries constitute the observations to be explained. Our regression framework is adapted from Stiroh (2002), whose specification reflected two time periods, pre- and post-1995 ending in 2000. Here, in contrast, we have three time intervals in which our 1977-2015 overall time period is split at 1995 and 2005. We begin with a simple equation that allows productivity growth to differ across the three intervals:

$$x_{it} = \alpha + \beta_1 M_{it} + \beta_2 L_{it} + \epsilon_{it} \ (1)$$

where the "M" ("mid") variable is a dummy equal to unity after 1995, and the "L" ("late") variable is a dummy equal to unity after 2005. The constant α represents average labor productivity growth for all industries during 1977-1995. The coefficient β_1 on "M" represents the difference between average labor productivity growth in 1995-2005 minus 1977-1995 for all industries, while the coefficient β_2 on the "L" term is the average difference between 2005-15 minus 1995-2005 for all industries.

We augment this model so that the α term becomes an industry specific constant α_i. This allows us to estimate a fixed effects regression of the form:

$$x_{it} = \alpha_i + \beta_1 M_{it} + \beta_2 L_{it} + \epsilon_{it} \ (2)$$

Now, the α_i term is the average productivity growth of industry i during 1977-95. This allows greater flexibility in the sense that industries are allowed to start from different initial values of productivity growth prior to 1995. The β_1 term still captures the average productivity growth change of all industries from 1977-95 to 1995-2005, and β_2 measures the average productivity growth change of all industries from 1995-2005 to 2005-2015.

The purpose of our regressions is to capture the effect of ICT-intensity in driving changes in productivity growth that occurred post-1995 and post-2005. The regressions differ from the decomposition of Table 3 in two ways. The first difference is by measuring the *change* in productivity growth across time intervals as contrasted with the *level* of productivity growth as displayed in Table 3. The second difference is that the regressions control for differences across industries in productivity growth during the 1977-95 base period, whereas these differences are not subtracted out in Table 3. Accordingly the regression format can be written as

$$x_{it} = \alpha_i + \beta_1 M_{it} + \beta_2 L_{it} + \gamma_1 M * ICT_{it} + \gamma_2 L * ICT_{it} + \epsilon_{it} \ (3)$$

The ICT variable is a dummy equal to unity if industry i is ICT intensive, with ICT intensity measured using either the "share" or "contribution" indicator as defined above. With this design, β_1 measures the average post-1995 acceleration of non-ICT-intensive industries, while $\beta_1 + \gamma_1$ captures the average post-1995 change in productivity growth of ICT-intensive industries. γ_1 then captures the *additional* productivity change (up or down) of ICT-intensive industries post-1995 relative to non-ICT industries. Similarly, β_2 represents the post-2005 acceleration or deceleration of non-ICT-intensive industries relative to 1995-2005 while $\beta_2 + \gamma_2$ measures the change in productivity growth of ICT intensive industries, with γ_2 capturing the difference between the two groups.

As in Table 3 we are interested in distinguishing the effect of the two industries that *produce* ICT from the other industries that are relatively intensive in the *use* of ICT. To measure the ICT-production effect, we allow these two industries (electric machinery and information/communication) to have separate coefficients that measure their contribution to the post-1995 and post-2005 changes in productivity growth. This leads us to add in four more regression terms to control for these ICT producing industries, as written in equation (4) below:

$$x_{it} = \alpha_i + \beta_1 M_{it} + \beta_2 L_{it} + \gamma_1 M * ICT_{it} + \gamma_2 L * ICT_{it} + \delta_1 M * EM_{it} + \delta_2 L * EM_{it} + \eta_1 M * IC_{it} + \eta_2 L * IC_{it} + \epsilon_{it} \quad (4)$$

Now the interpretation of the δ_1 term is the additional growth change of the electrical machinery industry relative to ICT-intensive industries; η_1 has a similar interpretation but for the information/communications industry. The δ_2 and η_2 coefficients provide equivalent interpretations for the post-2005 slowdown in productivity growth.

One issue with estimating equations (1) through (4) via ordinary least squares is that each regressor's coefficient will only capture (geometric) average changes in productivity growth. We may be worried about the influence of erratic behavior in relatively "small" industries on our estimates of each of the coefficients. For example, the U.S. agricultural industry experienced a post-1995 acceleration of 3.55 percentage points despite accounting for only 2 per cent of value added in the total economy. To address this issue, we estimate equation (4) using weighted least squares (WLS), with the weight of an industry equal to its value-added (VA) share in 1976. This weighting procedure follows that of Stiroh (2002), which in turn draws on Kahn and Lim (1998), and is based on the reasoning that (1) industries with smaller VA shares should be given less importance in analyzing determinants of aggregate growth and (2) industries with smaller VA shares have noisier productivity growth data. Our choice of the year 1976 preserves exogeneity of the weights, since the first data point in all of our regressions is 1977-78 productivity growth.

6. **Industry Regression Results**

Labor Productivity Growth

Table 4 presents results based on equation (4) above, where the observations are annual labor productivity growth rates between 1977 and 2015 for the 27 industries. The left half of the table refers to the U.S. and the right half refers to the EU-10 aggregate.[7] To conserve space the individual fixed-effect constants for the 27 industries are not listed separately. All columns are estimated with Weighted Least Squares. For the EU-10, data for only 26 industries are utilized, as the "wholesale and retail" industries are consolidated into a single sector in the European KLEMS data.

The grid of "Yes" boxes designates the differences between results listed in the individual columns of the table. Columns (A) and (D) refer to the total economy, while (B) selects the annual observations of the 15 commodities industries (including the sub-industries within manufacturing) and (C) selects the annual observations for the 12 services industries

[7] There are 27 industries for the U.S. but only 26 for the EU-10, because data limitations require us to combine the retail and wholesale industries for the EU-10 whereas separate retail and wholesale data are available for the U.S.

(including both market and non-market services). For the U.S., columns (A) through (C) use the share indicator as the ICT-intensity variable while (D) uses the contribution indicator.[8] Thus a comparison of columns (A) and (D) shows the difference made when the contribution indicator in (D) is substituted for the share indicator in (A).

Table 4. Labor Productivity Equations with ICT Dummies, U.S. vs. EU-10, 1977-2015

	United States				**EU-10**			
	(A)	**(B)**	**(C)**	**(D)**	**(E)**	**(F)**	**(G)**	**(H)**
(1) Post-1995	0.35	0.86	0.05	0.35	-0.56 **	-1.15 **	-0.13	-0.65 **
(2) Post-2005	-0.88	-1.90 *	-0.29	-1.04	-0.73 **	-1.21 **	-0.38	-0.74 **
(3) Post-1995 X ICT Use	1.64 **	-0.06	2.41 **	1.35 *	0.09	0.73	-0.37	0.28
(4) Post-2005 X ICT Use	-1.55 *	0.78	-2.66 **	-0.96	0.14	0.23	0.10	0.15
(5) Post-1995 X EM	5.58 **	6.76 **		5.86 **	-0.25	-0.29		-0.06
(6) Post-2005 X EM	-8.07 ***	-9.39 ***		-8.50 ***	-1.23	-0.85		-1.08
(7) Post-1995 X I&C	-0.17		-0.64	0.11	2.33 *		2.36 **	2.23 *
(8) Post-2005 X I&C	1.44		1.96	1.02	-0.98		-1.30	-0.98
Commodities Only		Yes				Yes		
Services Only			Yes				Yes	
Share Indicator	Yes	Yes	Yes		Yes	Yes	Yes	
Contribution Indicator				Yes				Yes
Number of Observations	1026	570	456	1026	988	570	418	988
Number of Industries	27	15	12	27	26	15	11	26

Source: KLEMS Database. * indicates statistical significance at the 10% level, ** at the 5% level, and *** at the 1% level. "ICT Use" is a dummy variable equal to unity if the ICT indicator (either share or contribution as defined in the text) is above the median when industries are ranked by the value of that indicator. "EM" is a dummy equal to one for the Electrical Machinery industry, while "I&C" is a dummy equal to one for the "Information & Communications" industry. All regressions include industry fixed effects and are estimated by Weighted Least Squares, where WLS weights are taken as an industry's nominal value-added share for 1976. The "Services" category includes the four non-market-economy services-producing industries.

We first examine the results for the U.S. as displayed in columns (A) through (D). The low magnitudes and lack of significance on all U.S. coefficients in line (1) for the post-1995 dummy reflect the fact that non-ICT-intensive industries had little additional productivity growth after 1995 compared to their 1977-95 growth rate. The U.S. ICT-use post-1995 interaction coefficients in line (3) are positive and generally significant (except for commodities industries in column (B)); this suggests that, unlike the non-ICT-intensive industries, the U.S. industries intensive in ICT use had a significant acceleration of productivity growth after 1995. In the total

[8] An identical version of this Table with results for only the contribution variable can be found in Appendix Table A2.

U.S. economy this extra post-1995 growth was 1.64 points for the share indicator and 1.35 points for the contribution indicator, and in the services sector was a considerably higher 2.41 points.

Recall that the post-1995 dummy variable refers to 1995-2015, not 1995-2005, and so the coefficient on the post-2005 dummy variable measures the change in productivity after 2005 as compared to 1995-2005, not as compared to 1977-95. This change in productivity growth after 2005 is shown in lines (2) and (4). There is a modest decline in line (2) for the U.S. non-ICT-intensive industries, but this decline is significant only in the commodities industries. There is a decline for the total U.S. economy in the ICT-use-intensive industries, a significant 1.55 for the share indicator and an insignificant -0.96 for the contribution indicator. The decline was a highly significant 2.66 in the services industries.

When we compare lines (1) and (2) for the U.S. non-ICT-intensive industries, the negative post-2005 coefficients are larger in absolute value than the positive post-1995 coefficients, reflecting the fact that productivity growth was slower after 2005 than before 1995. For the ICT-use-intensive industries the negative post-2005 coefficients are roughly the same size in absolute value as the positive post-1995 coefficients, indicating that for these industries U.S. productivity growth was roughly the same after 2005 as it was before 1995.
The coefficients for the "EM" (electric machinery) industry are shown on lines (5) and (6), where for the U.S. there was an enormous and highly significant post-1995 productivity growth acceleration and post-2005 slowdown. This is the industry that produces computer hardware that reached its peak of innovation in the 1995-2005 decade (Oliner-Sichel, 2000). The fact that the negative coefficient for the 2005-15 dummy variable is larger than the positive coefficient for the 1995-2015 dummy variable reflects the fact that productivity growth in this industry was lower after 2005 than before 1995. In contrast the U.S. coefficients for the "I&C" (information/communications) industry on lines (7) and (8) are all insignificant.

Turning now to the right half of Table 4 for the EU-10 in columns (E) through (H), we can highlight those aspects of the results that differ from those for the U.S. The first contrast appears on lines (1) and (2) where (except for the services industries in column (G)) the non-ICT-intensive industries in the EU-10 had a highly significant growth slowdown after 1995 and yet another significant slowdown after 2005. The post-1995 and post-2005 EU-10 slowdowns were of roughly the same magnitude. Again, in contrast to the U.S., there was no additional change up or down in the EU-10 ICT-use-intensive industries as shown in lines (3) and (4). Nor was there any significant growth change in the electric machinery industry in lines (5) and (6), which as we observed in Table 3 above actually experienced slower growth in 1995-2005 than before 1995. The only notable industry effect for the EU-10 was a highly significant post-1995 change in the information/communications industry that was only partly offset by an insignificant post-2005 decrease.

Our overall conclusion from Table 4 is that the U.S. behaved very differently from the EU-10. The U.S. experienced little post-1995 or post-2005 change in the rate of productivity growth for the non-ICT-intensive industries but a significant and temporary acceleration especially in the ICT production industries but also in the ICT-use-intensive industries. However, this zig-zag pattern is concentrated in the ICT-use services industries, as well as in the electric machinery industry, but is not evident in the other commodities ICT-use industries. The relative symmetry of these accelerations and decelerations support the broader interpretation that ICT investment in the U.S. can be viewed as a "temporary shock" that elevated aggregate productivity growth for a decade before dissipating as the fruits of the ICT revolution were reaped. Stated another way, the ICT revolution created a one-time increase in the *level* of U.S. labor productivity that took about a decade to work itself through the economy.

The conclusions for the EU-10 are quite different. There were two successive productivity growth slowdowns, one after 1995 and the second after 2005, and these were concentrated across the 15 industries producing commodities with no additional impact coming from the subset of those services industries that were ICT intensive. Further there were no significant slowdowns in the EU-10 service sector industries whether ICT-intensive or not, with the notable exception of the information/communications industry that experienced a marked increase in productivity growth after 1995 that only partly disappeared after 2005.

Total Factor Productivity Growth

In Table 2 we examined a standard decomposition of sources of growth that divides up contributions to labor productivity growth among labor composition, ICT and non-ICT capital deepening, and a residual TFP growth component. Here we are interested in the channels by which ICT intensity alters productivity growth. We have seen in Table 4 that, for the U.S., ICT-intensive industries experienced a temporary acceleration of labor productivity growth during 1995-2005 that was not shared by non-ICT-intensive industries. Is this ICT contribution to growth channeled exclusively through capital deepening? Or, as suggested by Oliner and Sichel (2000), does ICT innovation "spill over" and raise the growth rate of TFP beyond the direct effect of ICT through capital deepening? Oliner and Sichel were particularly interested in the spillover from innovation in the intermediate goods industry making integrated circuit chips to the final goods industry making computer hardware. Here we are interested more generally in spillovers from all types of ICT investment into TFP growth in the industries that are ICT intensive.

Table 5 is arranged just like Table 4, with results for the U.S. on the left and for the EU-10 on the right. We repeat the results for labor productivity growth in the total economy from Table 4 for ease of comparison with our new results explaining TFP growth. Thus, in Table 5, columns (A) and (B) repeat the U.S. results shown in Table 4 for the total economy, columns (A) and (D). Likewise columns (E) and (F) repeat the EU-10 results shown in Table 5, columns (E) and (H); these differ only in the choice of the ICT indicator.

Table 5. Labor Productivity and Total Factor Productivity Equations with ICT Dummies, U.S. vs. EU-10, 1977-2015								
	United States				EU-10			
	Labor Productivity		Total Factor Productivity		Labor Productivity		Total Factor Productivity	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
(1) Post-1995	0.35	0.35	0.17	-0.09	-0.56 **	-0.65 **	-0.70 ***	-0.69 **
(2) Post-2005	-0.88	-1.04	-0.40	-0.46	-0.73 **	-0.74 **	-0.62 **	-0.74 **
(3) Post-1995 X ICT Use	1.64 **	1.35 *	1.34 *	1.61 **	0.09	0.28	0.46	0.38
(4) Post-2005 X ICT Use	-1.55 *	-0.96	-0.96	-0.68	0.14	0.15	0.49	0.69
(5) Post-1995 X EM	5.58 **	5.86 **	4.41 *	4.39 *	-0.25	-0.06	0.42	0.87
(6) Post-2005 X EM	-8.07 ***	-8.50 ***	-7.34 **	-7.56 ***	-1.23	-1.08	-0.68	-0.07
(7) Post-1995 X I&C	-0.17	0.11	-2.26	-2.28	2.33 *	2.23 *	3.02 **	3.08 ***
(8) Post-2005 X I&C	1.44	1.02	2.00	1.78	-0.98	-0.98	-1.10	-1.18
Share Indicator	Yes		Yes		Yes		Yes	
Contribution Indicator		Yes		Yes		Yes		Yes
Number of Observations	1026	1026	1026	1026	988	988	988	988
Number of Industries	27	27	27	27	26	26	26	26

Source: KLEMS Database. * indicates statistical significance at the 10% level, ** at the 5% level, and *** at the 1% level. "ICT Use" is a dummy variable equal to unity if the ICT indicator (either share or contribution as defined in the text) is above the median when industries are ranked by the value of that indicator. "EM" is a dummy equal to one for the Electrical Machinery industry, while "I&C" is a dummy equal to one for the "Information & Communications" industry. All regressions include industry fixed effects and are estimated by Weighted Least Squares, where WLS weights are taken as an industry's nominal value-added share for 1976. The "Services" category includes the four non-market-economy services-producing industries.

The new results for TFP growth are shown in columns (C) and (D) for the U.S. and in columns (G) and (H) for the EU-10. The pattern of significance values and the size of coefficients for each TFP equation are so similar to the corresponding labor productivity equation that the differences are negligible and can be described briefly. For the U.S. the first six rows of the TFP coefficients in columns (C) and (D) have the same pattern of significance indicators and slightly smaller numerical values as the labor productivity results in columns (A) and (B), except that the post-1995 ICT-intensive acceleration in line (3) column (D) is slightly larger for the TFP equation than the corresponding productivity growth equation in column (B). TFP coefficients are consistently larger in lines (7) and (8) for the I&C industry effect although those coefficients are all insignificantly different from zero and from each other.

The same pattern emerges when the EU-10 TFP growth equations in columns (G) and (H) are compared with the corresponding EU-10 productivity growth equations in columns (E) and (F). Coefficient values and significance levels are almost identical for the post-1995 and post-2005 non-ICT effects shown on lines (1) and (2). Coefficients for the extra ICT-use-intensive and EM effects are all insignificant in the TFP equations just as they are in the labor productivity equations. However, the "I&C" effect for the information and communications industry shows a post-1995 acceleration that is even larger and more significant in the TFP equations in columns (G) and (H) than in the corresponding labor productivity growth equations in columns (E) and (F).

If the effect of ICT investment was simply to boost labor productivity growth through capital deepening, with no further impact on TFP growth, we would expect no correlation between ICT intensity and TFP growth. If, however, the effect of ICT investment was to cause a reorganization of business practices that went beyond the mere installation of new equipment, we might expect to see that the industry-by-industry differences in labor productivity growth were mirrored in similar differences in TFP growth. Indeed, this appears to be the conclusion implied by the results of Table 5. In the U.S. those industries that were ICT-intensive experienced a similar acceleration in both labor productivity growth and TFP growth in 1995-2005 that was reversed after 2005. And in the EU-10 all industries (whether ICT-intensive or not) experienced a similar deceleration in both labor productivity growth and TFP growth after 1995 and again after 2005.

Cross Effects

Are the differences in productivity and TFP growth between the U.S. and EU-10 industries due to differing values of ICT indicators or to a differing responsiveness to those indicators? That question can be answered by looking at "cross effects," the results of recalculating predicted values from the regression equations with values of the ICT indicators and regression coefficients from opposite sides of the Atlantic.

The top section of Table 6 reports the results for the U.S. and the bottom section shows those for the EU-10. Calculations for labor productivity growth are shown on the left and for TFP growth are shown on the right. Since we are interested in the effect of the actual values of the ICT indicators, not just whether they are set equal to 0 or 1 as in the regressions of Tables 4 and 5, we base the results of Table 6 on alternative versions of the productivity and TFP equations in which the 0 or 1 values of the ICT indicator dummy variable are replaced by the numerical values of the ICT indicator.

We could base these calculations on the ICT share indicator or the ICT contribution indicator. However, as shown above in Figure 1, the EU-10 values of the ICT share indicator are quite similar to the U.S. values, with a regression coefficient of 0.91 of EU-10 indicator values for each industry on U.S. indicator values. Thus it is not surprising that it makes little difference when we recalculate predicted values of productivity growth by substituting the share indicator values from across the Atlantic. All the difference in predicted values comes from differing coefficients in the productivity equations and none from differing share indicator values.

The results using the ICT contribution indicators are more interesting, since as shown in Figure 2 above the EU-10 contribution indicator values are quite different than the U.S. values, having a coefficient of 0.49 when regressed on U.S. indicator values. The estimated coefficients of the alternative "continuous value" versions of the ICT contribution equations are shown in Appendix Table A3.

Table 6. Cross Effects for EU-10 and U.S. Labor Productivity and TFP

	Labor Productivity		Total Factor Productivity	
	1995-2005	**2005-15**	**1995-2005**	**2005-15**
Actual U.S. Data	2.17	0.87	0.70	0.17
(A) Predicted U.S. Values with				
(1) U.S. ICT coefficients and U.S. ICT data	2.20	0.60	0.73	-0.11
(2) U.S. ICT coefficients and EU ICT data	1.96	0.64	0.47	-0.22
(3) EU ICT coefficients and U.S. ICT data	1.78	1.14	0.28	0.57
(4) EU ICT coefficients and EU ICT data	1.69	0.98	0.18	0.21
Actual EU-10 Data	1.26	0.63	0.27	-0.02
(B) Predicted EU-10 Values with				
(1) EU ICT coefficients and EU ICT data	1.69	1.02	0.33	-0.09
(2) EU ICT coefficients and U.S. ICT data	1.78	1.19	0.43	0.27
(3) U.S. ICT coefficients and EU ICT data	1.96	0.68	0.61	-0.52
(4) U.S. ICT coefficients and U.S. ICT data	2.21	0.65	0.88	-0.41

Source : KLEMS Database. Coefficient estimates are taken from the specifications in Table 5, where the 0,1 ICT intensity dummy variables for the contribution indicator are replaced by the continuous numerical values of that indicator as listed in Appendix Table A1. These coefficient estimates can be found in columns (B), (D), (F), and (H) of Table A3.

The top row and left column of Table 6 shows for the total U.S. economy that the actual productivity growth rate for 1995-2005 was 2.17 per cent. Underneath this actual value, line (A1) shows that the predicted value of labor productivity growth when using the continuous version of the ICT contribution equation is a nearly identical 2.20 per cent. If EU-10 data for the ICT contribution indicator are substituted for the U.S. values, the predicted value declines by 0.24 percentage points to 1.96, as shown in line A2. Then line A3 shows that if we switch back to U.S. data for the contribution indicator and use the EU-10 regression coefficients, the predicted value falls to 1.78, 0.42 percentage points below the predicted value of 2.20 when the same U.S. indicator values are combined with U.S. regression coefficients. Finally with EU-10 values for both the indicator data and the regression coefficients, the predicted value falls to 1.69 per cent, or 0.27 points below the 1.96 predicted value when EU data are combined with U.S. coefficients. Thus, U.S. productivity growth was faster than in the EU-10 for 1995-2005 *both* because the U.S. values of the ICT contribution indicator were higher and also because U.S. ICT-intensive industries had a substantially greater positive post-1995 productivity growth response relative to U.S. non-ICT-intensive industries than occurred in the EU-10.

The bottom half of Table 6 in the first column shows that this same interpretation works in reverse for the EU-10. With its own indicator data and regression coefficients, the predicted EU-10 productivity growth in 1995-2005 is 1.69 per cent. Substituting U.S. indicator data raises predicted productivity growth from 1.69 to 1.78 per cent using EU regression coefficients and from 1.96 to 2.21 per cent using U.S. regression coefficients. Substituting U.S. regression coefficients raises the predicted value from 1.69 to 1.96 per cent using EU indicator data and from 1.78 to 2.21 per cent using U.S. indicator data. Thus 1995-2005 EU-10 productivity growth was slower than in the U.S. both because EU-10 ICT contribution data were smaller and also because EU-10 ICT-intensive industries had virtually no excess 1995-2005 productivity growth response relative to EU non-ICT intensive industries as compared to a substantial excess response in the U.S.

Turning to the second column in Table 6, the top section for the U.S. shows the predicted values of labor productivity growth for 2005-15, when the actual growth rate of 0.87 was much slower than the 2.17 per cent actual rate recorded for 1995-2005. A comparison of lines A1 and A2 indicates that the negative U.S. post-2005 ICT coefficients generate a predicted value of 0.60 per cent with the U.S. indicator data and a similar 0.64 per cent with the EU indicator data. A switch from the negative U.S. post-2005 coefficients on line A1 to the positive EU post-2005 coefficients on line A3 causes a jump in the predicted value from 0.60 to 1.14 per cent. With EU indicator data, the same switch from U.S. to EU coefficients causes a smaller jump in the predicted value from 0.64 to 0.98 per cent when the EU indicator values are used, because the size of those EU indicators is smaller (recall Figure 2).

For the EU-10 in the bottom half of column (2) substituting the U.S. indicator values makes a relatively small difference. A much larger difference occurs when the negative U.S. coefficients are substituted for the positive EU coefficients. This switch of coefficients with EU indicator values changes predicted productivity growth from 1.02 per cent on line B1 to 0.68 per cent on line B3. The same switch in coefficients with U.S. indicator values changes predicted productivity growth from 1.19 per cent on line B2 to 0.65 per cent on line B4 — the drop in predicted growth in this case is greater because U.S. indicator values are larger and are applied to negative coefficients.

The right half of Table 6 repeats the same exercise for the same equations when TFP growth is used as the dependent variable instead of labor productivity growth. Again we reach the conclusion that both indicator values and estimated coefficients matter in the interpretation of differences in behavior between the U.S. and the EU. after 1995 and again after 2005. In the 1995-2005 interval the U.S. enjoyed a TFP growth acceleration not only because U.S. ICT-intensive industries had higher values of the ICT contribution indicator, but also because TFP growth responded by a greater positive amount than in the EU-10 to that ICT indicator. The EU-10 not only had lower values of the ICT contribution indicator in several industries, as shown in

Figure 2, but also had a much smaller (and insignificant) positive productivity response to the ICT contribution indicator.

After 2005, TFP growth slowed down on both sides of the Atlantic. In the U.S. this slowdown was concentrated in ICT-intensive industries as suggested by the negative ICT post-2005 coefficients. Predicted TFP growth is higher when the small but positive EU ICT coefficients are substituted for the large negative U.S. ICT coefficients. In contrast the EU-10 experienced a balanced TFP growth slowdown after 2005, with only small (and insignificant) positive coefficients in the ICT-intensive industries. So when the relatively large and negative U.S. coefficients are substituted for the relatively small and positive EU post-2005 ICT coefficients, predicted growth is substantially lower.

Which Industries Drive the Results?

A central result that emerges from our regression analysis is that the 1995-2005 acceleration in U.S. labor productivity and TFP growth together with the subsequent post-2005 U.S. growth slowdown were both driven not just by ICT production in the electric machinery industry but by ICT-use industries in the services sector. It appears that this post-1995 ICT stimulus does not occur in ICT-intensive commodities-producing industries once the special role of the electric machinery industry is taken into account. Which are the specific ICT-intensive industries in the services sector that account for post-1995 U.S. productivity growth behavior?

Table 7 is designed to answer this question. The top section shows the top six industries in the market sector when ranked by the value of the contribution indicator of ICT intensiveness. Displayed for each industry are the U.S. and EU values of the contribution indicator, the 1995-2005 growth rate of labor productivity in the U.S. and EU as well as the difference between them, and the share of each industry in market-sector value added. The top four industries (highlighted on the right side of Figure 2) are all in the services sector and the next two are in manufacturing. Not surprisingly the list includes information/communications, which produces data and software, as well as electric machinery, which produces ICT hardware. Also included are the finance/insurance and professional/administrative industries that are heavy users of ICT equipment and software, and the wholesale/retail sector. As shown in the far right column, these six industries account for 53 percent of U.S. market-sector value added.

Table 7. Comparative Data for Focus Industries, U.S. vs. EU-10						
	ICT Contribution Indicator		Labor Productivity Growth			Market Value-Added Share
Industry	U.S.	EU-10	U.S. 1995-2005	EU-10 1995-2005	U.S. - EU-10 1995-2005	U.S. 1977-2015
Group 1: High U.S. ICT Indicator						
Information & Communications	2.31	1.18	4.04	3.84	0.20	0.09
Finance & Insurance	1.36	0.61	3.77	2.14	1.63	0.09
Professions & Administrative	1.05	0.79	1.20	-1.03	2.23	0.12
Wholesale & Retail	0.70	0.28	4.33	1.81	2.53	0.19
Electrical Machinery	0.53	0.12	17.57	4.78	12.80	0.03
Other Manufacturing	0.27	0.12	3.32	2.82	0.50	0.01
Group 2: Low U.S. ICT Indicator but Rapid U.S. 1995-2005 LP Growth						
Petroleum	0.13	0.22	10.99	-0.39	11.38	0.01
Agriculture	0.03	-0.02	7.27	3.47	3.80	0.02
Transportation Equipment	-0.03	0.24	4.63	2.58	2.05	0.03
Textiles & Apparel	0.04	0.02	3.63	2.99	0.64	0.01
Chemicals	0.07	0.16	3.22	4.05	-0.83	0.03
Rubber & Plastics	0.14	0.10	3.19	2.42	0.77	0.01
Machinery NEC	-0.09	0.16	3.02	2.86	0.16	0.02

Source : KLEMS Database and Table A1.

Notably, all of the six industries have faster 1995-2005 labor productivity growth in the U.S. than in the EU. While the margin is slimmer in information/communications and other manufacturing, the difference is large in the four remaining industries and massive in electric machinery. Part of this difference in labor productivity growth between the U.S. and EU is explained by the first two columns that show a substantially higher value of the ICT indicator in the U.S. than in the EU. But, as shown by the cross-effects analysis of Table 6, higher U.S. productivity growth is explained not just by higher values of the ICT indicator but also by a greater response of productivity growth to a given value of that indicator.

But these six ICT-intensive industries were not the only reason that U.S. productivity growth was temporarily high during 1995-2005. Shown in the bottom section of Table 7 are seven additional industries ranked by their 1995-2005 U.S. labor productivity growth. All of the seven are commodities-producing, and six are subindustries within manufacturing. What distinguishes these U.S. industries is that they all achieved rapid productivity growth faster than 3.0 per cent in 1995-2005 with relatively small values (all below 0.15) of the ICT contribution indicator. In all of these industries but chemicals manufacturing, the U.S. rate of productivity growth was faster than in the EU, very substantially so in the case of petroleum and agriculture.

This list of seven commodities-producing industries that experienced rapid U.S. productivity growth during 1995-2005 provides a cautionary note to generalizations that credit ICT in general, or ICT only in the services sector, for all of the post-1995 U.S. productivity growth acceleration. These seven industries all had relatively low values of the contribution-based ICT indicator and so achieved their growth for reasons other than a large infusion of ICT investment.[9] Notably, with the exception of petroleum, 1995-2005 productivity growth in the EU-10 in this group of industries was relatively healthy with a relatively modest shortfall compared to U.S. productivity growth.

7. Summary and Conclusions

A retardation in the growth of labor productivity and of total factor productivity (TFP) has characterized both the United States and western Europe, in the sense that on both sides of the Atlantic growth has been slower since 2005 than it was before 1995. The notable difference in performance occurred in the middle interval of 1995-2005, when a sharp acceleration of growth in the U.S. contrasted to a growth slowdown in western Europe. As a result, the story of U.S. productivity growth since the mid-1970s has been one of slow-fast-slow over the three intervals divided at 1995 and 2005, in contrast to a two-step deceleration in Europe.

A substantial literature about the 1995-2005 U.S. productivity growth revival credits most or all of it to a surge of innovation and investment in information and communication technology (ICT). Does this finding of a dominant role for ICT hold up to a new examination of the data? If so, how is the post-2005 U.S. growth slowdown explained? If valid, a dominant role for ICT during 1995-2005 raises questions about the European slowdown that occurred at the same time. Did Europe invest less in ICT or was its problem a weaker exploitation of the benefits of new ICT hardware and software? In which industries did Europe lag most substantially behind the U.S. growth performance, and were these industries relatively heavy users or producers of ICT investment?

This paper explores these questions at the level of the total economy and of 27 separate industries in the EUKLEMS dataset. This allows us to study sources of productivity growth and to develop alternative indicators of "ICT-intensity" for individual industries on both sides of the Atlantic. To avoid being swamped by industry-level data for numerous European countries, we have combined time series for 10 western European countries into an aggregate that we call the "EU-10" that can be compared directly to parallel data for the U.S.

Our initial assessment is based on a decomposition of sources of growth in which labor productivity growth is divided up among the contributions of ICT and non-ICT capital deepening, changes in labor quality, and changes in TFP. Surprisingly, in view of the emphasis in past literature on the role of ICT, we find that the direct contribution of ICT capital deepening

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[9] These industries also had relatively low values of the alternative share ICT indicator, as shown in Appendix Table A1.

accounts for one-third or less of the post-1995 U.S. productivity growth revival or post-2005 growth slowdown. For the EU-10, ICT capital deepening plays virtually no role in explaining the two-step productivity growth slowdown. About one-third of the faster labor productivity growth during 1995-2005 in the U.S. vs. the EU-10 is explained by the higher contribution of ICT capital deepening in the U.S. Thus, the initial growth accounting exercise appears to cast doubt on a dominant role of ICT in the post-1995 U.S. growth revival.

To measure ICT intensity we develop two indicators, one based on the ICT share of total investment and the other based on the KLEMS measure of the ICT contribution to value-added growth. When industries are divided up into "ICT producing," "ICT-use-intensive" and "non-ICT-intensive", we emerge with a different conclusion regarding the importance of ICT for U.S. behavior. Most of the post-1995 U.S. productivity growth revival and post-2005 slowdown occur in industries classified as either ICT-producing or ICT-use-intensive. This is particularly true in the services sector where the industries with the highest values of our ICT use indicators are located. For the EU-10, the story is simpler, as the two-step slowdown occurs in all three categories of industries, with the exception only of the ICT software-producing information/communications ("I&C") industry. Thus unlike the U.S. the ICT-use-intensive industries in the EU-10 do not register productivity growth that differs from the non-ICT industries either during 1995-2005 or after 2005.

We run regressions for 27 industries on annual data for 1977-2015 to measure the response across all three periods to ICT intensity of labor productivity growth. Separate responses are included for the ICT-producing electric machinery ("EM") and I&C industries. The results support the role of ICT-intensive industries in the services sector as the main locus of the post-1995 U.S. growth revival and post-2005 growth slowdown, with a major extra contribution coming from the ICT-producing EM industry. The EU-10 regressions differ, indicating no additional role in causing the two-step productivity deceleration of the ICT-use-intensive industries beyond the contribution of the non-ICT-intensive industries.

Why does the initial growth accounting exercise suggest a minimal U.S. role for ICT, but the ICT decomposition and ICT regressions support a major U.S. role? The answer is provided when the dependent variable in the regressions is switched from growth in labor productivity to growth in TFP. The coefficients are almost identical, indicating that the ICT stimulus to productivity growth operates through spillovers to TFP growth, not just via the ICT capital deepening effect as measured in the growth accounting exercise. There is no separate ICT influence on TFP growth in the EU-10 with the exception of the I&C industry. While the post-2005 slowdown in U.S. productivity growth is largely symmetric with the post-1995 growth acceleration, there is a noticeable difference. Non-ICT-intensive industries in the commodities sector contribute more to the post-2005 slowdown than to the post-1995 revival. Not only is this true of all non-ICT U.S. commodities industries, but in addition the post-2005 slowdown in the ICT-producing EM industry is particularly sharp, reinforcing the temporary character of the late 1990s ICT revolution.

A few differences stand out in the results for the EU-10. In most respects the two-step slowdown after 1995 and again after 2005 were unrelenting, applying to all industries. There is a modest tendency for ICT-intensive commodities industries in the EU-10 to have most of their slowdown after 2005 rather than during 1995-2005, indicating that ICT investment may have "buoyed" productivity growth enough largely to offset the other causes of the 1995-2005 EU slowdown. After 2005, productivity growth dropped across all EU-10 industries. The role of ICT-producing industries is quite different in the EU-10, with a much weaker performance in hardware-producing EM but a strong performance almost up to the U.S. achievement in software-producing I&C.

Overall the results support a strong role for ICT-intensive industries, particularly in the market services sector, in driving not just the U.S. 1995-2005 productivity growth acceleration but also the post-2005 slowdown. We find that the standard growth accounting approach is deficient when it separates sources of growth between growth in ICT capital deepening and TFP growth, because much of the effect of the U.S. ICT revolution appears to have been channeled through spillovers to TFP growth rather than being limited to the capital deepening pathway. Three aspects of the U.S. 1995-2005 ICT revolution stand out besides its spilling over to TFP growth. First, the growth-inducing aspects of the revolution were temporary, as growth rates in almost every industry went into reverse after 2005. Second, the sharpest decline in productivity growth occurred at the heart of the ICT revolution in the EM industry that produces ICT hardware, with less of a relative slowdown in the software-producing I&C industry. Third, there were sharp post-2005 declines in several commodities-producing industries that were minimal users of ICT, including especially agriculture, petroleum, and across the board in manufacturing sub-industries.

Why did the EU-10 fail to benefit from the ICT revolution and instead why did it experience a two-step slowdown in labor productivity and TFP growth? The diagnosis has four components. First, despite all the U.S.-led innovation that drove its ICT-hardware EM industry to register a 17 per cent annual rate of productivity growth in 1995-2005, that same industry in the EU-10 actually experienced a productivity growth slowdown during the same decade. Second, the EU-10 had substantially lower values of the contribution-based ICT-use-intensity indicator variable, indicating less rapid growth of ICT investment. Third, the regressions reveal virtually no difference in the extent of the EU growth slowdown experienced by ICT-intensive versus non-intensive industries, indicating a failure of EU-10 industries to exploit the efficiency opportunities provided by the limited ICT investment that did occur. And fourth, the EU-10 shortfall in productivity growth during 1995-2005 can be traced to particular industries in which performance fell far short of the same industries in the U.S. These outlier industries include not just ICT-producing electric machinery but also agriculture, petroleum refining, and the large wholesale and retail sector where for many reasons EU nations lagged behind the U.S in adopting the big-box retail format which exploited the opportunities provided by the ICT revolution.

Stepping back and viewing the postwar growth experience more broadly, the EU-10 started out in 1950-72 with rapid productivity growth of 4.86 percent per year, which we have previously interpreted as reflecting a process of catching up to the benefits of innovations that had buoyed U.S. productivity growth during the interwar and wartime periods (Gordon-Sayed, 2019). Then the EU-10 transitioned to a slower productivity growth path of 2.31 percent in 1972-95, mimicking the 2.54 percent growth rate that the U.S. had previously achieved during 1950-72. Skipping over the very different experiences of 1995-2005, the EU-10 wound up in 2005-2015 with a productivity growth rate of a mere 0.63 percent, little different from the U.S. rate for the same interval of 0.87 percent. The remarkable similarity of the U.S. slowdown to 2005-15 from 1950-72 with the EU-10 slowdown to the same late interval from 1972-95 is, we think, more than a coincidence. The same process of the diminishing potency of ongoing innovation was occurring on both sides of the Atlantic.

In short the postwar transatlantic productivity experience can be boiled down to three issues – the causes of the overall joint early-to-late slowdown, the sources of the temporary U.S. 1995-2005 acceleration, and the factors that held Europe back from enjoying a similar 1995-2005 revival. Our diagnosis of the first is the diminished impact of innovation over the postwar period that operated on both sides of the Atlantic, of the second is the U.S. success during 1995-2005 in achieving a one-time boost in the *level* of efficiency in the production and use of ICT, and of the third is the multi-faceted failure of the EU-10 to mimic the U.S. achievement in producing ICT hardware, in making a similar level of investment in ICT, and in capturing the efficiency gains of the lower level of investment that actually occurred.

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APPENDIX TABLES

Table A1. Summary of ICT Variables and Indicators for the U.S. and EU-10

	ICT Values		Productivity Growth			Total Factor Productivity Growth			Value-Added Share
Industry	**Share**	**Contribution**	**1977-1995**	**1995-2005**	**2005-2015**	**1977-1995**	**1995-2005**	**2005-2015**	**1977-2015**
United States									
Agriculture	0.03	0.03	2.57	7.27	1.05	2.77	5.62	-0.42	0.01
Mining	0.05	0.06	2.66	-1.87	2.98	-0.02	-2.04	4.54	0.02
Manufacturing	0.12	0.15	2.85	5.53	1.90	1.52	3.18	0.28	0.16
Utilities	0.10	0.13	1.22	1.20	-0.03	-0.15	-1.18	-1.14	0.02
Construction	0.15 *	0.09	-0.97	-1.02	-0.92	-1.09	-1.79	-1.69	0.04
Wholesale & Retail			-	-	-	-	-	-	-
Wholesale	0.28 *	1.02 *	3.32	6.13	0.81	1.65	4.57	-0.08	0.06
Retail	0.16 *	0.52 *	2.37	5.38	0.66	1.46	3.05	0.30	0.07
Transportation	0.21 *	0.12	2.45	1.48	-0.69	1.95	0.51	-1.10	0.04
Hotels & Restaurants	0.06	0.09	0.13	1.81	-0.67	-0.06	1.21	-0.71	0.03
Information & Communications	0.37 *	2.31 *	2.22	4.04	3.05	1.77	1.02	1.66	0.06
Finance & Insurance	0.42 *	1.36 *	0.94	3.77	0.80	-3.05	1.03	-0.22	0.06
Real Estate	0.00	0.05	0.96	0.96	1.91	-0.20	-0.04	1.34	0.11
Professions & Administrative	0.32 *	1.05 *	-0.76	1.20	1.07	-1.72	-1.30	0.43	0.08
Public Sector	0.08	0.18 *	0.21	0.55	0.33	-1.08	-0.30	-0.39	0.14
Education	0.14 *	0.56 *	-0.46	0.87	0.99	-1.30	-0.16	0.29	0.01
Health	0.13 *	0.14 *	-1.38	-0.25	0.34	-1.92	-0.89	-0.22	0.06
Arts & Entertainment	0.09	0.25 *	0.94	-0.05	-0.10	0.89	-0.70	-0.36	0.03
Manufacturing Sub-Industries									
Food	0.10	0.13	3.14	0.05	-0.43	1.74	-1.18	-1.10	0.02
Textiles & Apparel	0.08	0.04	3.64	3.63	1.20	2.44	1.28	-0.41	0.01
Wood & Paper	0.09	0.13 *	0.26	2.15	1.46	-0.85	1.13	0.38	0.01
Petroleum	0.10	0.13	4.81	10.99	-1.08	2.94	9.84	-5.00	0.01
Chemicals	0.10	0.07	2.12	3.22	1.37	0.22	-0.77	-2.07	0.02
Rubber & Plastics	0.07	0.14 *	2.63	3.19	-0.78	1.84	1.69	-1.55	0.01
Metals	0.14 *	0.00	2.07	2.25	0.50	1.18	1.47	-0.21	0.02
Electrical Machinery	0.16 *	0.53 *	10.01	17.57	7.07	8.32	14.23	5.53	0.02
Machinery NEC	0.21 *	-0.09	0.14	3.02	0.64	-1.36	0.55	-0.19	0.01
Transportation Equipment	0.10	-0.03	0.50	4.63	2.26	-0.21	2.43	1.48	0.02
Other Manufacturing	0.12 *	0.27 *	1.06	3.32	1.79	0.14	1.32	0.63	0.01
EU-10									
Agriculture	0.01	-0.02	4.46	3.47	1.37	4.46	2.78	0.59	0.02
Mining	0.06	-0.42	4.71	-0.72	-0.29	0.71	-0.47	-1.72	0.01
Manufacturing	0.14	0.14	3.38	2.87	1.84	1.72	1.46	0.89	0.20
Utilities	0.06	0.27 *	2.64	3.21	-1.38	0.47	0.69	-2.17	0.03
Construction	0.07	0.10	1.34	-0.10	-0.30	0.87	-0.32	-1.06	0.06
Wholesale & Retail	0.20 *	0.28 *	2.29	1.81	1.29	1.09	0.74	0.58	0.11
Transportation	0.07	0.25 *	3.61	2.46	0.42	2.38	0.94	-0.41	0.05
Hotels & Restaurants	0.10	0.12	-0.60	-0.52	-0.58	-1.21	-1.06	-0.51	0.03
Information & Communications	0.44 *	1.18 *	1.98	3.84	2.26	0.09	2.87	1.63	0.04
Finance & Insurance	0.40 *	0.61 *	1.35	2.14	1.14	0.01	0.49	0.31	0.05
Real Estate	0.00	0.03	-1.24	-0.21	0.58	0.57	0.14	0.04	0.09
Professions & Administrative	0.21 *	0.79 *	0.59	-1.03	-0.24	-1.23	-1.96	-0.71	0.09
Public Sector	0.06	0.29 *	1.43	1.26	1.11	0.51	0.00	0.33	0.07
Education	0.11	0.05	0.59	-0.19	-0.70	-0.10	-1.07	-0.97	0.05
Health	0.10	0.18 *	0.13	0.36	0.22	-0.45	-0.32	-0.10	0.06
Arts & Entertainment	0.14 *	0.37 *	0.58	0.40	-0.51	-0.67	-0.70	-0.86	0.03
Manufacturing Sub-Industries									
Food	0.12 *	0.13	2.17	0.92	0.42	0.72	-0.01	-0.13	0.03
Textiles & Apparel	0.17 *	0.02	3.30	2.99	2.11	1.76	1.61	1.27	0.01
Wood & Paper	0.15 *	0.20 *	2.48	2.38	2.02	1.14	1.27	1.51	0.01
Petroleum	0.07	0.22 *	-0.84	-0.39	-3.53	-3.72	-1.62	-6.01	0.00
Chemicals	0.11 *	0.16 *	5.40	4.05	1.94	3.64	1.92	0.88	0.02
Rubber & Plastics	0.10	0.10	3.32	2.42	1.42	1.89	1.92	0.41	0.02
Metals	0.09	0.10	2.85	2.01	1.62	2.19	1.19	0.90	0.03
Electrical Machinery	0.23 *	0.12	5.49	4.78	2.95	2.73	2.91	2.09	0.02
Machinery NEC	0.17 *	0.16	2.58	2.86	0.97	1.26	1.70	0.04	0.02
Transportation Equipment	0.12 *	0.24 *	3.81	2.58	3.15	1.70	1.11	1.71	0.02
Other Manufacturing	0.18 *	0.12	1.09	2.82	1.12	0.33	2.17	0.57	0.02

Source: KLEMS Database. A "*" next to a nominal variable indicates that the dummy variable for that industry is equal to one; the dummy is zero otherwise. The "Share" variable is the nominal share of ICT investment in total investemnt of an industry from 1991-1995. The "Contribution" variable is the 1999-2005 contribution of ICT-capital to real value-added. Dummies are marked as one for these nominal variables if an industry's nominal ICT variable is above the median, and zero otherwise.

Table A2. Labor Productivity Equations with ICT Dummies for Contribution Indicator, U.S. vs. EU-10, 1977-2015

	United States			EU-10		
	(A)	(B)	(C)	(D)	(E)	(F)
(1) Post-1995	0.35	0.74	-0.19	-0.65 **	-0.95 **	-0.20
(2) Post-2005	-1.04	-1.55 *	-0.33	-0.74 **	-0.88 *	-0.53
(3) Post-1995 X ICT Use	1.35 *	0.78	1.91 *	0.28	0.42	-0.12
(4) Post-2005 X ICT Use	-0.96	-0.44	-1.67	0.15	-0.93	0.30
(5) Post-1995 X EM	5.86 **	6.05 *		-0.06	0.23	
(6) Post-2005 X EM	-8.50 ***	-8.50 **		-1.08	-0.94	
(7) Post-1995 X I&C	0.11		0.10	2.23 *		2.18 **
(8) Post-2005 X I&C	1.02		1.02	-0.98		-1.35
Commodities Only		Yes			Yes	
Services Only			Yes			Yes
Number of Observations	1026	570	456	988	570	418
Number of Industries	27	15	12	26	15	11

Source: KLEMS Database. * indicates statistical significance at the 10% level, ** at the 5% level, and *** at the 1% level. “ICT Use” is a dummy variable equal to unity if the ICT indicator (either share or contribution as defined in the text) is above the median when industries are ranked by the value of that indicator. "EM" is a dummy equal to one for the Electrical Machinery industry, while "I&C" is a dummy equal to one for the "Information & Communications" industry. All regressions include industry fixed effects and are estimated by Weighted Least Squares, where WLS weights are taken as an industry's nominal value-added share for 1976. The "Services" category includes the four non-market-economy services-producing industries.

Table A3. Labor Productivity and Total Factor Productivity Equations with Continuous Measure of ICT, U.S. vs. EU-10, 1977-2015								
	United States				EU-10			
	Labor Productivity		Total Factor Productivity		Labor Productivity		Total Factor Productivity	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
(1) Post-1995	0.11	0.43	-0.18	0.07	-0.75 **	-0.67 **	-0.99 ***	-0.68 **
(2) Post-2005	-0.36	-0.85	-0.11	-0.41	-0.74 *	-0.81 **	-0.83 **	-0.86 ***
(3) Post-1995 X ICT Use	6.55 *	1.92 *	6.51 *	2.11 **	1.88	0.69	3.86 *	0.80
(4) Post-2005 X ICT Use	-8.33 *	-2.17 *	-4.97	-1.26	0.54	0.62	3.29	2.04 *
(5) Post-1995 X EM	39.10 **	11.60 **	30.90 **	8.99 *	-1.72	-1.07	1.23	6.48
(6) Post-2005 X EM	-53.90 ***	-16.20 ***	-47.70 ***	-14.50 ***	-5.27	-9.21	-3.23	-1.65
(7) Post-1995 X I&C	-1.91	-1.32	-8.05	-2.46 **	4.10	1.45	4.76	2.13 *
(8) Post-2005 X I&C	6.62	2.10	6.99	1.71	-2.46	-1.27	-4.23	-2.35 *
Share Indicator	Yes		Yes		Yes		Yes	
Contribution Indicator		Yes		Yes		Yes		Yes
Number of Observations	1026	1026	1026	1026	988	988	988	988
Number of Industries	27	27	27	27	26	26	26	26

Source: KLEMS Database. * indicates statistical significance at the 10% level, ** at the 5% level, and *** at the 1% level. "ICT Use" is a dummy variable equal to unity if the ICT indicator (either share or contribution as defined in the text) is above the median when industries are ranked by the value of that indicator. "EM" is a dummy equal to one for the Electrical Machinery industry multiplied by its ICT value, while "I&C" is a dummy equal to one for the "Information & Communications" industry multiplied by its ICT value. All regressions include industry fixed effects and are estimated by Weighted Least Squares, where WLS weights are taken as an industry's nominal value-added share for 1976. The "Services" category includes the four non-market-economy services-producing industries.