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Information technology (IT) productivity paradox in the 21st century

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Abstract

Information technology (IT) investment since the 1970s coincided with poor productivity gains: the 'IT productivity paradox'. This phenomenon is still poorly understood. This research replicates methods employed by previous studies for comparability but employs a two-level approach: First macroeconomic indicators; second labor and multi-factor productivity. The findings suggest IT investment has high positive correlation with gross domestic product (GDP) growth, but not labor or multi-factor productivity. This ambiguity suggests the paradox is still poorly understood. Studies reporting an end to the paradox are likely due to rapid IT industry growth in the run up to the Year 2000 phenomenon.

JEL classification: O47; O11; D24; J24;

Key words: IT productivity paradox; productivity; multifactor productivity; capital investment

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Why revisit the IT Productivity Paradox?

Information and communication technology (ICT) can be considered the key factor driving economic growth in industrial societies (Pohjola, 2000). Investing in information technology (IT) is widely regarded as having enormous potential for reducing costs, enhancing productivity, and improving living standards (Murakami, 1997). However, since the 1970s productivity growth in most world economies has slowed, while expenditures on ICT have risen (Rei, 2004). This phenomenon became known as the 'IT productivity paradox'. Some researchers have reporting an end to the paradox, but this paper brings the research up-to-date suggesting that reports of an end to the paradox is most likely due to rapid IT industry growth in the run up to the Year 2000 phenomenon.

During recent decades, the IT productivity paradox has been revisited periodically by many researchers (Baily, 1986; Berndt & Malone, 1995; Brynjolfsson & Hitt, 1995; David, 1990; Dewan & Kraemer, 1998; Jorgenson & Stiroh, 1995; Kraemer & Dedrick, 1994; Lee & Khatri, 2003; Oliner & Sichel, 2000; Oliner, Sichel, & Stiroh, 2007; Pilat, 2004; Pohjola, 2000; Rei, 2004; Spithoven, 2003; Vijselaar & Albers, 2004). The majority analyzed productivity trends in the United States: the leading country in technology investment. Later, attention was drawn to other developed countries. Extensive multi-dimensional statistical (firm-level, industry-level, country-level and cross country) analysis found little evidence that ICT significantly increased productivity in the 1970s and 1980s. Most authors, however, agreed that the observed phenomenon might have emerged due to inaccurate productivity measurement, time lags related to technology diffusion, mismanagement issues, ineffective use of technologies as well as other factors. Some studies of Brynjolfsson and Hitt (1996a, b), Dedrick and Kraemer (2001) and Pilat (2004) however, suggest ICT has consistently produced positive results, implying there was no IT productivity paradox.

Ambiguity of findings created more questions than answers, prompting further research. This study, as previous studies, takes an overview of aggregate

investment in IT for a number of economies. However, firm-level studies examining financial impact on long-term stock price performance and profitability measures such as return on assets and return on sales from specific IT systems such as Enterprise Resource Planning (ERP), Supply Chain Management (SCM), and Customer Relationship Management (CRM) systems, yielded mixed results (Hendricks, Singhal, & Stratman, 2007). In the case of ERP systems, Hendricks et al. find some evidence of improvements in profitability, but not in stock returns. These are interesting findings since ERP systems are very expensive to implement, yet demonstrate such ambiguous results. On average they find adopters of SCM systems experience positive stock returns as well as improvements in profitability. This is not the case for CRM investment.

Modern methods make it possible to capture more accurate data. New data processing and collection approaches are able to quantify previously difficult to measure impacts of ICT, revealing new opportunities for research. Many arguments relating to time lags (David, 1990), can now be tested by updating and extending the research to the current period.

It is thus important to revisit the productivity paradox. Investment in ICT exceeds all other categories of investment yet evidence from firm level studies suggest returns are questionable, and evidence from aggregate studies suggest either poor productivity gains, or more recently, positive correlation between investment in ICT and productivity gains. This paper provides an update on the phenomena and tests these more recent findings.

There is no up-to-date information related to aggregate productivity issues (previous studies cover the period up to 2000), this research extends coverage to the 1995 to 2005 period, avoiding the latter half of the first decade of the 21st century during which productivity data might be dominated by the effects of the sub-prime mortgage disaster and resulting recession.

This research focuses on the twenty one member nations of the OECD. Findings are compared with previous studies to monitor the changes of the phenomenon over time. Data is collected from secondary sources including OECD online database, reports and publications.

The problem of the IT productivity paradox, which still cannot be entirely explained, is interesting and relevant since it reflects real problems, observed globally, which impact organisational decision making. The findings of this paper can be generalized because the twenty one countries in the study account for more than 70% of the global economy. The findings are presented in the following way: first, gross output and ICT investment data are compared to understand the productivity dynamics on a global scale; second, multi-factor and labor productivity are analyzed and correlated to ICT investment. The results are compared with those revealed in previous research.

Background

Stiroh (2001) defines IT investment to include computer hardware, computer software and communications equipment – the way in which it is currently reflected in the OECD reports. Brynjolfsson & Hitt (1995) provide sufficient justification to classify IT as a factor of production in the modern economy along with labor, capital, natural resources and land.

Contrary to the presumed benefits of ICT, data following the first decade of IT exploitation presented astonishing results. The US economy showed a persistent decline in productivity growth in almost all major sectors of the economy (Baily, 1986), while a substantial portion of total industry investment was in IT. By 1979 68% of total investment in US service sectors and 32% in non-service sectors were attributable to IT spending (Brynjolfsson & Yang, 1996).

Evidence from Japan, UK, Germany and France in the 1980s suggested the phenomenon was of international dimensions (Dewan & Kraemer, 1998). Solow's

(1987) statement: “We see the computer age everywhere but in the productivity statistics” initiated wide publicity of the issue later called the ‘the IT productivity paradox’.

Growing ICT investment with slow productivity gains (Spithoven, 2003) attracted much academic and practitioner attention. Studies conducted from 1980s onwards are summarized in **Error! Reference source not found.** Irrespective of the level of analysis, they yielded ambiguous findings.

Place Table 1 about here

Productivity pre 1990

From 1974 productivity growth slowed significantly in the United States and other OECD countries (Gera, Gu, & Lee, 1999; Griliches, 1994). In the USA labor productivity growth averaging 2.56% in 1953-1968 dropped to 0.68% in 1973-1979 (Baily, 1986). **Error! Reference source not found.** demonstrates the trend of real output per worker for five developed countries between 1965 and 1990: USA, Japan, France, Germany and UK. The decline in productivity growth was not confined to the USA.

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Studies conducted in the 1980s mainly analyzed the USA economy. Productivity declined more for manufacturing than services. Initially, economists were not able to connect the productivity issue to IT investment. According to Denning (1980) inexpensive, powerful small computers and ICT were becoming indispensable to business. The share of ICT in total producer investment in durable equipment, in current prices, more than doubled from about 17% in 1960 to 36% in 1992 (Griliches, 1994). This was later called ‘Technology Overdose’ by Roach (1991). Accelerated growth of ICT investment was accompanied by a rapid decline of prices

for computing equipment (Gordon, 2000) while growing processing power of computers resulted in annual price changes of 35%.

Massive investment in ICT during the 1980s did not improve productivity. Increased spending on ICT as a fixed asset, shifted firms from variable to fixed costs without concomitant productivity benefits (Roach, 1991). Most of the results acquired before the 1990s suggested little contribution of IT compared to growing investment, and supported the existence of an IT productivity paradox.

Productivity issue post 1990

The productivity resurgence of the late 1990s initiated new studies that attempted to measure the relative importance of IT in productivity gains. Most came to optimistic results. In the period from the mid-1990s to 2000, macroeconomic performance of the United States was remarkable (Vijsselaar & Albers, 2004). Oliner and Sichel (2000) note that real GDP rose at an annual rate of more than 4%, significantly higher than earlier years, and explain this by a rebound in the growth of labor productivity. According to Gordon (2000) this change in the US economy was a fundamental transformation, wiping out the 1972-1995 productivity slowdown, along with inflation, the budget deficit, and the business cycle.

Data from Australia, Canada, Finland, France, Germany, Italy, Japan, and the United Kingdom indicate positive effects of ICT on economic growth (Colecchia & Schreyer, 2002). During the second half of the 1990s, the average contribution to economic growth in these countries rose from 0.3 to 0.9 percentage points per year.

Even skeptics Oliner and Sichel (2000) noted the contribution of IT capital to output growth surged in the second half of 1990s, and doubled to reach 1.1% indicating IT contributed nearly 50% of the boost in labor productivity from 1.5% to 2.6%. The productivity revival encouraged optimists to declare the emergence of a 'New

Economy', in which IT-led productivity (and other factors such as globalization) would lead to a long period of inflation-free prosperity (Dedrick & Kraemer, 2001).

Estimates show a productivity growth advantage in the EU over the USA during 1990-1995 (Ark, Melka, Mulder, Timmer, & Ypma, 2002). However, after 1995, the USA overtook the EU in ICT performance partly due to smaller contributions in the EU from ICT capital, as well as from lower total factor productivity (TFP) growth from ICT production. These results suggest that not only did ICT contribute less to growth in the EU in comparison to the USA, but spillovers from investment in ICT were less favorable in Europe than in America.

The period from 1980s to 1995 was characterized by the transition from mainframe to personal computers and their accelerating price reduction (Gordon, 2000). Research intensified again to understand the reasons behind the productivity boom. As an explanation Roach (1998) suggests heightened competitive pressure forced companies to focus on cost cutting as never before delivering a productivity renaissance.

ICT investment peaked by the year 2000. Anderson et al. (2003) assert that increased investment in ICT was mainly connected with the Year 2000 problem (Y2K) spending, thus increased economic output, and the apparent end of the IT productivity paradox for the Y2K period, is partially due to the ICT industry boom associated with Y2K.

Like Anderson et al. (2003) Gordon (2000) states most productivity gains in the US economy were concentrated within ICT industries meaning the productivity upturn occurred primarily within the IT sector itself. The 12% share of the economy involved in manufacturing durable goods produced a massive productivity spillover that affected the aggregate figures. However, Gordon could not identify productivity growth in the remaining 88% of the economy. This view is supported by other research, but the growth in MFP after the year 2000 is only partially explained by investment in the IT sector (Oliner et al., 2007).

By the end of 2000, the United States experienced a stock market collapse resulting in a sharp decline in technology stocks and slump in the ICT equipment industry, directly affecting the trend of ICT investment. Technology-led NASDAQ index which peaked at 5,132 on March 10, 2000 closed at 1,185 on September 23, 2002. ICT investment growth resumed from the start of 2002. As economic growth underpinned by strong performance in the United States, China and Korea, started to improve, the recovery in the ICT sector spread to Japan and Europe. Labor productivity rose rapidly, mirroring output growth. Expanding segments such as telecommunications services continued to grow, but manufacturing productivity continued to decline from 2001 (OECD, 2004). During the period from 2007 to 2010 the recession triggered by the sub-prime mortgage crisis impacted productivity growth, this study therefore specifically excludes this period as a possible outlier, or incomplete economic cycle that might skew findings.

Economic literature has identified several distinct possible causes of the paradox including cyclical factors (slowdown in productivity due to the negative stage of business cycle) (Gordon, 2000); insufficient or improper use of computer technologies (Oliner & Sichel, 1994); sectoral shifts in the economy (shifts from industries and agriculture to the dominating role of services) (Spithoven, 2003); energy crises.

Measurement Errors or Mismeasurement.

By far the most commonly agreed and discussed, researchers such as Santos (1991), Griliches (1994), Brynjolfsson and Hitt (1995), Berndt and Malone (1995), Jorgenson and Stiroh (1995), Wyckoff (1995), Lehr and Lichtenberg (1999) pinpoint mismeasurement as one of the core reasons why we cannot see the productivity gained from ICT investment. Measurement errors are mainly related to difficulties assessing service sector productivity, and an inability of national statistics to take into account any qualitative contribution of IT.

Time lags or Diffusion lags.

David (1990) suggested productivity gains from ICT investment materialize only after time and depend on changes in the complementary infrastructure. Also, there is a critical mass of diffusion and experience only after which would ICT produce measurable impact on productivity (Rei, 2004).

Mismanagement.

Management were not prepared to take full advantage of disposable technological resources making ineffective decisions which led to great IT project failures directly affecting productivity data for IT investment.

Income Distribution.

IT brings competitive advantage and productivity to certain companies, while rivals fail to perform effectively. Thus productivity could not be observed in the aggregate data at national or regional level. This reason is partially interconnected with measurement errors in that aggregation of statistics at country level disperses the true value of IT productivity. This initiated increased interest in firm-level studies. Consequently some firm-level studies found positive returns on investment in IT (Gurbaxani, Melville, & Kraemer, 1998), but not others (Hendricks et al., 2007).

Ambiguity of findings

Irrespective of the level of analysis (country-level, industry-level or firm-level) the results remain ambiguous (Spithoven, 2003). Most studies conducted after 1995 tend to conclude there is no IT productivity paradox, while earlier research strongly supports its existence.

The period pre 1990s was characterized by two-digit ICT investment growth, coinciding with rapid decline in price for computer equipment. The productivity

trends inherent to all developed countries however, sharply decreased in comparison to post-war economic boom.

In the period after 1990 all developed countries demonstrated remarkable economic growth. During the late 1990s, ICT investment accounted for a large and growing share of total investment in production and contributed significantly to output growth, particularly in the United States, Australia, Finland, Korea and Ireland (OECD, 2002).

It is important to note that even though the IT productivity paradox has been researched extensively no study could provide sufficient justification to resolve the issue. More recent studies however, relate the ambiguity of findings to the shortfalls of methods, and inaccuracy of statistical data.

Research Methodology

The research approach was chosen to be congruent with previous studies for comparability of findings, and includes techniques used in previous studies of Spithoven (2003), Dedrick et al. (2003), Saito (2001), Dewan and Kraemer (1998), Brynjolfsson and Hitt (1996a, b), Kraemer and Dedrick (1994) and Baily (1986). On the first level, country-level macroeconomic indicators are analyzed and compared to ICT investment dynamics. The second level analyses productivity-specific indicators: MFP (multi-factor productivity) (Appendix B) and labor productivity. The approach is consistent with previous studies while overcoming shortfalls of narrow firm-level studies.

Some of the key questions attracting major dispute include:

Is there an IT productivity paradox?

What is a best measure of IT productivity?

Is it possible to usefully measure the contribution of IT?

The most up-to-date studies cover trends only up to the year 2000 and ultimately there is no available research examining ICT investment and productivity after the 'Dot-Com boom'. Moreover, variables (IT, labor force, companies, legislation etc.) involved in the 'paradox' have undergone certain transformations affecting the performance of business activity (Brynjolfsson & Hitt, 2000). Structural and technological changes, such as the tendency to remove barriers to international trade, continuing tension in energy markets, and phenomenal growth of the Internet, have given rise to a revolution in global business (Nataraj & Lee, 2002) reflected (either positively or negatively) in the productivity of ICT investment. This research sets the goal of testing the existence and analyzing the trends of 'the IT productivity paradox' in the first years of 21st century and aims to answer the following research questions:

What is the effect of IT investment on national productivity, and is there an 'IT productivity paradox' in the modern economy?

How have ICT and productivity tendencies changed over time?

The research focuses on analysis of data from 21 members of OECD. Findings are compared with previous findings to test the existence of 'the IT productivity paradox' during the period from 1995 to 2005. The choice of leading world economies is based on previous publications (Daveri, 2003; Dewan & Kraemer, 1998; Spithoven, 2003). This provides an opportunity to conduct a comparative study and analyze longer-term trends.

The choice of developed economies minimizes the affect of 'time lags' associated with the gap between investment in IT and the time when technologies actually yield productivity gains. Data for the research is acquired using secondary sources. The fundamental measures of country-level productivity such as Gross Domestic Product (GDP), its dynamics, per capita growth, ICT investment, their share in gross capital formation, employment and labor force productivity statistics, were all acquired from the OECD online database and its specialized publications. Use of a single data source was crucial since unmatched input and output statistics could lead to the distortion of final results. To test the correlation between variables

Pearson product-moment correlation coefficient and statistical significance, SPSS (Statistical Package for Social Sciences) was used.

Real GDP and its growth are used because it is adjusted for inflation and therefore provides a more accurate measure of output. For comparability of data all indicators are presented in US dollars or percentage change in relation to the previous year. The terms IT (Information Technology) and ICT (Information and Communication Technology) are used interchangeably in this paper.

To appreciate global trends of economic productivity, real GDP per capita growth measuring the level of output per person, is related to the dynamics of ICT investment. To provide an historical outlook and compare longer-term dynamics, some of the observable data periods start from 1985. The division of data into two particular periods is based on Stiroh's (2001) study of the American economy revealing a breakpoint of productivity in 1995. The same trend was observed in European countries (Ark et al., 2002). This gives insight into the directions of change and allows comparison of earlier and later periods.

At the last stage, labor productivity (as a percentage change to previous year) and multi-factor productivity (MFP) are analyzed. Labor productivity is a useful measure: it relates to the single most important factor of production (OECD, 2001b) and is relatively easy to measure. Also, labor productivity is a key determinant of living standards, measured as per capita income and reflects how efficiently labor is combined with other factors of production (OECD, 2001a, b). It shows how productively combined inputs (labor and capital) are used to generate gross output. The summary of main productivity measurers is presented in the **Error! Reference source not found.**

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Results and Discussion

This section presents the findings of the study. First, on a macro level, examining the trends of output (GDP) per capita in comparison to the change in ICT investment. Technology investment is reviewed as part of gross fixed capital formation (GFCF) to evaluate the significance of IT as a factor of production in the modern economy (Appendix A). Second, on a micro level, labor productivity and multi-factor productivity (MFP) are analyzed. In addition, to expand the understanding of labor productivity trends, the annual working hour's dynamics is examined for all twenty one countries.

Gross output and ICT investment dynamics

OECD data for twenty one developed countries shows total investment in ICT reached nearly 1 trillion US dollars by the year 2000, approximately 2.6% of the cumulative GDP of those countries. The positive growth dynamics of investment, averaging 12.7% per year from 1995 onwards, remained constant up to the year 2000, when the economies consumed more than 950 billion US dollars in IT investment, an annual growth rate of 14.8% (**Error! Reference source not found.**).

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However, when considering a broader time span from 1985 on, we can observe a general negative trend in ICT investment growth (**Error! Reference source not found.**), most likely explained by the high level of IT penetration and considerable accumulated IT stock.

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Almost half of total IT spending for countries in the dataset (48%) was attributable to the United States alone, reinforcing the position of the USA as global leader in technology investment. The economic slowdown experienced by the USA in the end of 2001, and later reflected in global trends, affected the intensity of investment

activity including investment in ICT. As a result, in the following two years (2002 and 2003) the growth of investment in ICT, for the first time since the IT productivity paradox phenomenon was recognized, turned negative: -6.2% and -0.7% respectively (**Error! Reference source not found.**).

The analysis of GDP per capita and net ICT investment growth (**Error! Reference source not found.**) revealed a very high correlation between these two indicators. The Pearson correlation coefficient (r) measuring the degree to which the variation in one variable is related to the variation in another variable (Malhotra & Birks, 2003) was 0.846 (significance level = 0.01). This means that net growth of ICT investments is strongly associated with the growth of output per person. Furthermore, the positive sign of r implies a positive relationship; the higher the net growth in investments, the greater the amount of GDP per capita. This means that the net growth of ICT investment is strongly associated with the growth of output per person confirming the findings of Gust and Marquez (2002) who also identified a positive relationship of ICT expenditures and productivity. At this stage it can be inferred that at least there is a positive relationship between investment in ICT and real productivity growth.

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The value of r^2 , measuring the proportion of variation in one variable that can be explained by another, is in this case 0.72, meaning that 72% of variance of GDP growth can be explained by ICT investment growth or vice versa. In other words, correlation coefficients provide insufficient information as to whether GDP growth is affected by ICT investment growth, or growth of ICT investment is caused by growth in GDP.

ICT investment internal structure analysis

Comparison of ICT investment to all other expenditures connected with the production process illustrates the growing significance of ICT in the modern

economy as a factor of production. **Error! Reference source not found.** presents the trends of IT spending as a part of non-residential GFCF.

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GFCF is measured by the total value of a producer's acquisitions of fixed assets, less disposals, during the accounting period, plus certain additions to the value of non-produced assets (such as land or subsoil assets) realized by the productive activity of institutional units (OECD, 2001a). By 2005, ICT investment in OECD countries had reached a mean of nearly 25% of all capital expenditures.

Labor and multi-factor productivity

Error! Reference source not found. presents the comparison of labor productivity and ICT investment dynamics. The average productivity growth measured as a percentage change to previous year between 1995 and 2005 constituted 1.6%. The highest rates of labor productivity growth were exhibited by Korea and Ireland, exceeding 3% a year. Spain exhibited the lowest productivity rates averaging only 0.2% a year. The labor force performance for Italy, New Zealand and the Netherlands was also relatively poor remaining under 1% a year.

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Analysis of the relationship between average labor productivity growth and average growth rate of ICT investment does not suggest high association between them. To appreciate the issue of individual performance, another indicator of the labor statistics is analyzed – average total hours worked per person within a year (**Error! Reference source not found.**). At the same time, all the countries have demonstrated positive GDP growth. This situation of decreasing labor input (working hours) and an increase in output can be explained by a more efficient use of labor resources: i.e. growing productivity.

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The last indicator used is multi-factor productivity (MFP). This is a complex measure of productivity reported by OECD. It is the difference between the rate of change of output (presented as the logarithmic value of annual change of GDP at constant prices for the entire economy) and total production inputs including labor, capital and their cost of shares. The **Error! Reference source not found.** presents the average MFP dynamics for 19 OECD countries for the period from 1995 to 2005.

To understand the bigger picture **Error! Reference source not found.** shows average, minimum and maximum values of multi-factor productivity for 19 developed countries. The coefficient of correlation between MFP and ICT investment growth was 0.565. Even though it is slightly greater than in the case of labor productivity, it still does not give sufficient justification to consider significant association between the two variables.

Place figure 7 about here:

Negative minimum values indicate that some countries in the dataset exhibited decreasing productivity, which cannot be noticed in aggregation. The **Error! Reference source not found.** presents the differences in MFP between countries from 1995 to 2000, from 2001 to 2005 and for the whole period from 1995 to 2005. The countries are divided into two categories: those which experienced a decline in productivity after the year 2000, and those which did not, including Japan, the United States, Sweden and Greece.

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All twenty one countries demonstrated phenomenal ICT growth dynamics from 1995 to 2000 averaging 12.7% per year. However, economic recession experienced by the USA spreading later to other countries, negatively affected the trend. For the first

time in the observable dataset there was a decline in ICT investment. Remaining negative during 2002 and 2003, growth started to recover in 2004 and 2005.

The test of correlation of ICT investment with gross output growth revealed a strong positive relationship implying that the change of one indicator affects another in the same direction. This initial finding rejects the IT productivity paradox, at least during the observation period.

Analysis of labor productivity statistics did not reveal any particular trend. Average productivity growth remained positive, fluctuating between 0.8% and 2.1% from 1995 to 2005. The test for a relationship between multi-factor or labor productivity and ICT investment growth demonstrated no significant correlation. This implies that investment in IT does not significantly affect the performance of labor or multi-factor productivity. Therefore the existence of the IT productivity paradox cannot be dismissed.

Conclusion

Spending on information technologies is still high. This research identified high correlation between output per capita and ICT investment growth. Average growth of technology investment in developed countries, fluctuating at around 12.6% per year between 1995 and 2000, was reflected in GDP growth averaging 3.6%. After the economic decline in 2001-2002, GDP growth slowed to about 2%. ICT investment accounts for almost 15% to 25% of GFCF in developed countries, therefore the contribution of ICT should be rescaled to between 1.9% and 3.2%. In this case the observable total output growth is absolutely accordant to the growth of ICT spending. Thus, the examination of macroeconomic indicators suggests strong positive correlation between the growth in ICT investment and productivity in national economies. This finding is consistent with the previous results of Kraemer and Dedrick (1994), Dewan and Kraemer (1998) and provides preliminary evidence to challenge the notion of the IT productivity paradox after 1995.

At the same time, there is no significant correlation between investment in IT and labor or multi-factor productivity. It is important to note that there is a general decreasing trend of average multi-factor productivity for 19 countries. The labor productivity indicator demonstrates highly fluctuating behavior which is not correlated to ICT investment growth. There were periods (for example 1998) when these two indicators were moving in opposite directions. Thus, another finding from the study is that during the period from 1995 to 2005 the growth in ICT investment was not correlated to changes in labor or multi-factor productivity. Moreover, throughout the observation period the growth of both productivity indicators was relatively weak and less than that of the real GDP. This is consistent with the findings of Baily and Gordon (1988), Berndt and Morrison (1995) and supports the existence of the IT productivity paradox phenomenon in the 1995-2005 period.

The findings of this research have not produced a clear answer to the first research question. The aggregate level productivity statistics (GDP growth per capita) were found to be highly correlated with ICT investment growth. This correlation was positive suggesting the increase in ICT growth was accompanied by the corresponding growth in GDP per capita, or vice versa. However, in the years leading up to the year 2000 much of the economic growth was due to investment in the ICT industry itself. Economic and ICT investment post 2000 reflects recovery from recession and the correlation between economic growth and ICT investment may not reflect a causal relationship. Thus we are still unable to confirm or reject the existence of an IT productivity paradox. In the latter half of first decade of the twenty-first century a global recession and banking crisis may have had a serious impact on productivity and GDP but it is prudent to wait until recovery is well under way before analyzing data from that period for its influence on the IT paradox phenomenon.

Analysis of labor and multi-factor productivity did not reveal a particular relationship with the growth of spending on IT. However, the average absolute values of labor and multi-factor productivity were positive for 21 developed countries, implying there

was a growth in productivity. The peculiarity is that the growth in productivity did not follow the trend of ICT investment growth. Thus, based on the results, we can neither confirm nor reject the existence of the IT productivity paradox during the 1995-2005 period.

This ambiguous outcome and failure to reject the IT productivity paradox is an important finding. Given the share of total investment dedicated to ICT, an at best questionable level of increased productivity resulting from investment in ICT is still an important issue to examine. Since many earlier issues such as time lag and poor management have had time to work their way through the system this is a timely finding. Moreover, it can be noted that the total amount of ICT investment continues to grow, occupying a greater and greater share of gross non-residential fixed capital formation, reflecting growing importance of ICT in the modern economy.

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Appendices

Place appendix A figure 9 about here:

Appendix B. Computation of multi-factor productivity growth.

1) Rates of change of output

Output (Q) is measured as GDP at constant prices for the entire economy (main source: OECD Annual National Accounts). Year-to-year changes are computed as logarithmic differences:

$$\ln\left(\frac{Q_t}{Q_{t-1}}\right)$$

2) Rates of change of labor input

Labor input (L) is measured as total hours actually worked in the entire economy. Data on total hours has been specifically developed for the present purpose. Year-to-year changes are computed as logarithmic differences:

$$\ln\left(\frac{L_t}{L_{t-1}}\right)$$

3) Rates of change of capital input

Capital input (S) is measured as the volume of capital services, assumed to be in a fixed proportion to the productive capital stock. Capital services are computed for seven different types of assets (S_t^i $i = 1, 2, \dots, 7$) and aggregated to an overall rate of change of capital services by means of a Törnqvist index:

$$(1) \quad \ln\left(\frac{S_t}{S_{t-1}}\right) = \sum_{i=1}^7 \frac{1}{2} (v_t^i + v_{t-1}^i) \ln\left(\frac{S_t^i}{S_{t-1}^i}\right) \quad \text{with} \quad v_t^i \equiv \frac{u_t^i S_t^i}{\sum_{i=1}^7 u_t^i S_t^i}$$

Where v_t^i is the share of each asset in the total value of $\sum_{i=1}^7 u_t^i S_t^i$ capital services .

In this expression, the value of capital services for each asset is measured by $u_t^i S_t^i$ where u_t^i is the user cost price per unit of capital services and S_t^i is the quantity of capital services in year t.

4) Cost shares of inputs

The total cost of inputs is the sum of the remuneration for labor input and the remuneration for capital services. Remuneration for labor input has been computed as the average remuneration per employee multiplied by the total number of persons employed. This adjustment was necessary to correct for self-employed persons whose income is not part of the compensation of employees as registered in the national accounts.

$$w_t L_t = \left(\frac{COMP_t}{EE_t} \right) E_t$$

where

$w_t L_t$: remuneration for labor input in period t

$COMP_t$: compensation of employees in period t

:

EE_t : number of employees in period t

E_t : total number employed (employees plus self-employed) in period t.

Total cost of inputs is then given by:

$$C_t = w_t L_t + \sum_{i=1}^6 u_t^i S_t^i \quad \text{and the corresponding cost shares are}$$

$$s_t^L \equiv \frac{w_t L_t}{C_t} \quad \text{for labor input and}$$

$$s_t^S \equiv \frac{\sum_{i=1}^6 u_t^i S_t^i}{C_t} \quad \text{for capital input.}$$

5) Total inputs

The rate of change of total inputs is a weighted average of the rate of change of labor and capital input with the respective cost shares as weights. Aggregation is by way of a Törnqvist index number formula:

$$\ln \left(\frac{X_t}{X_{t-1}} \right) = \frac{1}{2} (s_t^L + s_{t-1}^L) \ln \left(\frac{L_t}{L_{t-1}} \right) + \frac{1}{2} (s_t^S + s_{t-1}^S) \ln \left(\frac{S_t}{S_{t-1}} \right)$$

6) Multi-factor productivity

Multi-factor productivity is measured as the difference between output and input change, or as 'apparent multi-factor productivity'

$$\ln \left(\frac{MFP_t}{MFP_{t-1}} \right) = \ln \left(\frac{Q_t}{Q_{t-1}} \right) - \ln \left(\frac{X_t}{X_{t-1}} \right).$$

Source: OECD Productivity Database