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Abstract

What accounts for the exceptional TFP growth performance of the U.S. and to some extent some of the other OECD countries after the mid-1990s? Most commentators have pointed to enormous productivity gains in the production of Information and Communications Technology (ICT) as the answer. But according to standard neoclassical theory, technical progress in one industry should not raise TFP growth in other industries. Yet the TFP acceleration is due mostly to industries that use, but do not produce, ICT capital. This paper investigates two explanations for this apparent puzzle, one based on the existence of intangible capital that is not measured in the National Income Accounts, and the other based on productive externalities. While both explanations can match the observed behavior of TFP growth, the two have very different implications for economic policy and welfare The study shows that the two explanations can be distinguished using a cross-country, cross-industry data set. Using newly constructed very comprehensive data covering 16 OECD countries for 24 industries for a period of 32 years, the paper finds evidence of intangible capital accumulation, but no evidence of positive spillovers to ICT investment. These results are robust across different estimation techniques and under different assumptions regarding market structure.

Key words: productivity growth, information and communications technology, ICT

Résumé

Quelles sont les raisons de la croissance exceptionnelle de la productivité totale des facteurs (PTF) aux États-Unis et, dans une certaine mesure, dans d'autres pays de l'OCDE à partir de la deuxième moitié des années 90? La plupart des analystes attirent l'attention sur les gains de productivité considérables réalisés dans le secteur des technologies de l'information et des communications (TIC). Cependant, selon la théorie néoclassique, le progrès technique d'une industrie n'est pas censé faire progresser la croissance de la PTF dans une autre industrie. Cela dit, la croissance de la PTF est principalement attribuable aux industries qui utilisent le capital des TIC, mais qui n'en produisent pas. La présente étude se penche sur deux explications possibles de cette énigme. La première a trait à l'existence d'un capital incorporel qui ne figure pas dans les comptes du revenu national, alors que la seconde porte sur les externalités de production. Bien qu'il y ait un rapprochement à faire entre les deux hypothèses et la croissance de la PTF, ces dernières ont des implications très différentes sur le plan de la politique économique et du bien-être, et peuvent être différenciées au moyen d'un ensemble de données portant sur plusieurs industries dans plusieurs pays. Grâce à l'analyse d'un ensemble de données exhaustif constitué récemment et portant sur 24 industries dans 16 pays de l'OCDE sur une période de 32 ans, l'étude révèle l'existence d'une accumulation de capital incorporel, mais aucun indice de retombées sur les investissements dans les TIC. Ces résultats sont robustes par rapport à différentes méthodes d'estimation et à différentes hypothèses sur la structure du marché.

Mots clés : croissance de productivité, technologies de l'information et des communications, TIC

I. Introduction

After the mid-1990s, both labor and total factor productivity (TFP) accelerated in the United States and, to a lesser extent, in some other OECD countries. A large body of work has explored the sources and breadth of the U.S. acceleration and suggested reasons for the exceptionally good performance of the U.S. economy. Much of this research focuses on the role of information and communications technology (ICT).[1] Jorgenson, Ho and Stiroh (2006), for example, argue that the overall increase in the U.S. "speed limit" for growth is due to ICT. Growth accounting at an industry level for data from 1987-2004 shows that the simple explanation based on only ICT-producing industries for the U.S. TFP acceleration is incomplete at best. A growing body of literature finds that the TFP acceleration was, in fact, broad-based—not narrowly located in ICT production. Using industry-level data for the United States, Corrado et al (2006), and Bosworth and Triplett (2006) find that non-ICT-producing sectors saw a sizeable acceleration in TFP in the 2000s, whereas TFP growth slowed in ICT-producing sectors in the 2000s.

This finding is a puzzle. From the perspective of neoclassical economics, which underlies almost all the recent discussions of this issue, there is no reason to expect acceleration in the pace of TFP growth outside of ICT production. According to this theory, the fall in input prices do not shift production functions of the output sector. Of course, the fall in price leads to ICT capital deepening throughout the economy boosting labor productivity in ICT-using sectors—but does not change TFP in sectors that only use but do not produce ICT.

However, there are potentially two channels that the fall in the price of ICT could affect TFP of ICT-using industries. The first channel is that the resulting ICT deepening may lead to more use of complementary intangible capital, and the second channel is that there might be presence of positive externality of ICT use.[2] Let us discuss both lines of argument further.

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[1] Jorgenson (2001) and Oliner and Sichel (2000) provide early discussions of the role of information technology in the productivity acceleration.

[2] Tevlin and Whelan (2000) for the U.S. and Bakhshi *et al* (2003) for the U.K. provide econometric evidence that falling relative prices of ICT equipment fuelled the ICT investment boom.

Firm-level studies suggest that benefiting from ICT investments requires substantial and costly co-investments in complementary capital, with long and variable lags.[3] For example, firms that use computers more intensively may reorganize production, thereby creating 'intangible capital' in the form of organizational knowledge. The use of ICT may also prompt for more R&D investment some part of which might be intangible as well. The resulting "organizational capital" is analogous to physical capital that companies accumulate in a purposeful way. Conceptually, we think of this unobserved complementary capital as an additional input into a standard neoclassical production function.[4] In addition to the firm-level studies cited above, macro studies also argue that complementary investment is quantitatively significant (see, e.g., Laitner and Stolyarov, 2003).

The literature also suggests the likelihood of sizeable externalities to ICT. For example, successful new managerial ideas—including those that take advantage of ICT, such as the use of a new business information system—seem likely to diffuse to other firms. Imitation may be easier and less costly than the initial co-invention of, say, a new organization change, because one learns by watching and analyzing the experimentation, the successes and, importantly, the mistakes made by others.[5]

The first set of considerations is completely consistent with the growth accounting framework but suggest that the production function is mismeasured because we don't observe all inputs (the service flow from complementary, intangible capital) or all outputs (the investment in complementary capital). Hence, TFP is mismeasured. The second set of ideas, related to externalities, suggests that ICT might also explain "true" technology change (although the

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[3] See, for example, Brynjolfsson and Hitt (2000) and Bresnahan (undated) for a discussion of the kinds of complementary investments and co-invention that firms undertake in order to benefit from ICT, given its 'general purpose' attributes. Bloom, Sadun and Van Reenen (2005) use data on cross-country mergers to provide additional firm-level evidence for the importance of (partially transferable) intangible capital.

[4] Much of Brynjolfsson's work tries to quantify the role of unobserved complementary capital. Macroeconomic studies of the effects of organizational capital include Greenwood and Yorokoglu (1997), Hornstein and Krusell (1996), Hall (2001), and Laitner and Stolyarov (2003).

change would be endogenous, not exogenous). Empirically, the challenge is to infer the presence of ICT externalities while allowing for the existence of unobserved complementary investments.

This paper suggests a method to distinguish between these two explanations for the speedup of TFP in ICT-using industries. For that, the paper develops an estimating equation based on the model initiated by Basu, Fernald, Oulton and Srinivasan (2003; henceforth BFOS). In the BFOS model, reaping the full benefits of ICT requires firms to accumulate a stock of intangible knowledge capital. And, according to this model observed investments in ICT are a proxy for unobserved investments in reorganization or other intangible knowledge.

Note that the BFOS story hews as closely as possible to neoclassical assumptions while explaining the puzzle of TFP growth in ICT-using industries. If growth accounting could include intangible capital as an input to production then it would show no technical change in ICT-using industries. (Of course, measuring intangible capital directly is very difficult at best; see Corrado, Hulten and Sichel (2006).) But the story can easily be extended to include non-neoclassical features that would explain true technical progress in ICT-using industries via other mechanisms, such as externalities. Indeed, to the extent that much of the intangible capital accumulated by ICT users is knowledge, which is a non-rival good, it would be natural to expect externalities. For example, the innovations that have made Amazon.com and Wal-Mart market leaders could presumably be imitated at a fraction of the cost it took to develop these new ideas in the first place, at least in the long run.

Unfortunately, once one allows for the existence of intangible capital, accumulated in proportion to investment in ICT, it is very difficult to detect externalities using conventional techniques. The paper documents this basic identification problem. But allowing for intangibles is important, as a variety of papers have made a strong case for its existence. The paper then

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[5] Bresnahan and Trajtenberg (1995) highlight both 'vertical' externalities (between general purpose technology producers and each application sector) and 'horizontal' externalities (across application sectors).

suggests that international industry data can help distinguish the effects of intangibles from true externalities. This method is particularly appropriate for OECD countries which are more trade oriented and are leaders in the business applications of ICT. Accordingly, we use data for 16 OECD countries () for 24 industries covering the period 1973 to 2004.[6]

Indeed, we find evidence that firms accumulate intangible capital in the way our theory predicts. We find evidence of positive spillovers to ICT investment neither within a country nor across national boundaries. Reassuringly, we do find positive and statistically significant spillover effects of R&D investment at the domestic level and also at the foreign level in recent decade. These findings are robust with different estimation techniques. The result that there is no ICT spillover remains unchanged whether we impose or relax the assumptions of perfect competition and constant return to scale. However, the presence of intangible capital story survives only if we do not impose the assumptions of CRS and perfect competition.

The rest of the paper is structured as follows. First, we review the basic intangible-capital model presented in BFOS, and derive an estimating equation. In Section III, we show that it is difficult to use the basic BFOS framework to identify externalities—there is an identification problem. We then show that the problem can be solved by using cross-country, cross-industry data. Section IV gives an overview of the data we use. Section V discusses the results. Section VI concludes.

II. The Basic Model

We now turn to a formal model which is based on the model by Basu, Fernald, Oulton and Srinivasan (2003; henceforth BFOS). In the BFOS model, capturing the full benefits of ICT requires firms to make intangible investment. The assumption that complementary investments are needed to derive the full benefits of ICT is supported both by GPT theory and by firm-level

[6] The 16 countries included in the study are: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, South Korea, the Netherlands, Spain, Sweden, the United Kingdom and the United States.

evidence.[7] These investments may include resources diverted to learning; they may involve purposeful innovation arising from R&D. Since (intangible) capital accumulation is a slow process, the full benefits of the ICT revolution show up in the ICT-using sectors with significant lags.

Formally, value added in industries *i* at time *t* that use, but do not produce, ICT is given by (we suppress the country subscript):

$$(1) \quad Q_{it} \equiv Y_{it} + A_{it} = F\left(Z_t\, G(K_{it}^{IT}, C_{it}), K_{it}^{NT}, L_{it}\right), \quad i = 1,\ \ldots,\ N$$

where Q is total output; the difference in terms of measurement is that *Y* is observable output by national accountants, and *A* is the investment flow that is not measured.[8] It is the time and resource cost of training and creating new business structures.[9] Each industry hires labor *L* and rents ICT capital K^{IT} and non-ICT capital K^{NT} in competitive, economy-wide markets. *Z* is a technology term that each industry takes as exogenous. *F* and *G* are homogeneous of degree 1 in their arguments. For simplicity, we ignore materials input, imperfect competition, increasing returns, and capital adjustment costs. All could be added, at the cost of considerable notation. But it is straightforward to include all of these features in the empirical work, and we do.

Industries forego producing market output *Y* to accumulate complementary C capital as follows (for the rest of the theoretical model, we suppress industry subscript *i*):

$$(2) \quad C_t = A_t + \left(1 - \delta_C\right) C_{t-1},$$

where δ_C is the depreciation rate of investment A. The economic difference between *A* and *NT* capital is that they interact in different ways with ICT capital. The main economic implication of the separability assumption built into is that the marginal productivities of K^{IT} and *C* are closely tied to one another. We assume that the elasticity of substitution between the two inputs in the

[7] For evidence, see Bresnahan, Brynjolfsson and Hitt (2002).
[8] Some fraction of *A* is probably measured: for example, consultant services and many forms of software.
[9] Chandler (1977) discusses innovations in inventory management made possible by railroads. Wal-Mart inventory management system provides an example of innovations made possible by ITC.

production of G is relatively small. We also assume Inada-like conditions to the effect that the marginal productivity of each input is very low if the level of the other is close to zero. Thus, when the GPT arrives and ICT capital starts getting cheap, the incentive to also accumulate C is very strong.

Note that conceptually, 'innovation' as traditionally construed can take two forms. First, we lump purposeful unmeasured innovations into C (indeed, we have assumed that *all* purposeful innovation is closely linked to ICT). Second, we interpret Z as all 'exogenous' increases in technology, including the component of organizational change that spills over as an externality from the sector of origin—for example, the idea of using individual electric motors at each workstation in a factory, rather than relying on the single drive train of a steam engine.

Differentiating (1), imposing constant returns to scale and perfect competition assumptions, and manipulating the expression algebraically, we have an expression for the measured Solow residual:

$$(3) \quad \Delta y^{NT} - \frac{P_{K^{IT}} K^{IT}}{PY} \Delta k^{IT} - \frac{P_{K^{NT}} K^{NT}}{PY} \Delta k^{NT} - \frac{WL}{PY} \Delta l \equiv \Delta TFP = \frac{F_C C}{Y} \Delta c - \frac{A}{Y} \Delta a + s_Z \Delta z ,$$

where P, $P_{K^{IT}}$, $P_{K^{NT}}$ are prices of output, ICT capital and non-ICT capital respectively; $\Delta x = d \log X/dt$, and $s_Z \equiv (F_Z Z/Y)$. Note that in this model, TFP growth is not equal to technological change (as in traditional neoclassical model), that is, $\Delta TFP \neq s_Z \Delta z$. Hence, omission of complementary inputs can cause either overestimate or underestimate of TFP growth. When unmeasured *output* is growing ($\Delta a > 0$), TFP growth is underestimated (the "1974" story) as resources are diverted to investment. When unmeasured *input* is growing ($\Delta c > 0$), TFP growth is overestimated. This point is simple but important. Of course, if one corrects only output mismeasurement (Δa), then ICT will appear fantastically productive, far beyond what is ordinarily measured. But firms divert resources to unobserved investment Δa in order to create an intangible capital stock, which contributes to future production. The resulting unmeasured flow of capital services implies a bias in the other direction.

The net bias may be either positive or negative at a point in time, but in a dynamically efficient economy the mismeasurement is necessarily positive: True steady-state TFP growth is *lower* than measured, not higher.[10] In steady state, of course, the accumulation equation implies that $\Delta c = \Delta a$. Hence, steady-state mismeasurement depends on g, the steady-state rate of growth, and r^*, the steady-state real interest rate.

We now seek an observable proxy for unobserved investment in, and growth in the stock of, complementary capital. As shown in Appendix B, with the assumption that the production function of G is CES in inputs C and ICT, equation (3) becomes:

$$(4) \quad \Delta TFP_t = \left[F_C - 1\right]\beta \tilde{k}_t^{IT} + \left[\frac{(1-\delta_C)}{(1+g)}\right]\beta \tilde{k}_{t-1}^{IT} + s_G \Delta z_t ,$$

where $\beta = \left(\frac{1-\alpha}{\alpha}\right)^{\sigma}\left(\frac{P}{P_C}\right)\left(\frac{P_{K^{IT}}}{P_C}\right)^{\sigma-1}$; $\tilde{k}_t^{IT} = s_{K^{IT}}\left[\Delta k_t^{IT} + \sigma \Delta \ln\left(\frac{P_{K^{IT}}}{P_C}\right)_t\right]$, and $s_{K^{IT}} = P_{K^{IT}} K^{IT} / PY$

So *ceteris paribus* the mismeasurement of complementary capital is more important in those industries where $s_{K^{IT}}$,the share of ICT in revenue, is high.

Finally, the TFP growth represents more than just pure technological change, including positive externality created by some factors. In accordance with this fact, we decompose the Δz term to represent externalities, Δe, as well as exogenous technical change, Δt. So far we have suppressed industry subscript i, but now need to introduce them for estimation using a panel of industries (we still continue to suppress country subscript). Hence,

$$(5) \quad \Delta TFP_{it} = \left[F_C - 1\right]\beta \tilde{k}_{it}^{IT} + \left[\frac{(1-\delta_C)}{(1+g)}\right]\beta \tilde{k}_{i,t-1}^{IT} + s_G \Delta e_{it} + s_G \Delta t_{it} .$$

[10] Dynamic efficiency requires that the output elasticity equal or exceed the investment rate. In our discrete time economy, one can show that dynamic efficiency requires that $MPK = (r + \delta_c) \geq (g + \delta_c)/(1+g)$.

This model has several general implications. First, one might find a link between ICT use and measured TFP even if there are no "externalities" to ICT use. Second, the correct "proxy" for ICT use involves the interaction of ICT-intensity (the ICT share) and the growth rate. Third, one needs to control for both current and lagged $\tilde{k}$. Since these values are correlated in the data, if one omits one of them, then the regression has an omitted variable problem. Fourth, the first term on the right-hand side of (5) is proportional to $(r^* + \delta_c - 1)$, so under reasonable circumstances it is negative. The second term, on the other hand, is clearly positive. Hence, other things equal, the productivity acceleration should be positively correlated with lagged ICT capital growth but negatively correlated with current ICT capital growth (with these growth rates 'scaled' by the share of ICT capital in output).[11]

III. A Basic Identification Problem and its Solution

There are a number of challenges in implementing this framework empirically. First, it is unclear how long the lags are between ICT investment and complementary investment. In other words, the length of a period is a free parameter, and theory gives little guidance. The lagged $\tilde{k}$ may be last year's ICT capital accumulation, or the last decade's. Furthermore, equation for the accumulation of complementary capital has no adjustment costs, or time-to-build or time-to-plan lags in the accumulation of *C*. But such frictions and lags are likely to be important in practice, making it even harder to uncover the link between ICT and measured TFP.

Second, if we estimate coefficient of $\tilde{k}$ (our main variable of interest) to be positively significant, interpretation of the results may be clouded by uncertainty of whether our proxies are capturing only unobserved organizational capital, or whether the proxies are affecting TFP

[11] Hence one needs to generalize the approach followed by, e.g., Stiroh (2002) and Stiroh and Botsch (2006), who look for ICT spillovers by regressing TFP growth on only the current-year growth rate of IT capital. Brynjolfsson and Hitt (2002) also find significant lags in firm-level data, which nicely complements our more aggregate evidence.

directly through spillovers. Since the coefficient of $\tilde{k}$ represents the impact of the product of ICT share and ICT growth on same industry's TFP growth, its positive significance may imply that there are intra-industry (within firms) ICT spillovers. That is, the firm cannot reap all the benefits of its ICT use and part of it is spilled to firms within the same industry. Alternatively, its significance might be an outcome of unmeasured intangible capital that went along with ICT use. In other words, one can no longer tell whether the $\tilde{k}$ terms represent intra-industry externalities that are internalized within the industry or accumulation of other private capital stock. Similarly, if we find that lagged $\tilde{k}$ is important for explaining current productivity growth we do not know whether that finding supports the theory we have outlined, or whether it indicates that the externality is a function of lagged capital.

Third and more fundamentally, consider the problem of estimating the externalities represented by Δ*e* in equation (5). Besides the possibility of intra-industry ICT spillovers, there could be presence of inter-industry spillovers (firms in one industry benefits from ICT use by firms in other industries) as well. We can estimate this inter-industry ICT spillover by using aggregate ICT capital in the economy (more precisely ICT of all other industries in the economy). However, there are other factors that are considered to have spillovers to TFP, and we need to control these factors so that their effects are not erroneously captured by ICT variables. R&D is considered one such variable that spills positive affects to TFP. Hence, we can measure the Δ*e* by the growth rate of economy-wide aggregate ICT (Δk_t), own industry R&D growth (Δr_{it}), and all other industries' (within a country) aggregate R&D growth (Δr_t) such that $\Delta e_{it} = \gamma \Delta k_t^{IT} + \lambda_1 \Delta r_{it} + \lambda_2 \Delta r_t$. In this case, equation (5) can be written as:

$$(6) \qquad \Delta TFP_{it} = \alpha + \beta_1 \tilde{k}_{it}^{IT} + \beta_2 \tilde{k}_{i,t-1}^{IT} + \gamma \Delta k_t^{IT} + \lambda_1 \Delta r_{it} + \lambda_2 \Delta r_t + s_G \Delta t_{it} + u_{ijt} .$$

So, if coefficient γ is significant then it would mean the presence of domestic inter-industry ICT spillover. In that case, if both or one β is also significant, we would have reason to believe that $\tilde{k}$ more likely captures intra-industry ICT spillover rather than intangible, as firms potentially learn more from the activities of other firms in their own industry than from other random firms in the economy. If γ is not significant but β is, we still face the same problem of whether $\tilde{k}$ captures the effect of intangible capital or intra-industry ICT spillover. In this case, the country dimension of the data allows us to cut through the confusion so that we can estimate externalities that is robust to the existence of intangible capital. If there are industry-level externalities at the domestic level (the possible explanation of the positive β), it is reasonable to expect that they do not stop at national boundaries. Indeed, Stockman (1988) defines technology change (including the effects of possible externalities) as shocks that change output in the same industry across a group of countries. Hence for positive β to imply intra-industry ICT spillover, one would like to see positive impact of foreign intra-industry ICT. If β is significant but the coefficient on foreign intra-industry coefficient is not, then the story is more in line with intangible capital.

Hence, we estimate the equation by adding ICT growth in the same industry in a foreign country. Besides, we also control for foreign intra-industry R&D (Δr_{it}^{*})—R&D in all foreign countries in the same industry, foreign aggregate ICT in all other industries (Δr_{t}^{*}) and foreign aggregate R&D in all other industries (Δk_{t}^{*}). Note that the variables with "star" as superscript are respective foreign variables. Thus the full form estimating equation (with country subscript *j* added) would be

$$\begin{aligned} \Delta TFP_{ijt} &= \alpha + \beta_1 \tilde{k}_{ijt}^{IT} + \beta_2 \tilde{k}_{ijt-1}^{IT} + \gamma_1 \Delta k_{jt}^{IT} + \lambda_1 \Delta r_{ijt} + \lambda_2 \Delta r_{jt} \\ &\quad + \gamma_1^{*} \Delta k_{ijt}^{IT*} + \gamma_2^{*} \Delta k_{jt}^{IT*} + \lambda_1^{*} \Delta r_{ijt}^{*} + \lambda_2^{*} \Delta r_{jt}^{*} + u_{ijt} \end{aligned} \tag{7}$$

Intuitively, the reason that equation (7) is robust to intangible capital accumulation is that intangible assets should be accumulated in proportion to one's own investment, but not to the investment of an industry in another country. Thus, cross-country data can solve the identification problem. Of course, one might argue that the externality from foreign capital is not quite as large as the externality to investment in one's own home industry. To that extent, estimates of (7) will represent a conservative lower bound to the external effects of domestic ICT investment.

We run regression of equation (5) as a first step. Then we estimate equation (6) using both aggregate and industry-level data for the countries in our sample (note that Δk_t and Δr_t appear without industry subscript). Finally, we estimate the full equation (7) with foreign variables included.

IV. Data

The data used in this paper are from EUKLEMS database compiled by Groningen Growth and Development Centre (GGDC), OECD's Analytical Business Expenditure for Research and Development (ANBERD) database. For few countries, several data series have been supplemented from national statistical agencies. We use data for 16 OECD countries (Australia, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, South Korea, the Netherlands, Spain, Sweden, the United Kingdom and the United States) and 24 industries covering the period 1973 to 2004. Among the 24 industries, 13 are manufacturing, nine are services industries, one is electricity, gas and water supply industry and the remaining one is construction industry. The only industries that are missing from the study are agriculture, fishing and forestry industries, as they do not have R&D data available (the industry list is given in Appendix A, Table A1).

Data on gross output, value added, intermediate input, hours of work, ICT capital, non-ICT capital are taken from EUKLEMS database. The detailed description of the EUKLEMS data is available in Inklaar, Timmer and van Ark (2006). Data on R&D stock is taken from OECD's ANBERD database. Again, in several cases, both these data have been supplemented by national statistical agencies (see Appendix B for data description). In the database, output is defined at constant price. Labor input is measured as composition-adjusted hours worked. This is the product of total hours worked and an adjustment for differences in the marginal product of heterogeneous workers based on their relative wages.

Instead of using data on capital services we use data on capital stock. Capital services data are available only in index form and capital stock data are available in levels. Since we estimate production function also at the level form and it is not straight forward to derive level from capital services in index, we prefer to use capital stock (rather than capital services). However since ICT capital stock was computed by adding three separate assets and non-ICT capital was obtained by adding five different assets (with different depreciation rates), there is no additional benefit of data precision in using capital services over capital stock.

We use three types of ICT capital stock both individually and also by aggregating them into one series. The three types of ICT capital are computers, communication equipment and software. The non-ICT capital is used only as an aggregate series. For detail on how these capital stock data are estimated, see Timmer et al (2007).

The R&D expenditure data are in national currency current price which were converted to constant price using industry value added deflators then transferred to PPP at 1997 rate (using industry level PPP for each country) and constructed capital stock with 15% depreciation rates.

The Appendix A presents average data across time (1973-2004) for 16 countries and 24 industries, with data availability information in Table A1. With 24 industries and 32 years of data, there are maximum of 768 observations for each country. Similarly with 16 countries, for each industry, the maximum number of observation is 512. Among the 24 industries, 23 are ICT-using industries and electrical and optical equipment industry is the only one that is ICT-producing. As our focus is on ICT-using industries, we will exclude ICT-producing industry from our estimation.

Looking at the upper panel, the data on value added and labor are complete for all countries. The data availability is quite good for both types of capital for all countries except for Ireland and Sweden. For Ireland, the capital stock data starts only from 1995 and those for Sweden only from 1993. On R&D variable, Korea has the smallest number of observation, as its data start only from 1995. By industry, the data points for value added, labor, ICT and non-ICT capital are almost similar (although not complete for capital stock as some countries' data are missing for the earlier years as mentioned above). The data availability on R&D, however, varies by industry, with minimum observation of 204 for hotel and restaurant industry.

An inspection at the data show that there is quite a variation across industries and countries in value added (Table A2), hours of work (Table A3), R&D capital stock (Table A4), ICT capital stock (Table A5), non-ICT capital stock (Table A6), share of ICT to total capital stock (Table A7), R&D intensity in terms of value added (Table A8) and ICT intensity in terms of value added (Table A9). The share of ICT to total capital stock ranges from 0.1% in real estate activities to 28% in post and telecommunications (Table A6). The industry mean of share of ICT to total capital stock is 3.6% with median of 4.5%. Taking industry median value as a cut off point, 11 industries have the share higher than median and 12 industries have share lower than median. Only four manufacturing industries have ICT to capital share higher that that of industry median. The country median ranges from low of 2% for Canada and Belgium to high of 8.2% for Sweden.

Looking at ICT intensity (ICT to GDP share) in Table A8, we see that it ranges from as low as 1.2% for real state activities industry to as high as 147% to post and telecommunication industry in the US. Almost similar variation is noticed across countries in the same industry. For example, in renting of M&E and other business industry, (the industry with second highest ICT share after post and telecommunication industry) the ICT intensity varies from low of 6% in Belgium to high of 51% in Korea. Most of the industries that have higher share of ICT in total capital stock are also the industries which have higher share of ICT capital stock to value added. There are few exceptions. For example, the electricity, gas and water supply is highly capital-intensive in terms of value added (11%) but very low share of ICT in total capital stock (1.8%). A similar but less pronounced difference in two shares is found for transport storage (19% vs. 5%). It implies that both these industries have very high capital to value added ratio. There are only two industries whose ICT share in total capital is higher than their respective capital to value added shares. They are construction and wholesale trade. As a result, they have the lowest capital to value added shares.

Finally, one might argue that using firm-level data would allow us to avoid the complexity of using cross-country data sets. Returning to equation (7), the beneficial externalities to a firm presumably come from the investments of other firms within the same industry. So why not estimate (7), with i indexing firms, and the externality coming from industry-level ICT investment?

The main reason why firm-level data are not suitable for the purpose of estimating externalities in our framework is the lack of true price deflators for firm-level output. In the realistic case where firms within an industry produce heterogeneous output, Klette and Griliches (1996) have shown that the procedure of replacing the true firm-level deflator with an aggregate industry deflator leads to an omitted variable problem that is particulary worrisome for the purpose at hand. They show that the omitted variable is correlated with industry inputs, even controlling for firm inputs—that is, it has exactly the characteristics of an externality! But the source of the correlation with industry inputs is the mismeasurement of real output, not a true productive externality. Thus, using firm-level data—which would be preferred according to theory—will not give useful answers as long as one needs to deflate firm revenues with an aggregate industry price index.

Although industry data have other problems, including the problem of distinguishing own unobserved investment from a productive externality, there are true price deflators for industry output, and thus the Klette-Griliches problem does not apply. Furthermore, the industry level data makes it possible to use data for so many countries, industries and across years.

V. Results

At the beginning, we omit controls for intangible capital; those will be added later. For most part of the analysis, we allow for non-constant returns to scale and perfect competition. Thus, our dependent variable is output rather than TFP, and we enter the inputs separately on the right-hand side. Towards the end of the paper, we impose CRS and perfect competition and use TFP as dependent variable. To begin with we estimate *level* equation and revert to *growth* one subsequently. We use OLS for most of the estimation and use GMM as robustness check. We also decompose the most preferred estimation in two ways: first, into decade-long three sub-periods and second aggregate ICT into three components: software, information technology and communication technology.

The results for level equation are presented in Table 1, using all industries (both ICT-producing and ICT-using) in specifications 1-6 and using only ICT-using industries (dropping one industry—ICT-producing, electrical and optical equipment industry) in specifications 7 and 8. For the first seven specifications, we use gross output as the dependent variable and value added for the last specification. We also augment our basic estimating equation with own industry domestic R&D (specifications 6-8).

We estimate fairly standard coefficients for all the inputs except labor, whose coefficient seems too low. The coefficient for non-ICT capital is also implausibly low once we introduce industry fixed effects. Since the variation in capital and especially in non-ICT capital is across industries (cross-section) rather than across time within the same industry (time series), the use of industry fixed effect as a control lowers the magnitude of its coefficient. The estimation of low coefficients, especially on capital, is a common outcome from fixed effects regression (see Griliches and Mairesse 1998). On the other hand, the coefficient of intermediate input is quite high once the industry fixed effect is introduced.

Overall, the labor and capital coefficients are generally smaller than their respective average factor shares, whereas the coefficient of intermediate input is larger than its average factor share in the raw data.The sum of coefficients is very close to unity in all specifications except for specifications when we start having all three (country, industry and time) effects (in specifications 5). The sum of coefficient falls further with the introduction of R&D variable (specification 6), with the dropping of ICT-producing industry (specification 7) and value added as dependent variable (specification 8). The data reject the null hypothesis that there is constant return to scale, i.e. the sum of coefficients (labor, capital and intermediate input) is unity in all specifications. All the coefficients, including those on R&D capital, are significant at the 1% level.

Results in Table 2 are in some way repetition of the specifications of Table 1, but now estimated using growth rates and considering only ICT-using 23 industries (dropping ICT-producing, electrical and optical equipment, industry from the estimation sample). Here, as expected, the estimated coefficients on the capital input variables fall and are often close to zero. This is particularly true for ICT capital, which of course has a smaller share to start with. The coefficient of non-ICT capital is significant once we introduce time fixed effect and insignificant when industry or country fixed effect is introduced. Domestic R&D continues to be significant in most specifications.[12] Even though industry and country fixed effects are wiped out in first difference equation, we still carry them in some specifications in this table. But our preferred specification is (3) with only time fixed effect and we continue this method for the rest of the estimations.

In Table 3, we introduce the variables that should proxy for intangible capital accumulation, as required by the model in Section II. We extend the growth equations that provided results for Table 2 by adding first the ICT capital share in gross output (specification 1) and then the product of the ICT ratio to gross output and ICT capital growth (specification 2). Then we check the impact of this product variable in one period lag (spec. 3). Although the theory we have developed is not a guide on how far the lags should, it suggests that to control for intangible capital accumulation we need enter the variable for two time periods. Accordingly, we extend the estimation to include contemporaneous and one-period lags (spec. 4). As the theory suggest, regarding the control for intangible, the more recent variable should have a negative sign and the longer lag should have a positive sign. This is exactly the sign pattern we find in specification 5, although only the longer lag is statistically significant. Specification (6) shows that the data do not advise further longer lags.

Number 5 is our preferred specification, where first term enters with no effect (negative coefficient) and second term implies positive impact (as suggested by the theory) at 10% level. For the rest of the analysis, we will extend this specification to the full form as given in equation (7). Without further control, the difficulty with this estimation is that there is no way of knowing whether the significance of this variable indicates the impact of intangible or the benefits of ICT use of one firms spills to other firms in the same industry (called within-industry ICT spillover). If there are spillovers at the industry level (if the full reward of ICT use is not captured at the

[12] By allowing country and industry fixed effects on growth regression, we are assuming that productivity shock is not uniform; they vary across countries and across industries. By measuring the differences by industry and country fixed effects, we are assuming that the productivity shocks across industries and countries differ only by a constant.

firm level), then the coefficient will show up with positive sign indicating industry level ICT use efficiency.

Besides, there is also the case that the ICT spillovers might be across industries. That is, a firm in an industry may benefit not only from the ICT use of firms within the same industry, but also from ICT use of firms in other industries (called inter-industry spillover). We want to estimate this channel of ICT spillover as well. Furthermore, along with intra-industry R&D spillover, we would like to control for inter-industry R& spillover.

We begin to look for external effects, using as a baseline our results from Table 3, where we allow for intangible capital accumulation. We take the specification 5 in Table 3 and estimate equation (7) in its full form except for the fact that the different price levels that appear in the equation are not considered. However, as one does not expect the relative price of ICT in the sample countries to be very different, their exclusion should not bias our results. We begin by looking for within-country spillovers by adding aggregate ICT which is the domestic total ICT of all other industries (named inter-industry aggregate ICT), and aggregate R&D in specification 1. These two variables are significant at the 10% and the 1% levels, respectively, implying that there are spillovers from other industries' use of ICT and other industries' R&D capital.

Furthermore, even in the presence of these two variables, the ICT ratio and ICT growth (product) term is negative in one year lag and positively significant (at 10% level) in 2 years lag. The significance of this variable may indicate either intra-industry ICT spillovers or presence of intangible. More importantly, in the presence of the positive inter-industry ICT spillovers that we have estimated, it is hard to believe that there is no intra-industry spillover, as firms generally learn from firm in the same industry than firms in other industries. Hence, the significant result on the coefficient of the product of ICT ratio and ICT growth in specification 1 is more in line with domestic intra-industry ICT spillover rather than intangible capital story.

But the use of industry and country fixed effects in growth rate regression is not consistent with long run model, as a result model with only time as fixed effect is the preferred specification.

To explore further, we introduce foreign intra-industry ICT in the estimation. As explained above, our line of reasoning is that if the spillovers indicate domestic intra-industry efficiency, then foreign intra-industry variable should also be significant. The notion is that unless there is a convincing case that spillovers stop at the border (which is not the case in R&D as several studies have shown) then foreign intra-industry spillover should be present (may be in lower magnitude) if there is domestic intra-industry ICT spillover.

When we add foreign intra-industry ICT growth variable (spec. 2) —ICT capital growth in the same industry in all foreign countries—the domestic aggregate ICT variable loses its significance. Next we add foreign intra-industry R&D, foreign inter-industry ICT (ICT in all other industries in all foreign countries) and foreign inter-industry R&D (spec. 3). None of them are significant; all of them have wrong sign except for inter-industry R&D and oddly intra-industry R&D variable is statistically significant. In this full specification 3, the two-period lag of the product of ICT ratio and ICT growth is significant but neither domestic inter nor foreign intra and inter industry ICT variables are significant. Since there is no trace of domestic inter and foreign intra- and inter-industry ICT, the positive impact of the variable product of ICT ratio and ICT growth implies the impact of intangible capital that goes along with the ICT investment.

In specification (4), we remove all R&D related variables (both domestic and foreign) and estimate the impact of ICT. Interestingly, the product term loses its significance. Even more interesting is the case that the aggregate domestic ICT variable is quite significant, whereas the foreign ICT variables are not significant. This is a perfect case of domestic inter-industry ICT spillovers, and no trace of intangible capital impact. However, this is an outcome of model misspecification, as R&D, the TFP spillers, is taken out of the estimation.

Thus, we find some qualified support for positive externalities from aggregate domestic ICT growth (specification 1). That support vanishes, though, while we introduce the foreign ICT variables, which themselves are not significant either. Hence there is no support for the proposition that foreign within-industry and foreign inter-industry ICT usage has positive externalities (specifications 2 & 3). The significance of the ICT variable at the domestic level but insignificance at the foreign level indicates that the positive impact on productivity might be generated by intangible capital than by ICT spillovers. Another finding is that once we remove R&D variable, the aggregate ICT growth spillover becomes stronger (specification 4) suggesting that while estimating the impact of ICT on TFP, the control of R&D is essential otherwise the result would be biased. Furthermore, the models that do not control for R&D while measuring impact of ICT would be wrongly ascribing R&D spillovers to ICT spillovers.

The domestic aggregate R&D is consistently significant in all specifications, whereas own-industry R&D is positively significant only if domestic aggregate R&D is taken out from the estimation. While introduced together, the inter-industry R&D growth nullify the impact of own industry R&D growth as these two variables—own industry R&D and domestic inter-industry R&D—are positively related. A higher inter-industry R&D growth rate leads to higher TFP growth, whereas own industry's higher R&D growth rate does not reflect into higher TFP growth.

An important question is whether the nature of ICT spillover has changed over time. To test this, we decompose the estimation in specification (3) into three sub-periods with 10 years each (1975-1984, 1985-1994 and 1995-2004; the samples from 1973 and 1974 are excluded) and present results in specifications 5 through 7. This sub-division allows us to evaluate whether there was anything different in the post 1995 period—the time when both the US average labor productivity growth and TFP growth accelerated. In none of the three decades domestic aggregate (inter-industry) ICT variable is significant. The foreign intra-industry ICT is positive (insignificant) for the first decade, negative (insignificant) for the second decade and negatively significant at the 10% level for the last decade (1995-2004). The foreign inter-industry ICT coefficients are negative but insignificant in all three decades. For R&D, however, the situation is different. The coefficient on aggregate domestic R&D is significant for the last two decades; foreign intra-industry R&D is negative throughout and (wrongly) significant in the first decade, whereas foreign inter-industry R&D is positively significant for the recent decade.

As long as ICT story is concerned, this decomposition confirms the finding in previous specification that there is no ICT spillovers, neither inter nor intra; neither domestic nor foreign. Any indication of positive ICT spillovers can occur due to either misspecification of the model or due to missing measurement of intangible capital.

What is somewhat surprising is the negatively significant coefficients of ICT capital in specifications 1 through 3 (at 10% level) of Table 4 (spec. 4 is not the preferred model as R&D variables are excluded). Taken literally, this could mean that the ICT capital is unproductive. This is not the first time the own industry ICT capital growth is found to be negatively correlated with its own TFP growth. In the US data from 1984 to 1999, Stiroh (2002), under different estimation techniques, finds that ICT growth is negatively related with TFP growth even at the lower level of significance. In his study, the strong negative effect is driven by telecom capital, as the coefficient of computer capital is negative but not significant. In our case, the decomposition shows that this negative coefficient was caused by the situation in the first decade of the study (Spec 5); in the last two decades, the impact of ICT capital growth on TFP growth was nil (Specs 6 and 7).

To understand if any of the three ICT assets have spillover and which asset types caused this negative impact we decompose the ICT capital into: information technology (IT), communication technology (CT) and software.[13] Results in Table 5 show that the negative coefficient on ICT in Table 4 was driven only by CT whose coefficient is negatively significant at the 5% level for the sample of entire study period. Furthermore, the regression results for three

[13] In terms of total stock, the sizes of three assets were comparable at about 0.6% of gross output (average of all countries, industries and years considered in the paper). By way of comparison, the share of non-ICT capital to gross output was 14.5 percent.

sub-periods show that the coefficient was negative only for the first sub-period, 1975-1984 (results not reported to avoid clutter) and that too only for CT. During the periods 1985-1994 (again results not reported) and 1995-2004 (reported in Table 5), none of the three ICT assets were significant. To sum up, the ICT capital is not a drag in TFP growth especially not so in the more recent years, but the industries with higher ICT growth may not be the ones which necessarily acquire higher TFP growth. The results at the domestic aggregate category show that none of the three assets generated spillover type effects.

In Table 6, we conduct a robustness check using generalized method of moment (GMM) system estimation to address the potential issue of endogeneity in the above panel (within) estimation. The first specification is copied from specification (3) of Table 4. Specifications 2-4 use system GMM and treat different variables as endogenous. In specification (2), we treat two variables, intermediate input and labor hour, as endogenous and use their lags of two period and back as GMM-type instruments. All other variables are used as exogenous and the difference of each of these variables (difference of the difference as these variables are already in difference form) is used as standard instrument. All of these are instruments for difference equation. For the level equation, we use the second lag of the difference of all endogenous and exogenous variables as instruments. Only the second lags of the variables are used because the moment conditions using the higher lags are redundant (Blundell and Bund, 1998). The model is estimated using two-step GMM and the standard errors are robust. The p-value for AR(1) shows that, as required by theory, there is first order serial correlation (the null is rejected), but the null that there is no second order correlation is not rejected at 10% and higher level, contrary to what theory requires us to do.

In specification (3), we use only intermediate input as endogenous. All instruments are as explained above. The non-rejection of AR(2) at 7% level and above strongly rejects the model. In Specification (4) we use only labor hour as endogenous. In terms of AR(2), this specification is better because as required by theory we cannot reject the null that there is no second order serial correlation at least for the 11% level. Among the three specifications in GMM, our preferred and theoretically sound model is specification (4).

The major difference in the results between OLS and GMM estimations are the following: (i) the coefficients on non-ICT is significant in OLS and turns insignificant in GMM, (ii) the lag effects strengthens (iii) the strong positive coefficient on domestic aggregate R&D in OLS either loses strength or becomes nil in GMM, (iv) the foreign intra-industry ICT which was insignificant in OLS turns significant in spec. (4) and (v) the negatively significant coefficient on foreign intra-industry R&D in OLS turns insignificant in GMM. In terms of the impact of ICT, the prime interest for this paper, none of these differences qualitatively cast doubt on the previous finding that any potential spillover impacts of ICT abode well with the intangible capital story but not with the presence of its spillovers. Overall, the GMM estimations suggest that the OLS results were not driven by simultaneity issue; even when we control for potential endogeneity, the results qualitatively remain the same.

Finally, in Table 7, we run regressions similar to those of Table 4, but now using TFP growth rather than output growth as the dependent variable (and removing own-inputs from the right-hand side of all the specifications). Using TFP rather than estimating the coefficients on the inputs is an attempt to gain power by imposing the conditions for cost minimization (although, since we do not include an input aggregate on the right-hand side, as in Hall (1990), we are also imposing constant returns to scale). The qualitatively new result is that when we estimate using TFP, the share-weighted lags of own ICT investment retain the negative and positive signs predicted by theory, although, none of the lags is significant. Second, looking at the full specification (4), we see that foreign intra-industry ICT and foreign inter-industry R&D which were insignificant in Table 4, turns negatively significant with TFP as dependent variable which is difficult to rationalize. As before within a country, R&D has spillovers that are statistically significant. Impact of foreign aggregate ICT growth is insignificant. In specification (5), we introduced cross country aggregate R&D and ICT as an interaction term, and as a result, the oddly negative coefficient (inter-industry aggregate R&D) turns insignificant. Among the four foreign variables only intra-industry ICT is (negatively) significant. In the last specification, we take out all R&D related variables and as a result both domestic and foreign aggregate ICT variables become significant. This result is capturing the positive impact of excluded variable R&D. Overall, the story holds; there is no evidence of aggregate ICT positive externalities, either within or across countries.

VI. Conclusions

Using a simple model, we show that it is difficult to estimate ICT spillovers when one also allows for intangible investment that is complementary to ICT. Yet a variety of evidence, both micro and macro in nature, suggest that intangible investment is very important, and is particularly strongly associated with ICT investment. We then propose a solution to this problem, if ICT spillovers operate across borders. Since intangible capital investment is confined within country boundaries, using cross-country, cross-industry data allows us to solve this fundamental identification problem.

We assemble a large data set for 24 industries in 16 OECD countries over 32 years. This rich data set allows us to test for externalities even if there is intangible capital accumulation. Indeed, we find evidence that firms accumulate intangible capital in the way our theory predicts. Allowing for the intangible capital accumulation—which might otherwise be mistaken for positive externalities to lagged ICT capital investment—we find no evidence of positive spillovers to ICT investment across national boundaries and within countries. This is true across two estimation techniques we have used. This is also true whether we use gross output or TFP growth (imposing the conditions for cost minimization) as our dependent variable. Reassuringly, we do find positive and statistically significant effects of R&D investment at the domestic level and at the international level in more recent period. This finding, in keeping with the large literature on R&D spillovers, suggests that our failure to find ICT externalities is not due to some quirk of our data or specification.

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Table 1. Level equation, 1973-2004

	All Industries						Only ICT-using industries	
	Gross output as dependent variable						Gross output as dependent variable	Value added as dependent variable
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(7)
Employment	0.120 (0.003)[a]	0.134 (0.003)[a]	0.131 (0.004)[a]	0.115 (0.003)[a]	0.106 (0.006)[a]	0.066 (0.008)[a]	0.069 (0.008)[a]	0.332 (0.021)[a]
ICT	0.031 (0.002)[a]	0.030 (0.002)[a]	0.026 (0.002)[a]	0.037 (0.002)[a]	0.031 (0.002)[a]	0.034 (0.002)[a]	0.036 (0.002)[a]	0.080 (0.006)[a]
Non-ICT	0.201 (0.003)[a]	0.204 (0.003)[a]	0.081 (0.005)[a]	0.198 (0.003)[a]	0.071 (0.005)[a]	0.062 (0.009)[a]	0.064 (0.006)[a]	0.233 (0.009)[a]
Intermediate inputs	0.668 (0.004)[a]	0.654 (0.004)[a]	0.767 (0.007)[a]	0.671 (0.004)[a]	0.715 (0.007)[a]	0.724 (0.006)[a]	0.705 (0.008)[a]	
Own industry R&D						0.016 (0.001)[a]	0.016 (0.001)[a]	0.079 (0.005)[a]
Country FE	NO	YES	NO	NO	YES	YES	YES	YES
Industry FE	NO	NO	YES	NO	YES	YES	YES	YES
Time FE	NO	NO	NO	YES	YES	YES	YES	YES
Constant	0.907 (0.018[a]	0.939 (0.023)[a]	0.954 (0.023)[a]	1.55 (0.050)[a]	1.65 (0.046)[a]	1.79 (0.052)[a]	1.94 (0.054)[a]	3.73 (0.124)[a]
R^2	0.98	0.98	0.99	0.98	0.99	0.99	0.99	0.95
N	11012	11012	11012	11012	11012	9352	8927	8927
Sum of coefficients	1.02	1.02	1.01	1.02	0.92	0.89	0.87	0.65

All regression variables are in log level.

Standard errors are in parentheses, and all are robust standard errors.
Employment is measured in millions of hours worked by persons engaged. The variable ICT is information and communication technology capital stock in real prices which is the sum of IT (information technology), CT (communication technology) and Software capital stocks. The sum of ICT and NICT is total capital stocks. The data on gross output, intermediate inputs, value added, ICT and NICT are in millions of US \$ 1997 PPP. The data are also in millions of US \$ 1997 PPP.

a = significant at the 1% level; b = significant at the 5% level; c = significant at the 10% level

The "sum of coefficient" includes the coefficients of only employment, ICT capital, non-ICT capital and intermediate inputs and not that on R&D capital. The same is true for the test of constant return to scale (CRS).

Table 2. Annual growth regression, 1973-2004

	Gross output as dependent variable						Value added as dependent variable
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Employment	0.157 (0.013)[a]	0.164 (0.014)[a]	0.141 (0.013)[a]	0.146 (0.013)[a]	0.141 (0.013)[a]	0.163 (0.014)[a]	0.145 (0.013)[a]
ICT	-0.001 (0.003)	0.001 (0.003)	-0.003 (0.003)	-0.002 (0.003)	-0.003 (0.003)	0.001 (0.003)	-0.002 (0.011)
Non-ICT	0.020 (0.012)	0.018 (0.012)	0.039 (0.012)[a]	0.029 (0.012)[b]	0.030 (0.013)[b]	0.010 (0.012)	0.098 (0.039)[b]
Intermediate inputs	0.647 (0.016)[a]	0.643 (0.016)[a]	0.638 (0.016)[a]	0.633 (0.016)[a]	0.638 (0.016)[a]	0.643 (0.016)[a]	0.436 (0.034)[a]
Own industry R&D	0.002 (0.001)	0.003 (0.001)[b]	0.002 (0.001)[c]	0.003 (0.001)[b]	0.002 (0.001)	0.003 (0.001)[b]	0.011 (0.003)[a]
Country FE	YES	NO	NO	NO	YES	YES	NO
Industry FE	NO	YES	NO	YES	NO	YES	NO
Time FE	NO	NO	YES	YES	YES	NO	YES
Constant	0.320 (0.174)[c]	0.596 (0.079)[a]	1.75 (0.223)[a]	1.70 (0.227)[a]	1.53 (0.270)[a]	0.303 (0.172)[c]	4.61 (0.742)[a]
R^2	0.80	0.80	0.80	0.81	0.81	0.80	0.10
N	8571	8571	8571	8571	8571	8571	8571

All regression variables are in annual log difference multiplied by 100.
Standard errors are in parentheses, and all are robust standard errors.

a = significant at the 1% level; b = significant at the 5% level; c = significant at the 10% level

Table 3. Introducing ICT share and its interaction in growth equation, 1973-2004

	(1)	(2)	(3)	(4)	(5)	(6)
Employment	0.138 (0.013)[a]	0.139 (0.013)[a]	0.141 (0.013)[a]	0.141 (0.013)[a]	0.141 (0.013)[a]	0.141 (0.014)[a]
ICT	-0.004 (0.003)	-0.007 (0.004)[c]	-0.007 (0.003)[b]	-0.008 (0.004)[c]	-0.005 (0.003)	-0.004 (0.003)
Non-ICT	0.039 (0.012)[a]	0.040 (0.013)[a]	0.032 (0.013)[b]	0.035 (0.013)[a]	0.028 (0.013)[b]	0.030 (0.014)[b]
Intermediate inputs	0.633 (0.016)[a]	0.634 (0.016)[a]	0.632 (0.017)[a]	0.629 (0.017)[a]	0.626 (0.018)[a]	0.619 (0.018)[a]
Own industry R&D	0.002 (0.001)[c]	0.002 (0.001)[c]	0.002 (0.001)[c]	0.002 (0.001)	0.002 (0.001)	0.002 (0.001)[c]
Incorporating ICT share and its interaction with ICT growth						
ICT share (in percent)	0.061 (0.018)[a]					
ICT Ratio × ICT		0.230 (0.165)		0.089 (0.297)		
ICT Ratio × ICT — one year LAG			0.263 (0.157)[c]	0.200 (0.280)	-0.049 (0.218)	
ICT Ratio × ICT — two year LAG					0.313 (0.178)[c]	0.188 (0.220)
ICT Ratio × ICT — three year LAG						0.128 (0.224)
Constant	-0.461 (0.264)[c]	-0.404 (0.264)	1.84 (0.235)[a]	-0.408 (0.269)	1.87 (0.239)[a]	1.11 (0.218)[a]
R^2	0.80	0.80	0.80	0.80	0.79	0.79
N	8395	8395	8136	8111	7853	7596

The dependent variable is gross output. The dependent variable and independent variables (employment, ICT, non-ICT and domestic R&D) are in annual log difference multiplied by 100. Standard errors are in parentheses, and all are robust standard errors.

a=significant at the 1% level; b=significant at the 5% level; c=significant at the 10% level.

The variable "ICT Ratio" is the ratio of ICT compensation to gross output, whereas "ICT Share" is ICT Ratio multiplied by 100. The variable "ICT Ratio x ICT" is the product of ICT Ratio and first log difference of ICT capital. We report the results up to lag of three year. Introducing longer lag reduces the preciseness of the estimation.

All regressions include only year fixed effects. Since we are estimating first difference equation, the cross-section fixed effect (country and/or industry) wipes out. We could use industry/country fixed effect only under the assumption that the original level equations have country and/or industry specific trends. And allowing there to be permanent country and/or industry effects in the differenced equation is incoherent in the long run.

Table 4. Introducing domestic and foreign ICT and R&D, 1973-2004

	All years				1975-84	1985-94	1995-04
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Employment	0.141	0.143	0.144	0.139	0.166	0.146	0.131
	(0.013)[a]	(0.013)[a]	(0.014)[a]	(0.016)[a]	(0.033)[a]	(0.027)[a]	(0.015)[a]
ICT	-0.007	-0.007	-0.007	-0.014	-0.017	0.003	-0.002
	(0.004)[c]	(0.004)[c]	(0.004)[c]	(0.004)[a]	(0.006)[a]	(0.007)	(0.005)
Non-ICT	0.026	0.028	0.028	0.070	-0.005	0.017	0.050
	(0.013)[c]	(0.014)[b]	(0.014)[b]	(0.014)[a]	(0.031)	(0.020)	(0.023)[b]
Intermediate inputs	0.625	0.625	0.625	0.639	0.645	0.592	0.638
	(0.018)[a]	(0.018)[a]	(0.018)[a]	(0.016)[a]	(0.045)[a]	(0.028)[a]	(0.019)[a]
Own industry R&D	0.001	0.001	0.002	0.002	0.001	0.001	0.003
	(0.001)	(0.001)	(0.001)	(0.001)	(0.007)	(0.002)	(0.002)
ICT Ratio × ICT — one year LAG	-0.058	-0.038	-0.023	0.007	-0.138	0.523	-0.126
	(0.220)	(0.221)	(0.223)	(0.209)	(0.702)	(0.375)	(0.271)
ICT Ratio × ICT — two year LAG	0.306	0.311	0.329	0.106	0.788	-0.397	0.491
	(0.177)[c]	(0.178)[c]	(0.179)[c]	(0.191)	(0.660)	(0.381)	(0.200)[b]
Domestic aggregate variables							
ICT— Inter-industry	0.015	0.014	0.013	0.045	0.030	-0.015	0.010
	(0.009)[c]	(0.009)	(0.010)	(0.010)[a]	(0.022)	(0.019)	(0.013)
R&D— Inter-industry	0.023	0.022	0.022		0.022	0.025	0.024
	(0.006)[a]	(0.006)[a]	(0.007)[a]		(0.037)	(0.010)[b]	(0.008)[a]
Foreign variables							
ICT— Intra-industry		-0.014	-0.014	-0.016	0.008	-0.014	-0.031
		(0.010)	(0.011)	(0.010)	(0.018)	(0.020)	(0.017)[c]
ICT— Inter-industry			-0.025	0.028	-0.021	-0.095	-0.008
			(0.055)	(0.052)	(0.135)	(0.105)	(0.076)
R&D — Intra-industry			-0.008		-0.023	-0.007	-0.004
			(0.004)[b]		(0.010)[b]	(0.005)	(0.009)
R&D — Inter-industry			0.019		-0.058	-0.117	0.359
			(0.064)		(0.128)	(0.103)	(0.126)[a]
R^2	0.79	0.79	0.79	0.73	0.80	0.78	0.81
N	7853	7853	7853	9185	1921	2614	3318

The dependent variable is gross output. The dependent variable and independent variables (employment, ICT, non-ICT and domestic R&D) are in annual log difference multiplied by 100. Standard errors are in parentheses, and all are robust standard errors.
a = significant at the 1% level; b = significant at the 5% level; c = significant at the 10% level.
The variable "inter-industry aggregate ICT (R&D) is the domestic total ICT (R&D) capital of all other industries. Among foreign variables, "intra-industry ICT (R&D)" are the sum of the same industry ICT(R&D) across all foreign countries. The share and lag variables are as defined in Table 3. All regressions include only year fixed effects but not country/industry fixed effects.

Table 5. Decomposing ICT into three components, 1973-2004

	All years		**Years 1995-2004**	
	Coefficients	Standard error	Coefficients	Standard error
Employment	0.142	(0.019)[a]	0.132	(0.017)[a]
Information technology (IT)	-0.001	(0.003)	-0.011	(0.005)
Communication technology (CT)	-0.005	(0.002)[b]	0.007	(0.006)
Software	-0.001	(0.004)	0.004	(0.007)
Non-ICT	0.030	(0.015)[b]	0.049	(0.048)[c]
Intermediate inputs	0.624	(0.019)[a]	0.634	(0.026)[c]
Own industry R&D	0.002	(0.001)	0.003	(0.002)
ICT Ratio × ICT — one year LAG	0.031	(0.244)	-0.055	(0.307)
ICT Ratio × ICT — two year LAG	0.367	(0.191)[c]	0.522	(0.213)[b]
Domestic aggregate variables				
IT— Inter-industry	0.006	(0.006)	0.011	(0.010)
CT — Inter-industry	0.007	(0.008)	-0.004	(0.009)
Software — Inter-industry	-0.004	(0.008)	0.016	(0.017)
R&D — Inter-industry	0.023	(0.009)[b]	0.024	(0.010)[b]
Foreign variables				
ICT— Intra-industry	-0.014	(0.012)	-0.038	(0.020)[c]
ICT— Inter-industry	-0.015	(0.058)	0.027	(0.085)
R&D — Intra-industry	-0.009	(0.004)	-0.003	(0.010)
R&D — Inter-industry	0.001	(0.067)	0.391	(0.134)[a]
R^2	0.79		0.80	
N	6949		2840	

The dependent variable is gross output. The dependent variable and independent variables (employment, IT, CT software, ICT, non-ICT and domestic R&D) are in annual log difference multiplied by 100. Standard errors are in parentheses, and all are robust standard errors.

All IT, CT and Software capital stocks are in real prices. The sum of these three is ICT. When we decompose the ICT data into three types of capital, we lose quite a large number of observations, as ICT data on Belgium and Canada are not available by three asset types. All other variables are as defined in Tables 3 and 4.

All regressions include only year fixed effects.

a = significant at the 1% level; b = significant at the 5% level; c = significant at the 10% level

Table 6. Robustness check using System GMM estimations, 1973-2004

	OLS	System GMM		
	(1)	(2)	(3)	(4)
Employment	0.144	0.163	0.124	0.179
	(0.014)[a]	(0.022)[a]	(0.028)[a]	(0.032)[a]
ICT	-0.007	-0.004	-0.003	-0.006
	(0.004)[c]	(0.008)	(0.007)	(0.006)[a]
Non-ICT	0.028	-0.008	0.004	-0.002
	(0.014)[b]	(0.025)	(0.036)	(0.017)
Intermediate inputs	0.625	0.637	0.632	0.624
	(0.018)[a]	(0.036)[a]	(0.052)[a]	(0.035)[a]
Own industry R&D	0.002	0.003	0.002	0.003
	(0.001)	(0.002)	(0.001)	(0.002)[c]
ICT Ratio × ICT — one year LAG	-0.023	-0.125	0.025	-0.128
	(0.223)	(0.166)	(0.164)	(0.120)
ICT Ratio × ICT — two year LAG	0.329	0.437	0.384	0.329
	(0.179)[c]	(0.150)[a]	(0.157)[b]	(0.150)[b]
Domestic aggregate variables				
ICT— Inter-industry	0.013	0.002	0.006	-0.006
	(0.010)	(0.017)	(0.015)	(0.016)
R&D— Inter-industry	0.022	0.014	0.017	0.018
	(0.007)[a]	(0.011)	(0.013)	(0.010)[c]
Foreign variables				
ICT— Intra-industry	-0.014	-0.036	-0.032	-0.049
	(0.011)	(0.022)	(0.020)	(0.022)[b]
ICT— Inter-industry	-0.025	-0.097	-0.042	-0.203
	(0.055)	(0.132)	(0.152)	(0.130)
R&D — Intra-industry	-0.008	-0.005	-0.005	-0.005
	(0.004)[b]	(0.005)	(0.006)	(0.006)
R&D — Inter-industry	0.019	-0.233	-0.314	-0.222
	(0.064)	(0.133)	(0.178)[c]	(0.146)
AR(1) p-value		0.00	0.00	0.00
AR(2) p-value		0.10	0.07	0.11

The dependent variable is gross output. The dependent variable and independent variables (employment, ICT, non-ICT and domestic R&D) are in annual log difference multiplied by 100. The System GMM is estimated using two-step procedure. Standard errors are in parentheses, and all are robust standard errors.
a = significant at the 1% level; b = significant at the 5% level; c = significant at the 10% level.

The share and lag variables are as defined in Table 3.The variables "inter-industry" and "intra-industry" both domestic and foreign are as defined in Table 4. All regressions include only year fixed.

In specification (2) employment and intermediate inputs are treated as endogenous, in specification (3), intermediate input treated as endogenous and in (4) employment is treated as endogenous.

Table 7. TFP growth as dependent variable, 1973-2004

	(1)	(2)	(3)	(4)	(5)	(6)
Own industry R&D	0.003	0.003	0.003	0.003	0.003	
	(0.001)[a]	(0.001)[a]	(0.001)[a]	(0.001)[a]	(0.001)[a]	
ICT Ratio × ICT — one year LAG	-0.306	-0.260	-0.259	-0.265	-0.267	-0.206
	(0.207)	(0.209)	(0.210)	(0.211)	(0.210)	(0.172)
ICT Ratio × ICT — two year LAG	0.239	0.236	0.229	0.213	0.214	0.309
	(0.234)	(0.237)	(0.239)	(0.241)	(0.241)	(0.194)
Domestic aggregate variables						
ICT— Inter-industry	0.001	-0.002	0.003	0.003	0.003	0.029
	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)[a]
R&D— Inter-industry	0.014	0.015	0.014	0.009	0.009	0.009
	(0.005)[a]	(0.005)[a]	(0.005)[a]	(0.005)[c]	(0.005)[c]	(0.005)[c]
Foreign variables						
ICT— Intra-industry		-0.034	-0.030	-0.030	-0.031	0.028
		(0.008)[a]	(0.009)[a]	(0.009)[a]	(0.009)[a]	(0.009)[a]
ICT— Inter-industry			0.095	0.083	0.137	0.250
			(0.062)	(0.063)	(0.100)	(0.057)[a]
R&D — Intra-industry		0.007	0.007	0.004	0.004	
		(0.003)[b]	(0.003)[a]	(0.003)	(0.003)	
R&D — Inter-industry				-0.246	-0.146	
				(0.053)[a]	(0.153)	
ICT— Inter-industry × R&D — Inter-industry					-0.009	
					(0.013)	
R-Square	0.03	0.03	0.03	0.03	0.03	0.03
N	8201	8201	8201	8201	8201	9151

The dependent variable is the TFP log difference, where TFP is computed based on gross output. All other variables are as defined in Tables 3 and 4.

a=significant at the 1% level; b=significant at the 5% level; c=significant at the 10% level.

All regressions include only year fixed effects.

Appendix A: Data summary

Table A1: Data availability (Number of Observation)

Country	Name	Value added	Labor	ICT Capital	Non-ICT Capital	R&D	
1	Australia (AUS)	768	768	768	768	672	
2	Belgium (BEL)	768	768	768	768	**411**	
3	Canada (CAN)	768	768	600	600	718	
4	Denmark (DNK)	768	768	768	768	640	
5	Finland (FIN)	768	768	764	768	664	
6	France (FRA)	768	768	768	768	562	
7	Germany (GER)	768	768	768	768	665	
8	Ireland (IRL)	768	768	**240**	**240**	527	
9	Italy (ITA)	768	768	768	768	700	
10	Japan (JPN)	768	768	768	768	545	
11	S. Korea (KOR)	768	768	672	672	**201**	
12	Netherlands (NLD)	768	768	768	768	661	
13	Spain (SPN)	768	768	768	768	715	
14	Sweden (SWE)	768	768	**288**	**288**	536	
15	UK	768	768	768	768	574	
16	US	768	768	768	768	736	
International Standard Industrial Classification -3							
1	15-16	512	512	459	459	476	1. Food , beverages and tobacco
2	17-19	512	512	457	459	272	2. Textiles, textile products , leather and footwear
3	20	512	512	459	459	438	3. Wood and products of wood and cork
4	21-22	512	512	459	459	458	4. Pulp, paper, paper products, printing & publishing
5	23	512	512	459	459	412	5. Coke, refined petroleum and nuclear fuel
6	24	512	512	459	459	476	6. Chemicals and chemical products
7	25	512	512	459	459	475	7. Rubber and plastic products
8	26	512	512	459	459	476	8. Other non-metallic mineral products
9	27-28	512	512	459	459	476	9. Basic metals and fabricated metal products
10	29	512	512	459	459	476	10. Machinery, not else classified (nec)
11	30-33	512	512	459	459	476	11. Electrical and optical equipment
12	34-35	512	512	459	459	475	12. Transport equipment
13	36-37	512	512	459	459	450	13. Manufacturing nec; recycling
14	E	512	512	459	459	423	14. Electricity, gas and water supply
15	F	512	512	459	459	429	15. Construction
16	51	512	512	459	459	305	16. Wholesale trade
17	50, 52	512	512	459	459	305	17. Retail trade
18	H	512	512	459	459	204	18. Hotels and restaurants
19	60 to 63	512	512	459	459	330	19. Transport and storage
20	64	512	512	459	459	345	20. Post and telecommunications
21	J	512	512	459	459	266	21. Financial intermediation
22	70	512	512	457	459	406	22. Real estate activities
23	71 to 74	512	512	459	459	406	23. Renting of m&eq and other business activities
24	L to Q	512	512	459	459	272	24. Community social and personal services

In this database the last category, "community, social and personal services" includes public administration and defence (ISIC 75), education (ISIC 80), health and social work (ISIC 85), other community, social and personal services (ISIC 90-93), private households with employed persons (95-97) and extra-territorial organizations and bodies (ISIC 99). The group of all these services can be considered as non-market services.

Table A2: Value added (in billons of US $ PPP), 1973-2004

Country	AUS	BEL	CAN	DNK	FIN	FRA	GER	IRL	ITA	JPN	KOR	NLD	SPN	SWE	UK	US	Industry share
Industry																	
1	8.8	4.9	13.2	3.9	1.8	20.8	39.5	2.6	17.3	44.5	3.8	9.0	14.2	2.9	22.6	122.6	**2.2**
2	2.3	2.3	3.9	0.6	0.6	8.9	9.7	0.4	22.0	27.8	6.0	1.4	8.7	0.4	9.4	48.1	**1.0**
3	1.7	0.4	6.0	0.5	1.3	3.3	7.1	0.2	5.6	7.0	0.8	0.4	3.4	1.8	1.7	38.8	**0.5**
4	4.8	2.7	16.1	2.3	5.7	16.9	29.9	1.8	11.8	43.7	3.0	4.5	8.2	8.2	18.7	160.9	**2.2**
5	0.4	0.7	1.0	0.0	0.2	1.6	18.2	0.0	2.9	21.1	2.0	0.7	2.3	0.1	4.0	14.9	**0.5**
6	2.6	6.7	9.4	1.8	1.8	15.7	39.1	6.3	17.1	40.5	15.5	10.4	10.2	4.5	19.1	141.4	**2.3**
7	1.3	1.9	3.5	0.9	0.7	11.7	20.5	0.4	15.8	22.1	3.5	1.8	6.2	1.0	11.7	47.6	**1.0**
8	2.7	2.6	3.0	1.2	0.8	9.2	20.5	0.6	18.4	20.8	4.6	2.3	10.9	0.9	8.5	35.9	**0.9**
9	7.8	6.2	12.3	1.6	2.4	46.7	49.8	0.6	42.3	89.0	8.8	6.1	18.5	5.5	22.5	133.5	**3.0**
10	2.1	2.5	7.3	2.5	2.2	12.5	56.2	0.4	29.2	59.7	5.1	2.7	6.6	4.0	21.4	117.8	**2.2**
11	1.7	3.3	5.4	1.1	2.7	17.9	44.7	2.0	13.2	86.8	19.2	3.3	5.4	5.6	18.3	239.5	**3.1**
12	3.4	2.5	14.1	0.4	0.5	13.7	37.7	0.2	10.6	62.1	8.9	1.6	9.0	3.0	13.7	143.4	**2.1**
13	1.8	1.6	3.8	1.6	0.7	6.0	12.8	0.3	13.1	14.4	2.2	2.7	5.1	0.8	12.7	42.0	**0.8**
14	7.5	3.4	17.6	1.4	2.0	13.7	22.0	0.4	16.3	35.7	4.9	3.1	8.0	5.7	15.6	174.6	**2.2**
15	23.0	9.8	38.3	5.0	7.8	47.4	87.7	2.9	62.8	191.9	34.4	13.1	39.9	6.9	45.0	315.5	**6.2**
16	12.0	14.6	25.4	7.6	5.9	40.8	100.0	1.9	34.3	89.9	9.4	22.0	20.6	7.1	30.3	322.0	**4.9**
17	20.8	11.8	30.2	8.8	4.6	63.7	88.3	3.8	64.0	118.6	11.2	17.6	38.0	9.5	60.6	359.3	**6.0**
18	5.4	2.3	11.8	1.4	0.8	22.0	21.3	1.0	21.7	41.9	5.9	4.3	23.1	1.1	15.0	144.5	**2.1**
19	16.8	5.7	24.8	4.2	4.9	30.0	32.7	1.3	28.0	91.6	13.6	17.8	17.1	6.2	33.2	192.6	**3.4**
20	7.5	4.5	17.5	2.4	1.7	26.8	39.1	1.0	17.0	36.6	6.6	5.5	8.5	8.6	52.5	134.0	**2.4**
21	27.7	13.1	32.2	5.8	2.9	54.6	67.4	4.2	51.0	119.3	21.5	20.7	29.4	6.4	70.0	376.9	**6.0**
22	27.2	20.0	53.9	12.7	6.2	95.2	148.1	3.4	128.1	154.2	21.1	19.5	47.8	15.1	67.4	744.9	**10.4**
23	17.1	11.5	22.4	5.1	2.9	66.3	103.5	3.2	62.3	69.7	12.6	18.3	20.0	9.2	66.1	587.5	**7.1**
24	75.4	51.6	162.4	33.2	22.5	291.0	383.1	11.9	223.4	548.7	93.0	92.3	136.9	48.0	265.8	1685.3	**27.3**
C-avg.	**11.7**	**7.8**	**22.3**	**4.4**	**3.5**	**39.0**	**61.6**	**2.1**	**38.7**	**84.9**	**13.2**	**11.7**	**20.7**	**6.8**	**37.7**	**263.5**	
C- share	**1.9**	**1.2**	**3.5**	**0.7**	**0.6**	**6.2**	**9.8**	**0.3**	**6.1**	**13.5**	**2.1**	**1.9**	**3.3**	**1.1**	**6.0**	**41.8**	**100**

1. Food , beverages and tobacco
2. Textiles, leather and footwear
3. Wood and products of wood and cork
4. Pulp, paper, printing & publishing
5. Coke, refined petroleum & nuclear fuel
6. Chemicals and chemical products
7. Rubber and plastics
8. Other non-metallic mineral
9. Basic metals & fabricated metal
10. Machinery, nec
11. Electrical and optical equip.
12. Transport equipment
13. Manufacturing nec; recycling
14. Electricity, gas & water supply
15. Construction
16. Wholesale trade
17. Retail trade
18. Hotels and restaurants
19. Transport and storage
20. Post and telecommunications
21. Financial intermediation
22. Real estate activities
23. Renting of M&E & other businesses
24. Community, social and personal services

Table A3: Employment in hours worked by persons engaged (in millons), 1973-2004

Country	AUS	BEL	CAN	DNK	FIN	FRA	GER	IRL	ITA	JPN	KOR	NLD	SPN	SWE	UK	US	Industry share
Industry																	
1	352	164	515	140	96	987	1768	110	888	3032	803	277	739	134	1070	3442	2.4
2	214	150	339	49	80	842	1095	40	1980	3224	2930	77	720	48	1045	3384	2.7
3	102	24	242	24	67	197	409	13	429	810	184	75	191	83	208	1490	0.8
4	235	90	487	86	140	580	1176	44	508	2334	514	220	309	196	927	4074	2.0
5	13	13	37	1	6	72	96	1	51	84	38	11	22	6	53	338	0.1
6	106	127	201	42	33	298	1026	40	447	914	466	134	289	64	621	2149	1.2
7	88	43	172	31	28	337	567	20	315	1403	490	50	158	47	533	1697	1.0
8	127	72	117	40	34	319	658	23	515	1250	456	75	348	43	418	1145	0.9
9	399	233	514	88	89	1129	2018	35	1531	3679	996	230	685	223	1515	4484	3.0
10	177	86	268	115	106	728	2124	30	1040	2801	833	149	290	197	1019	3697	2.3
11	135	121	264	76	78	784	2091	90	873	4334	1535	199	300	162	1205	5666	3.0
12	232	107	414	38	50	750	1414	17	615	2242	885	113	475	181	1113	3670	2.0
13	156	69	247	55	37	386	657	24	581	1533	473	150	352	81	478	1741	1.2
14	183	51	159	26	38	269	603	29	258	544	136	65	137	53	389	1574	0.7
15	1137	390	1541	282	368	3320	4835	201	2840	12459	3051	726	2409	479	3874	12577	8.4
16	819	329	1240	253	178	1543	2897	83	1885	7360	3893	662	803	363	2242	11627	6.0
17	1846	514	2740	390	365	3689	5504	259	5142	14661	3081	993	2966	528	5237	25168	12.1
18	518	147	1337	100	123	1331	1928	135	2000	7881	3059	308	1473	176	1825	11571	5.6
19	753	326	1015	225	236	1605	2926	93	1995	6419	1994	520	1146	364	2212	7193	4.8
20	274	140	389	81	71	611	807	45	545	1029	259	143	294	112	965	2470	1.4
21	524	218	937	126	86	1141	1847	76	886	3341	1010	364	562	122	1603	9289	3.7
22	154	21	153	49	55	397	405	12	127	1467	481	90	121	98	432	2722	1.1
23	989	469	1251	256	190	3553	3621	137	2289	6792	1165	1037	1132	427	4717	19056	7.8
24	3193	1713	6488	1315	1018	10047	14222	551	8491	20687	6049	2685	5311	2243	10726	61416	25.9
C-avg.	**530**	**234**	**878**	**162**	**149**	**1455**	**2279**	**88**	**1510**	**4595**	**1449**	**390**	**885**	**268**	**1851**	**8402**	
C- share	**2.1**	**0.93**	**3.5**	**0.64**	**0.59**	**5.8**	**9.1**	**0.35**	**6.0**	**18.3**	**5.8**	**1.6**	**3.5**	**1.1**	**7.4**	**33.4**	**100**

1. Food , beverages and tobacco
2. Textiles, leather and footwear
3. Wood and products of wood and cork
4. Pulp, paper, printing & publishing
5. Coke, refined petroleum & nuclear fuel
6. Chemicals and chemical products
7. Rubber and plastics
8. Other non-metallic mineral
9. Basic metals & fabricated metal
10. Machinery, nec
11. Electrical and optical equip.
12. Transport equipment
13. Manufacturing nec; recycling
14. Electricity, gas & water supply
15. Construction
16. Wholesale trade
17. Retail trade
18. Hotels and restaurants
19. Transport and storage
20. Post and telecommunications
21. Financial intermediation
22. Real estate activities
23. Renting of M&E & other businesses
24. Community, social and personal services

Table A4: R&D stock (in million of US $ PPP), 1973-2004

Country	AUS	BEL	CAN	DNK	FIN	FRA	GER	IRL	ITA	JPN	KOR	NLD	SPN	SWE	UK	US	Industry share
Industry																	
1	416	273	444	298	165	1043	1275	137	219	3319	253	1004	247	347	1713	7730	**1.5**
2	56	186	187	12	29	277	491	29	90	2415	155	52	131	23	139	1525	**0.5**
3	35	18	115	13	53	58	332	6	20	575	12	7	8	40	21	1705	**0.2**
4	159	161	673	24	440	315	426	14	38	2429	125	51	83	965	214	7911	**1.1**
5	24	99	586		39	353	2619		354	1923	301	516	215	21	2582	7021	**1.6**
6	755	5273	2017	1363	886	12507	27739	333	5067	28822	4612	6361	1464	3551	14409	81704	**16.1**
7	84	413	130	81	117	1999	2497	40	1217	5455	501	171	396	195	652	7038	**1.7**
8	161	286	89	112	92	1429	1649	29	167	4965	394	77	253	143	823	4197	**1.2**
9	593	730	1008	87	300	4602	4525	37	1120	14580	723	454	350	949	1533	12213	**3.6**
10	338	636	684	602	643	2268	15698	39	1752	20128	1350	498	471	1926	5298	22710	**6.1**
11	969	3006	5695	601	1787	16915	29501	408	4637	66696	19245	4554	1329	5773	13132	156581	**27.0**
12	659	430	3036	79	80	17242	26739	16	6193	28880	7540	510	1440	2430	11933	194897	**24.7**
13	46	122	137	480	33	261	286	18	157	1593	163	49	70	46	1099	3530	**0.7**
14	134	55	1044	7	115	1308	469	4	958	1726	521	31	172	389	757	1086	**0.7**
15	74	173	65	30	69	500	391	1	331	5213	1708	135	110	78	142	1187	**0.8**
16	445	94	953	367	51	-	582	5	96	41	43	302	30	29	129	42932	**4.0**
17	33	5	55	37	3	-	36	0	9	4	3	18	2	2	14	2469	**0.2**
18	7	4	3	3	0	-	6	0	1	4	-	1	0	-	1	553	**0.1**
19	71	51	155		13	118	636	5	10	979	47	37	39	5	18	1651	**0.3**
20	383	122	603	175	178	2921	-	50	161	-	1555	256	318	1450	4547	7428	**1.9**
21	445	117	533	87	6	-	77	7	115	4	10	105	21	165	25	5812	**0.7**
22	83	94	232	83	11	152	209	14	201	519	150	49	90	131	505	3373	**0.5**
23	751	549	2246	571	83	1233	1780	108	1946	4251	1437	532	609	1007	4376	35125	**4.6**
24	48	35	4	4	19	-	24	1	30	0	157	261	53	34	96	57	**0.1**
C-avg.	**282**	**539**	**862**	**232**	**217**	**3447**	**5130**	**57**	**1037**	**8457**	**1783**	**668**	**329**	**857**	**2673**	**25435**	
C- share	**0.54**	**1.0**	**1.7**	**0.45**	**0.42**	**6.6**	**9.9**	**0.11**	**2.0**	**16.3**	**3.4**	**1.3**	**0.63**	**1.6**	**5.1**	**48.9**	**100**

1. Food , beverages and tobacco
2. Textiles, leather and footwear
3. Wood and products of wood and cork
4. Pulp, paper, printing & publishing
5. Coke, refined petroleum & nuclear fuel
6. Chemicals and chemical products
7. Rubber and plastics
8. Other non-metallic mineral
9. Basic metals & fabricated metal
10. Machinery, nec
11. Electrical and optical equip.
12. Transport equipment
13. Manufacturing nec; recycling
14. Electricity, gas & water supply
15. Construction
16. Wholesale trade
17. Retail trade
18. Hotels and restaurants
19. Transport and storage
20. Post and telecommunications
21. Financial intermediation
22. Real estate activities
23. Renting of M&E & other businesses
24. Community, social and personal services

Table A5: Information and communication technology (ICT) capital stock in real price (in millions of US $ PPP), 1973-2004

Country	AUS	BEL	CAN	DNK	FIN	FRA	GER	IRL	ITA	JPN	KOR	NLD	SPN	SWE	UK	US	Industry share
Industry																	
1	1038	157	245	169	113	2075	1428	272	576	753	276	514	1123	556	1141	5772	**1.0**
2	98	75	37	24	13	325	323	22	948	428	181	53	434	11	350	1336	**0.3**
3	46	13	75	29	53	136	197	10	926	61	11	14	147	212	92	656	**0.2**
4	573	226	287	237	409	1233	3125	253	1015	1621	143	435	783	1445	1440	9332	**1.4**
5	49	38	70	18	15	550	361	4	143	220	184	528	130	132	104	2370	**0.3**
6	132	309	211	124	105	1418	2497	287	3900	2770	729	650	854	529	1628	11995	**1.8**
7	52	119	71	50	25	689	810	52	694	435	281	120	461	85	868	1307	**0.4**
8	331	67	56	49	44	629	1117	66	633	452	246	102	1148	30	382	1868	**0.5**
9	534	240	248	94	118	1384	1971	55	1577	3612	508	384	1254	933	743	6402	**1.3**
10	114	100	89	200	162	730	2912	36	1765	4200	376	233	317	590	1432	10722	**1.5**
11	204	257	217	219	202	3757	3989	315	2105	12199	2065	707	854	809	2196	22271	**3.4**
12	247	59	332	26	20	1858	3030	18	777	3287	903	139	635	1220	967	11914	**1.6**
13	88	44	44	128	30	329	491	41	1252	572	88	84	260	75	491	2804	**0.4**
14	2255	160	1431	57	161	3924	2987	140	507	3935	162	291	1126	608	2319	15962	**2.3**
15	1247	95	481	170	190	1162	1831	130	1683	3146	881	349	506	255	724	9553	**1.4**
16	1324	905	1341	868	610	2626	7958	224	1394	3717	122	2270	999	1365	4481	34563	**4.2**
17	2172	224	1085	968	398	1749	6585	674	2404	7756	358	1139	1815	1827	6226	28990	**4.1**
18	445	67	273	158	23	645	1468	441	489	419	65	91	405	72	751	4087	**0.6**
19	3300	1073	1440	562	529	2004	6231	357	15292	5001	290	2147	9071	1043	2541	47352	**6.3**
20	3226	1947	24446	485	833	5577	17811	418	8784	34550	4264	4371	3808	12322	42039	197116	**23.2**
21	5998	1496	4293	924	633	6093	10959	334	6956	13676	3509	4843	4635	1746	14019	97597	**11.4**
22	911	1093	1512	449	33	607	1153	268	707	424	17	251	817	11	1839	8671	**1.2**
23	2414	718	2336	1900	511	8995	21835	566	6112	23721	6377	2538	2565	4129	13734	116232	**13.8**
24	9354	1073	8216	2395	1738	10932	22930	2834	9435	48643	7471	7886	10614	3395	18782	102779	**17.2**
C-avg.	**1506**	**440**	**2035**	**429**	**290**	**2476**	**5167**	**326**	**2920**	**7316**	**1229**	**1256**	**1865**	**1392**	**4970**	**31319**	
C- share	**2.3**	**0.7**	**3.1**	**0.7**	**0.4**	**3.8**	**8.0**	**0.5**	**4.5**	**11.3**	**1.9**	**1.9**	**2.9**	**2.1**	**7.7**	**48.2**	**100**

1. Food , beverages and tobacco
2. Textiles, leather and footwear
3. Wood and products of wood and cork
4. Pulp, paper, printing & publishing
5. Coke, refined petroleum & nuclear fuel
6. Chemicals and chemical products
7. Rubber and plastics
8. Other non-metallic mineral
9. Basic metals & fabricated metal
10. Machinery, nec
11. Electrical and optical equip.
12. Transport equipment
13. Manufacturing nec; recycling
14. Electricity, gas & water supply
15. Construction
16. Wholesale trade
17. Retail trade
18. Hotels and restaurants
19. Transport and storage
20. Post and telecommunications
21. Financial intermediation
22. Real estate activities
23. Renting of M&E & other businesses
24. Community, social and personal services

Table A6: Non-information and communication technology (NICT) capital stock in real price (in billions of US $ PPP), 1973-2004

Country	AUS	BEL	CAN	DNK	FIN	FRA	GER	IRL	ITA	JPN	KOR	NLD	SPN	SWE	UK	US	Industry share
Industry																	
1	12.0	10.0	13.3	6.6	3.3	44.5	60.9	4.2	37.2	43.1	6.9	16.7	31.1	4.9	30.1	142.9	1.1
2	1.8	4.6	3.2	1.2	0.8	7.0	9.6	0.3	40.7	52.0	10.5	2.2	12.1	0.6	9.4	53.8	0.5
3	1.9	1.7	7.5	0.7	2.1	2.9	8.1	0.3	17.6	9.7	1.4	0.5	4.5	3.9	2.8	30.4	0.2
4	4.5	4.2	24.2	2.7	9.8	16.9	32.8	0.9	20.0	62.5	5.2	5.9	12.9	14.3	18.1	139.7	0.9
5	1.9	1.6	11.3	0.6	1.0	9.1	11.6	0.0	4.8	19.0	4.2	2.6	3.9	0.6	8.8	73.0	0.4
6	5.5	9.1	16.6	3.7	3.9	27.3	66.4	6.7	59.9	108.9	25.9	22.5	22.3	6.7	39.4	159.8	1.4
7	2.2	5.4	3.5	1.3	0.9	11.5	23.8	0.9	40.0	43.8	7.3	2.9	11.0	2.0	18.7	50.5	0.5
8	4.3	6.3	4.5	1.7	1.4	12.3	29.8	2.1	37.2	34.9	14.6	4.0	28.0	1.6	8.0	45.5	0.6
9	14.6	11.2	23.2	2.1	4.1	37.9	63.8	0.7	107.2	243.8	25.5	10.0	45.1	8.3	28.5	181.0	1.9
10	1.7	2.7	3.6	2.6	2.1	13.4	44.5	0.5	62.9	102.6	7.8	2.8	6.0	5.6	21.0	76.8	0.8
11	2.3	3.3	4.1	1.0	1.3	22.3	44.3	4.3	17.6	162.0	33.0	6.2	7.7	4.3	16.7	165.2	1.2
12	4.6	3.1	15.5	0.4	0.9	31.4	49.8	0.4	27.3	173.1	19.3	3.4	12.2	5.7	18.8	128.8	1.2
13	1.0	4.4	1.7	2.0	0.9	5.9	13.6	0.4	28.0	21.2	2.3	3.5	6.3	1.3	8.0	48.0	0.4
14	76.8	19.2	168.4	10.4	13.2	92.2	104.0	11.6	97.8	318.1	52.2	29.0	39.8	53.0	65.3	789.7	4.6
15	12.2	8.4	14.6	3.2	3.8	23.9	33.6	1.6	49.1	90.9	53.4	6.8	38.7	6.0	13.7	110.8	1.1
16	14.2	23.7	9.4	7.5	7.1	37.5	53.7	1.9	28.1	105.9	7.3	24.3	30.3	8.0	19.4	189.7	1.4
17	19.0	5.9	21.5	9.3	5.0	88.6	54.2	6.6	53.3	180.8	17.2	21.1	59.7	10.8	62.0	520.5	2.7
18	9.9	5.4	14.5	1.8	0.9	30.5	26.1	4.0	29.2	89.7	11.0	4.7	19.4	1.8	23.6	222.4	1.2
19	115.4	24.8	112.1	16.0	26.4	89.3	118.5	3.4	74.6	435.6	79.9	65.5	62.2	31.4	83.7	531.9	4.5
20	23.0	45.0	38.2	8.6	4.3	65.2	86.8	5.0	36.9	120.6	11.3	10.6	9.1	45.1	77.6	366.2	2.3
21	40.7	23.1	26.1	5.3	1.4	55.4	92.2	3.0	105.2	73.2	16.7	36.9	19.5	4.9	63.2	329.0	2.1
22	322.9	196.9	70.6	324.7	111.6	2491.8	2769.6	99.1	130.8	1484.7	423.3	502.0	1292.8	146.0	1031.4	7383.4	44.7
23	15.4	129.3	3.0	3.6	1.5	52.8	89.9	4.6	762.6	92.9	242.4	12.3	8.7	8.5	32.0	201.6	4.0
24	148.8	94.2	365.8	75.2	40.5	897.9	1119.8	36.0	545.4	1254.2	338.0	335.9	295.1	83.0	540.6	2428.5	20.5
C-avg.	**35.7**	**26.8**	**40.7**	**20.5**	**10.3**	**173.6**	**208.6**	**8.3**	**100.6**	**221.8**	**59.0**	**47.2**	**86.6**	**19.1**	**93.4**	**598.7**	
C- share	**2.0**	**1.5**	**2.3**	**1.2**	**0.6**	**9.9**	**11.9**	**0.5**	**5.7**	**12.7**	**3.4**	**2.7**	**4.9**	**1.1**	**5.3**	**34.2**	**100**

1. Food , beverages and tobacco
2. Textiles, leather and footwear
3. Wood and products of wood and cork
4. Pulp, paper, printing & publishing
5. Coke, refined petroleum & nuclear fuel
6. Chemicals and chemical products
7. Rubber and plastics
8. Other non-metallic mineral
9. Basic metals & fabricated metal
10. Machinery, nec
11. Electrical and optical equip.
12. Transport equipment
13. Manufacturing nec; recycling
14. Electricity, gas & water supply
15. Construction
16. Wholesale trade
17. Retail trade
18. Hotels and restaurants
19. Transport and storage
20. Post and telecommunications
21. Financial intermediation
22. Real estate activities
23. Renting of M&E & other businesses
24. Community, social and personal services

Table A7: Share of information and communication technology (ICT) in total capital stock, 1973-2004

Country	AUS	BEL	CAN	DNK	FIN	FRA	GER	IRL	ITA	JPN	KOR	NLD	SPN	SWE	UK	US	Industry Average
Industry																	
1	8.0	1.5	1.8	2.5	3.3	4.5	2.3	6.1	1.5	1.7	3.8	3.0	3.5	10.2	3.7	3.9	3.3
2	5.2	1.6	1.1	2.0	1.6	4.4	3.3	6.8	2.3	0.8	1.7	2.4	3.5	1.8	3.6	2.4	2.2
3	2.4	0.8	1.0	4.0	2.5	4.5	2.4	3.2	5.0	0.6	0.8	2.7	3.2	5.2	3.2	2.1	2.7
4	11.3	5.1	1.2	8.1	4.0	6.8	8.7	21.9	4.8	2.5	2.7	6.9	5.7	9.2	7.4	6.3	5.7
5	2.5	2.3	0.6	2.9	1.5	5.7	3.0	100.0	2.9	1.1	4.2	16.9	3.2	18.0	1.2	3.1	3.1
6	2.3	3.3	1.3	3.2	2.6	4.9	3.6	4.1	6.1	2.5	2.7	2.8	3.7	7.3	4.0	7.0	4.6
7	2.3	2.2	2.0	3.7	2.7	5.7	3.3	5.5	1.7	1.0	3.7	4.0	4.0	4.1	4.4	2.5	2.6
8	7.1	1.1	1.2	2.8	3.0	4.9	3.6	3.0	1.7	1.3	1.7	2.5	3.9	1.8	4.6	3.9	3.0
9	3.5	2.1	1.1	4.3	2.8	3.5	3.0	7.3	1.4	1.5	2.0	3.7	2.7	10.1	2.5	3.4	2.4
10	6.3	3.6	2.4	7.1	7.2	5.2	6.1	6.7	2.7	3.9	4.6	7.7	5.0	9.5	6.4	12.3	6.3
11	8.1	7.2	5.0	18.0	13.4	14.4	8.3	6.8	10.7	7.0	5.9	10.2	10.0	15.8	11.6	11.9	9.6
12	5.1	1.9	2.1	6.1	2.2	5.6	5.7	4.3	2.8	1.9	4.5	3.9	4.9	17.6	4.9	8.5	4.9
13	8.1	1.0	2.5	6.0	3.2	5.3	3.5	9.3	4.3	2.6	3.7	2.3	4.0	5.5	5.8	5.5	4.4
14	2.9	0.8	0.8	0.5	1.2	4.1	2.8	1.2	0.5	1.2	0.3	1.0	2.8	1.1	3.4	2.0	1.8
15	9.3	1.1	3.2	5.0	4.8	4.6	5.2	7.5	3.3	3.3	1.6	4.9	1.3	4.1	5.0	7.9	4.5
16	8.5	3.7	12.5	10.4	7.9	6.5	12.9	10.5	4.7	3.4	1.6	8.5	3.2	14.6	18.8	15.4	10.2
17	10.3	3.7	4.8	9.4	7.4	1.9	10.8	9.3	4.3	4.1	2.0	5.1	3.0	14.5	9.1	5.3	5.4
18	4.3	1.2	1.8	8.1	2.5	2.1	5.3	9.9	1.6	0.5	0.6	1.9	2.0	3.8	3.1	1.8	2.0
19	2.8	4.1	1.3	3.4	2.0	2.2	5.0	9.5	17.0	1.1	0.4	3.2	12.7	3.2	2.9	8.2	5.0
20	12.3	4.1	39.0	5.3	16.2	7.9	17.0	7.7	19.2	22.3	27.4	29.2	29.5	21.5	35.1	35.0	27.5
21	12.8	6.1	14.1	14.8	31.1	9.9	10.6	10.0	6.2	15.7	17.4	11.6	19.2	26.3	18.2	22.9	16.6
22	0.3	0.6	2.1	0.1	0.0	0.0	0.0	0.3	0.5	0.0	0.0	0.0	0.1	0.0	0.2	0.1	0.1
23	13.6	0.6	43.8	34.5	25.4	14.6	19.5	11.0	0.8	20.3	2.6	17.1	22.8	32.7	30.0	36.6	11.4
24	5.9	1.1	2.2	3.1	4.1	1.2	2.0	7.3	1.7	3.7	2.2	2.3	3.5	3.9	3.4	4.1	3.0
Mean	4.0	1.6	4.8	2.1	2.7	1.4	2.4	3.8	2.8	3.2	2.0	2.6	2.1	6.8	5.1	5.0	3.6
Median	6.1	2.0	2.0	4.7	3.1	4.9	4.3	7.3	2.8	2.2	2.4	3.8	3.6	8.2	4.5	5.4	4.5

1. Food , beverages and tobacco
2. Textiles, leather and footwear
3. Wood and products of wood and cork
4. Pulp, paper, printing & publishing
5. Coke, refined petroleum & nuclear fuel
6. Chemicals and chemical products
7. Rubber and plastics
8. Other non-metallic mineral
9. Basic metals & fabricated metal
10. Machinery, nec
11. Electrical and optical equip.
12. Transport equipment
13. Manufacturing nec; recycling
14. Electricity, gas & water supply
15. Construction
16. Wholesale trade
17. Retail trade
18. Hotels and restaurants
19. Transport and storage
20. Post and telecommunications
21. Financial intermediation
22. Real estate activities
23. Renting of M&E & other businesses
24. Community, social and personal services

Table A8: ICT capital stock-value added ratio (in percent), 1973-2004

Country	AUS	BEL	CAN	DNK	FIN	FRA	GER	IRL	ITA	JPN	KOR	NLD	SPN	SWE	UK	US	Industry average
Industry																	
1	11.8	3.2	1.9	4.3	6.3	10.0	3.6	10.4	3.3	1.7	7.3	5.7	7.9	19.4	5.1	4.7	**4.9**
2	4.3	3.3	1.0	3.7	2.2	3.7	3.3	5.6	4.3	1.5	3.0	3.7	5.0	2.8	3.7	2.8	**3.1**
3	2.7	3.4	1.3	6.0	4.1	4.2	2.8	5.9	16.7	0.9	1.4	3.9	4.4	12.0	5.4	1.7	**3.4**
4	12.0	8.2	1.8	10.3	7.2	7.3	10.5	14.4	8.6	3.7	4.7	9.6	9.6	17.6	7.7	5.8	**6.7**
5	11.2	5.4	6.8	40.4	7.9	34.4	2.0	15.8	4.9	1.0	9.0	80.0	5.8	103.0	2.6	15.9	**7.0**
6	5.0	4.6	2.2	6.9	6.0	9.0	6.4	4.6	22.9	6.8	4.7	6.2	8.4	11.7	8.5	8.5	**8.2**
7	4.0	6.2	2.0	5.3	3.8	5.9	3.9	12.6	4.4	2.0	8.1	6.5	7.5	8.4	7.4	2.7	**4.1**
8	12.1	2.6	1.9	4.2	5.7	6.8	5.5	11.2	3.4	2.2	5.4	4.5	10.6	3.2	4.5	5.2	**5.1**
9	6.9	3.9	2.0	5.8	5.0	3.0	4.0	9.7	3.7	4.1	5.8	6.3	6.8	17.1	3.3	4.8	**4.4**
10	5.5	4.0	1.2	8.1	7.2	5.8	5.2	9.0	6.0	7.0	7.4	8.7	4.8	14.9	6.7	9.1	**7.2**
11	12.1	7.7	4.0	19.8	7.4	21.0	8.9	16.1	15.9	14.1	10.7	21.3	15.9	14.6	12.0	9.3	**11.1**
12	7.4	2.4	2.4	6.9	3.8	13.6	8.0	11.2	7.3	5.3	10.2	8.7	7.1	40.0	7.1	8.3	**7.8**
13	4.9	2.7	1.2	7.8	4.1	5.5	3.8	15.4	9.5	4.0	4.0	3.2	5.1	9.4	3.9	6.7	**5.6**
14	29.9	4.7	8.1	4.1	8.1	28.5	13.6	31.2	3.1	11.0	3.3	9.5	14.0	10.6	14.9	9.1	**10.9**
15	5.4	1.0	1.3	3.4	2.4	2.5	2.1	4.5	2.7	1.6	2.6	2.7	1.3	3.7	1.6	3.0	**2.4**
16	11.0	6.2	5.3	11.4	10.3	6.4	8.0	11.5	4.1	4.1	1.3	10.3	4.8	19.3	14.8	10.7	**8.7**
17	10.4	1.9	3.6	11.0	8.6	2.7	7.5	17.9	3.8	6.5	3.2	6.5	4.8	19.3	10.3	8.1	**7.1**
18	8.3	2.9	2.3	11.3	2.9	2.9	6.9	45.6	2.3	1.0	1.1	2.1	1.8	6.4	5.0	2.8	**3.1**
19	19.6	18.7	5.8	13.2	10.8	6.7	19.1	27.2	54.5	5.5	2.1	12.0	53.1	16.7	7.6	24.6	**18.9**
20	43.0	43.0	139.8	20.5	49.3	20.8	45.5	41.8	51.6	94.4	64.7	80.2	44.8	142.7	80.1	147.1	**97.9**
21	21.6	11.4	13.3	16.0	21.7	11.2	16.3	8.0	13.6	11.5	16.3	23.4	15.7	27.4	20.0	25.9	**19.7**
22	3.3	5.5	2.8	3.5	0.5	0.6	0.8	8.0	0.6	0.3	0.1	1.3	1.7	0.1	2.7	1.2	**1.2**
23	14.1	6.2	10.4	37.5	17.7	13.6	21.1	17.7	9.8	34.0	50.8	13.9	12.9	45.0	20.8	19.8	**19.9**
24	12.4	2.1	5.1	7.2	7.7	3.8	6.0	23.8	4.2	8.9	8.0	8.5	7.8	7.1	7.1	6.1	**6.5**
C-avg.	**12.8**	**5.7**	**9.1**	**9.7**	**8.3**	**6.3**	**8.4**	**15.5**	**7.5**	**8.6**	**9.3**	**10.7**	**9.0**	**20.6**	**13.2**	**11.9**	

1. Food , beverages and tobacco
2. Textiles, leather and footwear
3. Wood and products of wood and cork
4. Pulp, paper, printing & publishing
5. Coke, refined petroleum & nuclear fuel
6. Chemicals and chemical products
7. Rubber and plastics
8. Other non-metallic mineral
9. Basic metals & fabricated metal
10. Machinery, nec
11. Electrical and optical equip.
12. Transport equipment
13. Manufacturing nec; recycling
14. Electricity, gas & water supply
15. Construction
16. Wholesale trade
17. Retail trade
18. Hotels and restaurants
19. Transport and storage
20. Post and telecommunications
21. Financial intermediation
22. Real estate activities
23. Renting of M&E & other businesses
24. Community, social and personal services

Table A9: R&D expenditure intensity in value added (in percent), 1973-2004

Country	AUS	BEL	CAN	DNK	FIN	FRA	GER	IRL	ITA	JPN	KOR	NLD	SPN	SWE	UK	US	Industry average
Industry																	
1	0.98	1.41	0.54	1.59	1.87	1.00	0.59	1.04	0.28	1.45	2.15	2.02	0.42	1.87	1.21	1.09	**1.04**
2	0.58	1.94	1.16	0.45	1.14	0.76	1.28	1.56	0.14	1.71	0.85	0.89	0.47	1.17	0.31	0.70	**0.85**
3	0.37	0.92	0.41	0.48	0.88	0.35	0.80	1.58	0.08	1.59	0.53	0.28	0.09	0.52	0.32	0.71	**0.67**
4	0.75	1.23	0.87	0.29	1.43	0.29	0.28	0.15	0.07	0.86	1.09	0.24	0.24	2.02	0.28	0.99	**0.80**
5	1.48	2.87	8.92	0.00	4.08	6.17	2.05	0.00	1.69	1.34	4.44	9.31	1.17	3.64	9.40	8.42	**4.47**
6	4.99	19.34	5.09	19.05	11.62	16.50	13.22	1.46	5.79	16.35	10.25	11.50	3.56	19.17	16.29	10.31	**11.58**
7	1.21	5.61	0.79	1.85	4.01	5.05	2.45	2.29	1.42	4.88	4.58	1.86	1.36	3.44	0.90	2.56	**2.81**
8	1.13	2.50	0.44	1.41	2.07	2.39	1.58	1.02	0.20	4.30	2.52	0.68	0.48	2.13	1.30	1.81	**1.81**
9	1.53	2.85	1.55	0.96	2.81	1.41	1.59	1.29	0.47	2.93	2.48	1.44	0.44	2.80	0.97	1.46	**1.66**
10	3.06	5.92	1.95	5.01	5.79	4.20	4.89	2.50	1.33	7.23	9.35	4.72	1.85	9.01	4.42	3.32	**4.38**
11	11.45	21.04	25.05	12.77	23.11	19.14	12.14	5.79	7.04	21.14	41.42	26.56	5.34	37.11	12.75	18.14	**18.77**
12	4.69	4.26	4.46	2.47	3.15	21.95	14.33	1.90	10.01	10.47	26.78	5.94	3.67	18.99	14.08	22.10	**16.60**
13	0.52	1.71	0.80	4.47	1.31	1.13	0.51	1.22	0.19	2.12	2.32	0.51	0.39	1.11	1.17	1.52	**1.23**
14	0.32	0.46	0.95	0.17	1.20	1.80	0.37	0.31	0.81	0.98	2.96	0.22	0.48	1.33	0.88	0.10	**0.49**
15	0.10	0.42	0.04	0.11	0.23	0.16	0.08	0.01	0.06	0.44	1.50	0.17	0.06	0.28	0.06	0.07	**0.21**
16	0.89	0.17	0.94	0.94	0.20	0.00	0.10	0.11	0.10	0.16	0.17	0.49	0.08	0.09	0.41	3.23	**1.63**
17	0.04	0.01	0.04	0.07	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.03	0.00	0.01	0.02	0.16	**0.08**
18	0.05	0.08	0.01	0.06	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.02	0.09	**0.06**
19	0.12	0.24	0.10	0.00	0.07	0.09	0.46	0.10	0.02	0.14	0.10	0.07	0.05	0.03	0.05	0.18	**0.16**
20	1.58	1.06	0.90	2.22	3.30	3.32	0.00	1.19	0.21	0.00	8.35	1.00	1.09	4.04	2.15	1.05	**1.53**
21	0.53	0.22	0.37	0.87	0.07	0.00	0.02	0.10	0.12	0.01	0.02	0.19	0.08	1.52	0.06	0.33	**0.22**
22	0.11	0.13	0.13	0.18	0.09	0.04	0.05	0.17	0.04	0.22	0.29	0.08	0.05	0.22	0.17	0.14	**0.12**
23	1.52	1.33	2.75	3.07	1.47	0.40	0.50	1.38	0.67	4.15	4.57	0.67	0.72	2.59	1.35	1.51	**1.51**
24	0.02	0.02	0.00	0.00	0.04	0.00	0.00	0.01	0.00	0.00	0.06	0.05	0.02	0.05	0.01	0.00	**0.01**
C-avg.	0.58	1.69	0.87	1.22	1.69	1.76	1.58	0.73	0.51	2.42	4.98	1.12	0.38	3.32	1.34	2.01	

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7. Rubber and plastics
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9. Basic metals & fabricated metal
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Appendix B: Derivation of the estimating equation

We can write the production function (equation 1) in growth rates as:

(B1) $$\Delta q = \frac{F_{K^{IT}} K^{IT}}{Q} \Delta k^{IT} + \frac{F_C C}{Q} \Delta c + \frac{F_{K^{NT}} K^{NT}}{Q} \Delta k^{NT} + \frac{F_L L}{Q} \Delta l + \frac{F_Z Z}{Q} \Delta z$$

where $\Delta x = d \log X / dt$. If one assumes constant returns to scale and perfect competition, we will have

(B2) $$\frac{F_C C}{Q} + \frac{F_{K^{IT}} K^{IT}}{Q} + \frac{F_{K^{NT}} K^{NT}}{Q} + \frac{F_L L}{Q} = \frac{F_C C}{Q} + \frac{P_K^{IT} K^{IT}}{PQ} + \frac{P_K^{NT} K^{NT}}{PQ} + \frac{WL}{PQ} = 1 .$$

If we observed total output Q, and knew the required rates of return to capital, we could back out the elasticity of output with respect to complementary capital, C as follow:

(B3) $$\frac{F_C C}{Q} = 1 - \frac{WL}{PQ} - \frac{P_K^{IT} K^{IT}}{PQ} - \frac{P_K^{NT} K^{NT}}{PQ} .$$

Without independent information on the flow of A or the stock of C (perhaps from stock market valuations), one cannot implement this procedure using measured output, Y. Rewrite equation (B3) as:

$$\frac{F_C C}{Y} = \frac{Q}{Y} - \frac{WL}{PY} - \frac{P_K^{IT} K^{IT}}{PY} - \frac{P_K^{NT} K^{NT}}{PY} .$$

Since Q/Y is not observed, we cannot get away with this approach and hence we need to make an assumption regarding the use of intangible capital. We do that by assuming that observed growth in ICT capital provides a reasonable proxy for unobserved investment in, and growth in the stock of, complementary capital. Suppose G takes a CES form:[14]

$$G = [\alpha K^{IT\frac{\sigma-1}{\sigma}} + (1-\alpha) C^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}}$$

Consider the optimization sub-problem of producing G at minimum cost each period. Let $P_{K^{IT}} / P_C$ be the relative rental rate of ICT capital to C-capital. The first order condition of cost minimization implies that:

(B4) $$\left(C/K^{IT}\right)_t = \left(\frac{1-\alpha}{\alpha}\right)^{\sigma} \left(P_{K^{IT}}/P_C\right)_t^{\sigma} ,$$

(B4') $$\Delta c_t = \Delta k_t^{IT} + \sigma \Delta \ln(P_{K^{IT}} / P_C)_t$$

This equation links growth in complementary capital and growth of observed ICT capital.

We can use the accumulation equation to express unobserved investment Δa in terms of current and lagged growth in unobserved capital Δc: $\Delta a_t = (C/A)\left[\Delta c_t - \left((1-\delta_C)/(1+g)\right)\Delta c_{t-1}\right]$. Substituting this expression in equation (3) in the text, we have $\Delta TFP = \frac{F_C C}{Y}\Delta c_t - \frac{C}{Y}\left[\Delta c_t - \frac{(1-\delta_C)}{(1+g)}\Delta c_{t-1}\right] + s_Z \Delta z$. Substituting equation (B4') for Δc into this expression, we have in principle an equation for TFP growth that indicates the importance of complementary capital accumulation:

(B5) $$\Delta TFP_t = \left[\frac{F_C C}{Y} - \frac{C}{Y}\right]\left[\Delta k_t^{IT} + \sigma \Delta \ln\left(\frac{P_{K^{IT}}}{P_C}\right)_t\right] + \left[\frac{C}{Y}\frac{(1-\delta_C)}{(1+g)}\right]\left[\Delta k_{t-1}^{IT} + \sigma \Delta \ln\left(\frac{P_{K^{IT}}}{P_C}\right)_{t-1}\right] + s_Z \Delta z_t$$

As an estimating equation, (B5) has the difficulty in a sense that industries are likely to differ in their long-run C/Y ratios. Using equation (B4) and dividing both sides by Y and multiplying and dividing the right-hand side by $P_{K^{IT}} / P_C$ and P, we have

[14] Whether the ICT investment proxies intangible capital across countries and industries equally, as we assume in this paper, is an empirical issue. Furthermore, it is also possible that the intangible capital is compliment to non-ICT capital, along with ICT as we assume here. However, we don't expect these two assumptions to bias our results as the country, industry and time fixed effects that we will use in empirical estimation will capture these potential differences.

$$\frac{C}{Y}=\left(\frac{1-\alpha}{\alpha}\right)^{\sigma}\left(\frac{P}{P_C}\right)\left(\frac{P_{K^{IT}}}{P_C}\right)^{\sigma-1}\frac{P_{K^{IT}}K^{IT}}{PY}=\beta s_{K^{IT}}$$, where $\beta=\left(\frac{1-\alpha}{\alpha}\right)^{\sigma}\left(\frac{P}{P_C}\right)\left(\frac{P_{K^{IT}}}{P_C}\right)^{\sigma-1}$; $s_{K^{IT}}$ is the revenue share of ICT capital. Substituting this expression in equation (B5), we have

(B6) $$\Delta TFP_t=\beta s_{K^{IT}}\left[F_C-1\right]\left[\Delta k_t^{IT}+\sigma\Delta\ln\left(\frac{P_{K^{IT}}}{P_C}\right)_t\right]+\beta s_{K^{IT}}\left[\frac{(1-\delta_C)}{(1+g)}\right]\left[\Delta k_{t-1}^{IT}+\sigma\left(\frac{P_{K^{IT}}}{P_C}\right)_{t-1}\right]+s_z\Delta z_t$$

This is the equation reproduced as equation (4) in the text.

Appendix C: Data description

1. Converting current price data into constant price

From EUKLEMS database we use data on industry gross output, industry value added, intermediate input, labor compensation, total capital compensation and both ICT and non-ICT capital compensation, all at current price. This database also have volume indices (1995 = 100) on gross output, value added, intermediate input, labor services, total capital services, ICT capital services and non-ICT capital services. Using their respective volume indices, we convert current price gross output, value added and intermediate input into constant price. For labor compensation, total capital compensation, ICT capital compensation and non-ICT capital compensation we use the indices of respective services to convert into constant price. For example, capital compensation at current price is converted into constant price using capital services.

We do the conversion from current price to constant price in the following way. Let us suppose that there are only three years 1990, 1995 and 2005 and we have variable called py (the product of price and volume). Then the time series of the variable at current price will be given by $p_{90}y_{90}$, $p_{95}y_{95}$ and $p_{2000}y_{2000}$. In that case, the data on volume indices (1995 = 100) were computed using following mechanism at the first place.

$$i_{1990}=\frac{p_{95}y_{90}}{p_{95}y_{95}}\times 100;\ i_{1995}=\frac{p_{95}y_{95}}{p_{95}y_{95}}\times 100;\ i_{2000}=\frac{p_{95}y_{2000}}{p_{95}y_{95}}\times 100$$

Thus we have

(C1) $i_t=\left(p_{95}/\left(p_{95}y_{95}\right)\right)\times 100\times y_t$ t = 1990, 1995, 2000

Using this relation, the value at constant price can be computed as follows:

(C2) $p_{95}y_t=\left(i_t\times p_{95}y_{95}\right)/100$. Note that for $p_{95}y_{95}$, we can use the current value series for year 1995. So, multiplication of year specific indices with base year current price value (which would be the same at constant price as well) and division by 100 would provide the value at constant price.

With two sets of data on both current and constant prices, the value added deflator can be computed as:

$$deflator_t=p_t y_t/p_{95}y_t\ .$$

It will be equal to 1 for the reference year 1995. We have used this deflator to deflate the R&D data.

2. Capital input data

EUKLEMS database has data on capital inputs by eight asset types, of which three are information and communication technology (ICT), and five are non-ICT assets. The three ICT assets are: (1) computing equipment (IT), (2) communications equipment (CT) and software. For detail on how these capital stock data are estimated, see Timmer et al (2007). In EUKLEMS database, these capital stock data are available only for 13 countries: Australia, Austria, Denmark, Finland, Germany, Italy, Japan, Korea, Netherlands, Portugal, Sweden, UK and the US. Among the remaining five countries in the sample, data for four countries (Belgium, France, Ireland, and Spain) were obtained through respective national offices of EUKLEMS consortium. For Canada, the data are from Statistics Canada. Note that for Belgium and Canada, there are only two types of asset available: ICT and non-ICT.

In terms of data availability, since the data on Germany were available only from 1991, the data for West Germany has been used till 1990. For Korea, the capital stock data start from 1977, and for Canada they start only from 1980. Data on Sweden start at 1993. The country with the least number of data points is Ireland, whose capital stock data are available only from 1995.

For all 10 Euro zone countries (Austria, Belgium, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal and Spain), the data are in Euros, whereas for remaining eight sample countries they are in respective national currencies at constant price for year 1995. These data at Euros and other national currencies were converted to US$ PPP using the industry level PPP data provided in EUKLEMS website. In EUKLEMS database, data are provided for 1997 PPP (in national currency per German Euro). These data have been converted to national currency per US$ using national currency per German Euro / US $ per German Euro. Then the real variables on gross output, value added, labor compensation, total capital services, ICT capital services, NICT capital services, R&D stock at national currency were converted into 1997 US$ based PPP by dividing the national currency variable by PPP.

At EUKLEMS database, the data on capital compensation and share of ICT capital and non-ICT capital are given. We multiply share of ICT and non-ICT capital by value of capital compensation to decompose total value of capital compensation into value of ICT and non-ICT capital. Once these compensations for ICT and non-ICT capital are computed we use the indices of ICT capital service and non-ICT capital services to have constant price data.

3. R&D data

R&D data are available from STAN ANBERD 2 and ANBERD 3 databases. The R&D data generally extends from 1973 to 2004 with few exceptions. For Belgium, the data are available from only 1987 and Korea only from 1995. The data for 2004 are missing for Australia, France, Japan, Sweden and the US. However, for these countries we have estimated the R&D investment for 2004 using the growth rate of R&D investment in 2003 over that in 2002.

The data are taken in national currency at current price. First, the national currency data are converted to national currency constant price using GDP deflator based on EUKLEMS mentioned above. Then the constant price data are converted to PPP US$ using 1997 PPP exchange rate of national currency per US$ at PPP. Then these PPP US$ adjusted constant price R&D expenditure data are used to compute R&D capital stock using perpetual inventory method with annual discount rate of 15%. To establish capital stock for the first year, 1973, we use average annual growth rate (across time from 1973 to 2004) which varies by both country and industry. In very few cases, the average annual growth rates were slightly negative; in that case, we use the growth rate of 3% instead of using average growth rate of across countries and industries in the sample.