

ICTs & Productivity

The title 'ICTs & Productivity' is rendered in a blue, 3D-style font. The ampersand is replaced by a blue gear icon. A larger, light orange gear icon is positioned behind the text, partially overlapping the ampersand and the word 'Productivity'.

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1 - Context

Back in 1987, the New York Review of Books (NYRB) magazine quoted Robert Solow saying “you can see the computer age everywhere, except in the productivity statistics”. The sentence was related to what Solow was working on, as a member of the MIT’s Commission on Industrial Productivity.

In 1989, the book “Made in America: Regaining the Productive Edge¹”, by Solow, Michael Dertouzos, Richard Lester and the MIT Commission, helped to reiterate that idea. The numbers showed *higher* multi-factor productivity growth (gMFP) and *higher* labour productivity growth (gLP) from 1948 to 1973, relatively to what was measured after, the after being the years when the computer industry boomed.

From 1948 to 1973, the average U.S. gMFP and gLP were, respectively, 1.9% and 2.9%; from 1974 to 1997, the same values were 0.2% and 1.1%. This slowdown is also observed in most OECD industrialized countries.

Because the slowdown coincides with the rapid increase in the use of Information and Communication Technologies (ICTs), it suggests to some researchers a negative correlation between the economywide productivity and the ICTs.

One early paper with such interpretation is Roach^[2], where the author compares information workers (white collars) with production workers (blue collars), and measures that in the period from 1975 to 1986, the output per information worker decreased 6%, while the output per production worker increased 6.6%, concluding to “have isolated America’s productivity shortfall and shown it to be concentrated in that portion of the Economy that is the largest employer of white collars”...

Figures 1 and 2 illustrate Roach’s basis. Figure 1 shows computer sales clearly going up from 1975; figure 2 shows the decrease of non-manufacturing productivity, versus the increase of manufacturing productivity.

Apparently, the higher the spending in ICT, the lower the productivity! However, there are many other productivity factors, and at least until 1981 – year of the IBM PC – computers were still tools that relatively few could afford or knew how to use, meaning that they shouldn’t have contributed much to the U.S. GDP.

Curiously, other studies – mentioned later – measure computer based capital as a small share of the whole capital stock, inferring this is why computers can’t contribute much to the Economy output growth.

During the 1990s growth trends improved³, but it is interesting to note that some countries, including Portugal and most of Western Europe, actually lost pace during the second half of the decade of the Internet boom... See figure 3.

Is there a computer productivity paradox? Shouldn’t the huge investments and progresses in ICTs have induced a non slowing productivity? How do ICTs translate to productivity?

These are questions this document reflects on.

¹ <http://www.amazon.co.uk/exec/obidos/ISBN=0262041006/arturmarques> - Amazon sells the book and allows visitors to browse through the first 20 pages of the second chapter.

² Roach (1991), “S.s. services under siege – the restructuring imperative”.

³ <http://www1.oecd.org/publications/e-book/92-2001-04-1-2987/gD-3-a.htm> - the OECD Science, Technology and Industry Scoreboard 2001, provides data in both PDF and XLS formats.

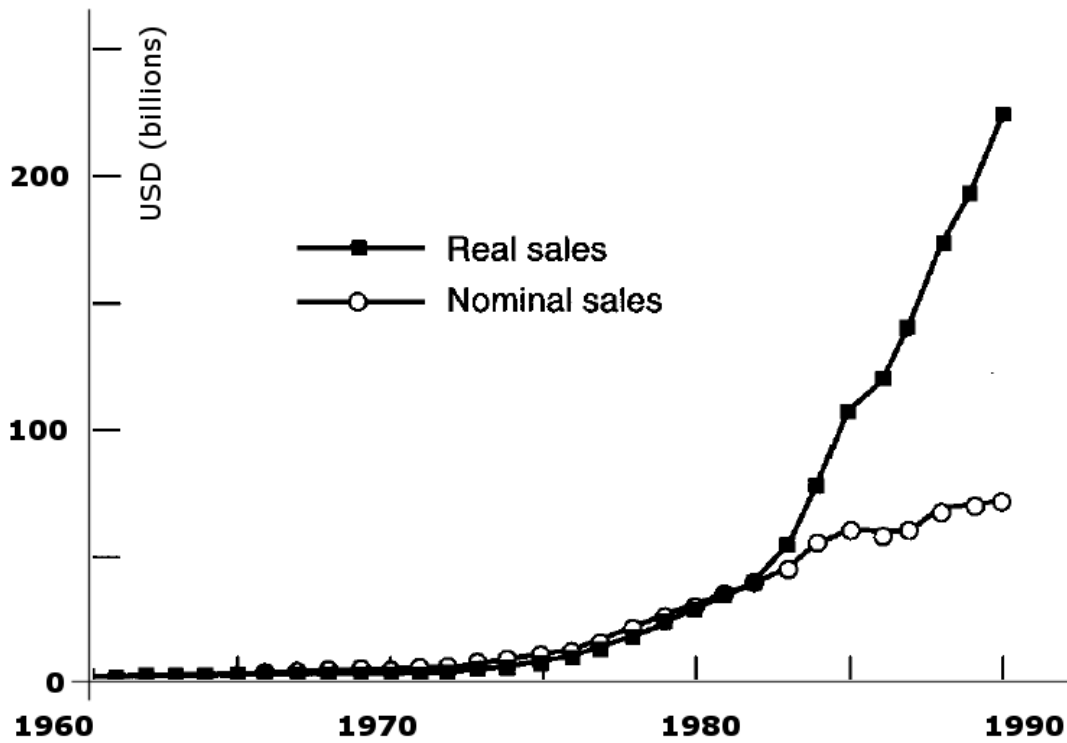


Figure 1 – U.S. Computer sales, 1960-1990 – source: : Association for Computing Machinery

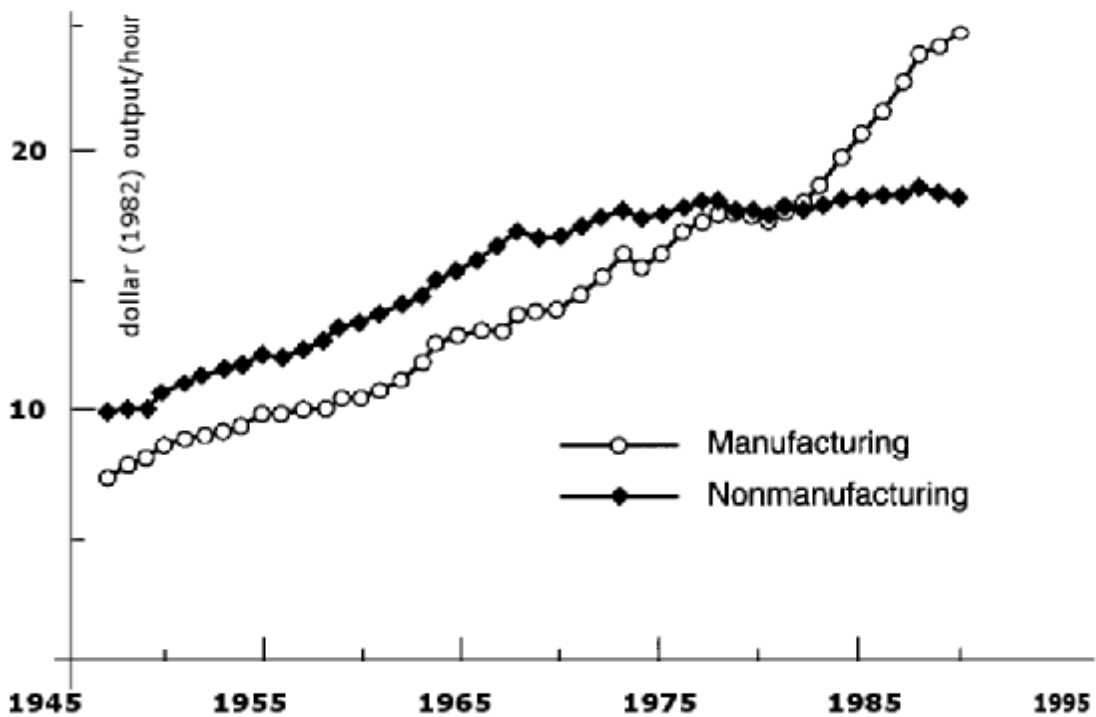


Figure 2 - Productivity in dollar output/hour – source: Association for Computing Machinery

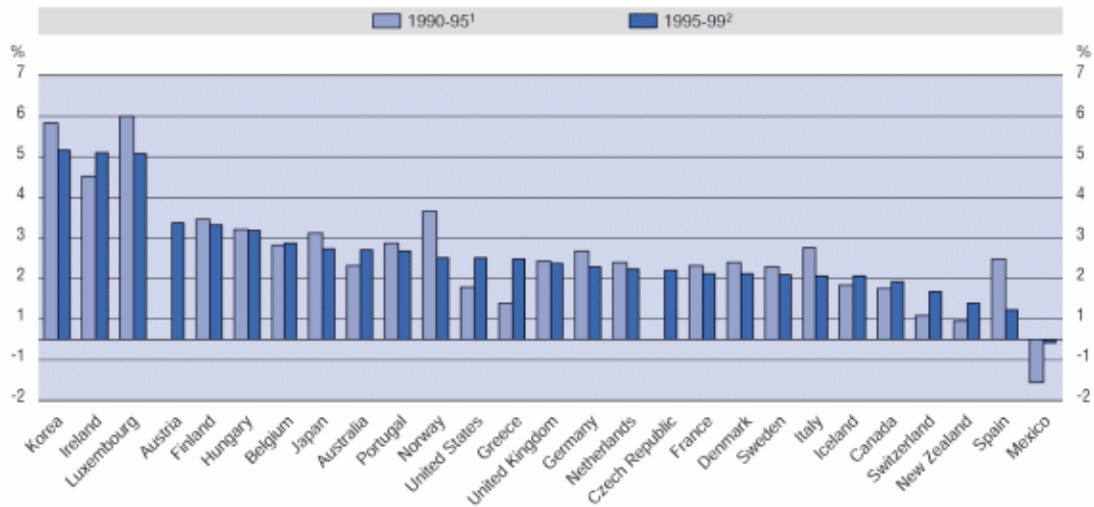


Figure 3 - Trend growth in GDP per hour worked - source: OECD

2 - The paradox

Formally, a paradox is a logical contradiction: a sentence which can be true *and* false. For example, take Bertrand Russel's barber paradox, where the premise is that a barber shaves all and only those who don't shave themselves. Question: is it true or false that the barber shaves himself?

If he does, then he doesn't (because he can't shave those who shave themselves), but if he doesn't, then he does (because he shaves all those who do not shave themselves)...

The "computer productivity paradox" is not a logical paradox, but rather an issue that nurtures puzzling conclusions. Much of these puzzling conclusions are about measured data versus common sense...

3 - Measuring the share of Kc – What is a computer?!

Despite common sense saying that “computers are everywhere”, Oliner & Sichel (OS1994) and Jorgenson & Stiroh (JS1994) measure the opposite.

In an economical sense, “computers being everywhere” should mean a very high share of computers in capital stock and as inputs to capital services; a small share implies a small contribution to output growth.

Both papers account output growth by the expression:

$$gY = S_c * gK_c + S_{nc} * gK_{nc} + SL * L + gMFP$$

where:

gY = “growth of output”

gK_c = “growth of computer capital, including computer capital based services”

gK_{nc} = “growth of non-computer capital”

$gMFP$ = “growth of multi-factor productivity”

L = “Labour”

S_x = “share of input x”.

As the table below summarizes, the papers report a relatively small contribution of computer equipment to the output growth, even during the 1980s. Considering that the 1980s were a decade of seminal events in computer hardware and software, like IBM’s PC architecture and Microsoft’s Windows operating system, one can say that not even the lightning fast growth of some capital input, can represent a big contribution to the Economy output, when its share is small.

	OS1994		JS1994		
USA data	1970-79	1980-92	1979-85	1985-90	1990-96
Average annual output growth (%)	3.42	2.27	2.35	3.09	2.36
Contributions of computing equipment	0.09	0.21	0.15	0.14	0.12

Romer (1986) states that computers have higher returns than other capital inputs, but because the mathematical expression for gY treats computer capital (K_c) and non-computer capital (K_{nc}) equally, the only way to test for such higher returns effects, is by combining several inputs into K_c , as in summing computer hardware, computer software and computer related labour. This way, the contribution of “computers” naturally increases, yet up to maximum of 0.4: still a relatively small slice of output growth.

While trying to understand computer growth, K_c input substitution is often mentioned, due to falling prices, improved performance and greater versatility, generation after generation of new equipments, but this is just the tip of the iceberg: computers’ synergies are deeper and wider than what any labelling perspective can capture.

In fact, I think that nowadays it is very delicate to make a sound difference between K_c and K_{nc} , except for very elementar technology.

After all, what is a computer? João Pavão Martins, defines “computer” as an information manipulation machine that is (1) automatic, (2) universal, (3) electronic, and (4) digital. Automatic means that it can perform some task without human intervention, after being programmed to such purpose; universal means that it can solve any problem for which there is a programmable solution; electronic means that it uses electricity to represent information; and digital means that all information is numerical, usually binary. So what is *not* a computer? Nearly all devices with electrical parts have the *potential* to fit the concept.

Computer equipment shouldn't be reduced to beige bricks with attached fans, and to the usual peripherals. It is not easy to point a single object used in the modern world that isn't extremely reliant on computers [or a computer, depending on the definition]...

Moreover, even if we don't know yet how to translate the productivity [boost] associated with Kc, we live with it everyday: the food we eat, the water we drink, our travelling, our wastes... all are *only* viable because of computers. For example, a city like Hong-Kong, with over seven million habitants in 1000 sq km, is absolutely dependent on the [computerized] automation of thousands of processes that control food and water supply, garbage collecting, and traffic routing.

Maybe computers are everywhere indeed, and we're just not accepting that...

4 - Computer Usage

Another question usually studied when facing the computers & productivity issue, is what people actually do with computers. The so-called average user is often quoted as admitting that he/she didn't use x% of his/her old PC, so he/she will be using even less of the newer one. Where is the gain?

McCarthy [4] writes that “the theoretical increase in computers' potential output, as measured by the increases in their input characteristics, is unlikely to ever be realized in practice. Also, the increasing size and complexity of operating systems and software are likely to be resulting in increasing relative inefficiencies between the hardware and software... The greater complexity means that some part of the increased computer speed is diverted from the task of processing to handling the software itself.”

Bluntly, this view is *amazingly* misinformed. Regarding the “increase” in input characteristics, McCarthy must have been thinking about system buses or about the resolution of the arithmetic & logic unit of the CPU (ALU), as in 32 bits vs. 64 bits... This attribute is related to the numerical resolution of the computations or to the addressing capabilities of the system.

But to speak of “increasing relative inefficiencies between the hardware and software”, due to “the increasing size and complexity of operating systems and software” is really ignoring the Computer Science (CS) history, including recent developments. What CS in general, and programming languages in particular, have been doing for many decades, is rising the abstraction level, so that software can run no matter the hardware platform.

The syntax of programming languages, has been approaching that of natural languages, and hardware independency has come to the extreme of virtual machines, such as SUN's JAVA and Microsoft's .NET platform. A JAVA or .NET piece

⁴ McCarthy, Paul (1997), “Computer prices: how good is the quality adjustment?”.

of software can run on any hardware with the corresponding virtual machine, no matter if it is a mobile phone, a desktop PC or a Lego! The programmer does *not* need to understand the physical hardware: it suffices to understand the virtual machine. The problem of building the virtual machine to some device, is something in the hands of dedicated SUN and Microsoft research teams.

Furthermore, the whole discipline of Software Engineering is about productivity in the process of software: here one learns how to *not* reinvent the wheel, how to reuse code, how to use particular methodologies and programming paradigms, so that other people can easily build on someone else's work.

Finally, McCarthy's idea that "greater complexity means that some part of the increased computer speed is diverted from the task of processing to handling the software itself" makes little sense, because handling the software is processing it... There is no other processing a CPU can do. Even when doing nothing most CPUs are doing something, which is executing the *do nothing* instruction (NOP mnemonic in x86 architecture assembly)!

If McCarthy is trying to say that some progress in hardware will soon be eaten by "heavier" software, that seems intuitively true, in the sense that users can only run software as good as their hardware can handle. Higher levels of abstraction, demand more computing power, due to deeper layers. But even this might not hold for long: think of an architecture where the end user machine trusts on a remote service that handles most of the processing needs, thus alleviating the client's hardware specifications in all fields, except communications.

Software quality can be measured using Software Engineering metrics and hardware quality can be measured using Computer Architecture metrics, but "computer usage quality", as a metric for productivity, is something much more intricate. One can't say that a person is less productive than another, just by measuring the quantity of its output: a bigger book is not necessarily better than a shorter one.

5 - Higher level, higher difficulty

Software developers design software for people – the friendlier the software is, the more people are likely to use it. Operating systems' interfaces are a great example: we have covered a long path since text-only interaction, to the current graphical metaphors, but we are still far from having a machine that everyone can use.

Natural language interaction, gestures recognition and even mind reading are intense areas of research – most people wouldn't believe if they were told that they can [present tense] control the mouse pointer, just by thinking about it⁵...

Of course that it is not only operating systems that benefit from higher level interfaces; for example, the electronic games industry is a another avid and valuable customer of that field of research.

Notice that Kc works as a positive feedback mechanism. The higher the Kc at any given time, the more Kc can be injected in the Economy, because the bigger is the installed base of some technology, the bigger is the potential market for related equipment, like peripherals and software. This positive feedback also applies to software: the better the [software] authoring tools, the higher is the probability for better next ones.

⁵ Commercial product available from <http://www.officeorganix.com/Leap1.htm>.

If better software helps people to be more productive then, at least, that should show on labour productivity figures. As for electronic games, they fuel consumption and usually represent the edge of know-how, thus are the seed for concepts that will, rather sooner than later, be applied to other contexts.

New generations of Kc help Kc grow as an input to the production function, but there can be Kc inputs due to the reorganization of the old capital. For example Pixar (NASDAQ:PIXR, makers of Toy Story...) renders digital movies using computer farms, which are rooms where many machines work together in parallel, as if they were a much more powerful single computer.

What if Pixar decided to join two computer farms? The new "mega" farm would offer higher productivity from Pixar's point-of-view (more frames rendered per unit of time), relatively to any of the two previous configurations, but it might not exceed the sum of the previous individual productivities... nevertheless, there was no capital investment – just a reorganization of resources.

Globalization also brings new problems to productivity and input accounting. Imagine a firm like Zoran (NASDAQ:ZRAN): Zoran markets integrated circuits (ICs), mostly for DVD-Video appliances. These ICs might be produced in Asia, and might ship to the U.S. under an African flag; now suppose that the company does its billing and financial transactions in some offshore... exactly what gains should appear in the U.S. statistics?

6 - Reading measurements

According to Griliches [⁶], 70% of private U.S. computer investment was concentrated in wholesale and retail trade, finance, insurance, real estate and services, which are the sectors where output is "least well measured" or a concept not defined at all!

Griliches writes that "the major answer to the computer productivity puzzle is simple: the investment has gone into immeasurable sectors and thus its productivity effects, which are likely to be quite real, are largely invisible in the data."

Similarly, Stiroh [⁷] analyzed the contribution of computers to growth, at the sectorial level, focusing on the most computer intensive industries. His conclusions are that "the average gMFP fell while Kc grew", hence either computers are not productive or output growth is underestimated.

One potential underestimation is in the banking sector, where some authors argue that the increased convenience in using automatic services, such ATMs and Internet home-banking, is *not* considered in the sector's output. Consequently computers' contribution to growth is measured smaller than it should be.

But that depends: for example, Berger and Mester [⁸] mention that, in the U.S., the ATM costs per transaction are 50% lower than those for the same operation involving a bank employee, but transactions are smaller and twice the operations are needed for the same volume, so there is no obvious impact on banking productivity...

⁶ Griliches, Zvi (1994), "Productivity, R&D, and the data constraint".

⁷ Stiroh, Kevin J. (1998), "Computers, productivity and input substitution".

⁸ Berger, Allen N., and Loretta J. Mester (1997), "Efficiency and productivity trends in the U.S. commercial banking industry: a comparison of the 1980s and the 1990s".

When the ATM service is free and operations by the teller are not (example: account transfers in Portugal), consumers get a surplus that can be seen as a contribution of technology to productivity.

However, in the U.S., most ATM services are not free. According to Frei and Harker⁹, ATMs were introduced with the expectation to lower the bank's distribution system cost structure, but consumer behaviour changed, cost savings were not realized, and some banks decided to charge usage fees. The same pattern applies to Call Centers and PC Banking.

Nirvikar Singh [¹⁰] writes the opposite: "...by automating all basic banking transactions (cash withdrawals, deposits, account inquiries) they [ATMs] reduced costs for banks."

So, even a single technology [ATMs] can lead to very different readings, depending on exactly what banks were studied.

7 - Maybe it takes time

In 1882, Thomas Edison established the first permanent incandescent light and power station for private consumers, called the Pearl Street generating station, in New York City. During the next four decades, despite hundreds of factories becoming clients of the [expanded] system, the productivity growth statistics didn't log a progress, until 1922.

According to David [¹¹], maybe it is just a matter of time before the computer productivity puzzle dissolves; after all, it took 40 years for factory electrification to show an impact on productivity growth.

Other researchers, like Jack Triplett, consider this analogy dangerous, because nothing compares to the price behaviour of commercial computers: Triplett estimates that computer prices fell by a factor of 2000, in just 45 years.

Even more impressive is the computers' development pace: assuming that Greg Moore's law is correct, then every 18 months translate to twice the previous processing power, hence a factor of $2^{(45 \cdot 12 / 18 - 1)} = 2^{29}$ for the last 45 years... this is a huge number!

As an innovation, electric power is different from computers. Its diffusion process was not as invasive: the initial applications didn't replace older technologies, like steam power and water power. With computers, older technologies were completely wiped out very early on the diffusion process: what happened to mechanical calculators and typewriter machines?

⁹ Frei, Frances X., and Harker, Patric T., "Value creation and process management: evidence from retail banking", available @ <http://fic.wharton.upenn.edu/fic/papers/99/9916.pdf>.

¹⁰ Nirvikar Singh, "Electronic commerce and strategy", chapter 20, available @ <http://econ.ucsc.edu/~boxjenk/bookchapters/Bkch20.pdf>.

¹¹ David, Paul A. (1990), "The dynamo and the computer: an historical perspective on the modern productivity paradox".

8 - Not productive at all?

Despite the fact that the Personal Computer didn't change *fundamentally* over the past 20 years, the many little changes that happened, are enough for people to think about a constant revolution, draining money and not necessarily helping productivity!

Comparisons with cars are very common when discussing upgrading: some people say that, contrary to cars, computer upgrading is mandatory; not optional, because the road literally changes.

This can be true, but it is nothing more than a natural consequence of the unique rhythm of innovation in the computers industry. If new technologies always had to assure retro-compatibility, we would be paying higher prices and investing resources in the past, instead of focusing in the future.

Surprisingly, the current PC architecture, is basically the same of the original IBM AT: a motherboard that hosts the CPU and the peripheral daughterboards, all talking to each other via a system bus... Another example: today's most popular technology for hard disks, the parallel ATA interface, became commercially available in 1980!

The PC business is slowly shifting from selling new machines to selling upgrades: the productivity of upgrading is an interesting question.

The main problem is the downtime associated with the upgrade. Blinder and Quandt [¹²] refer that typically this important downtime is *not* logged, and only direct costs are recorded in the organization's books.

Some argue that computers cancel their own eventual productivity gains. Upgrading is one example; the expression "World Wide Wait" [instead of World Wide Web] for the WWW, is another one: the Internet might help and entertain, but the time some people spends searching and waiting, cancels [part of] the benefits.

The correct approach is that computers are just tools for humans: their productivity depends on their users.

If in the New Economy the most important assets are people and Information, then we should start looking at productivity that way. How many firms have a Chief Information Officer (CIO)?

A CIO should care about information management and not about the technology per se. Paul Strassman [¹³], author of "The Squandered Computer" – Amazon.com's #1 best seller in the Information management category – has a database with over 12000 U.S. firms, compiled from corporate filings with the Securities and Exchange Commission and from published annual reports. According to him, by 1999, only 8.1% of all U.S. corporations had capital ownership greater than their costs of information management! In his words "capital has become a commodity instead of a scarce resource..."

The road ahead is how to evaluate the contributions of ICTs in terms of information productivity (P), considering $P=V/C$, where V is value-added and C is cost, both relative to information management.

¹² Blinder, Alan S., and Richard E. Quandt (1997), "The computer and the economy: will information technology ever produce the productivity gains that were predicted?"

¹³ Paul Strassmann website @ <http://www.strassmann.com>

Synopsis

In the period [1974, 1997], most OECD industrialized countries measured smaller growths in multi-factor productivity and labour productivity, relatively to [1948, 1973], despite great progresses in ICTs.

This is puzzling: shouldn't computers have contributed to higher annual output growths and to increases in productivity?

One can try to understand this puzzle from many angles: (1) the share of Kc is too small to cause a significant output impact; (2) available data might be measuring a different concept of "computer"; (3) measurements don't handle very high level computer technologies; (4) it might take time for the correct numbers to show up in statistics, as it happened with electricity; and (5) maybe computers just really aren't productive tools.

(1) is counterintuitive; common sense says that "computers are everywhere".

(2) Maybe we need a broader concept of "computer", as technology gets (3) higher and more pervasive than ever.

As for time (4), ICTs are so different than everything else before, that analogies are risky.

(5) If there is a productivity problem, it has more to do with the computer user, than with the machine...

In the New Economy, people and information are the most important assets. We are now embedding the importance of information management and learning how to measure its effectiveness from information productivity, but the new values aren't easily comparable with the old ones.

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