9th seminar on national accounting

Definitions and measures of ICT impact on growth : what really is at stake

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The definition of the "new economy" is essentially based on stylized facts that have been outlined during the last American business cycle. Between 1992 and 2000, the hourly productivity average rate of growth has reached 3,7% per year in the business sector and 2,2% in the manufacturing sector. These growth rates are largely superior to long term trends that were respectively limited to 1,6% in the business sector and 2,9% in the manufacturing one (1974 – 1999). The average rate of inflation was a low 2,6% whereas the unemployment rate decreased by 3,5 percentage points from 7,5 to 4 percent. This was such an impressive record that it was not possible to expect any signs of a downturn. This economic performance challenged the business cycle approach, and the terminology "new economy" has been coined because this peculiar virtuous business cycle was broad and prolonged. However, despite a large consensus on macroeconomic features, confusion still arises around the true meaning of this terminology. We surveyed in a recent paper (January 2001) the way the American literature has treated this issue[2].

The present paper assesses different measurement problems related to the so-defined "new economy". In fact, to a certain extent, the remarkable dynamism observed in America in the second part of the nineties is the result of real statistical improvements designed to capture structural changes. Two comprehensive revisions of the NIPA (National Income and Product Accounts), one in 1995 and another in 1999, contributed to boost the average growth rate (figure 1). From 1972 to the third quarter of 1995 (last figure available in 1987 dollars), the average growth rate was 2,7% in 1987 dollars, but 2,9% expressed in 1992 chained dollars and 3,1% in 1996 chained dollars. In the same spirit, the use of hedonic indexes has contributed to increase quantities. Although, the efforts undertaken to puzzle out measurement problems have arisen different possible interpretations.

Figure 1 : Rates of change in real GDP : comparison of alternative measures during economic expansions

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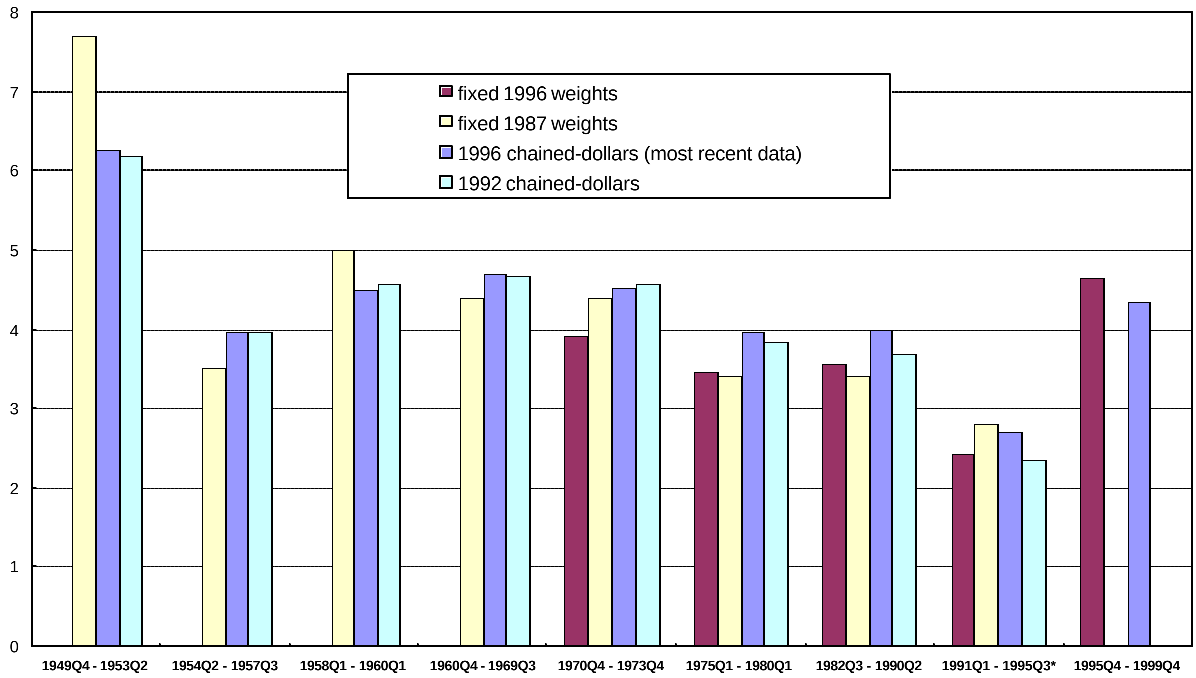
[2] Baudchon and Brossard (2001).



* 1995Q3 is the latest available point for fixed 1987 weights data.

Source : Bureau of Economic Analysis

In this paper, we consider two important issues. First, we draw a simple assessment of the way the NIPA have moved to catch the essence of the "new economy". We tackle with issues related to this change. Second, we try to challenge R. Gordon's view that information technology (IT) has not triggered enough increase in total factor productivity (TFP) in users sectors in order to speak about the advent of a third industrial revolution. We will show that most likely TFP increase is underestimated and that a detailed study of the TFP accounting can reveal some interpretations' errors.

Do changes in NIPA provide a satisfying answer ?

1. The changes in US NIPA

Surprisingly, NIPA changes were initiated before the "new economy" terminology was commonly used. Hedonic indexes appeared in December 1985. The 1995 revision of the NIPA introduced chain-type indexes. This innovation solved the substitution bias that is inherent to indexes built on fixed weights. It has contributed to a better understanding of the changes in relative prices and a better measurement of economic growth[3]. The comprehensive revision undertaken in 1999, by the time of the "new economy" boom, appears today both relevant and partial. The recognition that software expenditures were investment has boosted the computed growth rate.

[3] When the relative price of a product declines, quantities tend to grow more rapidly. Then, growth is underestimated during the period before the reference year and overestimated after. Because the weights are more accurate for the very recent period, up to a very recent time, indexes were regularly re-based to limit the scope of this problem. But if the recent growth was properly estimated, past figures were more uncertain. Then, the process to change the basis year used to rewrite automatically the economic history. Chain-type indexes provide the best methodology to compare level across time because they use the prices at the relevant period and not prices taken for a fixed year. These chained indexes are particularly useful for cyclical purposes. They give an accurate description of the depth and the strength of a recession. Fixed indexes led to soften both recessions and recoveries and were sources of misleading interpretations over long term economic growth.

1995 revision's of the NIPA led to an increase of 0,2 percentage point per year of the average growth rate between 1972 and 1995, but the disappearance of biases which statistically overestimate growth have led to a downward revision for the first half of the nineties[4]. Then, from the first quarter of 1991 to the second quarter of 1995, the average growth rate lost 0,5 percentage point and around 3/5th came from the computer prices drop (Landefeld and Grimm, 2000). To a certain extent, the American case could be useful for the rest of the world in pushing for a simultaneous adoption of both chain-type indexes and hedonic prices. These two reforms have moderated the impact on growth of the massive decrease in computer prices. It can even offset utterly this decrease by canceling the bias related to non computer goods whose prices have also declined. In countries that are small computer producers, this counter effect could be particularly large. Because they massively import such products it would imply virtually no impact on GDP.

Thanks to the 1999 revision's of the NIPA, software expenditures are not anymore counted as intermediate consumption but as investment. This change contributed to an additional growth per year of 0,2 percentage point over 1972 – 1995[5]. A comparison with previous accounting measures shows to what extent the changes is trivial before 1977 and relevant after 1992. Between 1977 and 1992, the average growth rate has gained 0,3 percentage point up to 2,9%[6], and 0,4 percentage point between 1992 and 1998 up to 3,6%[7]. Precisely, the average growth rate between the first quarter of 1991 (the beginning of the actual cycle) and the second quarter of 1999 (last point for which 1992 chained dollars are available) gained 0,4 percentage point to 3,5%.

The upward revision of the average GDP growth rate has also changed productivity figures. In the old accounts, the average productivity growth rate in the business sector was 1,1% in the period 1977 – 1992 and 1,6% in the period 1992 – 1998. Accounts (available before July 2001 revision) respectively reassess the figures at 1,4% and 2,0 %. Old accounts have showed an acceleration of productivity growth over the long term trend of 1,3% observed between 1974 and 1998. This movement is a bit amplified in the new accounts and the average productivity growth now reaches 1,6%. Because productivity growth continued to increase up to the mid-2000, stopping the computation in 1998 underestimate the acceleration of productivity growth The average increase between 1992 and 2000 is 2,4%, then 0,8 percentage point superior to the trend compare to 0,3 percentage point with the old accounts. The year 1995 has been marked as the turning point for the acceleration in productivity growth, therefore it is possible to draw a comparison between the first and the second half of the nineties. On the one hand, the old accounts show an acceleration of 0,3 percentage point during the two following sub periods 1992 – 1995 and 1995 – 1998. On the other hand, new accounts give respectively 0,2 and 0,7 percentage point for 1992 – 1995 and 1995 – 2000.

These different figures seem to puzzle out the productivity paradox and to provide a firm basis for any discussion on the diffusion of IT. Studies using the most recent figures are generally optimistic regarding this diffusion process. On the contrary, previous studies based

[4] For a complete presentation of the changes, see *Survey of Current Business* (from July to December 1995).

[5] For a complete view of this revision, see *Survey of Current Business* (from August to December 1995). The new average growth rate based on 1996 weights is only 2,7%, compare to 3,1% with 1996 chained dollars. The gap stresses the interest of chained weights.

[6] Seskin (1999).

[7] Following annual revisions in both July 2000 and 2001, this growth rate is now 3,7%.

on non revised data are not able to stress any compelling evidence[8]. The issue remains open because of the methodology adopted and because other revisions in the future may change again the scenario. Revising the NIPA is a continuous and endless process. Moreover, it is not easy for the NIPA to follow the technological progress' rhythm. Therefore, despite considerable progress, further improvements are expected in the near future, which will almost certainly change the way economic growth is accounted[9]. Even if revisions are expected to increase further the figures, the one undertaken in July 2001 is a counter example[10]. New data from the Census Bureau have helped to better account software expenditures. This improvement has lowered the economic growth of 0,9 percentage point and the productivity figures of 1,1 percentage point in the year 2000. The average growth rate is now 2,3% between 1995 and 2000 versus 2,6% before, and the acceleration reaches only 0,4 percentage point over the 1992 – 1995 period. Future studies on the diffusion of IT, that will also be based on the NAICS that has just began to be caught in the NIPA, might renew the debate.

2. NIPA innovations and their limits

If there is a large consensus for considering software expenditures as investment (and no more as an intermediate consumption), the use of hedonic indexes remains puzzling. As a matter of fact, hedonic indexes modify the separation between quantities and price of both capital goods and, by this way, also affect the measurement of TFP. Uncertainties are also pervasive on the measurement quality of these indexes (box 1)[11].

Does the use of hedonic indexes overestimate the computers price decline ?

There is a controversy on the use of hedonic indexes as an accurate measure to deflate computer expenditures. Are the indexes responsible for the acceleration of GDP growth, the high productivity growth and the moderate inflation rate that have been observed since 1995 ?

Hedonic indexes are heavily used in the American NIPA. Components now deflated by this kind of indexes account for 18% of the GDP. For instance, computers expenditures and peripheral equipment are totally deflated by these indexes, as well as half of software expenditures[12]. For most components, thanks to matching method that had already captured quality effects, the impact of hedonic indexes has been in effect limited. But for computers and peripheral equipment, whose prices dropped in the recent period at an average annual pace of 24%, the impact was really important.

Box 1 : The separation between quantities and prices effects on nominal investment[1]

Two different approaches exist to separate quantities and price effects on nominal investment. With the **cost based methodology**, quantities of capital goods move in relation with quantities of factors needed for its production, whatever the level of efficiency. With **quality adjusted prices**, quantities of capital goods depend on efficiency changes, whatever the quantity of inputs needed for the production. Obviously, for many goods the second methodology poses practical problems. Both hedonic and matching methods tend to approach this problem. The most frequent version of the **hedonic method** use econometric estimations to find price of goods that are of any interest (computers for instance). Explanatory variables are, for instance, the memory of the

[8] In addition to references mentioned in Baudchon and Brossard (2001), further elements can be found in Baily and Lawrence (2001), Nordhaus (2001) and Stiroh (2001).

[9] For a thorough and vast presentation, see Landefeld and Fraumeni (2001) or Haltiwanger and Jarmin (1999).

[10] For a detailed presentation see August 2001 *Survey of Current Business*.

[11] Lequiller (2001) stresses that statistical conventions over final expenditure / intermediate expenditure are more responsible for inefficiencies in the comparison between French and American accounts than the use of hedonic indexes.

[12] For a comparison of French and American practices, see Cette and *al*. (2000).

chips, the speed, the weight... [2]. The instability of the coefficients, the impossibility of taking account many features of the computers and a very poor understanding of the externalities for users are part of the estimations problems. The **matching methodology** computes the variation of prices from one period to another by observing the price evolution of goods available at both periods. The first period is used for the weights.

1. We use the definition proposed by Cette *and al.* (2000).
2. For a complete presentation of the methodology, see Triplett (1986).

Landefeld and Grimm (2000) have showed that in 1998 components corrected by hedonic indexes had contributed negatively 0,2 percentage point to the 1,3 percentage point increase in GDP price. Among this – 0,2 contribution, computers and peripheral equipment alone contributed to – 0,4 percentage point. Their computations gave a role of 0,5 percentage point to computers and software in the 1,4 point growth acceleration observed between 1973 – 1995 and 1995 – 1999. Because the figure is small in absolute terms, the two authors consider that “hedonic index contribution plays a limited role in the acceleration of growth”. However, it is still more than a third of the acceleration. Moreover, there is no clear evidence that the drop of computers prices is overestimated. Reliable estimations made by the *Bureau of Economic Analysis* or by other studies provide comparable results obtained with traditional methodologies.

Fallacies in the separation between quantities and prices of investment

Different American studies have attempted to focus both on the origin and the size of hourly productivity growth and on the nature and extent of the acceleration of TFP gains since 1995. Before 1999 revision of the NIPA, this acceleration was far from visible. On the contrary, the most recent papers have concluded that it was a widespread acceleration, not limited to producers sectors. Gordon (2000) has a different vision and localized the benefits only in the producers sector (table 1).

1. Contributions to productivity growth

Studies by	Jorgenson and Stiroh[2]		Oliner and Sichel		Council of Economic Advisers	
Period	1995-1998	Acce-leration [3]	1996-1999	Acce-leration [3]	1995-1999	Acce-leration [3]
Average growth of TFP	0,99% (*0,85%*)	0,63 (*0,62*)	1,25%	0,69	1,04%	0,93
Producers sectors contribution[1]	0,44 (*0,86*)	0,19 (*0,22*)	0,47	0,26	0,39	0,23
Other sectors contribution	0,55 (*– 0,01*)	0,44 (*0,4*)	0,78	0,43	0,65	0,70

1. For Jorgenson and Stiroh, information technology include computers, software and communications equipment. Oliner and Sichel include computers and semi-conductors embedded in computers. The *Council of Economic Advisers* only considers computers.
2. Figures in italic into brackets correspond to an assumption of a faster drop in prices of software and telecommunication equipment than the one given by the NIPA.
3. Jorgenson and Stiroh compare 1990 – 1995 with 1995 – 1998 ; Oliner and Sichel compare 1991 – 1995 with 1996 – 1999 ; the *Council of Economic Advisers* compares 1973 – 1995 with 1995 – 1999.

Sources : Jorgenson and Stiroh (2000) table 5, Oliner and Sichel (2000) table 4, *Council of Economic Advisers* (2000) table 2-3.

It seems clear that TFP gains acceleration in the eighties in the producers sectors came directly from the computer revolution. On the contrary, there is no guarantee that computers are at the root of other sectors’ improvements. First, there is no clear evidence that the benefits on TFP in users sectors[13] are derived from the use of IT. Second, the localization of the gains depends heavily on the methodology chosen to separate quantities and prices in measuring nominal investment

As Cette *and al.* (2000) emphasized, even if TFP gains acceleration and the diffusion of IT have happened at the same period, there is no proof that there is a correlation between the two phenomena. As far as the statisticians do their best to take into account quality changes and the efficiency of IT, a possible correlation implies externalities (unincorporated technological progress) but also measurement errors of the residual. The choice of a methodology relying on cost based prices or quality adjusted prices is essential for TFP measurement. The following example highlights the issues. Suppose that Sector 1 (S1) and Sector 2 (S2) are respectively producers and users. In 1990, 100 workers in Sector S1 produce capital goods for a value of 100. In sector S2, 100 workers plus capital goods produce consumer goods for a value of 200. In 2000, the capital goods still produced by 100 workers in sector S1 are now capable of a 50% increase in consumer goods output. The two measurements give different answers. At cost based prices, the capital goods still have a value of 100, whereas with quality adjusted prices, the value is now 200. Table 2 sums up the differences.

2.Prices measurement and the effects on productivity

	Cost based methodology			**Quality adjusted methodology**		
Sectors	S1	S2	Total	S1	S2	Total
Labor productivity gains	0%	50%	33%	100%	50%	67%
TFP gains	0%	50%	33%	100%	0%	25%

S1 : producer sector
S2 : user sector

The cost based methodology implies that productivity gains are concentrated in S2, the user sector, although, the alternative methodology implies the opposite. Precisely, S2 makes no TFP gains but enjoys labor productivity gains thanks to capital deepening. The increase in efficiency is already incorporated in capital goods. But this estimation does not take into account the possibility that S2 streamlines its production process which would imply real TFP gains.

This small exercise gives interesting insights. First, it shows that there is no consensus on the quality adjusted approach. As a matter of fact, since TFP is the residual of the production function, it shows our ignorance. So, the quality adjusted method is preferable to the extent that it reduces the residual. But if we consider that TFP is a measure of unincorporated technological progress, cost based methodology is able to assess efficiency gains linked to a better organization of production factors. Second, many reasons can be advocated to mention that a clear localization of TFP gains is almost impossible. In practice, in the NIPA the separation is made following the cost based methodology, and for some IT products, the hedonic indexes are the suitable method. Issues on the diffusion process from producers to users are then at stake. Then, we must look carefully at results mentioned in table 1. Gordon's view that IT gains are concentrated within the producers sectors must be reexamined. However, the introduction of hedonic indexes in the NIPA will mechanically

[13] For more details, see for instance Jorgenson and Stiroh (2000).

reinforce his position. Finally, to the extent that technological progress is incorporated, labor productivity appears to be a better measure.

Jorgenson and Stiroh (2000) provide a concrete example that emphasizes the problem. Because they assume that NIPA underestimate the declining price of software and telecommunications network, they rebuild deflators and show that TFP gains in the second half of the nineties comes from the producers sectors (table 1, figures in italic into brackets). Measurement improvement vanishes TFP gains in other sectors, which implies that there are no positive externalities from the diffusion of IT. It corresponds to the quality adjusted prices case. Although, contributions to the acceleration of TFP gains between the first and the second part of the nineties remain similar (0,2 for producers and 0,4 for the other sectors). A shared acceleration of TFP gains between sectors and the strong acceleration in other sectors are not challenged by a change in price measurement.

Limited and ad-hoc corrections for quality

Even if until now these corrections have mainly concerned IT capital goods, there is no reason why other sectors should be put outside of the scope of these corrections. Two reasons give a push to focus on corrections on IT capital goods. First, this sector is a priority for statisticians because the diffusion pace is extremely rapid. Second, long term consequences on economic growth need a good understanding of TFP gains originated in IT. Thus, the separation between quantities and prices is required to compute the level of current dollars capital stock. Both reasons can be questioned.

First of all, a clear distinction between the sectors is to a certain extent arbitrary. Companies that build computers and chips are considered as producers. But computers services, mobile phone enterprises and internet equipment providers are also producers of IT. Is putting them aside a big issue for a clean productivity measurement ? For these companies, technological progress improves quality. Reducing the scope of hedonic indexes to computers, some softwares and in the US to phone terminal is serious problems.

Does IT improve quality or quantity of final goods ? Then, Gordon's findings that TFP does not accelerate in the US out of the producers sectors could be an artifact. Statisticians do not undertake corrections when products do not embody IT, even if IT contributes also to quality improvement for a large range of products. Nordhaus (2001, a & b) has proposed interesting ideas. Following Griliches (1994) he builds an aggregate indicator that traces output and productivity in the US for a consistent sector in which quantities and price are properly separated. It includes : agriculture, forestry and fishing, mining, manufacturing, transportation, wholesale and retail trade. Construction, finance, insurance, real estate and other services are considered as unproperly measured. Productivity gains in well-measured sectors over the period 1978 – 1998 are continuously enhanced. The productivity paradox can be solved by the following assumption : if measurement problems generate differences in the level of productivity between sectors properly and unproperly measured, they can produce a Denison effect[14] since for many years workers have moved from industry to services.

[14] The Denison effect can be defined as follows. When employment moves from low productivity sectors to high productivity ones, for instance from agriculture to industry, the whole economy productivity growth rate accelerates, even if both sectors keep the same pace. This is exactly what happened during the twentieth century between agriculture and industry and more recently between industry and services. This last movement may have reversed the Denison effect.

Sectoral studies do not provide either a consensus on the relation between IT and the acceleration of TFP in non producers sectors. Since measurement problems are not solved from a statistical standpoint, it remains possible that TFP gains stay concentrated in producers sectors. Both the measure of output of some specific services[15] and accounting conventions[16] maintain that issue open.

Elements for a discussion on R. Gordon's views

Another productivity paradox has been stressed. The more you use an accurate measurement instrument for quantities and quality of IT goods, the less you can disentangle productivity gains between users and producers. Nevertheless, several authors consider that both the size and the source of TFP gains are fundamental issues (Artus (2001), Gordon (2000), Oliner and Sichel (2000), McGuckin and Stiroh (1998)). A sort of consensus has emerged. IT would be at the root of a technological revolution enhancing durable and pervasive economic growth if TFP growth picks up and if users sectors share it. Long lasting growth based only on capital deepening would be fragile as far as capital deepening can be based on transient causes (Brender and Pisani, 1999) like decreasing real interest rates, increasing labor cost or a change in the inter-temporal preferences of the saving decision. Moreover, if we follow Solow's growth model (1956), then output per capita can increase on line with autonomous technological progress (the residual), capital deepening has positive effect on output per capita, but it vanishes at the steady state. Then, TFP gains in producers sectors are too small to accelerate growth of the overall economy since these sectors account for a small part of output.

Except Nordhaus (2001) remarkable exception that will be considered below, most of the recent empirical studies have shown that IT generated an acceleration of productivity growth mostly in sectors that are IT producers. But the strong acceleration of TFP gains does not seem to be massively diffused to users industries. As Gordon (2000) has pointed out, if you take into account capital deepening linked to the drop of IT prices and the acceleration of TFP gains in producers sectors, nothing is left for other sectors. That is why R. Gordon strongly pretends that the Solow paradox is still alive and that the third industrial revolution is dismissed.

This conclusion gives us the opportunity to treat four points on which we disagree. We will first present the arguments and then after a detailed analysis :

1) R. Gordon's pessimistic view is essentially based on comparisons with previous industrial revolutions. A strict similarity between revolutions is hard to suppose.

2) Some extreme heterogeneity exists between sectors for inputs unproperly measured and ratio of capital to labor. Then, statisticians fail to capture welfare effect for consumers mainly because the Denison effect distorts the aggregate level of productivity (Nordhaus, 2001).

[15] Since there is a growing discrepancy between labor productivity gains in the manufacturing sector and in the overall business sector, the question is to know whether measurement problems have increased through time because of the diffusion of IT. Answering that question is still a puzzle itself.

[16] Baudchon and Brossard (2001) have showed that the frequent distinction in sectoral literature between users and non users is also arbitrary.

3) Growth comes from different sources. The methodology which separates labor productivity that comes from factor accumulation from autonomous technological progress prevents from being able to split the different productivity sources. The two following examples are interesting.

- Technological progress based on labor efficiency is always underestimated because it mechanically produces capital deepening. This is independent from the way quantities and prices are separated.
- Whatever the methodology used for separating quantities and prices, non decreasing returns are badly measured. Many reasons suggest that non decreasing returns exist for some products. In that case, a continuous acceleration of economic growth can be expected, even if signs give the impression that it comes from capital deepening. A confusion can arises between productivity gains generated by products innovations and by capital/labor substitution. In fact, both depend on R&D efficiency.

4) A small sector like IT capital goods can contribute massively to economic growth if prices in this sector drop.

Let us go into further details.

1. Do industrial revolutions always follow the same pattern ?

Gordon (2000) focuses on the fact that key features for the identification of industrial revolution given by P. David (1990) do not fit with the present diffusion of IT. David has shown that the diffusion of electricity in the US did not break the productivity trend "before more than fifty percent of the machines had incorporated the new energy". Following Gordon, this threshold is largely behind us if we look at the computers stock in users sectors (such as retail trade, real estate and finance) even if it is impossible to emphasize a break in the TFP trend. Transposing the pattern underlined by David without more precautions seems risky. Revolutions are not condemned to follow comparable stages, both threshold and learning the new process can vary widely. A great deal in the Internet and telecommunication revolution is placed on network effects. Those gains can be slow to come since a widespread diffusion of equipment is a condition for fully enjoying efficient network externalities.

2. Denison effect related to unproperly measured inputs and heterogeneity in ratios of capital to labor.

Productivity level differences between sectors are not only artificially derived from statistical corrections for quality. Two natural differences exist. Human capital is the first one : it is essential but badly measured in most sectors. Then those sectors enjoy an overestimation of the level of productivity. Differences in ratios of capital to labor are the second one. In some industries, the ratio is above the average which implies a higher level of labor productivity even if it is not possible to advocate that they contribute more to consumers welfare.

Then, Denison effect plays an extremely important role when sectors are diversified. Nordhaus (2001) shows that traditional methods underestimate the aggregate productivity level: he proposes a specific correction. He has found that the acceleration of labor productivity can also be attributed to sectors non classified under the "new economy" denomination. This methodology gives an acceleration of labor productivity of 1,8 percentage point in the US between 1996 and 1998. After the deduction of both the contributions of capital deepening and TFP gains in the "new economy" sectors, Nordhaus reaches a contribution of 0,65 percentage point for the acceleration of TFP gains in other sectors.

3. Errors in the source of productivity gains are not all related to measurement problems

Labor productivity gains in the nineties in the US are mostly attributed to TFP gains in producers sectors and to capital deepening in other sectors. Other factors such as the increase in the level of qualification and changes in management practice played a crucial role in several countries.

Quality adjusted prices are partially responsible for this false interpretation. Box 2 recalls that even the cost based methodology can be misleading and can attribute an autonomous increase in labor efficiency to capital deepening. The explanation relies on the fact that if growth is driven by an autonomous increase in labor efficiency, it produces a capital deepening and not the reverse. A true technological revolution can be overshadowed because growth can be explained to a large extent by the accumulation of capital, even if its sources are innovations that have enhanced labor efficiency. Box 2 stresses this kind of interpretation errors. Unfortunately, the cost based methodology is not a solution either. Labor intensification has been largely at work in the US in the nineties (Askenazy, 2000). Then, questioning the overestimation of capital deepening contribution to growth is consistent. Following that line, many cross sections estimations have shown that labor productivity gains based on IT introduction depends on a join reform of management practices (Askenazy (2000), Brynjolfsson & Hitt (1996), Baudchon & Brossard (2001)).

A similar measurement error could also come from the capital/labor substitution driven by innovations that have appeared during the diffusion of IT. Capital accumulation does not automatically increase the quantity of each capital good used, it can also widen the range of capital goods that can be accumulated. A computer connected on Internet can now transfer a text without any use of material support. Paper, time, ink can be saved. Previous generations of intermediate goods (fax machines, photocopy machines, envelopes, transportation cars) are now used for different purposes. The number and the availability of intermediate goods and the increased specialization of each one increase labor efficiency. Box 2 recalls the basic equations used in innovations product models. If a variety of intermediate goods enter the production function, capital deepening is not limited by decreasing return. It derives directly from incentive for firms to expand the range of intermediate goods used. If the current process of diffusion of IT fits that scenario, the residual does not proof our ignorance but emphasizes marginal innovations that enhance growth. The quality adjusted prices, by eliminating the residual, then underestimate the content of innovations that drive growth. Here again, the two approaches of capital price measurement are misleading for the source of economic growth since at least a contribution equals to $\alpha\hat{k}$ will be attributed to capital deepening. This phenomenon may be considered as temporary although the diminishing marginal return law does not prevail as far as it comes from a widening range of intermediate goods.

Box 2 : Diversity of technological progress and interpretation difficulties around productivity equations

A) technological progress labor augmenting

If the technological progress is Harrod-neutral, production function is :

$$Y=K^{\alpha}(Le^{xt})^{1-\alpha}$$

Y is output, *K* capital, *L* labor, *x* the rate of growth of labor efficiency. The rate of growth of labor productivity is now :

$$\hat{y}=\alpha\hat{k}+(1-\alpha)x$$

At the steady state (variable per capita grow at a constant rate) $\hat{y}=x$ and $\hat{k}=x$. With cost based prices, only a proportion (1-α) of growth is attributed to TFP (that comes here from an increase in labor efficiency) though growth is not possible without TFP. *A fortiori*, quality adjusted prices make the residual disappear and growth comes entirely from capital deepening (measured here by $\hat{k}+x$).

B) Variety of intermediate goods and non decreasing returns for capital

Endogenous growth literature is based on positive externalities from the accumulation of knowledge. It allows to show that there is no fatality to the diminishing return of aggregate capital (Romer, 1986). More recent models with product innovations have used new functions able to take into account innovations consequences that can widen the range of goods incorporated in the production function. Romer (1987) has for instance used this kind of function with a variety of intermediate goods.

Output of firm (*i*) is written :

$$(1) \qquad Y_i=(L_i)^{1-\alpha}.\int_0^N [X_i(j)]^{\alpha}dj$$

where $0<\alpha<1$, Y_i is the output, L_i labor and $X_i(j)$ the quantity of intermediate goods *j* used by firm *i*, *N* the number of intermediate goods used by each firm. At the symmetrical steady state $X_i(j) = X_i$, we find that :

$$(2) \qquad Y_i=L_i^{1-\alpha}.NX_i^{\alpha}=L_i^{1-\alpha}.(NX_i)^{\alpha}.N^{1-\alpha}$$

If the increase in NX_i comes from *N*, capital return does not diminish. It is possible to consider that $X_i(j)$ are non durable intermediate goods (intermediate consumption) or durable intermediate goods (capital).

In this family of models, growth is based on new intermediate goods (incremental innovations). The simplest way to tackle the problem is that investment in R&D produces with certainty a new product. It is then possible to show that the rate of growth of intermediate goods is constant ($\hat{N}=\gamma$) when the size of the population and the R&D costs are given. In the overall economy, the labor productivity is :

$$y=\left(\frac{N.X}{L}\right)^{\alpha}.N^{1-\alpha}$$

If intermediate goods are now durable, NX/L becomes the ratio of capital to labor usually written k. The rate of growth of labor productivity is now :

$$\hat{y} = \alpha\hat{k} + (1-\alpha)\hat{N}$$

with $\hat{k} = \hat{N} = \hat{y} = \gamma$.

Here again, it is difficult to disentangle TFP growth and capital deepening. TFP growth comes here from the increase of the quantity of intermediate goods. Even if the ratio of capital to labor contributes with a proportion α, growth is not transient as far as capital deepening derives from the increase in the unit of intermediate goods. This pace of increase depends only on costs and R&D efficiency. A drop in the user cost of capital is not a condition to prolong the process.

4. TFP source and durable growth: a misleading approach

Greenwood and Jovanovic (1998) have proceeded with an unusual methodology. They use a model derived from Solow (1960) in which the technological progress is incorporated in capital goods through a continuous decrease in the price of capital goods. In this model, a sector produces capital goods and enjoys a specific autonomous technological progress. Another sector produces final goods with this capital goods plus labor. In this sector, the technological progress is Solow-neutral. It is then possible to show that growth may be durable even it TFP gains come essentially from sectors producing capital goods (box 3).

Box 3 : Growth accounting in a bi-sectoral model with pecuniary externalities (Solow (1960), Greenwood and Jovanovic (1998))

If like Solow (1960), there are two sectors, one producing capital goods and the other one final goods.

The production function of final goods uses the following technology :

$$(1) \qquad y = zk_e^{a}l^{1-a}$$

z is TFP in the final good sector, k_e is capital goods stock and l labor. z grows at the rate g_z (the technological progress is Solow-neutral). The stock of capital goods follows the usual equation :

$$(2) \qquad \dot{k}_e = iq - dk_e$$

where i is investment (expressed in units of final goods used to build the capital goods), d is the depreciation rate of capital goods, q the technological progress for investment (included in new generations of capital). q grows at a rate g_q which is the technological progress in the capital goods sector. The relative price of capital goods is $p=1/q$ and decreases at a rate g_q.

The resource constraint for the economy is :

$$(3) \qquad c+i=y$$

where c is the consumption of final goods and i the quantity of final goods necessary for investment.

It is then easy to show that steady state growth verifies the following equation :

$$(4) \qquad g_y = \left(\frac{1}{1-a}\right)g_z + \left(\frac{a}{1-a}\right)g_q$$

Accounting based on the American economy made by Greenwood and Jovanovic (1998) gives respectively a contribution of 35% for Solow-neutral technological progress (g_z) and 65% for technological progress in the capital goods sector (g_q).

Greenwood and Jovanovic (1998) have then shown that TFP growth in the capital goods sector contributes to 65% of the post-war American growth, whereas TFP growth in the final goods sector only accounts for 35%. During more than forty years (1948 – 1992), technological progress in the capital goods sector might have been the main source of economic growth despite a small share in GDP (17% of compensations). These findings contradict Gordon's ones (2000). He pretends that the acceleration of technological progress in the capital goods sector is not able to explain the high growth rate since IT is a too small sector. Solow (1960) had already mentioned earlier that capital deepening can fuel growth if a durable technological progress persists in the capital goods sector. Box 3 shows that when the production function of final goods admits diminishing return of capital, it can be balanced by a decrease in the capital goods price at a rate g_q. Then, it does not seem tricky to view that current growth is stimulated by an acceleration of accumulation driven by computers price drop. Pursuing such an acceleration depends heavily on the expected continuation of the Moore law in the future ten years. Even if technological progress in computers vanishes, it is far too early to suppose that other sectors will not be able to relay.

Conclusion

The "new economy" debate is based on largely ambiguous empirical ground. Two reasons have been mentioned. Both measurement and analytical problems exist. Despite methodological progress to separate quantities and prices, the reality remains foggy. Quality problems scramble growth accounting exercises and the Denison effect is not corrected by indexes usually manipulated by NIPA statisticians. Interpretations problems are based on three imperfections. On the one hand, we expect IT evolution to be a genuine technological revolution only if TFP gains are equally diffused, like in previous revolutions. Nothing guarantees such a scenario. On the other hand, the role of capital accumulation is certainly overestimated. In the case of non decreasing capital returns or when technological progress improves labor efficiency, the relation goes from growth to the accumulation of capital, and not in the reversed direction. Even if growth accounting says that labor productivity growth is only explained by the accumulation of capital, it is hard to assume. There is no reason why capital accumulation based on increasing returns or on labor re-organization would be temporary. From the same standpoint, if technological progress is located in the capital goods sector, it produces a decrease in the relative price of capital goods and then a jump in the real capital coefficient (whatever the nominal value). Since decreasing returns affect current dollars capital stock rather than constant dollars capital stock, nothing prevents the process to be endless. On the contrary, we have recalled that it may have fueled American growth for decades.

Finally, we have shown that TFP gains out of producers sectors are likely to be underestimated. However, an acceleration of TFP gains limited to capital goods sectors is enough to mention the advent of a third technological revolution.

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