An Exercise in the Measurement of R&D Capital and its Contribution to Growth: Comparison between France and United-States and with ICT[#]

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Introduction

Innovation and technical change has long been considered in economic theory as a major source of long term economic growth and productivity. The recent developments in endogenous growth theories have significantly contributed in building more explicit links between the previous theoretical models where technological progress was more in the nature of "manna from heaven" and the many empirical case studies and econometric analyses showing that this progress was largely due to research and innovation and to education and training . The problems and puzzles, however, are particularly numerous in trying to assess precisely the contribution of research and innovation activities to growth and productivity.(see for example Griliches 1988 "The Productivity Puzzle and R&D: Another Non-explanation" and 1994 "Productivity, R&D, and the Data Constraint").

Many of these problems are related to major measurement difficulties and uncertainties. In particular, largely because of the integration of research and production activities within firms and the relatively limited extent of technological markets, there is an important lack of direct information on research and innovation outputs, and quantitative studies are mainly left with the important, yet limited, input measure of Research and Development (R&D) expenditures, which covers an important, yet limited part of innovative activities expenditures, and is basically an input measure. Moreover, for other practical reasons and accounting considerations, but inappropriately from the strict point of view of economic analysis, the present system of national accounts (SNA) does not treat R&D expenditures as being an investment. As a consequence, the contribution of R&D capital services is often ignored in standard accounting studies of growth and implicitly subsumed in the residual or Total Factor Productivity (TFP) as conventionally estimated.

In this study, we basically adopt the framework of traditional growth accounting and its main assumptions, but propose, as an exercise in measurement, to estimate R&D capital and its contribution to growth under different hypotheses or "conceptual variants". We thus try to assess the impact of important characteristics of R&D as an investment on its estimated contribution and the incidence of major uncertainties in our knowledge about them. We do this exercise both for France and the United States (USA), in the interest of the comparison but also as a good way to sharpen our appreciation of the results. We also think most instructive to extend our exercise to the measurement of capital in Information and Communication Technologies (ICT) and its contribution to growth in the two countries. The comparison with ICT is particularly interesting since business expenditures (investments) in R&D and ICT are of roughly similar orders of magnitude in the two countries (about 1 to 2% of GDP in France and 3% to 4% of GDP in the USA, in the 1990's), and because the impressive revival of growth and productivity of the "New economy", especially in the USA, has been largely imputed to ICT, both through standard capital-deepening effects in the ICT-using industries and through "direct" impacts on TFP in the ICT-producing industries (see, for example, amidst a burgeoning literature: Oliner-Sichel [2000, 2002], Jorgenson-Stiroh [2000], Jorgenson [2001]for the USA; Cette-Mairesse-Kocoglu [2000, 2002] for France; Colecchia-Schreyer [2001], Pilat-Lee [2001] for many OECD countries). ¨Even more deeply, the comparison is relevant since some of the important factual and conceptual uncertainties that concern our knowledge of R&D characteristics as an investment do also affect our knowledge of ICT. Moreover, as we shall see, there is actually an essential trade off between the contribution to growth and productivity imputed to ICT and that which can be imputed to R&D: the more is ascribed to ICT, the less to R&D, and conversely. This is basically a matter of interpretation and understanding, but one which should not be forgotten, especially when tempted to draw policy recommendations from necessary and useful, but largely conventional, growth accounting estimations.

In the first section of the paper, we document the relative magnitude of R&D and ICT investments in France and in the United States. In the second section, we discuss the largely interrelated conceptual and factual most important difficulties which bear directly on t the estimated R&D and ICT contributions to growth in a standard growth accounting analysis. In the third section, we explain our choice of three main "conceptual variants" in the estimation of R&D and ICT capital services and their contributions to growth, and why these variants can be viewed as alternative as well as complementary. In the last section, we present in detail and comment the corresponding estimates for the business sector over the period 1980-2002 for both France and the USA. We briefly summarize and conclude.

1 The relative magnitude of R&D and ICT in France and in the United States

******* To be extended

Tables 1A and 1B show the orders of magnitude of R&D expenditures (investments) and ICT investments (expenditures) in France and in the USA over the last forty years for the two economies and their business sectors as a whole, based on the two countries official national accounts for ICT and OECD compilation of the specialized country surveys for R&D.

· For France,

- In 2000, R&D investment (GERD) was slightly greater than ICT investment, respectively about 2.2% in proportion of GDP (31 billions Euros) and 2.0% (28 billions Euros). Until the beginning of 90s, GERD intensity was roughly twice larger than ICT intensity. But after 1993, while ICT intensity strongly increased (from 1.2% up to 2.0%), R&D intensity decreased significantly (from 2.4% to 2.2%).

· For United States

- The expenditures on R&D in the US economy up to 265 billions dollars in 2000 which represent 2.8% of GDP.

· Comparison between United States and France

- The US expenditures in R&D are nine times higher than French ones in absolute level and near 25% higher in relative level.

- The design of the evolutions of GERD ratio in GDP were very similar in these two countries during the years between 1960 and 1990. However, unlike the French economy spent in 1960 twice less money compare to GDP on R&D than the US, in 1993 the ratio were comparable with 2.4% in both countries (see Figure 1).

- The beginning of the nineties was characterized by a general slowdown in R&D expenditures. But unlike the US expenditures on R&D have strongly gone up, to reach 2.8% in 2000 after 2.4% in 1994, the French ones have followed decreasing to 2.2%. Consequently there is now strong gap in R&D investment between France and USA.

Table 1A: R&D Expenditures and ICT Investments, France

	Expenditures in values (in Million of Euros)					Expenditures as % of GDP				
	1960	1970	1980	1990	2000	1960	1970	1980	1990	2000
GERD[1] *of which*:	573	2 280	7 777	23 959	30 954	1.22	1.83	1.76	2.37	2.18
Business sector	259	1 269	4 694	14 476	19 348	0.55	1.02	1.07	1.43	1.37
Public sector[2]	314	1 011	3 083	9 483	11 606	0.67	0.81	0.74	0.94	0.81
ICT *of which*:	270	1 155	4 055	13 925	29 076	0.57	0.93	0.92	1.38	2.05
Business sector	212	964	3 439	11 475	23 992	0.45	0.77	0.78	1.14	1.69
Public sector[2]	58	191	616	2 450	5 084	0.12	0.15	0.14	0.24	0.36

[1] *GERD: Gross Domestic Expenditures on R&D, million Euros.*
[2] *Including High Education and Private non-profit.*

Sources: Authors calculations based on National Accounts (For ICT) and OECD (For R&D)

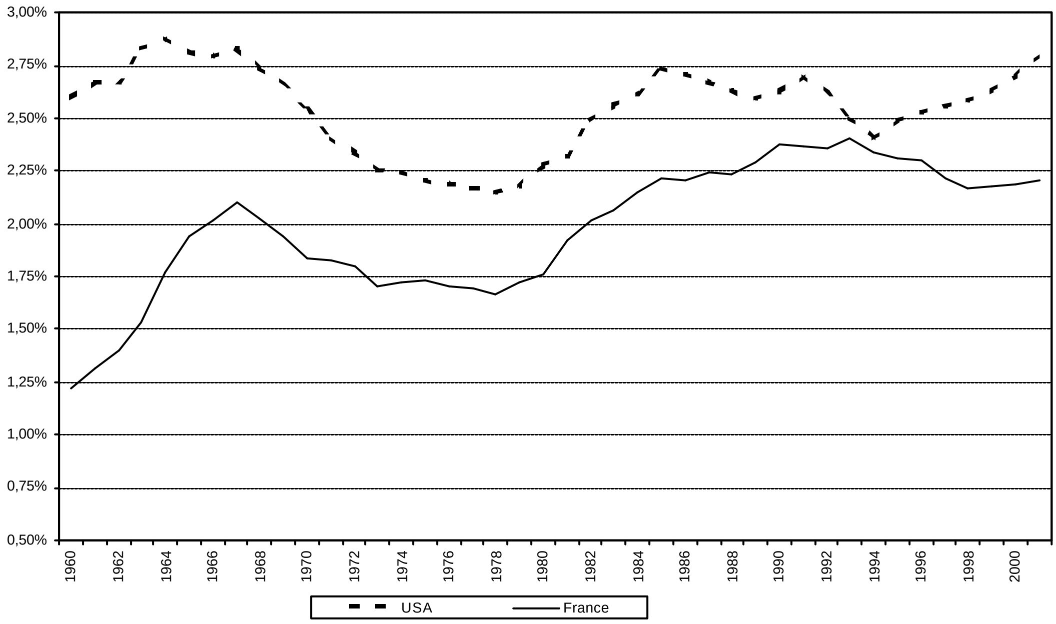
Table 1B: R&D Expenditures and ICT Investments, United States

	Expenditures in values (in Million of Dollars)					Expenditures as % of GDP				
	1960	1970	1980	1990	2000	1960	1970	1980	1990	2000
GERD[1] *of which*:	13 711	26 458	63 760	152 451	265 180	2.60	2.54	2.28	2.63	2.70
Business sector	10 509	18 067	44 505	109 727	199 539	1.99	1.74	1.59	1.89	2.03
Public sector[2]	3 202	8 391	19 255	42 724	65 641	0.61	0.80	0.69	0.74	0.67
ICT *of which*:										
Business sector	2 600	11 700	48 900	136 300	389 300	0.49	1.13	1.75	2.35	3.96
Public sector										

[1] *GERD: Gross Domestic Expenditures on R&D.*
[2] *Including High Education and Private non-profit.*

Source: Authors calculations based on BEA (For ICT) and OECD (For GERD).

Figure 1: GERD intensity as % of GDP



Source: Authors calculations based on National Science Foundation series (USA) and Annual Survey of R&D Expenditures (France).

Since the study estimates the contribution of R&D and ICT capital to growth in a growth accounting framework we focuses on business sectors. Tables 2 present the levels and the relative shares of R&D and ICT investment in the French and the US business sectors.

In France, R&D investment is about 10% of the total investment, which is slightly lower than the ICT one (13%). In France, ICT investment became higher than R&D investment only after 1997. Note that this increase of ICT investment probably has not affected the investment in other equipment that still around 8% of GVA during the last twenty years.

The US economy shows slightly different conclusions. First, like in France R&D investment is about 11% of total investment but close to 3% compare to GVA. Concerning the comparison with ICT investment, Table 2B shows that ICT investment has exceed that of R&D before 1980 (in 1979 to be more precise) that is eighteen years before the French case. The evolution of ICT has still higher than R&D one during the last two decades. Then, in 2000 ICT investment, with 5.6% of GVA, was the double than the R&D investment. The last difference with the French case is that the increase in ICT investment could have had an impact on others equipments investment. The latter decrease during the last twenty years from 9% of GVA to 7%, this result could be a sign of substitution between ICT equipment and others traditional equipments.

Table 2A: Levels and Relative Shares of Investments, France

	Values *Millions of Euros*				Share in total investment *(%)*				Ratio in GVA *(%)*			
	1980	1990	1995	2000	1980	1990	1995	2000	1980	1990	1995	2000
R&D[1]	4694	14476	16649	19348	7.7	9.7	11.6	10.2	1.4	1.8	1.9	1.8
ICT	3439	11475	12329	23992	5.6	7.7	8.6	12.6	1.0	1.5	1.4	2.2
Equipments	29708	71390	68049	92027	48.7	48.0	47.5	48.4	8.8	9.0	7.6	8.6
Structures	23162	51388	46341	54713	38.0	34.6	32.3	28.8	6.8	6.5	5.2	5.1
Total	61003	148729	143368	190080	100.0	100.0	100.0	100.0	18.0	18.8	16.0	17.7

[1] R&D performed by private firms.

Sources: Authors calculations based on National Accounts and OECD (for R&D)

Scope: Business Sector

Table 2B: Levels and Relative Shares of Investments, United States

	Values *Millions of dollars*				Share in total investment *(%)*				Ratio in GVA[2] *(%)*			
	1980	1990	1995	2000	1980	1990	1995	2000	1980	1990	1995	2000
R&D[1]	44505	109727	132103	199539	8.4	11.5	10.6	10.6	2.2	2.7	2.6	2.8
ICT	46500	131400	204200	401700	8.8	13.7	16.4	21.4	2.3	3.2	4.0	5.6
Equipments	183100	294100	404900	524500	34.5	30.8	32.5	27.9	9.0	7.2	7.8	7.3
Structures	256000	420900	503800	752700	48.3	44.0	40.5	40.1	12.6	10.4	9.8	10.5
Total	530105	956127	1245003	1878439	100.0	100.0	100.0	100.0	26.1	23.5	24.1	26.1

[1] R&D performed by private firms. [2] Including Household to be comparable with France.

Sources: Authors calculations based on National Accounts and OECD (For R&D)

Scope: Business Sector

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2 Conceptual Issues on the Measurement of R&D and ICT Investments and their Contributions to Growth

As we mentioned in introduction, R&D is not considered in National Accounts as an investment. Thus, there is no official R&D price indices nor R&D capital stocks estimates, and there is no systematic efforts addressing the specific problems involved in elaborating such estimates, even though statisticians and national accountants are increasingly concerned by this situation. The contribution of R&D to growth is thus usually not explicitly considered in growth accounting analyses, in spite of the fact that the importance of research and innovation activities for growth and productivity in the long run is generally not disputed. Furthermore, the recent developments in economic literature on the importance of the intangibles investments, like software for example, showed that it is become a necessity to consider R&D expenditures as an investment and so as a non negligible source of economic growth. However, to quantify the impact of R&D to growth we have to face to measurement difficulties of R&D capitalization and in particular the difficulty to quantify all the benefits (private and social) from the R&D activities. We'll discuss about these difficulties in this section.

2.1 A Reminder on the Growth Accounting Framework

Our results here focus on the respective magnitude of R&D and ICT contributions to growth and we do not consider the contributions to growth of other types of investments, either tangible (in equipments and structures) or intangible and of (the different types of) labor, and hence that of TFP (the residual).[1] Our results are based on the usual growth accounting methodology and its main economic assumptions (see box 1 for more details), though we do not make the hypothesis of constant returns to scale.[2] ,

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1 See Corrado-Hulten-Sichel, 2002, for an "expanded framework for measuring capital and technology" in which an exhaustive list of nine categories of tangible and intangible assets are defined and for which the authors have worked out series of estimates at the business sector level for the USA.

2 See Greenan-Mairesse-Topiol, 1999 and 2001, for two econometric attempts to directly and jointly assess the respective contributions of R&D and ICT to productivity on firm level data for French Manufacturing and Service sectors.

The share of the services of capital, entering directly into the calculation of its contribution to growth, can be itself estimated on the basis of the ratio of the total value of capital to the total value of production (or to the value added), multiplied by the (relative) user cost of capital (or imputed relative price of its services). It can be shown, adopting the usual Jorgensonian (simplifying) hypotheses, that the relative user cost of capital is equal to its net rate of return, plus its depreciation rate and minus the rate of change in its price.

Denoting c_i the relative user cost of capital of the *i*th type we can thus write $c_i = (r + d_i - \Delta p_i / p_i)$, where r stands for the net (equilibrium) rate of return on all forms of capital, d_i is the depreciation rate of the ith type capital and p_i the corresponding price index of investment. Hence we can write the share of services from of the ith type capital as $a_i = c_i(P_i K_i / PQ)$, and finally its contribution to growth as:

$$a_i * \frac{\Delta K_i}{K_i} = c_i * \frac{p_i K_i}{pQ} * \frac{\Delta K_i}{K_i} = (r + d_i - \frac{\Delta p_i}{p_i}) * \frac{p_i K_i}{pQ} * \frac{\Delta K_i}{K_i},$$

where pQ stands for the value of production (or value added), Q denoting its volume and p its price, and where $\Delta K_i / K_i$ is the growth rate in volume of the capital stock of ith type.

This last full expression shows that the estimated contributions of ICT and R&D to growth critically depend on their estimated user costs and hence, besides the net rate of return (r), on their depreciation rates (d) and price rates of change $(\Delta p / p)$. They also depend on the magnitude of the capital stocks ratios to output in value and of the growth rates of capital stocks in volume, themselves also crucially relying on the corresponding investment price changes and depreciation rates. It is already very difficult to measure precisely and surely enough such characteristics for most of the common (and less rapidly evolving) types of investments in equipments and buildings, and it is even much more so for R&D and ICT investments. It is thus important to consider even briefly the main problems, as concerns more specifically the estimation of the net returns, the depreciation rates and the price indices for R&D and ICT.

2.2 The Net Rate of Return to Capital

First it is useful to precise two points about the measurement of the net rate of return. Theoretically the net rate of return of one investment should correspond to the nominal interest rate because the firm compares the financial cost of this investment to its predicted benefits. Therefore, the equilibrium is hold when the interest rate is equal to the net rate of return. The second point is that, theoretically, the net rate of return should be the same for every investment. If the net rate of return for one type of investment was lower than the others this type of investment should be give up. This result is also valid even if risk and uncertainty attached to some particular investment, like R&D, are higher. The net rate of return take into account the expected benefits which means that the lower probability of success is taken into account by firms in their optimization program.

The net rate of return considered above concerns only the private net rate of return which reflected the profits received by the owner of capital. The private net rate of return is the correct measure of the benefits from capital when there is no externality which is associated to its use in production. When there are externalities, it is more accurate to consider the social rate of return which includes the spillover benefits. What are the externalities concerning the R&D activities? Generally speaking the spillovers from R&D activities are classified in two big categories (see Griliches [1994 and 1995]).

The first one concerns the fact that users can buy at the same price a product with higher quality or buy cheaper the same product. These kinds of financial externalities come directly from the results of R&D activities. The second category of externalities from R&D activities concerns the diffusion of knowledge, which is the main input and output of R&D activities. Knowledge has in some extent the same characteristics than a public good. That is knowledge could be used simultaneously by many researchers without bother each other. Moreover, the cost of knowledge diffusion is very low compare to its production cost and this fact favors the diffusion to the researchers community. The most important limit for researcher to the access of knowledge is simply to be able to understand it and to use it to improve his research. Since the present innovations are based on the past innovations which are for most part freely and cheaply available, the R&D activities through the externalities from the diffusion of knowledge create a social benefit. The second point is that the innovators can't take over all the benefits generated by his innovation. The most popular protection for innovators is the patent system or license system that gives to innovators a temporary monopoly on the use of his innovation. But this protection is limited in time and the patent system doesn't stop the diffusion of knowledge to other researchers, on the contrary the patent makes it public. For Arrow (1962) the results of R&D activities are comparable to information and that why it has very few chances to be paid. Therefore, this limitation to the innovators ability to take over all the benefits from his innovation creates social benefits which can be described with the standard analyze of Pigou about the differences between the private rate of return and the social rate of return. However and this is a crucial point, these kinds of externalities from the R&D activities are extremely hard to measure.

2.3 The Depreciation Rate of R&D Capital

The evaluation of investment as production factor also implies that of the capital stock resulting from its accumulation, since it is in this form (or, to be more exact, in the form of the services provided by this capital) that it contributes to growth. The stock of intangible assets like R&D is generally obtained by cumulating investment flows with "the chronological" method. The chronological method is the one that is widely used by national accounts statisticians to measure capital stock. The chronological method consists of simulating the process of capital accumulation using knowledge of the series for past investment, and specifying rules for the rates of decommissioning and depreciation. The depreciation of R&D is assumed to due to obsolescence of knowledge since new R&D activities destroy the oldest ones following Schumpeter's idea. The choice of depreciation pattern for R&D stocks is generally based on arbitral appreciation and not due to empirical surveys or observations. Furthermore, there are many debates about the pertinence to keep the same depreciation pattern for each kind of R&D activity[3]. One can imagine to get different depreciation pattern according to the three categories of R&D activities which are: "basic research" which concerns only theoretical work; "applied research" which concerns a specific need and application; and the last one is "development" which concerns the direct use of knowledge to improve materials, systems or method. It is believed that the depreciation rate of the "development" activities is higher than this of "applied research" which is higher than "basic research" one's.

Talking about the depreciation rate of R&D capital two points could be considered. One, is to take into account, like Fraumeni and Akubo (2002), the increased importance of ICT relative to other industries. Since the evolution of technological change is more rapid in ICT producing sectors, the obsolescence of innovation in ICT is more rapid so the depreciation of R&D could be also more rapid. The second point concerns the social rate of depreciation and argues for a decrease in depreciation rate of R&D capital whereas the former, which concerns the rate of technological change, argues for an increase. Since we considered the social rate of return of R&D activities is higher than private one, it's reasonable to consider also that the social depreciation rate of R&D activities is lower than the private one. One innovation could indeed continue to have some social benefits especially for imitators and for buyers even if for the innovator the benefits stopped.

[3] See Rosa and Rose (2004) and Rose and Lonmo (2003) for examples about debates on the rate of obsolescence for R&D capital.

2.4 The Deflation of R&D

Since the quantity series are used to set up the capital series, the price index are needed to split investment nominal value terms into two components quantity and price. Splitting investment value into price and quantity is difficult for standard product and extremely difficult when the production techniques and performances of investment products progress quickly, like ICT investment for example (see below). But concerning, R&D activities, since there have not been considered as investment by national account systems there is no official price index. So that, studies on R&D capital use generally the GDP price as deflator. This method has the advantage of simplicity but doesn't take into account the progress in quality of R&D activities. How is the progress of the quality of research activities could be measured? It's extremely hard to give any answer to this question. The hedonic methods which are used for ICT are based on econometric estimation of the progress on the main characteristics of the investment product (for example for IT it's the hard disk capacity, the processor speed…). For R&D expenditures, since there is no specific market for research it's extremely hard to identify their main characteristics and all the more so their price. However, since the technological progress in tangible and intangible products are largely due to the R&D activities, it seems to be reasonable to estimate the progress in quality of R&D expenditures in line with the technological progress of the economy. The hedonic methods (see below) which measure the technological progress for some ICT products could be used as an indicator of the progress in quality of R&D activities.

2.5 The deflation of ICT

The measurement of ICT products, which corresponds to computers and peripheral equipments, software and communication equipment, raise some methodological difficulties. One of the most important difficulty is the measurement of the evolution its components prices. Because of the rapid evolution of their productive performance, following the "Moore's Law", it's crucial to construct a price index "at constant quality" so that the evolution in volume includes the evolution in quality. The "hedonic" method used in complement to or in replacement of the matched-model method, seems to be the most suitable for this approach, and national account statisticians have been progressively adopting it, despite application difficulties, in fairly large number of countries. In particular, this true for the United States, where the Bureau of Economic Analysis (BEA) decided to introduce hedonic price for IT equipment and more recently for software (Grimm et *alii* [2002], Moylan and Robinson [2003]). As regards communication equipment the hedonic method for quality adjustment is used for telephone switching equipment and for local area network. These components represented nearly one half of total investment in communication equipment (Grimm et *alii* [2002]). The measurement of communication equipment price index, and to a less extent for software, could be improved in the next years to take better into account the progress in productive performance of these products. Therefore, the actual price index for ICT products could underestimate the rise of quality so the decline of the price could be higher.

However, the use of hedonics methods, especially for PCs and software, can be called into question for reason of fundamental justification. The technical capacity of PCs has expanded considerably and, generally speaking, only a small part of this capacity is actually called on by each user. Moreover, PCs are now equipped with software which, too, is used by the majority of users of users only to a small proportion of its capabilities. Triplett (1999) counters this argument by pointing out that the evolution in software, even if it is under-used, provides increased conveniences of use and this does indeed correspond to an improvement in quality.

3 Considering Three Conceptual Variants on R&D and ICT

The paper presents a comparative study in contribution to growth of R&D and ICT capital with an application to U.S and French economies. As it is discussed upper to get these contributions we have to cope with some difficulties about the net rate of return to R&D capital, the depreciation rate of R&D capital and the deflator of R&D and ICT products. To face up to these difficulties we adopted different assumptions and each of them is presented as an alternative scenario of R&D and ICT capital contributions to growth. There are three alternative scenarios for each capital. The assumptions concerns the components of the user cost of the capital: the price deflator, the depreciation rate and the net rate of return. The first section presents our three conceptual variants and in the second section we discuss our numerical choices.

3.1 Definition of the variants

Table 3 summarizes our assumptions for each of three conceptual variants. The first conceptual variant (noted V1 and called "**conservative**") concerns the very conservative case. This assumption is important because it gives to us the estimates without any adjustment for quality or for spillover effects. Therefore, we keep the GDP price both for R&D and for ICT. This price reflects mainly the cost component. The depreciation rate is the private depreciation rate and the net rate of return to capital is also the private net rate of return. V1 estimates consider in fact R&D and ICT investment like other tangible investment and then gives to us the starting point of R&D and ICT capital contributions to growth.

The second conceptual variant (noted V2 and called "**intermediate**") concerns the case where i) ICT equipments are fully adjusted for quality improvement and ii) the social benefits, via spillover effects, from R&D activities are taken into account. Note that the R&D investments are not adjusted for quality. Therefore, we keep the GDP price as deflator for R&D expenditures. The deflator of ICT investments is the GDP price adjusted to take into account the rapid progress in their performance. We supposed in this variant that all the technological progress is due to the producer of ICT. To take into account the fact that social benefit from R&D activities is higher than the private one, we consider a social depreciation rate and the social net rate of return. As regards ICT investment, it is considered, like other tangible investment good, that there is no spillover effect or any kind of social benefit from their use. Then the rate of return to ICT capital is only the private net rate of return and the depreciation rate is also the private one and is taken from the national account system.

Table 3: Definition of Conceptual Variants:

	Price Evolution ($\Delta P_j / P_j$)	Depreciation Rate (d_j)	Net Rate of Return *(i)*
R&D V1	GDP	Private	Private
R&D V2	GDP	Social	Social
R&D V3	GDP+Quality Effect	Social	Social
ICT V1	GDP	Private	Private
ICT V2	GDP+Full Quality Effect	Private	Private
ICT V3	GDP + Non-R&D Quality Effect	Private	Private

The last conceptual variant (noted V3 and called "**advanced**") assumes that there is quality improvement in R&D expenditures. Therefore the price deflator of R&D investment is the GDP price adjusted for quality. But, the results of progress in performance of R&D activities appear through the technological progress of all products of the economy. Then, the rapid progress of ICT performance is for a certain part due to the quality improvement of R&D investment. As it well known the technological progress in economy is not due to "manna from heaven" especially in ICT producing sectors which represent around 25% of R&D expenditures (OECD [1995] and OECD ANBERD data Base). So, to avoid double counting the same quality effect (one time in ICT investment and one time in R&D investment) we have to remove from ICT quality adjustment the component due to R&D investment. Therefore, the price deflator of ICT investment is adjusted only for "Non-R&D" quality improvement. As regard, the depreciation rate and the net rate of return, the assumptions of variant V1 are kept. That is, social depreciation rate and social net rate of return for R&D capital and, private depreciation rate and private net return for ICT capital.

3.2 Calibration of the variants

As mentioned above, the conceptual variants concern the value of three variables: the depreciation rate, the net rate of return to capital and the evolution of deflator price. This section discusses our numerical choice for each of these variables on each conceptual variant. Table 4 summarizes these choices.

3.2.1 The rates of depreciation of R&D and ICT

As concerns the rate of depreciation of R&D capital the literature is not very abundant (See Rosa and Rose [2004] for a review). Two methods are used to choice the depreciation rate of R&D capital. The first one is based on econometric estimations of production functions where R&D is included as an input as well as other tangible equipments (see Nadiri and Prucha [1993] for example). The second method, the simplest and the most popular, is based on the perpetual inventory method (or chronological method) and more or less arbitrarily fixed depreciation rate. The most popular point of view is that the chronological method with fixed geometric depreciation pattern is a good approximation to get R&D capital[4]. In this case the depreciation rate is included between 10% and 20%. There is debate about some particular point on the measurement of depreciation of R&D capital stock (see Rose and Lonmo [2004] for a summarized review). These debates asked if one should consider different depreciation rate according to the nature of R&D (if it's basic research the depreciation should be lower and if it's

[4] The assumption of a geometric series for decommissioning (mortality) at a constant rate d is the one adopted mainly by American national accounts statisticians (as well as by Jorgenson and Stiroh, 2000, and Oliner and Sichel, 2000). It has the advantage of enabling the stock of capital to be calculated by a simple recursive method and hence, in particular, to facilitate the calculation of variants. The volume of capital (K_{jt+1}) for good j, at the beginning of year t+1 (and the end of year t) is equal to the capital (K_{jt}) at the beginning of year t increased by the volume of investment (I_{jt}) in year t, and diminished by the decommissioning $(d_j K_{jt})$, giving the following relationship: $K_{jt+1} = (1-d_j)K_{jt} + I_{jt}$. This assumption, however, means that the decommissioning of capital does not depend on its age and the notion of gross capital is then blurred with that of net capital (and the notion of decommissioning with that of depreciation). The results relating to the medium- and long-term evolutions in capital that are of importance to us here are relatively similar, as we have been able to verify, to those obtained using decommissioning rules of the log-normal type used by preference in the French national accounts (cf. notably Mairesse, 1971 and Mairesse,1972).

applied research it should higher) or according to the nature of industrial activities (the knowledge used in industry with rapid technological progress, like computers, should have higher depreciation rate than knowledge used in industry with slower technological progress like mining for example). Even if these debates are important and interesting for the capitalization of R&D (especially from National Accounts perspective), this is not the main focus of the paper. Therefore, our starting point for depreciation of R&D capital is the simplest method. That is, for the variant V1, the chronological method with a fixed depreciation rate of 15% is used. Since, the literature shows a depreciation rate generally included between 10% and 20% the choice of 15% appears to be the most relevant. As concerns, the social depreciation rate, which is used in conceptual variants V2 and V3, there is no literature about its value. However, as we discussed in the section 2, the social depreciation rate is expected to be lower than the private one. So to be the most realistic as possible we decided to take the lower bound of the range of depreciation rate R&D capital estimated in the literature. That is, in the variants V2 and V3 the depreciation rate R&D capital is set at 10%.

The chronological method with a constant annual geometrical depreciation rate is also used to obtain the stock of capital in ICT. Generally, ICT equipments are divided into three components: Computers and peripheral, communication equipments and software. And for each component a capital stock is calculated with a specific depreciation rate. For example Mairesse, Cette and Kocoglu, [2002] retains 30% depreciation rate for IT equipment and software, 15% for communication equipment. These high rates seem realistic and are in general consistent with those implicitly used for the French national accounts. They are also close to those used in the United States national accounts. But in this paper, to simplify without any big impact on results, we consider the aggregate investments in ICT and the depreciation rate for ICT capital is the weighted average depreciation rate of the above three components. Therefore the depreciation rate of ICT capital is set to the constant rate of 24%[5]. Since we do not consider any social benefits from the use of ICT the social depreciation rate is the same than the private. Then, for every conceptual variant (V1, V2 and V3) the depreciation rate of ICT capital is set to 24%.

3.2.2 The Rates of Return to R&D and ICT

As mentioned in section 2.2, theoretically the net private rate of return to capital should equal to the nominal interest rate. Then, for the period concerned by the study (1980-2000) we retain the

[5] In fact the depreciation rate is different in United States and in France because the share of IT, communication equipments and software are different. Since the average depreciation rate over the period 1980-2000 is about 23% in France and 25% in the United States we keep the same depreciation rate for both countries.

average long-term interest rate of 10%, which is slightly higher than this really observed (around 9% in France). Since, ICT investment does not have any spillover effect, its net rate of return is then equal to 10% in variant V1, V2 and V3.

As concerns R&D investment the net rate of return is also 10% in variant V1 where we do not take into account its social benefits. The conceptual variants V2 and V3 take into account the idea that the social benefits from R&D activities is higher than the private one. How much is it higher? Despite a growing number of studies, of a general econometric nature, the estimates of the importance of externalities remain very imprecise and highly uncertain. Being very high, they lend credence to the idea of gross[6] social return on R&D that would be at least double, often three times or more the private one[7]. Despite measurement and methodological difficulties, one can summarize the econometric estimations for gross private and social rate of return to R&D capital. The gross private rate of return is, on average, between 20 to 30 percent and for the gross social rate of return the estimates are more heterogeneous and so the scope is larger, from 30 to 80 percent (Fraumeni and Okubo [2002]). The assumption adopted here is, in line with other study like (Fraumeni and Okubo [2002]), that the gross social rate of return is the double than the gross private one. The gross private rate of return is 25% here. Then the social rate of return to R&D capital is 50%, which is also the hypothesis made by Fraumeni and Akubo (2002) for U.S economy. This value of 50% for gross social rate of return to R&D capital is adopted both for conceptual variants noted V2 and V3.

3.2.3 The price indices of R&D and ICT

The price index is crucial in growth accounting framework because it plays a big part in the level of capital stock and also in its growth rate. Splitting the values of investment into quantity and price is extremely complex especially when there is a rapid change in the performances of the products which is the case for ICT and R&D.

As concern the conservative variant V1 there is no problem of deflator because we retain the GDP price as deflator. So the growth rate of ICT and R&D investment price is 0% relative to the price of GDP (see table 4). Variant V1 allow us to estimate and to compare the "net" contribution to growth of "quantity" in ICT and R&D investment without any quality or spillover effect.

6 The gross rate of return is equal to the net rate of return plus the depreciation rate of capital.

7 See notably the study by Griliches (1992) and by Mairesse and Mohnen (1996 and 1999).

The intermediate conceptual variant V1 takes into account the rapid progress in performance for ICT investment. As mentioned in the section 2.5 the hedonic methods are used the estimate the price evolution of computers, one part of software and a little part of communication equipment. Then the figure of ICT price index shows a decrease of 5% and 3%[8] per year from 1980 to 2000 respectively in the United States and in France.

However, there is a sensible methodological difference in the treatment of the three components of ICT investment because one non-negligible part of software and a big part of communication equipment are not adjusted to take into account the progress in their performance. Then when the price of computers decline on average by 15% per year the price of software and communication equipment decline respectively by 1.5% and 0.1% per year over the period 1980-2000 in the United States. This year BEA plans to improve the measurement for own account software to take into account changes in productivity over time (See Moylan and Robinson [2004] for more precisions). The new price index for own account software is a weighted average of actual input-output cost index (75 percent weight) and the BLS PPI for “prepackaged software applications sold separately” (25 percent weight). Because of this small change the new price index of software shows more rapid decrease over the period 1980-2002 (-1.5%) than the previous price index (-0.1%). Putting together these information it’s appears that the actual price index for software and communication equipment underestimates their quality effect and so the price of ICT at whole should displays more rapid decrease. Actually, the growth rate of ICT price relative to GDP price is about 8% and 7% respectively in the United States and in France. So to face the lack of hedonic price for one part of software and a big part of communication equipment we assume a relative decrease of ICT price of 10%[9] per year compare to the GDP price. To simplify this “full quality” effect is supposed to be the same in both countries.

To summarize, with the conceptual variant V2 the growth rate of ICT investment decreased by 10% per year relative to the GDP price index growth rate. As concerns R&D investment, since there is no quality adjustment its price index is again equal to the GDP price. The difference between the contributions of ICT capital to growth with V2 and with V1 shows the contribution of technological progress in ICT to growth.

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[8] The growth rate of ICT price index is different in France compare to that of United States because the French price index is adjusted to take into account of the variation of the exchange rate (See Cette, Mairesse and Kocoglu [2002]).

[9] The growth rate of an average 10% per year over the period 1980-2000 of ICT price index correspond roughly to a decrease of 5% per year of software and communication price index.

The last conceptual variant, V3, tries to take into account quality improvement in R&D activities. To estimate this quality improvement we made one first assumption: the sum of R&D capital and ICT capital contribution to growth with the variant V3 should be equal to the same sum with the variant V2. This assumption ensures that the contribution of technological progress remains the same between variant V2 and variant V3. Our object here is only to trade-off one part of ICT technological change to R&D activities because as we mentioned it in the section 3.1 one part of technological progress in ICT investment is due to R&D expenditures. But how much? What is the share of technological progress in ICT due to R&D expenditures? Here we made our second assumption. Since ICT industries, especially computers industries, are relatively intensive in R&D expenditures[10] and since there is no evaluation of this share we simply decide to consider that the half of technological progress in ICT is due to R&D expenditures of ICT industries. The other 50% is then due to other factors like improvement in organization and in human quality for example. With these two assumptions we obtain that the price index of R&D investment with quality adjustment shows a decrease of average 3%[11] per year compare to the GDP price index growth rate. So to summarize, with the conceptual variant V3 the ICT and R&D price index decrease by respectively 5% and 3% per year compare to the GDP price growth rate. Note that the technological progress still higher for ICT than for R&D and that we do not adjust R&D expenditures for the technological progress which affect the other part of the economy. The reason is simple: we don't know how rapid is this technological progress for the other component of the economy. Therefore, one can say that we still underestimate the quality adjustment of R&D price index.

[10] ICT industries R&D expenditures represents around 25% of total R&D expenditures in United States while the GVA of ICT industries represent around 10% of total US GVA.

[11] Note that i) this rate change year to year but to simplify we retain an average for all the period and ii) for United States the average is slightly higher than 3% and for France is slightly lower.

Table 4 : Numerical Values of Conceptual Variants

	Price Evolution (Relative to GDP price)	Gross Rate of Return	Depreciation Rate	Net Rate of Return
R&D V1	0	25%	15%	10%
R&D V2	0	50%	10%	40%
R&D V3	-3	50%	10%	40%
ICT V1	0	34%	24%	10%
ICT V2	-10	34%	24%	10%
ICT V3	-5	34%	24%	10%

4 R&D Contribution to Growth in the USA and France and Comparison with ICT

Before starting growth accounting analyze we must precise that we don't adjust either the GDP or the GVA value after we treated R&D as investment. So as Fraumeni [2002] showed it for US case, capitalizing R&D changes the estimates and the growth rate of GDP. For US, according the author, "it has a very small effect on the rate of growth of real GDP, but a significant effect on the composition of GDP". One can imagine that the French economy should exhibit results like the US one.

We estimate the contribution of R&D and ICT capital to growth for the United States and for France over the period 1980-2002. This section starts with describing the consequences of our conceptual variants on: investment series (price and quantity); growth rate of capital series; the share of capital services in GVA and finally the contribution of capital to growth.

4.1 Investment in R&D and ICT: Value, Price and Quantity

Tables 6 in annexes present the result of the evolution of R&D and ICT investment series. As concerns the series of investment value we can observe that on average in the growth rate over the period 1980-2000 were very close in the United States and in France with around 7% per year for R&D and around 10% per year for ICT. However, three observations are important to be noted.

First, during the period 1990-1995 the growth rate of investment in ICT sharply fell down in France (1.4% per year after 12.8% per year over 1980-1990) but it still remained high in the United States (9.2%). Then the gap in ICT investment between France and United States increased seriously during this period. Second, as concerns the R&D investment again the US economy increased his advance to France but during the period 1995-2000. The growth rate of R&D investment was roughly three times higher in the United States than in France (8.6% compare to 3.1%). The third information concerns the period 2000-2002 where we observed a big decrease in ICT investment compare to the period 1995-2000. In the United States we observed a decrease in ICT investment -7% per year after 14.5%!! In France the growth rate also sharply fell down but remain positive around to 1% per year after 14% per year.

As concerns the evolution of R&D investment price there is nothing special to note. We have the evolution of GDP price for variants V1 and V2 and the GDP price less 3 point for the variant V3. Then on average the growth rate of GDP price was slightly lower in the United States than in France over the period 1980-2000 respectively 3.2% and 3.8% per year. For ICT price evolution we just note the case of variant V2 with the "full quality effect". In this case, the decrease of ICT price was slightly more rapid in the United States than in France, –6.8% per year compare to –6.2% per year. The difference appears because the French GDP price is lower than the US one. The difference in ICT price evolution between both countries is then sensible only during the period 1980-1990 where the inflation rate in France was high.

A brief look at the quantity series shows that if we do not adjust series for improvement in quality (variant V1) investment in ICT decreased slightly in France over the periods 1990-1995 and over 2000-2002. This decrease concerns only the last two years for the United States but the size is more important than in France (-8.6% compare to –0.6%). The decrease in ICT investment in the United States during the period 2000-2002 was so important that even with the variant V3, which takes into account the progress in ICT performance, the evolution of ICT investment quantity was negative (-3.9% per year).

4.2 R&D and ICT Capital Stocks

The resulting estimates of the capital stock, as regards evolutions in volume and shares of value, both of which come into the calculation of contributions to growth, exhibit some interesting results (see Tables 7 and Figures 2 in annexes). First, when we compare the growth rate of R&D and ICT capital calculated without any adjustment for quality (that is variant V1), we observe that despite more rapid depreciation rate the stock of capital of ICT has grown over the long run more rapidly than R&D capital stock. The difference is however bigger in the United States (7.8%

compare to 4%) than in France (5% compare to 4.1%). Second, if the growth rate of R&D capital was roughly the same in both countries, as concerns ICT capital the growth rate was considerably faster in the United States. This last result shows the United States economy advance in ICT compare to France and more generally compare to other industrialized big countries (See Cette, Mairesse and Kocoglu [2002] and Colechia and Shreyer [2002] fore more detailed comparisons). Last observation concerns the ratio of capital stocks in gross value added (GVA). In both countries the ratio of R&D capital stock in GVA is higher than the ratio of ICT capital stock. It is slightly higher in the United States (11.6% compare to 9.4%) but sensitively higher in France (9.1% compare to 4.8%).

Now let look to the impact on capital stock growth rate of the assumptions made in conceptual variant V2. Remind that variant V2 adjusts R&D investment for its social benefits and adjusts ICT investment for its technological progress (see tables 3 and 4). AS concerns R&D the social depreciation rate of 10% instead of 15% in the private case has no effect on its capital stock growth rate. This result is well known (see Mairesse [1971 and 1972]) when one use a constant geometric depreciation pattern the rate of depreciation has no effect on the long run capital growth rate since the path of investment growth is more or less regular. But it has sensitive impact on the level of capital stock. For example, capital stock to value added ratio grows from 11.6% to 15.3% in the United States over the long run.

AS concerns ICT capital growth rate it is the higher with variant V2 since we adjust the ICT price for "full" quality effect. Then the growth rate of ICT capital reach 16% per year in France and 19% per year in the United States over the long run. Then in variant V2, the growth rate of ICT capital is, compare to R&D capital growth rate, around five times and four times more rapid respectively in the United States and in France. This is extremely rapid growth rate for capital stock if one reminds that the depreciation rate is quite high with 24%. The impact of the quality adjustment on the level of ICT capital stock is well known: the ratio to value added of capital stock decreases when one replaces investment price index with slow growth rate by new price index with very high growth rate. Then, the ICT capital stock ratio to value added in the United States is with the variant V2 6.9% compare to 9.4% with the first variant V1.

As concerns the third conceptual variant, noted V3, compare to the results of V2 the growth rate of R&D capital stock is higher and that of ICT capital stock is lower. Since we adjust R&D price for progress in performance, the growth rate of its investment in volume increases so that increases also the growth rate of capital stock (3.8% compare to 7.0% in the United States). The lower growth rate of ICT capital stock reflects also the assumption about the quality effect. Since we remove the component of progress in performance due to R&D, the price of ICT exhibits lower decrease and lower growth in quantity and then lower growth rate of capital stock (13.3% compare to 19.3% in the United States).

4.3 User Cost of Capital and Share of Capital Services

Let remind that the relative user cost of capital is equal to its net rate of return, increased by its depreciation rate and reduced (or increased) by the rate of price growth. Since the conceptual variants concern each component of the relative user cost of capital its value changes sensitively from one variant to another. Results about the relative user cost of capital and the share of capital services are given in tables 8 and figures 2 presents the also the latter.

Let start with the "conservative" variant V1. Here the net rate of return to capital and the price evolution are the same for R&D and ICT capital hence the difference between the relative user cost of the R&D capital and ICT capital reflect only the higher depreciation rate of ICT capital stock (24% compare to 15%). As concerns the variant V2, we made two changes: we double the gross rate of return to R&D capital (from 25% to 50%) and we add 10 percentages point to the evolution ICT price. Then the relative user cost of R&D and ICT capital increases respectively about 25 percentages point (from 21.5% to 46.5%) and about 10 percentages (from 30.5% to 40.5%) in the United States over the long run. With these two changes the user cost of ICT capital becomes higher than the user cost of R&D capital. And finally since the last variant V3 remove quality effect from ICT to add it to R&D investment, the user cost of R&D capital grows by 3 percentages point and that of ICT decline by 5 percentage points.

The share of capital services, which is equal to its relative user cost multiplied by its ratio in GVA, shows different figure. The share of ICT capital services is not affected by our different assumptions. Whatever the conceptual variant we take the share of ICT capital services is about 2.8% in the United States and about 1.4% in France. One could understand that there is compensation between the increase of the relative user cost and the decrease of the ratio of capital stock in GVA. This result is important because it's means that the contribution of ICT capital to growth will vary only with the growth rate of its capital stock. As regards share of R&D capital services the figure is quite different. The second interesting result is that the share of ICT capital services is in the United States twice as higher as in France. This means that even if the growth rate of ICT capital is the same in France and in the United States its contribution to growth will be double in the United States than in France.

As concerns R&D the share of capital services grows sharply when we introduce the social benefits (from 2.5% to 7.1% in the United States) and decline slightly when we adjust R&D price for quality (from 7.1% to 6.4%). Finally the contribution of R&D capital will vary with the growth rate of its capital stock but also with its share of capital services.

4.4 R&D and ICT Capitals Contribution to Growth

The contribution of R&D and ICT capital to growth are given in tables 5 and Figures 3 and 4 for United States and France over the period 1980-2002. The first variant V1, which is the standard framework for estimates of R&D contribution to growth, shows as it usual a very low contribution of R&D capital to growth: around 0.08% per year and 0.10% per year respectively in France and in the United States. This negligible contribution of R&D capital is the source of the "R&D puzzle" that is traditional economic analyzes are not able to confirm the important role assigned by theoretical literature on R&D expenditures. When we adjust R&D for spillovers effects through higher gross rate of return (Variant V2), contribution of R&D to growth increase sensitively, it is multiplied on average by roughly 3 in both countries. The contribution of R&D capital growth increases from 0.10% to 0.28% in the United States and from 0.08% to 23% in France. One can deduces that the contribution to growth of the social benefits of R&D activities is about 0.18% per year in the United States and about 0.15% per year in France. This result highlights how much is important to take account of the spillovers effect in growth accounting framework with R&D capital. When we adjust R&D price to take into account progress in performance (variant V3) the contribution of R&D capital increases by another 0.17 percentage point in the United States and by 0.12 percentage point in France. It is easy to deduce that these increase in R&D capital contribution measure the component of quality adjustments.

At the end, the contribution of R&D capital to growth increased by 0.35 percentage points in The United States and by 0.28 percentage point in France. Roughly the half of this increase is due to adjustment for spillover effect and the other is due to adjustment for progress in performance. Then R&D capital contribution to growth appears to be about 0.45% per year in The United States and about 0.35% per year in France. These contributions are in each country 4.5 times higher than those obtained with the conservative and traditional growth accounting framework!! Moreover, remind that our quality adjustment of R&D price underestimates the technological progress in R&D because we only adjusted its price for ICT technological progress and put aside the technological progress of other investment.

Let know talk about ICT capital contribution to growth. The variant V1 give to us what would be the ICT capital contribution if the hedonics methods were never been used. In the long run (1980-2000) this contribution would be very low in France (0.08% per year) but quite more sensitive in the United States (0.23% per year). Remarkable result appears with the boom of ICT capital contribution to growth after 1995 in the United States: it increased from 0.14% over 1990-1995 to 0.37% over the period 1995-2000. Even, if we don't take account for progress in performance the rapid increase in ICT investment occurred during these years is enough to show a shoot up by 0.24% per year of the ICT capital contribution to growth. Note that in France, because of lower increase in ICT investment during the period 1995-2000 (see table 6), the shoot up is very lower but appears more sensitive over the last two years (2000-2002). These results are far from those of recent literature estimates. Jorgenson, Ho and Stiroh (2002) and Oliner and Sichel (2002) estimates the contribution of ICT capital to productivity growth in the United States respectively to 0.80% and 1.0% per year over the period 1995-2000. Their estimations are at least the double of those obtained here with the conservative assumptions. As concerns France, Cette, Mairesse and Kocoglu (2002) presents results where the contributions of ICT capital are on average three times higher than those presented here with variant V1.

When we adjust ICT price for progress in their performance, the contribution of ICT capital to growth increased to 0.56% per year in the United States (more than double compare the result of variant V1) and about 0.24% per year in France (multiplied by three compare to result of variant V1) over the period 1980-2000. These results are closed to those presented in the literature cited above[12]. The differences in ICT contribution to growth between V1 and V2 measure the contribution to growth of ICT technological progress. This contribution is then about 0.33% in the United States and about 0.16% in France. Finally, when we remove the technological progress due to R&D from ICT price, the contribution of ICT to growth falls to 0.39% in the United States and to 0.15% in France.

Let now compare more precisely R&D capital contribution to growth with that of ICT capital. If one follows traditional growth accounting studies he will compare the results from variant V1 for R&D capital with the results from variant V2 for ICT capital (see Figures 4 and 5). There is no doubt about the result of this comparison. ICT capital contribution to growth is widely higher than the contribution of R&D capital: 0.56% per year for ICT capital compare to 0.10% per year for R&D capital over the period 1980-2000 in the United States. This gap will be bigger if one compares the period 1995-2000: 0.83% per year for ICT compare to 0.10% per year for R&D. However this comparison is not really relevant because there is a big methodological discrepancy: the price of one investment (ICT) is fully adjusted for progress in performance but the price of the other investment (R&D) is not adjusted at all. Then to correct this methodological discrepancy we have to compare R&D capital contributions from variant V3 with ICT capital contributions from

[12] Note that precise comparisons between the estimates presented here and those presented in the literature is not relevant because here the complete growth accounting is not done. Then the crucial hypothesis of constant rate of return to is not verified.

variant V3 where both products are adjusted for their progress in performance. The match appears to be more balanced. In France, R&D capital contribution to growth is higher than that of ICT over the period 1980-2000 and becomes lower after with a quite small gap (0.33% for R&D compare to 0.38% for ICT). As concerns the United States the figure is slightly different. ICT capital contribution to growth becomes higher than that of R&D earlier than in France. After 1995, ICT contribution to growth is higher than that of R&D capital but the gap is not very important about 0.10% per year (0.46% compare to 0.60%). Finally, it's appears that over the long run (1980-2000) R&D capital contribution to growth was at least equal (even higher on average) to that of ICT capital but the contribution to growth of ICT capital increased more rapidly after 1995 and then became slightly higher than that of R&D. Therefore, conclusion is as regards contribution to growth measured with adjusted growth accounting framework, R&D investment is almost as important as ICT investment. Then if during the last decades the economic literature on growth accounting highlights the role of ICT and neglected the role of R&D, it should pay more attention to the empirical relations between R&D and growth. Moreover the recent developments in economic literature about the importance of intangible investments could be a strong incentive to do it.

Table 5: Contribution of R&D and ICT Capital to Growth, France and United States

(Average annual growth rate or average contribution per year, %)

FRANCE

	1980-2000	1980-1990	1990-1995	1995-2000	2000-2002
GVA	**2.07**	**2.63**	**0.48**	**2.55**	**1.61**
Contribution from:					
- R&D					
R&D – V1	**0.08**	0.08	0.10	0.05	0.06
R&D – V2	**0.23**	0.23	0.27	0.16	0.17
R&D – V3	**0.35**	0.34	0.42	0.32	0.33
- ICT					
ICT – V1	**0.08**	0.08	0.03	0.12	0.25
ICT – V2	**0.24**	0.21	0.19	0.33	0.52
ICT – V3	**0.15**	0.14	0.11	0.22	0.38

Scope: Business Sector
Sources: Authors calculations based on National Accounts and OECD (for R&D)

UNITED STATES

	1980-2000	1980-1990	1990-1995	1995-2000	2000-2002
GVA	**3.12**	**3.09**	**2.41**	**4.28**	**1.13**
Contribution from:					
- R&D					
R&D – V1	**0.10**	0.11	0.07	0.10	0.14
R&D – V2	**0.28**	0.29	0.23	0.28	0.37
R&D – V3	**0.45**	0.47	0.41	0.46	0.57
- ICT					
ICT – V1	**0.23**	0.21	0.14	0.37	0.41
ICT – V2	**0.56**	0.47	0.46	0.83	0.94
ICT – V3	**0.39**	0.33	0.30	0.60	0.67

Scope: Business Sector
Sources: Authors calculations based on National Accounts and OECD (for R&D)

Conclusion

The aim of this paper was to present some explanatory elements on R&D capital contribution to growth from methodological and measurement point of view. The starting point was the puzzle between the theoretical evidence of important role of R&D for economic growth and the difficulties of its measurement especially in growth accounting framework. We discussed here on three particular concepts used in growth accounting exercise: the rate of R&D capital depreciation, the net rate of return to R&D capital and the quality adjustment of R&D price. The assumptions made in this paper seem to be reasonable as regard literature but have to be asses more precisely. Whatever, when R&D is adjusted for its social benefits and for technological progress the contribution to growth of its capital becomes significant: around 0.50% per year in the United States and around 0.30% per year in France. Comparison with ICT capital contribution to growth shows that traditional growth accounting exercise concludes largely in favor of ICT contribution because of methodological discrepancy: ICT price is adjusted for technological progress but not R&D price. If we adjust both investment prices for quality improvement then the match appears to be more balanced. The contribution of R&D capital is on average higher than that of ICT capital over the period 1980-1995 and become slightly lower after. This exercise shows how it is important to consider all the conceptual aspects when one estimates growth accounting with R&D capital. Future research should pay more attention on these aspects. Moreover since there is strong development of intangible investment in economy, which creates a renewed interest in its measurement, economist in growth accounting should pay more attention to the estimates on R&D contribution to growth.

Annexes: Tables and Figures

Table 6: Growth Rates of Investment Values, Prices and Volumes
(Average annual growth rate, %)

France

	1980-2000	1980-1990	1990-1995	1995-2000	2000-2002
Values					
R&D	**7.3**	11.9	2.8	3.1	3.6
ICT	**10.2**	12.8	1.4	14.2	1.2
Prices					
R&D – V1	**3.8**	6.1	2.1	1.0	1.8
R&D – V2	**3.8**	6.1	2.1	1.0	1.8
R&D – V3	**0.8**	3.1	-0.9	-2.0	-1.2
ICT – V1	**3.8**	6.1	2.1	1.0	1.8
ICT – V2	**-6.2**	-4.0	-7.9	-9.0	-8.2
ICT – V3	**-1.2**	1.0	-2.9	-4.0	-3.2
Volumes					
R&D – V1	**3.4**	5.5	0.7	2.0	1.8
R&D – V2	**3.4**	5.5	0.7	2.0	1.8
R&D – V3	**6.5**	8.6	3.7	5.1	4.9
ICT – V1	**6.2**	6.4	-0.7	13.1	-0.6
ICT – V2	**17.5**	17.5	10.1	25.5	10.3
ICT – V3	**11.6**	11.6	4.5	19.0	4.6

Scope: Business Sector
Sources: Authors calculations based on National Accounts and OECD (For R&D)

Table 6: Growth Rates of Investment Values, Prices and Volumes

(Average annual growth rate, %)

United-States

	1980-2000	1980-1990	1990-1995	1995-2000	2000-2002
Values					
R&D	**7.8**	9.4	3.8	8.6	4.3
ICT	**11.4**	10.9	9.2	14.5	-7.0
Prices					
R&D – V1	**3.2**	4.3	2.5	1.7	1.7
R&D – V2	**3.2**	4.3	2.5	1.7	1.7
R&D – V3	**0.2**	1.3	-0.5	-1.3	-1.3
ICT – V1	**3.2**	4.3	2.5	1.7	1.7
ICT – V2	**-6.8**	-5.7	-7.5	-8.3	-8.3
ICT – V3	**-1.8**	-0.7	-2.5	-3.3	-3.3
Volumes					
R&D – V1	**4.5**	5.0	1.2	6.8	2.5
R&D – V2	**4.5**	5.0	1.2	6.8	2.5
R&D – V3	**7.6**	8.1	4.3	10.3	5.6
ICT – V1	**7.9**	6.4	6.5	12.5	-8.6
ICT – V2	**19.5**	17.7	18.0	24.8	1.4
ICT – V3	**13.4**	11.8	12.0	18.4	-3.9

Scope: Business Sector

Sources: Authors calculations based on National Accounts and OECD (For R&D)

Table 7: Growth Rates of Capital Stocks and Capital Stocks to Value-Added Ratios

France

	1980-2000	1980-1990	1990-1995	1995-2000	2000-2002
Growth rates of capital stocks in volumes *(?K_j / K_j)* (average annual growth rate, %)					
R&D – V1	**4.1**	5.0	4.4	1.9	2.5
R&D – V2	**4.2**	5.0	4.4	2.4	2.6
R&D – V3	**7.2**	8.0	7.5	5.2	5.7
ICT – V1	**5.0**	6.2	1.8	6.0	10.7
ICT – V2	**16.2**	17.2	12.0	18.4	23.6
ICT – V3	**10.3**	11.4	6.6	11.9	16.9
Capital stocks to value-added ratios *(P_jK_j / PQ)* (in %)					
R&D – V1	**9.1**	8.0	9.8	10.6	10.4
R&D – V2	**11.9**	10.4	12.6	14.0	13.8
R&D – V3	**10.1**	8.9	10.8	11.8	11.5
ICT – V1	**4.8**	4.2	5.2	6.1	6.9
ICT – V2	**3.5**	3.1	3.7	4.3	5.0
ICT – V3	**4.1**	3.6	4.4	5.1	5.8

Scope: Business Sector

Sources: Authors calculations based on National Accounts and OECD (For R&D)

Table 7: Growth Rates of Capital Stocks and Capital Stocks to Value-Added Ratios

United-States

	1980-2000	1980-1990	1990-1995	1995-2000	2000-2002
Growth rates of capital stocks in volumes *(?K_j / K_j)* (average annual growth rate, %)					
R&D – V1	**4.0**	4.8	2.6	3.8	4.9
R&D – V2	**3.8**	4.3	3.0	3.7	4.7
R&D – V3	**7.0**	7.6	5.8	6.8	8.0
ICT – V1	**7.8**	8.8	4.2	9.5	8.4
ICT – V2	**19.3**	20.1	15.1	22.2	19.8
ICT – V3	**13.3**	14.2	9.4	15.5	13.8
Capital stocks to value-added ratios *(P_jK_j / PQ)* (in %)					
R&D – V1	**11.6**	11.1	12.3	11.8	12.6
R&D – V2	**15.3**	14.7	16.2	15.7	16.6
R&D – V3	**12.9**	12.4	13.7	13.2	13.9
ICT – V1	**9.4**	7.8	10.1	12.6	14.7
ICT – V2	**6.9**	5.8	7.3	9.2	10.8
ICT – V3	**8.0**	6.7	8.6	10.7	12.5

Scope: Business Sector

Sources: Authors calculations based on National Accounts and OECD (For R&D)

Table 8: User Cost of Capital and Shares of Capital Services

France

	1980-2000	1980-1990	1990-1995	1995-2000	2000-2002
User Cost of Capital (%), $(i+d_j-\Delta p_j/p_j)$					
R&D – V1	**20.8**	18.4	22.7	23.9	23.2
R&D – V2	**45.8**	43.4	47.7	48.9	48.2
R&D – V3	**48.8**	46.4	50.7	51.9	51.2
ICT – V1	**29.8**	28.2	32.0	32.8	32.5
ICT – V2	**39.8**	38.2	42.0	42.8	42.5
ICT – V3	**34.8**	33.2	37.0	37.8	37.5
Shares of services (%), $(i+d_j-\Delta p_j/p_j)*(P_jK_j/PQ)$					
R&D – V1	**1.9**	1.5	2.2	2.5	2.4
R&D – V2	**5.5**	4.5	6.0	6.8	6.6
R&D – V3	**5.0**	4.2	5.5	6.1	5.9
ICT – V1	**1.4**	1.2	1.7	1.9	2.1
ICT – V2	**1.4**	1.2	1.6	1.7	2.0
ICT – V3	**1.4**	1.2	1.6	1.8	2.0

Scope: Business Sector

Sources: Authors calculations based on National Accounts and OECD (For R&D)

Table 8: User Cost of Capital and Shares of Capital Services

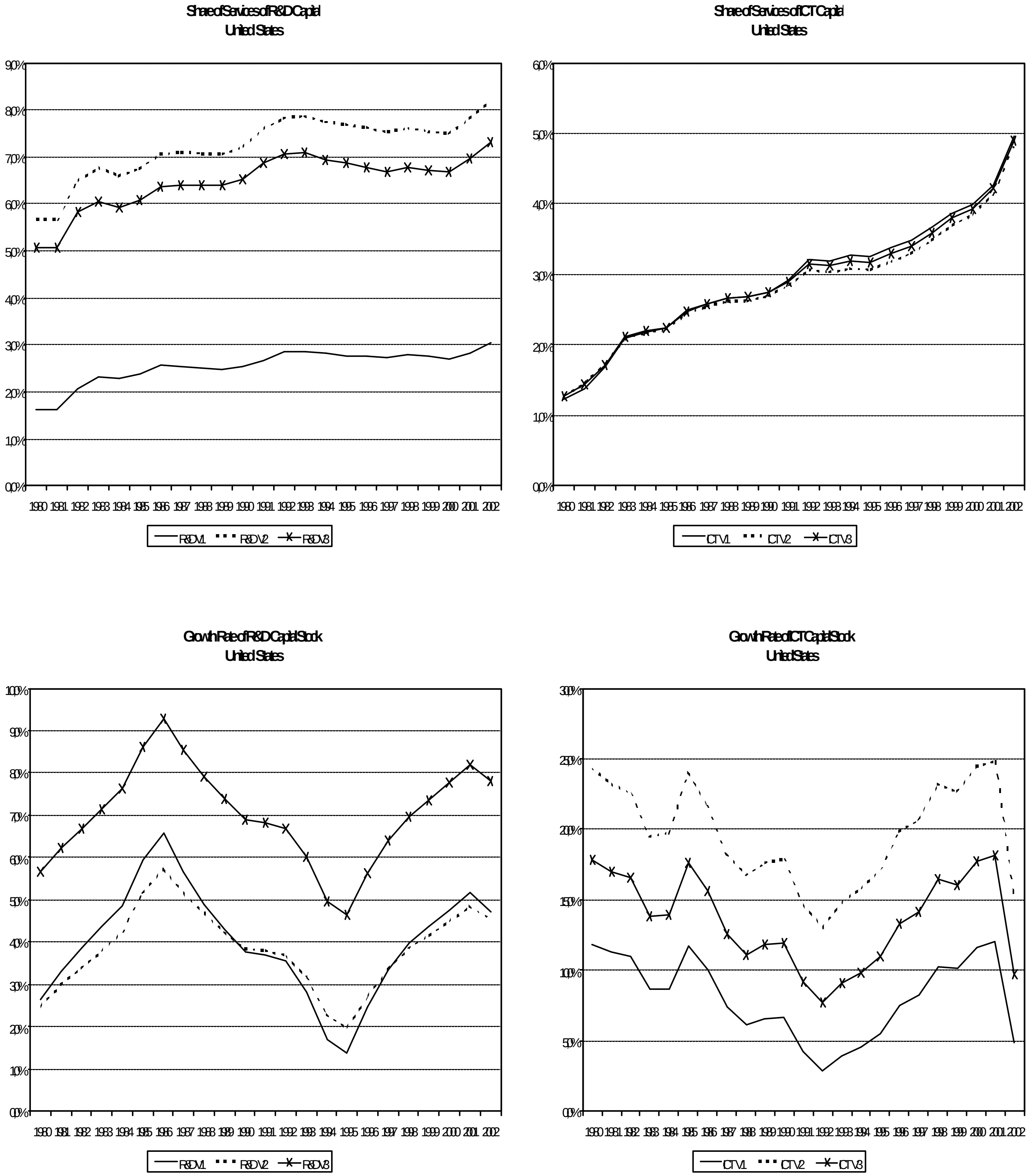
United-States

	1980-2000	1980-1990	1990-1995	1995-2000	2000-2002
User Cost of Capital (%), $(i+d_j-\Delta p_j/p_j)$					
R&D – V1	**21.5**	20.3	22.2	23.2	23.2
R&D – V2	**46.5**	45.3	47.2	48.2	48.2
R&D – V3	**49.5**	48.3	50.2	51.2	51.2
ICT – V1	**30.5**	29.8	31.6	31.2	32.1
ICT – V2	**40.5**	39.8	41.6	42.2	42.1
ICT – V3	**35.5**	34.8	36.6	37.2	37.1
Shares of services (%), $(i+d_j-\Delta p_j/p_j)*(P_jK_j/PQ)$					
R&D – V1	**2.5**	2.3	2.7	2.7	2.9
R&D – V2	**7.1**	6.7	7.7	7.6	8.0
R&D – V3	**6.4**	6.0	6.9	6.7	7.1
ICT – V1	**2.8**	2.3	3.2	3.8	4.4
ICT – V2	**2.7**	2.3	3.0	3.6	4.3
ICT – V3	**2.8**	2.3	3.1	3.7	4.4

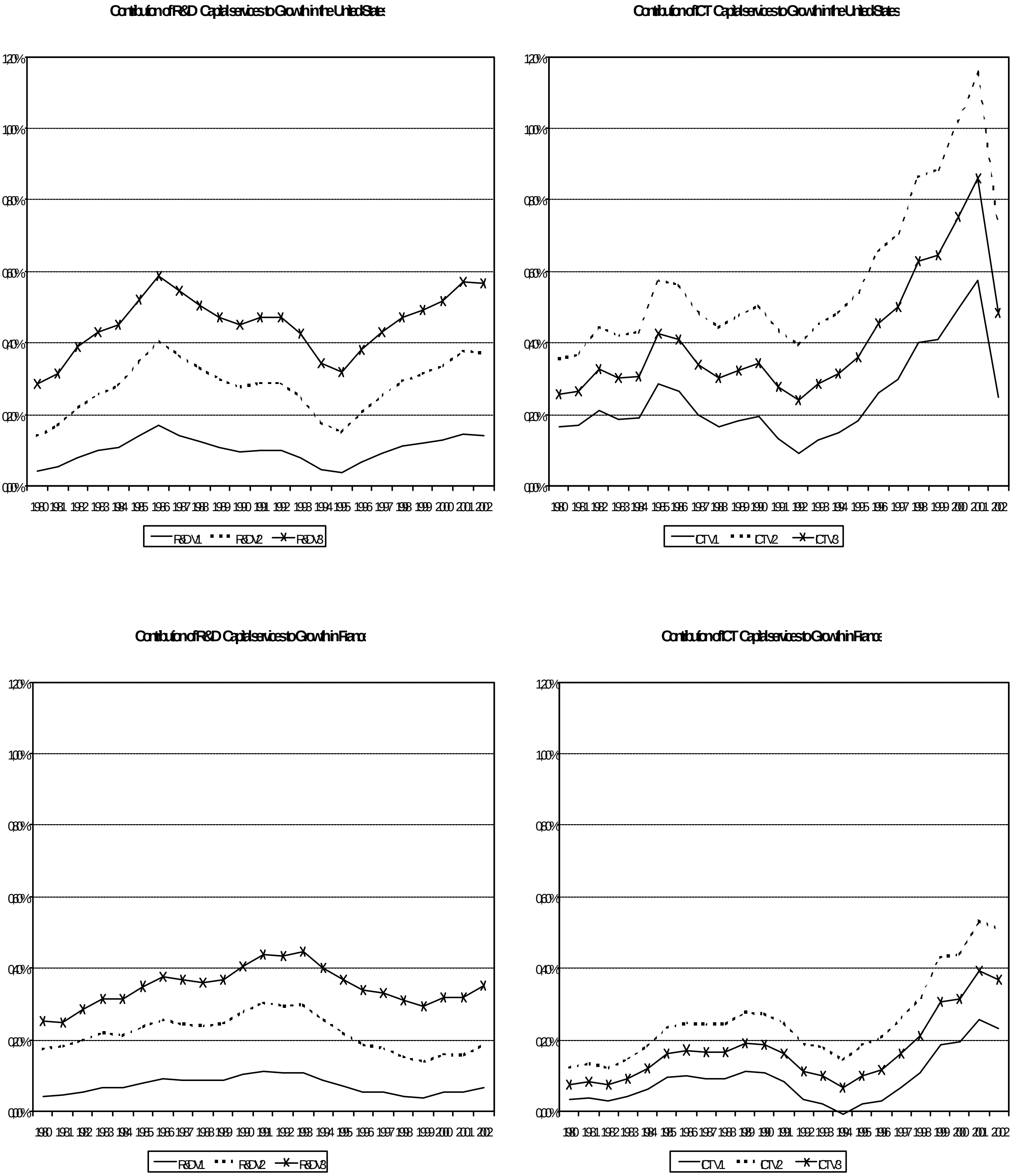
Scope: Business Sector

Sources: Authors calculations based on National Accounts and OECD (For R&D)

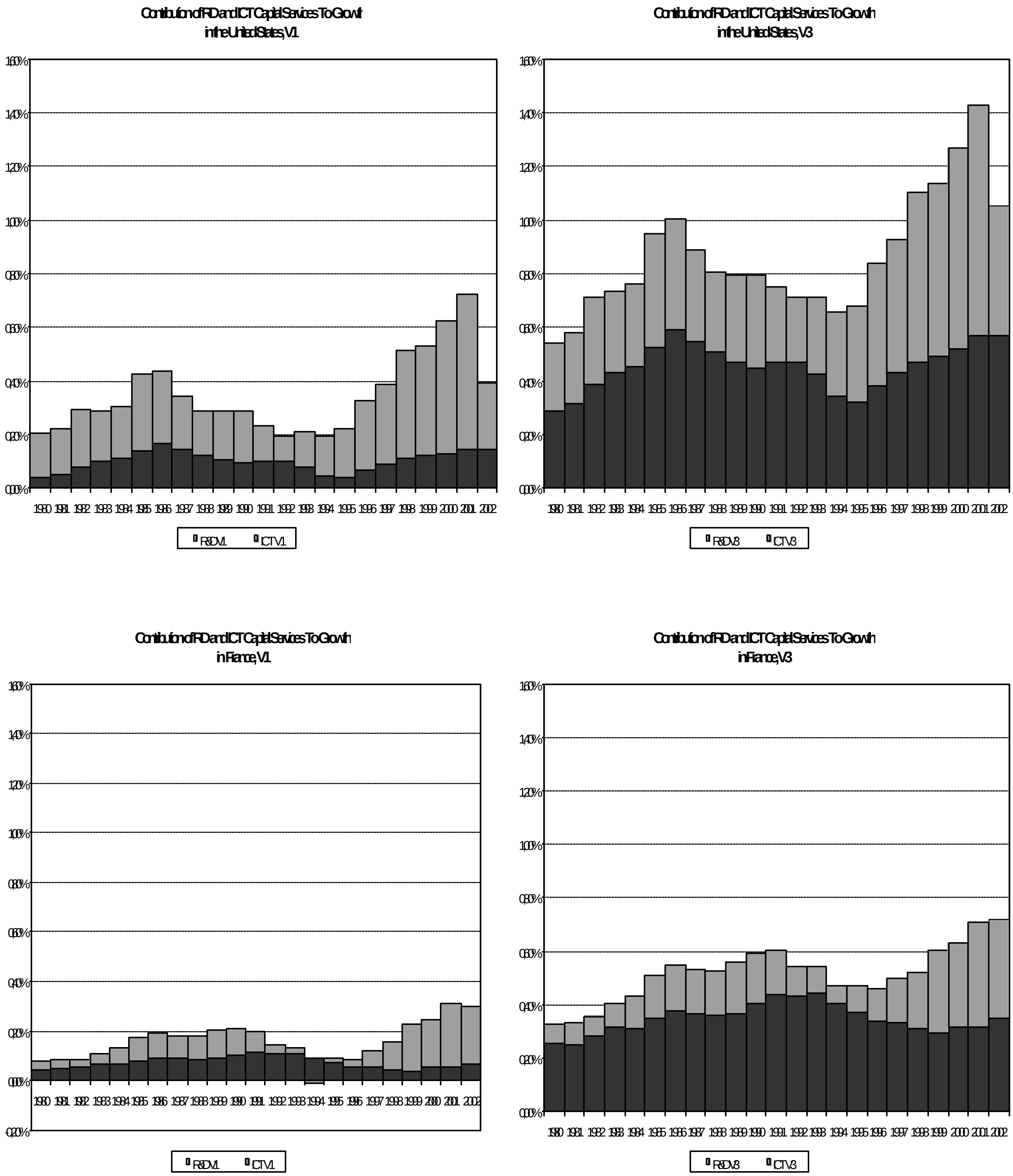
Figures 2 : R&D and ICT Capitals: Three Conceptual Variants



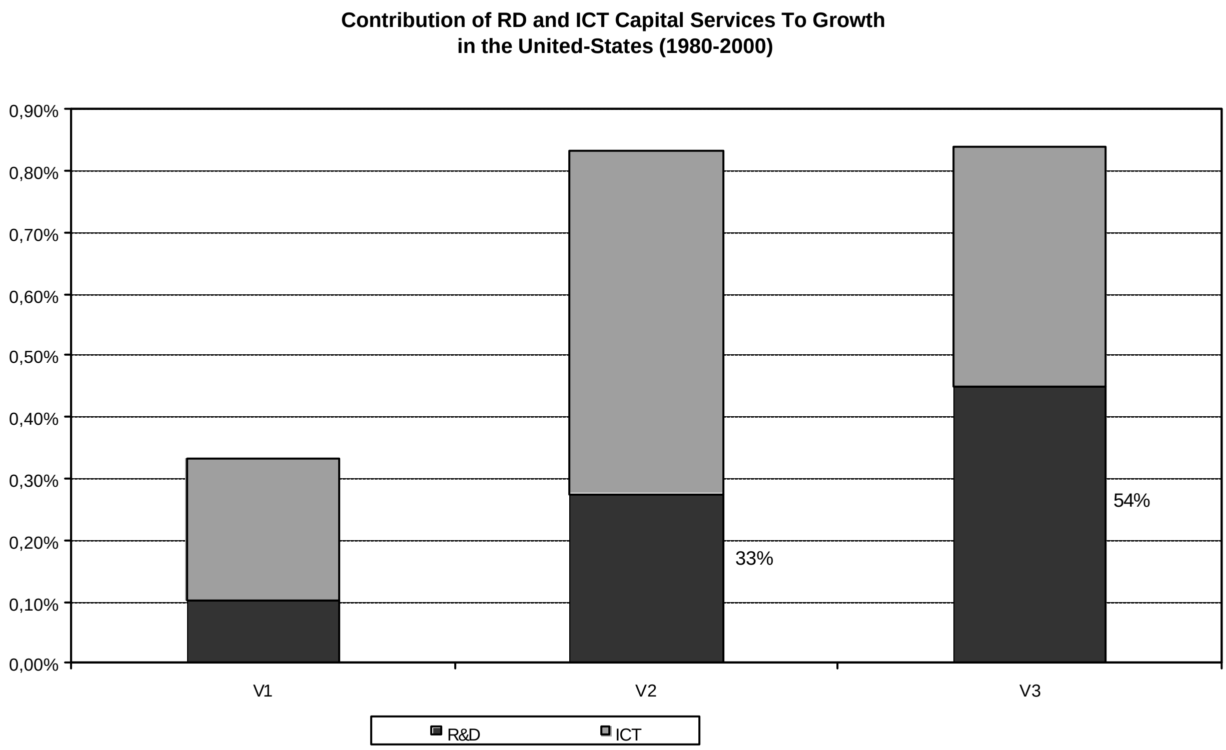
Figures 3: Contributions to Growth of R&D and ICT Capitals: Three Conceptual Variants

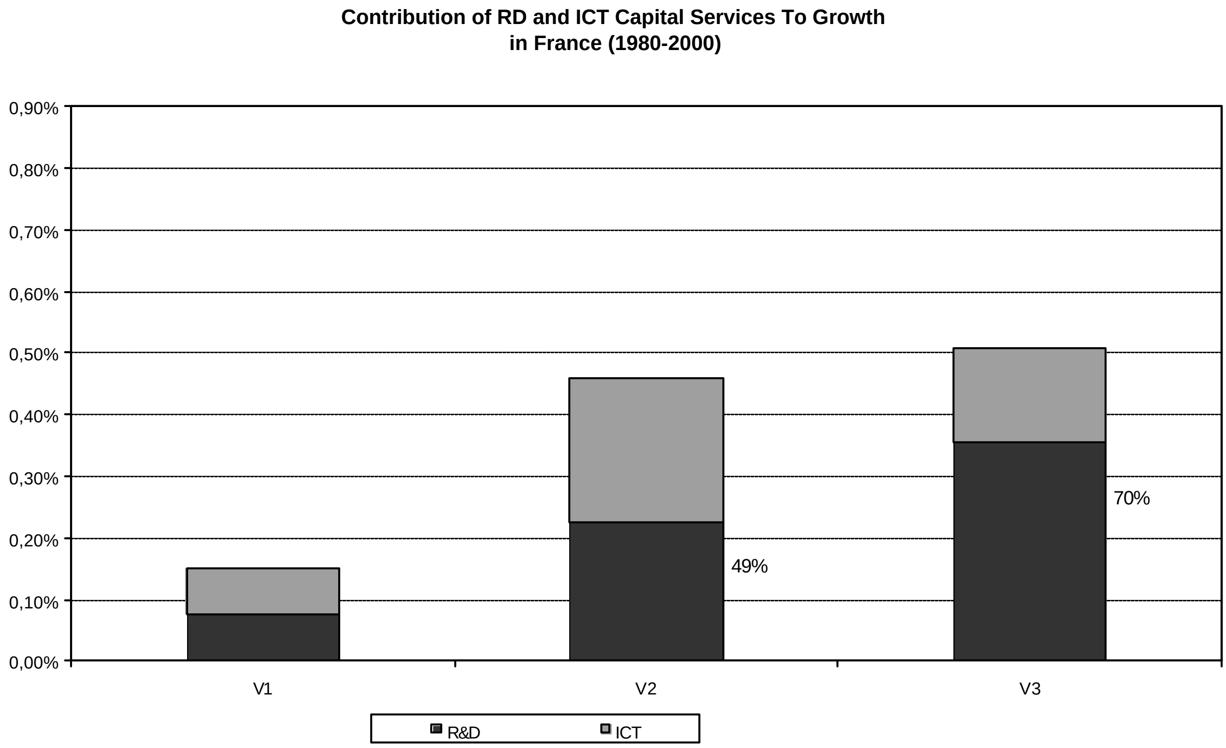


Figures 4: Comparisons of R&D and ICT Capitals Contribution to Growth (1)



Figures 5: Comparisons of R&D and ICT Capitals Contribution to Growth (2)





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