

The impact of information and communication technology capital on labour productivity : A complete macro economic framework

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ABSTRACT :

This paper aims at measuring the net impact of Information and Communication Technology (ICT). We hold a general definition of ICT capital widely adopted in the literature including computer hardware, software and communication equipment. For numerical application to the French economy we use national accounting data on capital stock and investment. We concentrate on ICT capital accumulation and do not tackle the issue of ICT producing industries, which lies outside the range of this paper.

In a first part, focusing on the supply-side of the economy, we take the growth accounting methodology as a starting point. We show that it cannot provide us with a measure of the net economic impact of ICT capital accumulation, since it does not take into account substitution among production factors. We develop an alternative theoretical framework, which enables us to define a counterfactual "non ICT" scenario, that is to say a scenario in which such a development of ICT capital does not appear.

This framework relies on the profit optimising behaviour of firms. Therefore the share of ICT capital in total capital stock depends on its relative cost. We use a production function with a constant elasticity of substitution (CES type) between labour and capital. The capital itself is defined as an aggregated good through a second CES production function combining ICT capital and non-ICT capital. Although suffering from strong restrictions on our production process, this simple framework enables us to measure the impact of the shock on the relative cost of ICT capital on labour productivity with substitution effects between production factors. As for the results during the period considered 1995-2000 with the most common parameters value economists agreed on we find that the net impact of ICT capital accumulation would be half the one generally measured when resorting to growth accounting methods.

In a second part, we insert this framework in a macro econometric model. We use Mesange, a model of the French economy developed by the Forecasting Directorate (Ministry of the Economy, Finance and Industry) and the INSEE (French National Institute of Statistics). It is a quarterly model with about 500 equations, including 40 econometric ones that reflect economic agents' behavior. It has traditional features : in the short-run output depends on demand, whereas long-run properties are derived from a coherent theoretical description of the supply-side of the economy.

We add to this description the effects derived from the first part of the paper. The use of a macro econometric model enables us to take into account convergence time to the long run equilibrium and short-term effects like the impact of ICT capital accumulation on aggregate demand and prices. We find that long-term effects are very slow to appear, and the demand effects are the relevant ones over the period 1995-2000. However, total impact is rather weak, less than 0.1 percentage of PIB per year.

Keywords : Information and Communication Technologies, Growth accounting, Aggregate productivity, Elasticity of substitution, Macro econometric models

INTRODUCTION

This paper aims at measuring the impact of Information and Communication Technology (ICT) capital accumulation¹ on the French economy within a simple theoretical framework. We hold a general definition of ICT capital widely adopted in the literature including computer hardware, software and communication equipment².

Econometric methods should be the most relevant to measure the effect of ICT capital accumulation. It seems however that all the attempts to exhibit econometrically on macroeconomic data a positive impact of ICT capital on labour productivity proved to be fruitless (see for instance Berndt & Morrison (1995) for a discussion on American data). This failure explains that most of the studies in this area resort to growth accounting methods that exhibit a positive impact of ICT capital accumulation on labour productivity³.

In the latter approach when evaluating the contribution of ICT capital accumulation the authors do not refer to a precise alternative scenario. Indeed this contribution is directly measured as the product of the change in capital intensity (for ICT goods) by the share of these goods in the remuneration of production factors. From this point of view, the effect generally captured is more the part of ICT accumulation in total economic growth rather than a net effect of ICT capital on growth or on labour productivity.

In order to really capture a net effect it is necessary to take into account the substitutions between the different factors of production. In the frame of this different approach it matters building a counterfactual scenario describing the rate of growth of both ICT and non-ICT capital stock. Furthermore, since we are dealing with a global macroeconomic framework, we have to take into account the impact of ICT capital accumulation on aggregate demand and prices.

Our theoretical framework relies on the profit optimising behaviour of firms. Therefore the ratio of ICT capital stock (defined as the share of ICT capital in the total capital stock in volume) depends on its relative cost. For twenty years this cost measured at constant quality has been exhibiting a general decrease in line with the law of Moore postulating a faster technological progress in the ICT production. This decline first led during the 1980's and in the beginning of the 1990's to a stabilization of the ICT share in the total capital stock value, then to a significant rise of this share since 1995. This evolution could be interpreted as a structural change in the middle of the 1990's of the elasticity of substitution between the two types of capital goods ICT and non-ICT. This justifies our choice to assess the impact of ICT capital accumulation during the period 1995-2000⁴.

The paper is organized as follows : in a first part, focusing on the supply-side of the economy, we take the growth accounting methodology as a starting point. We introduce substitution effects by developing an alternative theoretical framework, which enables us to quantify the net ICT effect on the French economy during the period 1995-2000. In a second part, we introduce these effects in a macro econometric model, in order to take into account convergence time to the long run equilibrium and short-term effects like the impact of ICT capital accumulation on aggregate output and prices.

I. Growth accounting and substitution among production factors

A. Growth accounting

1. *The failure of econometric modeling*

The econometric approach seems to be the most natural way to measure the impact of ICT capital accumulation on the French economy and in particular on labour productivity. In a first step we tried to estimate in cross-section

¹ ICT producing industries lie outside the range of this paper.

² The series stem from the national accounting official classification (annual series) for investment and capital stock.

³ See for instance Oliner & Sichel (2000) and Jorgenson & Stiroh (2000) for studies on American data or Cette, Kocoglu & Mairesse (2000) on French data. When mentioning growth accounting we will refer to this class of articles.

⁴ The drawback with this period is that it corresponds to an economic boom. Yet nothing can let us think that ICT capital development is cyclical. The preceding economic boom (at the end of the eighties) did not give birth to such a significant development.

(on disaggregated data in the European classification NACE) a Cobb-Douglas type production function with four production factors : qualified and unqualified labour, ICT capital and non-ICT capital. It proved impossible to exhibit a positive and significant relation between ICT capital and value added whenever we considered individually each branch or built aggregated branches with a more homogenous behaviour. This failure seems to be quite general through the empirical studies on this topic resorting to macroeconomic data, particularly on American data⁵.

Several explanations of this failure have been suggested none of them being really convincing. According to Kiley (2000) the investment in ICT goods implies significant adjustment costs. From this regard this investment needs some delay to become profitable. Hence the impact on labour productivity may be negative in the medium term during periods of steep investment. We must bear in mind that the considerable expansion of ICT cannot be considered as a recent even ; besides, it has known a sharp increase since 1995 in European countries as well as in the United States. Consequently, positive effects in terms of productivity gains should recently become more obvious with econometric studies on past dates. Moreover, econometric models relating labour productivity to lag values of investment in ICT (accounting for the above delays) have not so far led to conclusive results⁶.

The issue of the measurement of value added has also been mentioned, particularly concerning the services. It is indeed extremely difficult to define a volume of production in this branch essentially because we need not only quantitative measures but also quality indicators. Presently, in national accounting, the value added in volume of these fields is generally based on a computation multiplying the compensation of employees by an exogenous productivity trend independent of volume and quality. This practice could explain the difficulty to reveal a positive and econometrically significant relation between labour productivity and ICT investment. However this difficulty also appears when we restrict our study to the manufacturing field where the measurement concern is less relevant.

Finally this failure of the econometric approach might be due to general problems inherent in the estimation of aggregated production functions, whether it is for the whole economy or some of its parts. It is in general difficult to identify the structural parameters of these functions in presence of several demand shocks. The aggregation concern is also relevant : when summing stocks of capital and labour and value added of firms with radically different production functions, such a macroeconomic approach is doomed to fail when it seeks precision and distinguishes several production factors (ICT and non ICT capital, qualified and unqualified labour, etc.). Conclusive results at the microeconomic level on firm's data (see Brynjolfsson et Hitt (2000) for a survey) seem to confirm this point.

As a consequence this general failure of econometric methods explains economists opt for growth accounting.

2. An overview of growth accounting

Given a three factors production function : labour, ICT and non-ICT capital. In a pure competition framework, the elasticity of value added to a factor equals the share of remuneration of this factor in the value added. Under the additional hypothesis of unitary returns to scale the equation relating the value added rate of growth to the rates of its production factors⁷ can be rewritten in terms of labour productivity gains under the following form :

$$(1) \quad (\dot{Y} - \dot{L}) = (1 - \alpha)[\pi_1(\dot{K}_1 - \dot{L}) + (1 - \pi_1)(\dot{K}_2 - \dot{L})] + \dot{TFP}$$

where Y , L , K , K_1 et K_2 respectively stand for the volumes of value added, labour, total capital stock, ICT capital stock and non ICT capital stock. In the following, the same variables in lower-case letters stand for the corresponding logarithms. The dotted letters denote the growth of rate of the associated variable. The notation \dot{x} refers to the growth rate of a variable.

TFP stands for total factor productivity,

$$\alpha \text{ stands for the share of the remuneration of labour in the value added : } \alpha = \frac{WL}{PY},$$

⁵ In a recent paper Stiroh (2001) obtained a positive and significant coefficient for the ICT capital when regressing the rate of growth of labour productivity on the others production factors. However the coefficient of the non-ICT capital was negative relativizing the results of the estimation.

⁶ See for instance Berndt & Morrison (1995) for a cross-section approach.

⁷ $\dot{Y} = (1 - \alpha)[\pi_1\dot{K}_1 + (1 - \pi_1)\dot{K}_2] + \alpha\dot{L} + \dot{TFP}$

π_1 is the share of the remuneration of ICT in the total remuneration of capital : $\pi_1 = \frac{C_1 K_1}{CK}$

with P the value added deflator, W , C , C_1 et C_2 respectively the cost of labour, total capital stock⁸, ICT capital stock and non ICT capital stock.

The most widely held in the literature formula of the contribution of ICT capital accumulation on labour productivity is the following denoted F_1 :

$$\boxed{(1 - \alpha)\pi_1(\dot{K}_1 - \dot{L})}$$

Note that most of these studies also assess the contribution of ICT production by decomposing equation (1) by branch. This contribution is computed as the gains of total factor productivity in the ICT producing branches. Yet the French data on these branches are not very satisfactory. Moreover, the issue of ICT producing industries lies outside the range of this paper. From now on we do not take into account the impact of ICT development on total factor productivity gains.

Hence, the method held in this literature, as indicated by its name is based on accounting. The aim of our paper is quite different, since we focus on the evaluation of a net effect of the accumulation of ICT capital on labour productivity (that is to say the additional productivity induced by the development of ICT). Although inspired by the same methods, it is necessary for us to account for the substitution effects when adopting such an alternative approach. In other words, we account for productivity gains referring to a counterfactual scenario with no ICT development.

The quantity under study can therefore be written as :

$$\partial[(\dot{Y} - \dot{L})/(1 - \alpha)] = \pi_1(\dot{K}_1 - \dot{L}) + (1 - \pi_1)(\dot{K}_2 - \dot{L}) - [\pi_1^*(\dot{K}_1 - \dot{L})^* + (1 - \pi_1^*)(\dot{K}_2 - \dot{L})^*]$$

where the variables with an asterisk stand for values in the counterfactual scenario with no ICT effect and $\partial x = x - x^*$, being the difference between the historical and counterfactual scenarios.

When rearranging the different terms, we get :

$$(2) \quad \boxed{\begin{aligned} \partial[(\dot{Y} - \dot{L})/(1 - \alpha)] &= \pi_1[(\dot{K}_1 - \dot{L}) - (\dot{K}_2 - \dot{L})] \\ &+ \pi_1^*[(\dot{K}_2 - \dot{L})^* - (\dot{K}_1 - \dot{L})^*] \\ &+ \partial(\dot{K}_2 - \dot{L}) \end{aligned}}$$

The difference between our alternative approach and the accounting approach appears clearly.

As a matter of fact we obtain that describing the results of growth accounting as a net effect of ICT development (which is a widespread reading of this type of studies), implies that the fake counterfactual scenario we generally refer to is characterized by the following points :

- the rate of growth of ICT capital intensity is equal in both scenarios :

$$\dot{K}_2 - \dot{L} = (\dot{K}_2 - \dot{L})^*$$

- the rate of growth of the non ICT capital intensity is equal to zero :

$$(\dot{K}_1 - \dot{L})^* = 0$$

⁸ The cost of capital is computed with the formula derived by Jorgenson.

- the share of remuneration of the ICT capital stock in the total remuneration of the capital stock is equal in both scenarios :

$$\pi_1 = \pi_1^*$$

This indeed implies a rather peculiar and hardly credible scenario.

Following Berthier (2000), who resorts to this concept for the study of the ICT producing sectors, some authors refer to the notion of a productivity surplus when evaluating the impact of ICT capital as an input in the production process of the ICT users sectors. This provides an intermediate evaluation between an accounting approach and an alternative one. The reference to an explicit scenario with no ICT effect is in that case clearer since to compute this productivity surplus, the historical rate of growth of labour productivity is compared to what it would have been with an ICT capital stock growing at the same rate as the other capital goods.

This productivity surplus therefore can be written as :

$$(1 - \alpha)\pi_1 [(\dot{K}_1 - \dot{L}) - (\dot{K}_2 - \dot{L})]$$

We will refer to this formula as F_2

F_1 as well as F_2 does not measure the net effect of the contribution of ICT capital accumulation, as it appears in equation (2).

In fact :

- the term $\pi_1^* [(\dot{K}_2 - \dot{L})^* - (\dot{K}_1 - \dot{L})^*]$ does not appear. This implies that the share of ICT capital in the total is kept unchanged in the counterfactual scenario with no ICT effect. This hypothesis seems rather credible even in an alternative approach.
- the impact of the diffusion of ICT on the non-ICT capital intensity $\partial(\dot{K}_2 - \dot{L})$ does not figure in this computation either. But then in an alternative approach this intensity should vary as a consequence of the substitution between labour and composite capital due to the reducing cost of the aggregated capital and as a consequence of a substitution between ICT capital and non-ICT capital due to a decline of the relative cost of ICT capital. Those two effects act in opposite directions and the final result for the non-ICT capital intensity is indeterminate unless we specify a more theoretical framework.

In the following part we attempt to measure this net effect resorting to formula (2). This implies building a real no ICT effect scenario by specifying our technology of production. From then on, compared with the growth accounting methods, our alternative approach presents the disadvantage to restrict our framework. In particular in order to quantify the productivity gains, we need to make assumptions on the values of the elasticities of substitution.

Our results are compared with those obtained with the productivity surplus formula (F_2). It must be noticed that the same discussion about the interpretation of the results as an indicator of the ICT effect also holds for (F_1). Indeed both expressions are numerically close, the term $\dot{K}_2 - \dot{L}$ being rather small in comparison to $\dot{K}_1 - \dot{L}$ on the period considered.

B. A measure of the net effect of ICT capital accumulation

We adopt the general framework of growth accounting theory and insert it in a production process leading way to substitution effects generally not taken into account in an accounting approach. It is therefore necessary to choose a technology of production. This haven been made we will be able to express the impact of ICT capital accumulation on labour productivity as a function of our technology parameters and of the size of the shock on the relative cost of ICT capital.

The comparison of the results (depending on the elasticities of substitution) with those obtained with the growth accounting framework enables us to quantify those substitution effects.

1. A modeling of the substitution between factors

We specify a technology of production for the economy in order to quantify in an explicit theoretical framework the impact of a fall of ICT relative cost of capital on the demand of capital (ICT and non ICT) and on the cost of aggregated capital. We use a constant elasticity of substitution production function, which we complete in order to introduce two types of capital goods : total capital is defined as a composite good being a constant elasticity of substitution aggregate of ICT and non ICT capital. As a result we have two overlapped CES production functions.

This choice is one of the most natural to run computations easily interpretable. The main restriction concerns the substitution between factors. In particular the substitution between labour and ICT capital is treated in a symmetrical way as the substitution between labour and non-ICT capital.

We keep as ICT capital goods : computer hardware (code 30.0C in the European classification NACE), computer software (72) and communications equipment (32.2).

Given a CES production function with two factors capital and labour :

$$Y = [aK^{1-1/\sigma} + (1-a)(EL)^{1-1/\sigma}]^{\sigma/(\sigma-1)}$$

where E stands for the technological progress related to labour (labour efficiency)

and σ is the elasticity of substitution between the two factors.

This CES type production function exhibits constant returns to scale and is therefore in line with the general assumptions of the growth accounting approach.

The usual optimising procedure enables us to derive the demand of factors on a given growth path :

$$(3) \quad y - l = \sigma(w - p) + (1 - \sigma)eff$$

$$(4) \quad y - k = \sigma(c - p)$$

as well as the factor price frontier

$$(5) \quad 1 = \alpha(w - p - eff) + (1 - \alpha)(c - p)$$

where eff stands for the logarithm of labour efficiency.

We assume that the capital itself is an aggregated good with constant elasticity of substitution between ICT capital and non ICT capital⁹ :

$$K = [bK_1^{1-1/\sigma'} + (1-b)K_2^{1-1/\sigma'}]^{\sigma'/(\sigma'-1)}$$

where σ' stands for the elasticity of substitution between the two types of capital.

Given a demand of aggregated capital k we derive the demand for ICT capital :

$$(6) \quad k - k_1 = \sigma'(c_1 - c)$$

as well as the cost of the aggregated capital :

$$(7) \quad c = \pi_1 c_1 + (1 - \pi_1) c_2$$

⁹ The aggregated production function resulting from this overlapping process exhibits itself constant returns to scale.

Provided with this complete theoretical framework, we are able to evaluate the impact of ICT capital accumulation in terms of labour productivity gains, as a function of the production function parameters and of the size of the shock on the relative cost of ICT capital.

2. Measuring the ICT net effect

We derive our results in difference with a counterfactual scenario, called no ICT effect, which is described in the following box. Thanks to formula (2), we are able to determine a net effect of the accumulation of ICT capital as a function of our model parameters described above.

In order to measure the difference between an accounting approach and our alternative approach we compare our results (namely the labour productivity discrepancy) when computed with formula (2) and with the surplus productivity formula.

The no ICT effect counterfactual scenario¹⁰

This scenario relies on the hypothesis that the relative cost of ICT capital *would have remained constant* :

$$(\dot{C}_1 - \dot{P})^* = (\dot{C}_2 - \dot{P})^*$$

Under the assumption that k_1 is small compared to k , the real cost of no ICT capital grows at the same rate as the real cost of the total capital stock :

$$(\dot{C}_2 - \dot{P})^* = (\dot{C} - \dot{P})^* \text{ and } \dot{C}_2 - \dot{P} = \dot{C} - \dot{P}$$

Besides, we assume that the no ICT real cost of capital has the same rate of growth in the two scenarios :

$$(\dot{C}_2 - \dot{P})^* = \dot{C}_2 - \dot{P}$$

Finally the alternative is defined as follows in terms of relative costs :

$$(\dot{C}_1 - \dot{P})^* = (\dot{C}_2 - \dot{P})^* = (\dot{C} - \dot{P})^* = \dot{C}_2 - \dot{P}$$

Historically, we observe a fall of the relative cost of ICT capital. We assume that the firms only take into account the long-term value of this cost and that the short-term fluctuations can from this point of view be neglected. From then on, we build a no ICT effect scenario by assuming that the relative cost of ICT capital is equal to its historical value from which we deduce each year the same constant discrepancy μ , this discrepancy being cumulated over the years.

That is to say :

$\forall t$:

$$\partial(c_1 - c_2) = t(\dot{C}_1 - \dot{C}_2) \quad (8)$$

with $\dot{C}_1 - \dot{C}_2 = \mu$

According to equation (6), and under the assumption that k_1 is small compared to k , the constancy of the relative cost of ICT capital in the counterfactual scenario implies the constancy of the ratio of the ICT capital stock in the total.

¹⁰ For sake of simplicity we call the counterfactual scenario “no ICT effect” in the sense that ICT capital behaves like no ICT capital.

In the following we will systematically reason in terms of differences between the levels of the variables in the historical scenario and their levels in the no ICT effect counterfactual one. This is a rather natural convention as we are mainly interested in the impact of the ICT in comparison with a no ICT effect scenario.

Recall that with the productivity surplus formula (F2) the impact in terms of labour productivity of the shock described in the upper box can be expressed as :

$$\partial(\dot{Y} - \dot{L}) = (1 - \alpha)\pi_1 [(\dot{K}_1 - \dot{L}) - (\dot{K}_2 - \dot{L})]$$

this becomes with our production function :

$$(9) \quad \boxed{\partial(\dot{Y} - \dot{L}) = (1 - \alpha)\pi_1 \sigma' (\dot{C}_2 - \dot{C}_1)}$$

Under the assumptions of the upper box, the demand of factors as well as the factor price frontier enable us to express (the computations, derived from equation (2), appear in appendix C) the impact on labour productivity as a function of the size of the shock on the relative cost of ICT capital and of the parameters of the production function¹¹ :

$$(10) \quad \boxed{\partial(\dot{Y} - \dot{L}) = \frac{\sigma(1 - \alpha)}{\alpha} \pi_1 (\dot{C}_2 - \dot{C}_1)}$$

The difference between formulas (9) and (10) can be written as :

$$\partial(\dot{K}_2 - \dot{L}) = \left(\sigma' - \frac{\sigma}{\alpha} \right) \pi_1 (\dot{C}_1 - \dot{C}_2)$$

We derive, when using formula (2), an evaluation of the ICT impact smaller than the productivity surplus under the condition that :

$$(11) \quad \boxed{\frac{\alpha\sigma'}{\sigma} > 1}$$

With the surplus formula, the impact of the fall of the relative cost on non-ICT capital stock disappears. We saw that in our alternative approach the direction of this impact is not obvious. The fall of the relative cost of ICT capital leads to a substitution between ICT and non-ICT capital in favour of the first one whereas the fall of the cost of the aggregated capital leads to a substitution between capital and labour.

This impact is therefore negative as soon as the first substitution between ICT capital and non ICT capital, characterized by the elasticity of substitution σ' , is stronger than the substitution between labour and non ICT capital characterized by the ratio between the elasticity of substitution σ and the share of the remuneration of labour in value added (see appendix A).

C. A numerical application to the French economy during the period 1995-2000

For the field considered (the non-financial firms and the individual workers) the share of compensation in the value added is close to 2/3 on the recent period. The condition (11) can be written as :

¹¹ We do not take into account the variation of α . We show in appendix 3 that its impact on labor productivity is 10 times smaller than the result we held in formula (10). Consequently we decide to neglect it for simplicity.

$$\frac{2\sigma'}{3\sigma} > 1$$

This inequality depends on the parameters of the production function, that is to say the elasticity of substitution between capital and labour, and between ICT capital and non-ICT capital. There is no generally agreed opinion on the value of these parameters for the French economy, their evaluation proving itself rather uncertain. Actually most of the French recent studies on this topic assume that qualified labour is complementary to capital whereas unqualified labour can be substituted to capital. In this respect those studies only provide us with an elasticity between capital and unqualified labour. Besides, its evaluation varies widely from 2.5 Laffargue (1996) to 1 for Biscourp & Gianella (2001) and 0.7 for Gianella (1999).

As for the elasticity of substitution between the two types of capital, we must bear in mind that according to our formulas its measure is only needed to compare the two methods. It is not necessary neither for the computation of the impact with the growth accounting method or for the computation of the net impact in our alternative approach (equation (10)). In the latter computation the result is indirectly related to σ' through the value of the share of the remuneration of ICT capital π_1 (equation (6)). However in the historical scenario this share π_1 is directly measured so that σ' is not needed to derive the net ICT effect on labour productivity.

In order to compare the two methods formulas (F2) and (9) must both hold during the period 1995-2000 considered. Consequently the macroeconomic data we use must satisfy the relation :

$$(6) \quad \partial(\dot{K}_1 - \dot{K}_2) = \sigma'(\dot{C}_2 - \dot{C}_1)$$

That becomes when integrated between $t_1 = 1995$ and $t_2 = 2000$:

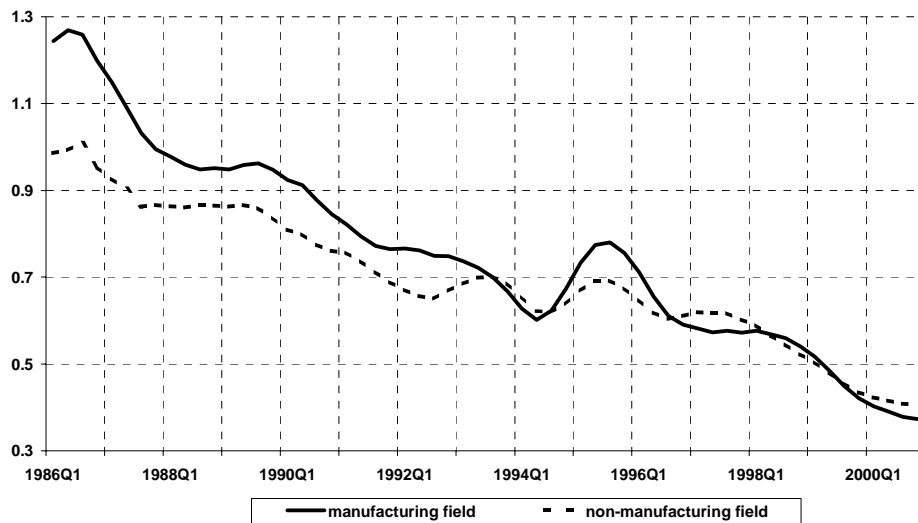
$$(6b) \quad \pi_{1t_2} - \pi_{1t_1} = (\sigma' - 1)((c_2 - c_1)_{t_2} - (c_2 - c_1)_{t_1})$$

This elasticity can be roughly calibrated by examining the macroeconomic data¹². The graph 1 shows that the fall of the relative cost of ICT capital is not a recent event. It has been rather regular for 15 years. However the share of the remuneration of ICT capital is quite stable, exhibiting only a small decline between 1985 and 1995 (graph 2). If we apply equation (6) on this period we get an evaluation of this substitution σ' equal to 1. On the contrary, since 1995, the fall of the relative cost of capital has led to an increase of the share of the remuneration of ICT capital in the total, providing us with an evaluation of the elasticity equal to 2.5.

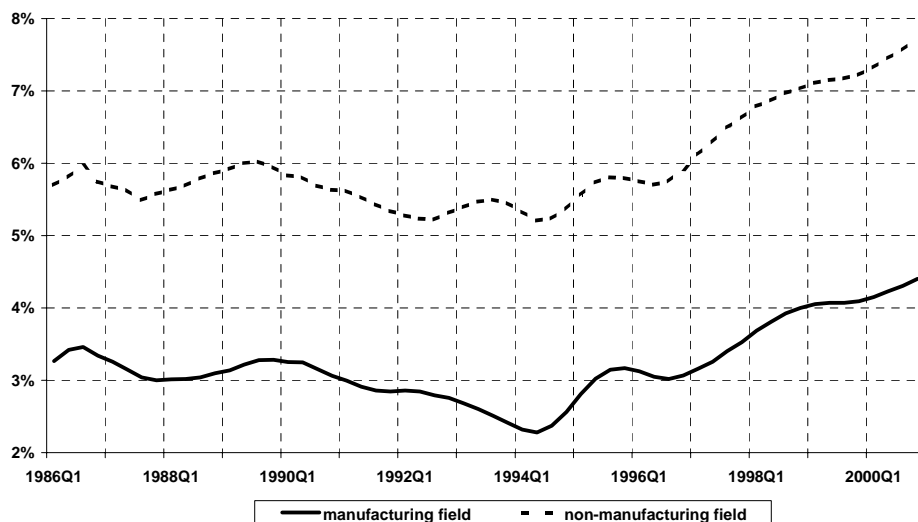
We must bear in mind that this evaluation is quite fragile. Not only because it relies on aggregated data, but also because it is based on a particular technology of production. Biscourp & Alii (2002) estimate a trans-log production function on firm data and found a negative value for the elasticity of substitution between ICT and non-ICT capital, implying complementarities between these two capital goods.

¹² The data on capital stock and investment in ICT goods and others come from the national accounting annual series and cover the field of non-financial firms and individual workers.

Graph 1: relative cost of ICT capital in logarithm



Graph 2 : share of the remuneration of ICT capital in total capital



We choose to realize our alternative exercise on the period 1995-2000. We keep our evaluation of 2.5 for σ' and consider two polar cases for σ .

case1: $\sigma = 2.5$

case2: $\sigma = 5/6$

During the period 1995-2000, the share of remuneration of ICT capital in the total is equal to 6% on average. The average decrease of ICT relative cost is equal to 5%.

Table A sums up our results with the different formulas. The results of formulas F_1 and F_2 are rather close, leading to an annual average impact on labour productivity of 0.29 point in the first case and of $\frac{1}{4}$ point in the second. The value computed with F_1 is very close to the one obtained with the same formula by Cette, Kocoglu & Mairesse

(2000), also using national accounting data and the same definition of ICT capital : they evaluate the contribution of ICT capital for the whole economy as equal to 0.27 point each year during the period 1995-99.

Our model (equation (10)) leads to an average impact of 0.4 point in the first case and of 1/8 point in the second.

Table 1 : comparison between the contributions of ICT capital to labour productivity

		Case 1 $\sigma = \sigma' = 2.5$	Case 2 $\sigma = 5/6, \sigma' = 2.5$
Growth accounting formulas	Usual formula (F_1)	0.29	0.29
	Surplus productivity formula (F_2)	0.25	1/4
Substitution effect (S)		0.11	-0.17
Net impact (equation (10)) = (F_1) + (S)		0.4	1/8

As a conclusion, it must be stated that without assumptions on the production function (and in particular on the elasticity of substitution between ICT capital and non ICT capital) the indeterminacy around the impact of the diffusion of ICT on the French economy since 1995 is extremely strong. We do have a positive impact in terms of labour productivity, but quite weak (1/4 point on an annual basis according to the growth accounting method, from 1/8 to 0.4 point according to our model). The most generally held value for σ being 5/6 we hold 1/8 as our net impact value for ICT capital accumulation during 1995-2000, half the effect measured by growth accounting literature.

II. The alternative scenario with a macro econometric model

In this part we introduce the alternative scenario presented in part I in a macro econometric model. The assessment of the impact of ICT capital accumulation obtained that way takes into account convergence time to the long-term value of factor demands, interaction of macroeconomic variables and the impact of ICT development on aggregated demand.

The first part of this paper is devoted to the supply-side aspect of ICT development, that is to say its impact on labour productivity. Yet there are delays in ICT capital accumulation and in the substitution between labour and capital. In the macro econometric models total adjustment of a factor quantity to its cost may require more than one decade. On the contrary, the additional investment generated by the increase of capital intensity, and above all by the substitution of ICT to non-ICT capital (whose depreciation rate is smaller), affects aggregated demand with shorter delays. This substitution also changes investment price. These effects might be more relevant for the period we consider, that is to say some years. We calculate them and then integrate the results in the macro econometric model, which does not by itself distinguish between ICT and non-ICT goods.

We use the model Mesange, which is developed by French forecast directory and INSEE. It is a quarterly model, so we have to change the frequency of the data used in part I. From now on, all the formulas presented in this part apply to quarterly data, \dot{x} is the quarterly growth rate of the variables and μ is the quarterly change of ICT capital relative cost in the ICT scenario : $\mu = -1.25\%$.

A. Assumptions

As for the numerical application in part I, we build the alternative during the period 1995-2000. The ICT scenario is the historical one, characterized by a fall of the relative cost of ICT capital of 5% a year on average. The alternative is the non-ICT scenario, with constant relative cost and relative price of ICT capital. We describe its construction in the following.

In the non-ICT scenario firms adjust their factor demand to the evolution of capital cost by keeping the ratio of ICT capital constant. In that, the very definition of the alternative scenario implies an instantaneous substitution

between ICT and non-ICT capital. This is obviously a strong assumption, yet, it is the unavoidable consequence of the choice to have an alternative scenario relying on the profit-optimising behaviour of firms.

The Mesange model includes economic interactions between France and other countries. France' main trading partners have also experienced ICT development, which implies to define ICT and non-ICT scenarios for them too. However, a detailed analysis for these countries lies outside the range of this paper. We make the assumption that seems most neutral : we assume that they experience the same mechanisms as the ones observed in France.

B. Computation of the ICT effects

In the model several channels make the ICT shock spread throughout the economy :

- in the long run, the shock on the relative cost of ICT capital leads to a substitution between capital and labour, and to an increase of labour productivity. Moreover, the fall of aggregated capital cost makes the value-added price decrease
- in the short run, the decrease of the price of investment for manufactured goods mechanically leads to a decrease of the value-added price, that is to say less inflation. Indeed, investment in manufactured goods accounts for 7% of GDP
- in the short run too, substitution between ICT and non ICT capital implies additional investment, since the depreciation rate of the former is inferior
- international trade widens the impact on output and prices

The effect of the fall of ICT capital relative cost on labour productivity (with our parameters, it amounts to 0,06 point a year, that is to say 0.36 point during the whole period 1995-2000) appears in the Mesange model through the long run of the error-correction equations :

- of employment : $\partial(y - l) = \sigma\partial(w - p)$
- of value-added price : $\partial(w - p) = -\frac{(1-\alpha)}{\alpha}\partial(c - p)$ ¹³

Convergence of the first equation appears reasonably quickly (less than two years) but for the second one it takes 5 to 10 years. As a consequence, long-run effects are extremely weak during the period we consider.

1. Capital cost

In the Mesange model capital cost is computed with the Jorgenson formula, with no distinction between ICT and non-ICT capital. We replace the original equation by the one derived from our theoretical model (the computations appear in appendix B) :

$$\partial(c - p) = (\dot{C}_1 - \dot{C}_2)\pi_1^* t \left(1 - (\sigma' - 1)(\dot{C}_1 - \dot{C}_2) \frac{t+1}{2} \right)$$

where time unit (t) is one quarter.

Recall that the cost of ICT and non-ICT capital (C_1 and C_2) are also computed with the Jorgenson formula.

2. Volume of investment

We distinguish the variation of the volume of investment with total capital unchanged :

¹³ This relationship is derived from the factor price frontier.

$$\partial I_{|K^*} = \partial I_{1|K^*} + \partial I_{2|K^*}$$

$$\text{from the rest : } \partial I_{|\partial K} = \partial I_{1|\partial K} + \partial I_{2|\partial K}$$

Indeed, we assume that substitution between ICT and non-ICT capital with total capital unchanged involves investment in manufactured goods only, whereas the change of aggregated capital volume does not modify its composition (*i.e.* the share of manufactured and non manufactured goods) :

$$\partial I_{dim} = \partial I_{|K^*} + \theta \partial I_{|\partial K}$$

$$\text{and } \partial I_{dhm} = (1 - \theta) \partial I_{|\partial K}$$

where I_{dim} and I_{dhm} stand for investment in manufactured and non-manufactured goods, and θ is the share of investment in manufactured goods in total investment (in volume).

In appendix D we show that :

$$\begin{cases} \partial I_{|K^*} = (\delta_1 \partial ratio1 + \delta_2 \partial ratio2)_{-1} K_{-1} \\ \partial I_{|\partial K} = (\delta_1 ratio1^* + \delta_2 ratio2^*)_{-1} \partial K_{-1} + \partial \Delta K \end{cases}$$

$ratio1$ and $ratio2$ stand for the share of ICT and non-ICT capital in total capital respectively. δ_1 (respectively δ_2) is the depreciation rate of ICT (resp. non ICT) capital.

The value of the change of total capital volume ∂K comes from the capital volume equation of the model Mesange. Recall (*cf.* appendix E) that in this equation capital cost only appears in the long run, and that convergence time is high. It follows that ∂K depends much more, in a 6 years span, on the variation of value-added led by the shock on the volume of investment.

3. Investment price

We add to the residual of the equation of the model (*cf.* appendix E) the exogenous shock on investment price.

Our theoretical framework implies a new relationship :

$$P_I = P_{I_1} ratioI_1 + (1 - ratioI_1) P_{I_2}$$

P_I , P_{I_1} and P_{I_2} stand for total, ICT and non-ICT investment price respectively, and $ratioI_1$ is the share of ICT investment in total volume of investment. We also assume that the “real price” of non-ICT capital is the same in the historical and alternative scenarios.

Then we can compute the impact of the change of capital composition on investment price :

$$\frac{\partial P_I}{P_I^*} = ratioI_1 \frac{P_{I_1}^*}{P_I^*} \frac{\partial P_{I_1}}{P_{I_1}^*} + \frac{P_{I_1}^* - P_{I_2}^*}{P_I^*} \partial ratioI_1$$

The alternative being built in the period 1995-2000, the preceding expression simplifies. Indeed, as we have already mentioned, relative investment prices remain at their 1995 level in the alternative. 1995 being the basis year for national accounting we have : $P_I^* = P_{I_1}^* = P_{I_2}^*$

Hence :

$$\frac{\partial P_I}{P_I^*} = \text{ratio} I_1 t (\dot{C}_1 - \dot{C}_2)$$

The shock on the relative price of investment passes on total investment price with a cushioning coefficient equal to the share of ICT investment in total volume of investment.

4. International trade

According to our sources (MINEFI (2001)), propensity to import seems to be close for ICT and manufactured goods in general in the French case. This is why we do not change the import equations of the Mesange model.

Since we cannot make a detailed study of each of the main trading partners of the French economy, we assume that ICT effects are the same for them as in France. This assumption seems reasonable for European countries. It might be a bit more questionable for the US where ICT capital accumulation and production are much more developed than in France.

To build the alternative we index foreign demand, export and import prices in manufactured and non-manufactured goods on French import demand and import and export prices respectively.

C. Results over the period 1995-2000

Instantaneous substitution between ICT and non-ICT capital initially requires an effort of investment because the two goods have a different depreciation rate. The composition of investment then changes, with the ICT share growing. This has a negative impact on investment price. This investment, composed essentially of manufactured goods, is mostly imported. Yet, since we assume that our trading partners experience the same shock, foreign demand increases in the same proportion as our demand of imports, and the contribution of foreign trade to the output discrepancy between the two scenarios is weak.

So ICT development has a positive impact on aggregated demand that is superior to its impact on productivity. Indeed, long-run productivity gains are weak with our parameters and they are slow to appear. All in all, labour demand increases.

The raise of employment increases the disposable income of households, all the more that real wages also increase (since the fall of investment price reduces inflation). This leads consumption to rise, by 0.16% in 6 years.

The impact on GDP is positive, yet very weak (+0.33%). It is close to 0.05 point on a yearly basis.

Table 2 : piled up impact in 2000 on volumes (relative discrepancy in %)

GDP	0.33
households consumption	0.16
firms investment	2.18
exports	0.69
imports	0.79
employment (business sector excluding agriculture)	0.32
labour productivity (business sector excluding agriculture)	0.11

Investment contributes for two-thirds to the increase of GDP, consumption for one quarter and international trade is overall neutral. As regards supply, the contribution of the increase of employment to output growth is superior to the contribution of labour productivity (respectively 0.3 and 0.1%).

So demand effects prevail during the period we consider. When long-run effects only are introduced, the impact is almost null : the additional GDP increase amounts to 0.6% in 6 years.

The inflation led by the output increase offsets the deflationary effect of capital price decrease. However, the impact on inflation is very sensitive to the specification we use for value-added price (*cf.* appendix E).

Table 3 : piled up impact in 2000 on prices (relative discrepancy in %)

GDP	0.09
value added	0.10
households consumption	0.09
firms investment	-2.62
exports	0.09
imports	0.04
wages	0.29
firms share of profit	-0.1

CONCLUSION

As a conclusion, the indeterminacy around the impact of the diffusion of ICT on the French economy since 1995 is extremely strong. This indeterminacy concerns as well short-term effects and long-term effects. We do have a positive impact in terms of labour productivity, but quite weak.

With reasonable assumptions on the production function (and in particular on the elasticity of substitution between ICT capital and non ICT capital), long-term impact on labour productivity is not greater than 0.1 point, half the effect measured by growth accounting literature.

The use of a macro econometric model enables us to take into account convergence time to the long run equilibrium and short-term effects like the impact of ICT capital accumulation on aggregate demand and prices. Effects on productivity are even weaker. Those on consumer price inflation depend highly on the specification for value added price equation.

III. References

- Allard-Prigent C. et alii. (2001), « Présentation du modèle MESANGE », *Paper supplied during the FOURGEAUD seminary*, 2nd of may 2001.
- Audenis C., Deroyon J., Fourcade N. (2001), « Présentation de la projection de moyen terme 2001 », *Note INSEE* 24-G221.
- Berndt E. et Morrison C. (1995), « High-tech capital formation and economic performance in manufacturing industries : an exploratory analysis », *Journal of Econometrics* n°65, pp. 9-43.
- Berthier J.P. (2000), « L'impact de la production des nouvelles technologies de l'information et de la communication sur la croissance », in *L'Economie française*, INSEE, 2000-2001 édition, pp. 89-104.
- Biscourp P. et Gianella C. (2001), « Substitution and complementarity between capital, skilled and less skilled workers : an analysis at the firm level in the French manufacturing industry », INSEE, *Working paper* G 2001 / 13.
- Biscourp P., Crepon B., Heckel T. et Riedinger N. (2002), « How do firms respond to cheaper computers ? Micro econometric evidence for France based on a production function approach », INSEE, *Working paper* forthcoming.
- Brynjolfsson E. et Hitt L. (2000), « Beyond computation : information technology, organizational transformation and business practices », *Journal of Economic Perspectives*, Vol. 14, n°4, pp. 23-48.
- Cette G., Kocoglu Y. et Mairesse J. (2000), « Les technologies de l'information et de la communication en France : diffusion et contribution à la croissance » *Economie et Statistique* n°339-340.
- Crepon B. et Heckel T. (2000), « La contribution de l'informatisation à la croissance française : une mesure à partir des données d'entreprise », *Economie et Statistique*, n° 339-340.
- Gianella C. (1999), « Une estimation de l'élasticité de l'emploi peu qualifié à son coût », INSEE, *Working paper* G 9912 bis.
- Jorgenson D. et Stiroh K. (2000), « Raising the speed limit : US economic growth in the information age », *Brookings Papers on Economic Activity*, pp. 125-211.
- Kiley M. (2000), « Computers and Growth with Frictions : Aggregate and Disaggregate Evidence », Federal Reserve Board, mimeo.
- Laffargue J.P. (1996), « Fiscalité, charges sociales, qualifications et emploi. Etude à l'aide du modèle d'équilibre général de l'économie française Julien », *Economie et Prévision* n° 125.
- Ministère de l'Economie, des Finances et de l'Industrie (2001), « L'industrie française des technologies de l'information et de la communication » *Chiffres clés*.
- Oliner S. et Sichel D. (2000), « The resurgence of growth in the late 1990s : is information technology the story ? » *Journal of Economic Perspectives*, Vol. 14, n° 4, pp. 3-22.
- Stiroh K. (2001), « Information technology and the U.S. productivity revival : what do the industry data say ? », mimeo.

IV. Appendixes

A. Rewriting the term $\Delta(\dot{k}_2 - \dot{l})$

We have $\partial(\dot{K} - \dot{L}) = \sigma \partial(\dot{W} - \dot{C})$

Then introducing the factor price frontier :

$$\partial(\dot{K} - \dot{L}) = \frac{\sigma}{\alpha} \partial(\dot{P} - \dot{C})$$

Besides,

$$\partial(\dot{K}_2 - \dot{K}) = \sigma' \partial(\dot{C} - \dot{P})$$

When combined these two equations lead to :

$$\partial(\dot{K}_2 - \dot{L}) = \left(\sigma' - \frac{\sigma}{\alpha} \right) \partial(\dot{C} - \dot{P})$$

Consequently $\partial(\dot{K}_2 - \dot{L})$ is negative if and only if $\boxed{\frac{\alpha \sigma'}{\sigma} > 1}$

In that case formula (10), quantifying the contribution of ICT capital accumulation, leads to an impact on labour productivity of the fall of the relative cost of ICT capital smaller than the one given by the productivity surplus formula.

B. Rewriting the term $\partial(c - p)$

According to (7) we may write :

$$(\dot{C} - \dot{P}) = \pi_1(\dot{C}_1 - \dot{C}_2) + (\dot{C}_2 - \dot{P})$$

$$\text{Hence : } \partial(\dot{C} - \dot{P}) = \pi_1 \partial(\dot{C}_1 - \dot{C}_2) + \partial \pi_1 (\dot{C}_1 - \dot{C}_2)^* + \partial(\dot{C}_2 - \dot{P})$$

According to the assumptions detailed in box 1 (constancy of the relative cost of ICT capital in our counterfactual scenario and same evolution of the non ICT real cost of capital in both scenarios) we have :

$$\partial(\dot{C} - \dot{P}) = \pi_1 (\dot{C}_1 - \dot{C}_2)$$

$$\text{Writing } \partial(c - p) = \sum_0^t \partial(\dot{C} - \dot{P})$$

$$\text{and } \pi_1 = \pi_1^* \left(1 + \frac{\partial \pi_1}{\pi_1^*} \right) \text{ we use equation (6)}^{14} \text{ to get :}$$

$$\partial(c - p) = (\dot{C}_1 - \dot{C}_2) \pi_1^* \sum_{i=0}^t (1 + (\sigma' - 1) \partial(c_2 - c_1))$$

$$(A2) \quad \partial(c - p) = (\dot{C}_1 - \dot{C}_2) \pi_1^* t \left(1 - (\sigma' - 1) (\dot{C}_1 - \dot{C}_2) \frac{t+1}{2} \right)$$

¹⁴ We approximate here $(c - c_1)$ by $(c_2 - c_1)$.

C. Rewriting $\partial(\dot{Y} - \dot{L})$

In this appendix we detail the rewriting of the term $\partial(\dot{Y} - \dot{L})$ as a function of the shock on ICT relative cost of capital and of the parameters of our production function.

According to formula (3), the variation of labour productivity in a CES production function equals :

$$\dot{Y} - \dot{L} = \sigma(\dot{W} - \dot{P} - \dot{E}) + \dot{E}$$

Hence introducing the factor price frontier formula (5) :

$$\dot{Y} - \dot{L} = -\frac{\sigma(1-\alpha)}{\alpha}(\dot{C} - \dot{P}) + \dot{E}$$

Then in terms of difference between the scenarios :

$$\partial(\dot{Y} - \dot{L}) = -\frac{\sigma(1-\alpha)}{\alpha}\partial(\dot{C} - \dot{P}) - \partial\left[\frac{\sigma(1-\alpha)}{\alpha}\right](\dot{C} - \dot{P})^* + \partial\dot{E}$$

We do not take into account the variations of the efficiency for the reasons mentioned in part I.A.2.

$$\text{With } \partial\left[\frac{\sigma(1-\alpha)}{\alpha}\right] = -\frac{\sigma}{\alpha}\frac{\partial\alpha}{\alpha^*}$$

$$\text{and } \frac{\partial\alpha}{\alpha^*} = -\frac{(\sigma-1)(1-\alpha)}{\alpha}\partial(c-p)$$

we get :

$$(A3) \quad \boxed{\partial(\dot{Y} - \dot{L}) = -\frac{\sigma(1-\alpha)}{\alpha}\partial(\dot{C} - \dot{P})\left[1 + \frac{(1-\sigma)}{\alpha}\frac{\partial(c-p)}{\partial(\dot{C} - \dot{P})}(\dot{C} - \dot{P})^*\right]}$$

The equation (A3) can then be rewritten in the following way using (A2) :

$$\partial(\dot{Y} - \dot{L}) = \frac{\sigma(1-\alpha)}{\alpha}\pi_1(\dot{C}_2 - \dot{C}_1)\left[1 + \frac{(1-\sigma)}{\alpha^*}t\frac{1 - (\sigma'-1)(\dot{C}_1 - \dot{C}_2)\frac{t+1}{2}}{1 - (\sigma'-1)(\dot{C}_1 - \dot{C}_2)t}(\dot{C} - \dot{P})^*\right]$$

The second term in brackets describes the impact of the fall of α , the share of wages in the value added. It depends on our production function parameters, is increasing with time, but its average value on the period 1995-2000 is always below 0.1 in absolute value. As a consequence we neglect it in our comparison with the productivity surplus formula.

Finally we derive :

$$(10) \quad \boxed{\partial(\dot{Y} - \dot{L}) = \frac{\sigma(1-\alpha)}{\alpha}\pi_1(\dot{C}_2 - \dot{C}_1)}$$

D. Computing the change of the volume of investment

Investment equals the depreciation of the volume of capital of the preceding period plus the increase of capital volume (ΔK) :

$$I = \delta_1 K_{-1}^1 + \delta_2 K_{-1}^2 + \Delta K$$

That is to say, in the alternative :

$$\partial I = \delta_1 \partial K_{-1}^1 + \delta_2 \partial K_{-1}^2 + \partial \Delta K$$

with

$$\begin{cases} \partial K^1 = \partial \text{ratio1} K + \text{ratio1}^* \partial K \\ \partial K^2 = \partial \text{ratio2} K + \text{ratio2}^* \partial K \end{cases}$$

ratio1 and *ratio2* stand for the share of ICT and non-ICT capital in total capital respectively.

Hence :

$$\partial I = (\delta_1 \partial \text{ratio1} + \delta_2 \partial \text{ratio2})_{-1} K_{-1} + (\delta_1 \text{ratio1}^* + \delta_2 \text{ratio2}^*)_{-1} \partial K_{-1} + \partial \Delta K$$

and

$$\begin{cases} \partial I_{|K^*} = (\delta_1 \partial \text{ratio1} + \delta_2 \partial \text{ratio2})_{-1} K_{-1} \\ \partial I_{|\partial K} = (\delta_1 \text{ratio1}^* + \delta_2 \text{ratio2}^*)_{-1} \partial K_{-1} + \partial \Delta K \end{cases}$$

E. Description of the macro-econometric model MESANGE

We use Mesange, a model of the French economy developed by the Forecasting Directorate (Ministry of the Economy, Finance and Industry) and the INSEE (French National Institute of Statistics). It is a quarterly model based on national accounting data consistent with the European System of Accounts (ESA) 1995 concepts. It has about 500 equations, including 40 econometric ones that reflect economic agents' behavior : consumption, investment, price making, etc. It has traditional features : in the short-run output depends on demand, whereas long-run properties are derived from a coherent theoretical description of the supply-side of the economy.

In this appendix we describe the equations of the model that are referred to in the paper.

Capital accumulation

The level of investment chosen by non-financial firms and unincorporated enterprises derives from a capital accumulation equation¹⁵ (Student statistics are in brackets) :

$$\Delta k = \underset{(3.53)}{0.002} + \underset{(143.5)}{0.94} \Delta k_{-1} + \underset{(10.11)}{0.049} \Delta y + \underset{(c)}{(1 - 0.940 - 0.049)} \Delta y_{-1} + \underset{(2.95)}{0.004} \Delta prof_{-2} - \underset{(3.40)}{0.002} [k_{-1} - y + 0,4(c - p)]_{-1}$$

Capital accumulation equation : $K = I + K_{-1}(1 - \delta)$

Where δ stands for capital depreciation rate, $prof$ for the logarithm of the net profitability rate of firms (defined as the gross operating surplus net of taxes divided by the value of capital stock), C for nominal capital cost (computed with the Jorgenson formula) and c for its logarithm :

$$C = P_I * [r + \delta + 12.25 - (P_I / P_{I-4} - 1) * 100]$$

Estimation period : 1979q2-1999q4, $R^2=0.99$, $SER=0.03\%$, $DW=2.15$.

r stands for long-term (10 years) nominal interest rate.

Investment price

In the model, the price of the investment of firms is indexed to the price of domestic output and imported goods. We present only the equation for the manufacturing sector, the equation for the non-manufacturing sector being virtually the same.

$$\Delta p_{I_{dim}} = \underset{(1.80)}{-0.001} + \underset{(1.70)}{0.15} \Delta p_{I_{dim-1}} + \underset{(4.90)}{0.48} \Delta p_{I_{dim-2}} + \underset{(c)}{(1 - 0.15 - 0.48)} PDOM_{-1} \Delta p_{pdom_dim} + \underset{(c)}{(1 - 0.15 - 0.48)} RIM_{-1} \Delta p_{rim_dim} - \underset{(1.67)}{0.048} (p_{I_{dim}} - p_{rnt_dim})_{-1}$$

Estimation period : 1982Q1-1998Q4, $R^2=0.43$, $SER=0.44\%$, $DW=2.28$.

¹⁵ Aggregate investment is then divided in manufactured and non-manufactured investment. The share of manufactured investment has been reasonably constant over the past 20 years.

Where $p_{I_{dim}}$, p_{pdom_dim} , p_{pdom_dim} and $p_{rnt-dim}$ stand for the logarithms of the price of investment of firms, of domestic output for domestic markets, of imports, and of total domestic resources (in manufactured goods) respectively.

$PDOM$ and RIM stand for the share of domestic output and imports respectively in total domestic resources ($PDOM + RIM = 1$) in manufactured goods.

Foreign trade

As for imports and exports, the MESANGE model distinguishes manufactured goods from non-manufactured goods. All these are determined by econometric equations. Imports depend on domestic demand, competitiveness and a trend (which represents the growing opening of the French economy). Exports depend on world demand, competitiveness and a trend.

Price of value added

The MESANGE model distinguishes the manufacturing sector from the non-manufacturing sector. The econometric equations describe the price-making process of firms. The long-term target is the factor price frontier. We present only the equation for the manufacturing sector, the equation for the non-manufacturing sector being virtually the same.

$$\begin{aligned} \Delta p_{dim} = & 0.048 + \frac{0.25}{(4.30)} \Delta cus_{dim} + (1 - 0.3 - \frac{0.25}{(c)} - 0.11 - 0.22) \Delta cus_{dim-1} + \frac{0.11}{(2.46)} \Delta cus_{dim-6} \\ & + \frac{0.22}{(4.73)} \Delta cus_{dim-7} + \frac{0.3}{(c)} \Delta p_{I_{dim-1}} - \frac{0.28}{(-3.23)} \Delta^2 p_{CI_{dim}} + \frac{0.19}{(2.87)} \Delta prod_{dim} - \frac{0.015}{(-3.30)} d823 \\ & - 0.040 \left[p_{dim} - \frac{0.7}{(c)} (w_{dim} - eff_{dim}) - \frac{0.3}{(c)} c \right]_{-8} \end{aligned}$$

Estimation period : 1981Q1-1999Q4, R2=0.77, SER=0.45, DW=1.58.

cus_{dim} , $prod_{dim}$ and w_{dim} are the logarithms of unit labor cost, total volume of production, and wage total compensation (by full-time equivalent) in the manufacturing sector.

p_{dim} and $p_{CI_{dim}}$ are the logarithms of the price of value added and intermediate consumption, and eff_{dim} long-term labor productivity in the manufacturing sector.

$d823$ is a dummy for 1982q3.

In this equation, the decrease of the price of investment has an impact on inflation in the long run, but also in the short run, with a short-term coefficient equal to 0.3. This is an original equation as regards economic theory (theoretically, the price of value added depend on capital cost, not on investment price). Besides, this short-term constraint is rejected by the data in the manufacturing sector. This specificity of the equation has a strong impact on the way the shock on investment price is transmitted to the rest of the economy. Indeed it speeds up the convergence to the factor price frontier, whereas the coefficient associated to the long-run target is especially small in this equation.

An alternative equation for the price of value added

We propose an alternative, more traditional equation for the price of value added. In what we call the alternative equation value added prices only depend on unit labour costs in the short run, with an estimated coefficient of 0.7. The results we comment on in part II.C. have been obtained with the alternative equation.

The choice of the equation of the price of value added has little impact on volumes. Yet there are big differences as regards prices. In this appendix we describe the results obtained with the original equation of the model MESANGE.

With this equation the shock on capital price is immediately transmitted to the price of value added. This has an impact on every price, with a decrease of the price of the investment of firms of 5.5%, and more than 2.5% for the

other goods. Convergence to the long-term of the equation of the price of value added is faster, and the increase in the real labour cost and long-run productivity is more important.

All in all, the increase of disposable income and consumption is stronger. Note that in this scenario the margin rate (the share of wage total compensation in value added) falls, since the price of value added decreases more rapidly than unit labour costs.

Table 1b : piled up impact in 2000 on volumes (relative discrepancy in %)

	MESANGE equation	Alternative equation
GDP	0.54	0.33
households consumption	0.47	0.16
firms investment	2.65	2.18
exports	0.91	0.69
imports	1.03	0.79
employment (business sector excluding agriculture)	0.39	0.32
labour productivity (business sector excluding agriculture)	0.30	0.11

Table 2b : piled up impact in 2000 on prices (relative discrepancy in %)

	MESANGE equation	Alternative equation
GDP	-3.00	0.09
value added	-3.08	0.10
households consumption	-2.87	0.09
firms investment	-5.52	-2.62
exports	-2.89	0.09
imports	-2.57	0.04
wages	-2.44	0.29
firms share of profit	-0.8	-0.1