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ICT demand behaviour: an international comparison

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Abstract:

This study aims to provide some empirical explanations for the gaps in ICT diffusion between industrialized countries, especially European countries vis-à-vis the United States. The panel data cover eleven OECD countries: Austria, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Spain, the United Kingdom and the United States. These annual macroeconomic data span the 1981-2005 period.

The analysis provides some original results: (i) the impact on ICT diffusion of the level of education and market rigidities has changed over time. The correlation of ICT diffusion, positive with the level of education and negative with market rigidities, increased over time (in absolute terms) until the middle of the 1990s; (ii) In each country, the estimates show a decrease over time of the price-elasticity of demand for ICT (in absolute terms). More precisely, the elasticity of substitution of ICT vis-à-vis all production factors are close to or greater than 2 at the beginning of the 1980s and close to 1 in the middle of the 2000s; (iii) The estimates confirm the positive impact of the share of the population with a higher education and the negative impact of market rigidities on ICT diffusion. These effects are heightened when ICT diffusion is already substantial.

JEL classification: E22, O47, O57, R24
Keywords: ICT, investment, factor demand, productivity

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The views expressed in this article are those of the authors and do not necessary reflect those of the institutions for which they work.

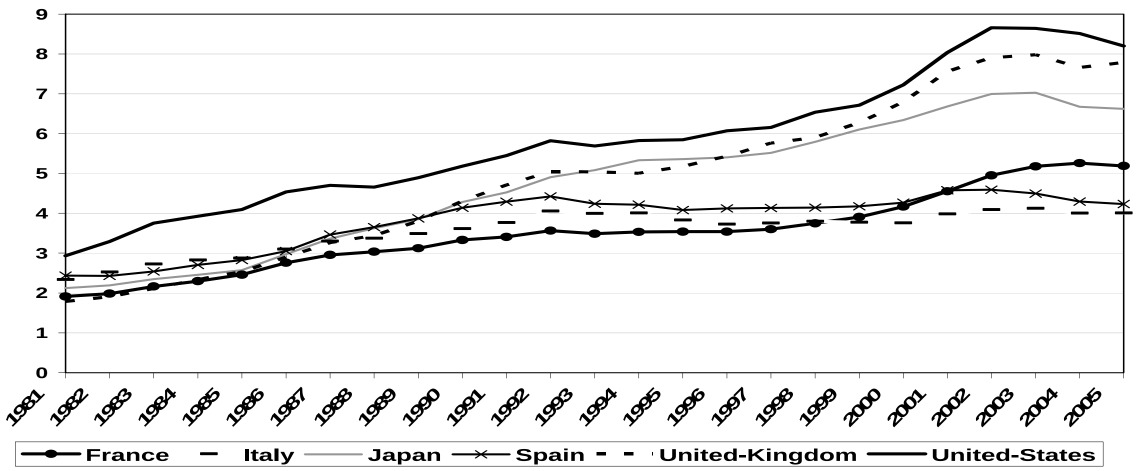
1. Introduction

A large body of literature (for example Shreyer, 2000, Colecchia and Shreyer, 2001, Pilat and Lee, 2001, OCDE, 2002 and 2003, van Ark et al. 2002a and b, van Ark, O'Mahony and Timmer, 2008, or Cette, Lopez and Noual, 2005) has shown that the level of the diffusion of information and communication technologies (herafter ICT) differs greatly across the main industrialized countries, the United States being the country where the diffusion appears to be the highest. Cette and Lopez (2008) have shown that the ICT capital coefficient has risen over the last few decades in the major advanced countries, and stabilized in the last few years (Chart 1). This apparent stabilisation of ICT diffusion occurs at very different levels across all countries, the United States being the country with the strongest ICT diffusion, and the United Kingdom coming in close behind. These gaps could have a major impact on productivity gains and growth of the different countries.

Chart 1

ICT capital coefficient (x 100), at current prices

Scope: the whole economy



Source: Cette and Lopez (2008) calculations using the EU-KLEMS database.

Gust and Marquez (2000) suggest that the gaps in ICT diffusion between advanced countries, and in particular the European lag vis-à-vis the United States, are temporary and should gradually disappear. However, the stability, or even the widening, of ICT diffusion gaps between Europe and the United States over several decades calls this approach into question.

A number of studies provide alternative explanations for the European ICT diffusion lag, using descriptive approaches (for example Antipa et al., 2007) or econometric investigations (for example Gust and Marquez, 2004, Cette, Lopez and Noual, 2005 or Aghion et al., 2008). Two explanatory factors are often put forward: the level of education and market rigidities.

An efficient use of ICT generally requires firm reorganization and institutional flexibility, which can be restricted by excessively stringent regulations. Moreover, in product markets, rigid regulations can reduce competitive pressure and thus lower the incentives to use the most efficient production techniques. In addition, the use of ICT generally requires labour with a higher degree of skills than other production technologies. In the United States, there are relatively few market rigidities and the share of the working-age population with a higher education is greater than in other advanced countries, albeit the market rigidities gap between the United States and other Anglo-Saxon countries remains quite small.

However, given the difficulty in obtaining adequate data, few empirical investigations have been carried out to account for the differences in terms of ICT diffusion observed across countries. These investigations rule out price elasticity differences as a possible explanatory factor (Cette, Lopez, Noual, 2005); besides, these differences remain to be explained. They also confirm an impact on ICT diffusion of the share of the population with a higher education and of product and labour market rigidities (Aghion et al., 2008). These results and lessons from these first analyses remain to be consolidated and looked into in greater depth. This is the aim of this study, following on from the above-mentioned analyses.

The data mobilized for this empirical investigation cover eleven OECD countries: Austria, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Spain, the United Kingdom and the United States. These annual macroeconomic data span the 1981-2005 period. The main data sources are the EU-KLEMS and OECD databases. A specific evaluation was conducted for certain variables – such as the investment price deflators, the productive capital stock and the user cost of capital – based, for each product, on calculation assumptions common to the different countries. The data are detailed in Cette and Lopez (2009) Appendix A.

After introducing the model used to characterise the demand for ICT and other production factors (2.), we present the estimates obtained from this model (3.) and end with some concluding remarks (4.).

2. <u>The model</u>

The selected specification is close to that detailed in Cette, Lopez and Noual (2005). We present the basic model (2.1.), certain difficulties related to measurement errors and the method used to deal with them (2.2.), the inclusion of the level of education and market rigidities in the equation (2.3.) and, finally, the estimated relationship (2.4.).

2.1. The basic model

Given the short temporal dimension, we estimate a static model corresponding to a long-term relationship on the basis of a simple and partially calibrated specification of factor demand. Factor demand stems from a very general specification and from weak assumptions, mainly the local approximation of the production function using a CES and constant returns to scale. The demand for factor j is then:

(1) $f_j^* = q^* + \beta_j.(c_j^* - p_q^*) - \gamma_t + cte$

where f_j and q are, respectively, the logarithm of the volume of factor j and of gross domestic product; c_j and p_q are, respectively, the logarithm of the user cost of factor j and of the gross domestic product deflator; β_j the elasticity of substitution of factor j vis-à-vis, simultaneously, the whole set of production factors, γ_t Hicks-neutral technical progress, i.e. total factor productivity (TFP), and cte a constant from the production function.[1] A variable with an '*' as an exponent denotes the optimal level of this variable at equilibrium. In order to simplify the presentation, the temporal and country indices (t and k) are reported only for the estimated relationship. The meaning of the relationship (1) is intuitive.

2.2. Specific measurement errors

Measurement errors, such as white noise or those corresponding to a simultaneity bias, are dealt with, in the estimation, by using appropriate instrumental variables. This section presents specific measurement errors specific to our data and the way in which the estimated relationship takes them into account.

National accounting rules on the breakdown of business spending between intermediate and final use differ for each factor from one country to the next; these differences may be considered as measurement errors. Assuming that these differences are time-invariant, the corresponding

[1] In this analysis the levels and logarithms of the variables are respectively denoted by upper cases and lower cases.

measurement errors are taken into account by country-product constants. The sign of these constants is *a priori* indeterminate and the corresponding estimates cannot be interpreted immediately.[2]

Relative factor costs may also contain important measurement errors. In the construction of our variables, it is assumed that the ratio of every asset price to the GDP deflator in every country is the same as that in the United States. Nevertheless, relative prices may also depend on country-specific determinants, such as the exchange rate or import and export mark-up behaviours, the import part of the investment components being, especially for ICT capital, higher than that of the whole production. The measurement error corresponding to this difficulty impacts in a complex way the measure of the cost and volume of the different components of capital. It is captured in the estimated equation by adding as explanatory variables the exchange rate and the average age of the equipment. As the purpose of these additional variables is to correct measurement errors both in explanatory and dependant variables, their estimates are *a priori* indeterminate.

Another source of error stems from the fact that asset prices may not take proper account of the changes in asset performances, mainly ICT capital. The measurement of computer equipment and software prices is based on specific methodologies (such as the 'hedonic' approach) that are better able to take changes in asset performances into account. For non-ICT products, performance gains are smaller but positive, and insufficiently taken into account, which also represents a measurement error. Like the previous error, this type of error affects the measurement of factor cost and volume in a complex way. Adding the average age of equipment to the list of explanatory variables enables us to capture, at least in part, the effect of this measurement error.[3] Nevertheless, introducing this control variable is not enough to correct the unavoidable measurement error resulting from the fact that the quality effects by equipment type are not properly taken into account.

2.3. Taking account of the level of education and market rigidities

In order to explain the persistent ICT diffusion gaps mentioned above, the estimated relationship is completed by adding indicators for the level of education and market rigidities to the list of explanatory variables. The preferred variable used to represent the level of education is the share of the population aged between 25 and 64 with at least some higher education (EDUC). To take better

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[2] As regards labour, adding country-product constants is justified by a 'normalization' problem: the explained variable is not independent from the currency. Further estimations conducted without including the labour factor show similar results for the other factors to those obtained when labour is included.

account of the effect of the level of education on the demand for ICT capital, we test a quadratic specification for this variable. For market rigidities, we use the OECD indicators of employment protection legislation (EPL) for the labour market and the OECD indicators of regulation in energy, transport and communications (ETCR[4]) for the product market.[5]

Both indicators of market rigidities often combine the following shortcomings: weak volatility and strong inter-correlation. When they are estimated simultaneously, these problems impact the results. One solution is to introduce both of them alternatively in the estimated relationship.[6] Another preferred solution is to cross both market rigidity indicators. This crossing is supported by a large body of literature (see especially Amable and Gatti, 2006, Koeniger and Vindigni, 2003, Blanchard and Giavazzi, 2003, Blanchard, 2005, Aghion et al., 2008). Moreover, the indicator obtained by crossing the two indicators of market rigidity shows a stronger volatility than each indicator individually.

The estimated relationship takes into account two other points. First, Chart 2 shows the changes in the correlation between the level of education, the indicators of market rigidity and ICT diffusion. This pattern could explain the increase in the ICT diffusion gaps in the 1990s. In addition, the recent literature highlights the role played by the distance to the technological frontier on the magnitude of the effect of rigidities on productivity and ICT investment (see especially Aghion and Howitt, 2006, Aghion et al., 2008). These two additional aspects are specified by the introduction of an ICT diffusion threshold effect on the parameters corresponding to the impact of the level of education and market rigidities on factor demand.[7]

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3 If the improvement in the physical investment productive capacity is measured with an error constant over time, then the measurement error on the productive capital stock increases with the average age of the equipment.

4 ETCR is made up of 4 components that measure, for each relevant sector, entry barriers, the public ownership in the leading firm of each sector, the market share of this firm and the level of vertical integration. Estimates using these indicators are briefly presented below

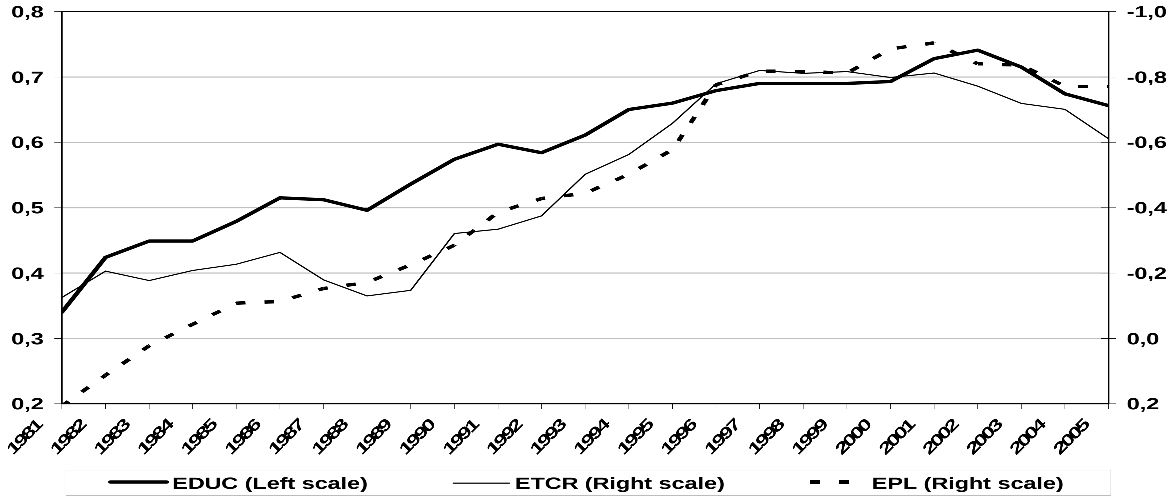
5 In order to facilitate the interpretation of the estimates, these indicators are re-scaled between 0-1, with 1 for the strongest rigidity.

6 As there are strong positive correlations between the market rigidity indicators, introducing both of them alternatively amounts to overestimating each specific impact, part of the explanatory power of the omitted indicator being carried forward on the present indicator.

7 The choice of the threshold is explained further on.

Chart 2

Correlation of the ICT capital coefficient with the level of education (EDUC) and product and labour market rigidities (respectively ETCR and EPL)



EDUC is the share of the working-age population with a higher education, completed or not. ETCR and EPL are, respectively, composite indicators of product and labour market rigidities. The construction of these three indicators is detailed in the appendix.

2.4. The estimated relationship

Taking account of the different types of measurement errors and introducing the indicators of the level of education and market rigidities into relationship (1) leads to the following relationship (2):

$$(2) \qquad f_{j,k,t} - q_{k,t} = a1_{j,k,t}.(c_{j,k,t} - p_{qk,t}) + a2_{k,t} + a3_{j,k,t}.AGE_{j,k,t} + a4_{j,k,t}.chg_{k,t} + (a5_j + d.a5_j').EDUC_{k,t} + e.a6_j.EDUC_{k,t}^2 + (a7_j + d.a7_j').RIGID_{k,t} + a8_{j,k} + u_{j,k,t}$$

In this relationship, for each country k and year t, the logarithm of the capital coefficient of factor j, $f_{j,k,t} - q_{k,t}$, depends on: (i) the logarithm of the relative price of factor j as compared to the price of all other factors, $c_{j,k,t} - p_{qk,t}$; (ii) total factor productivity effects denoted by annual constants $a2_{k,t}$; (iii) mismeasurement correction variables, i.e. the average age of equipment for factor j, $AGE_{j,k,t}$ and the logarithm of the exchange rate $chg_{k,t}$; (iv) the level of education $EDUC_{k,t}$ and, only for ICT, its squared value $EDUC_{k,t}^2$, as well as the level of market rigidities $RIGID_{k,t}$; (v) country-product dummies $a8_{j,k}$; (vi) error terms assumed to be identically and independently distributed ($u_{j,k,t} \sim> N(0,\sigma^2)$).

The coefficient $a1_{j,k,t}$ is the elasticity of substitution of factor j vis-à-vis, simultaneously, the whole set of production factors; the expected sign of this coefficient is negative. The signs of the coefficients

$a2_{k,t}$ and $a8_{j,k}$ are indeterminate. The coefficients $a3_{j,k,t}$ and $a4_{j,k,t}$ are equal to zero for labour and their signs are indeterminate in the other cases. The impact of the level of education and market rigidities on factor demand could differ according to the level of ICT diffusion in the country, the dummy d being equal to 1, for ICT, above the diffusion threshold and zero otherwise. The signs of the coefficients $a5_j$, $a6_j$ and $a7_j$ as well as $a5_j + d.a5_j'$, $a6_j + d.a6_j'$, $a7_j + d.a7_j'$ will be discussed in the presentation of the results. For the ICT capital coefficient, an overall positive effect of the level of education and a negative effect of market rigidities are expected. Opposite effects are expected for the labour coefficient.[8] For the other factors, the expected sign of these coefficients is indeterminate and depends on the substitution effects between factors.

The price elasticity of demand for factors $a1_{j,k,t}$ and coefficients $a3_{j,k,t}$ and $a4_{j,k,t}$ cannot, obviously, change simultaneously with factor j, country k and year t. The null hypothesis of equality of price elasticities between countries is rejected for the ICT factor (even at a 1% threshold). Nevertheless, the estimates of price elasticity of demand for ICT are very close.[9] As a result, in the estimated model, this elasticity is assumed to be identical in every country. For non-ICT factors, the price elasticity is forced to be time-invariant, whereas for ICT factors, we allow them to change over time. This assumption is presented (without any empirical findings) by Oulton (2002). This reflects the fact that ICT diffusion, linked to improved productivity, corresponds both to a widening of ICT diffusion (ICT equipment is installed in places where there was none before) and an intensification of this diffusion (replacement of obsolete ICT equipment by new and more efficient equipment). Given that the first effect is gradually subsiding while the second is still supporting ICT growth, the overall result is a slowdown in ICT diffusion and a decrease (in absolute terms) in the price elasticity of ICT demand.

This assumption of time-varying price elasticity is confirmed by the Bai and Perron (1998) break test. This break is strongly significant at the end of the 1990s, the negative price elasticity of demand for ICT decreasing after the break (in absolute terms). In order to capture price elasticity changes in a smoother way, we use a quadratic specification over time. This assumption is written:

(3) $a1_{j,k,t} = a1_j \ \forall k, t$ si $j \neq TIC$ and $a1_{j,k,t} = a1_j + a1_j'.t + a1_j''.t^2 \ \forall k, t$ if $j = TIC$

$a3_{j,k,t} = a3_j$ and $a4_{j,k,t} = a4_j \ \forall k, t$

As regards of the country-year dummies $a2_{k,t}$ corresponding to TFP effects, we need to consider a more parsimonious specification. The simplifying assumption used consists in distinguishing three TFP components: a year dummy identical for all countries and factors, a country-specific trend

8 This factor is equal to the opposite of productivity.

9 These estimates are available in Cette and Lopez (2009).

component and a country-specific cyclical component corresponding to the capacity utilisation rate (CUR).[10] This assumption is confirmed empirically and used for every country in the main estimations presented below. With N denoting total employment, we reach the following specification:

(4) $a2_{k,t} = a2_t + a2_k'.t + a2_k''.TUC_{k,t}$ $\forall j \neq N$ and $a2_{k,t} = a2_t + a2_k'.t$ if $j = N$

3. Estimating demand for ICT capital

We first present the data used (3.1.), then the results (3.2.).

3.1. Data

The data construction, mainly based on the EU-KLEMS database, is detailed in Cette and Lopez (2009) Appendix A. A specific evaluation was conducted for certain variables – such as investment price deflators (used to calculate the investment volume), the productive capital stock and the capital user cost – based for each product on calculation assumptions common to the different countries. In the construction of our variables, it is assumed that the ratio of every asset price to the GDP deflator in every country is the same as that in the United States. The reason for this convention is that the United States uses more advanced methodologies to take into account the quality improvements in goods, especially ICT.

The relations are estimated on pooled data corresponding to the crossing:

- of the five production factors: ICT, transport equipment, other equipment, structure and total employment. ICT capital is calculated by distinguishing between its three standard components (computer equipment, software and communication equipment). Given the instability of the estimates obtained with this differentiation, we are led to consider ICT as a whole. This instability could be explained by the difficulties in the accounting breakdown between the components (a good example is the integrated software products, which are recorded under computer equipment);
- of the eleven countries with sufficiently robust data, the information on some variables being insufficient for the other countries. These eleven countries are: Austria, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Spain, the United Kingdom and the United States;

10 When estimations are conducted using a coefficient for the capacity utilisation rate specific to each country and product, the assumption of a non-significant parameter is rejected for all factors except labour. It is assumed thereafter that the capacity utilisation rate does not impact labour demand ($a2_{k,t} = a2_t + a2_k'.t$ if $j = N$).

- over the 1981-2005 period, which appears sufficiently robust for the different series.

3.2. Estimation results

Table 1 shows the results from the estimation of relationship (2), under the simplifying assumptions (3) and (4). These estimates were obtained using the ordinary least squares method (OLS) or the instrumental variable method (IV), in order to deal with the above-mentioned measurement errors, such as white noise or those corresponding to a simultaneity bias, and involving the capital user cost, the average age of capital and the production capacity utilisation rate. Among the many sets of instruments alternatively tested, the one finally used showed the best results with both the Sargan test of exogeneity (1958) and the Davidson and MacKinnon test (1993) of convergence of the ordinary least square estimator. These instruments are the first differences of the instrumented variables lagged by one and two periods. The relevance of the instruments is confirmed by the Nelson and Startz (1990) F-test.

An important step of the estimation is choosing the ICT diffusion threshold (above which the variable d is equal to one, and zero otherwise). Using a threshold is a simplistic method for dealing with the changes in a parameter according to ICT diffusion, but it is the only one compatible with the sample dimensions. The threshold is selected by scanning, the selection criteria being the minimisation of the sum of the squared estimation residuals. It should be noted that whatever the threshold scanned, the tests of equality of the coefficients below and above the threshold always reject the null hypothesis of equality for ICT capital demand. The selected threshold is 3.5%. For the mobilized data, the percentage of observations above this threshold is 30.9% over the whole period 1981-2005, 76.5% in the last ten years 1996-2005 and 100% in the last year 2005.[11] The estimates are robust to the chosen threshold (see Cette and Lopez 2009).

The estimation results are very robust to the estimation method (MCO or IV): when they are statistically significant, the elasticities estimated by both methods are very close.

When they are statistically significant, the price elasticities show a negative sign, as expected. For all non-ICT factors, these estimated price elasticities are small (in absolute terms); this could stem from factor complementarity. This weakness is consistent with the usual results obtained in the empirical literature on this topic (see, for instance, Tevlin and Whelan 2003).

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[11] In addition, this threshold is reached in 1995 for Denmark, in 1996 for the United States, in 1997 for the United Kingdom and Japan, in 1998 for the Netherlands, in 1999 for Finland and Germany and in 2000 for Austria, Spain, France and Italy.

The assumption that the price elasticity of demand for ICT is quadratic over time is confirmed by the statistically significant parameters measuring this specific trend. The estimations show a decrease over time (in absolute terms) of the price elasticity of demand for ICT (Chart 3). This price elasticity is close to -2 at the beginning of the 1980s and close to -1 in the middle of the 2000s. These estimates provide some empirical evidence that the broadening of ICT diffusion is gradually slowing, whereas the intensification of this diffusion continues to be in line with the increase in ICT performances. This slowdown could lead to the end of the contribution of ICT to growth. This seems fully consistent with the apparent stabilisation, in the last few years, of the ICT capital coefficient. These empirical results are, to our knowledge, original.

Chart 3

Estimates of the price elasticity of demand for ICT capital

Results from the estimation of relationship (2), under the simplifying assumptions (3) and (4), using the OLS method (results provided table 1 column [5]) or the IV method (table 1 column [6])

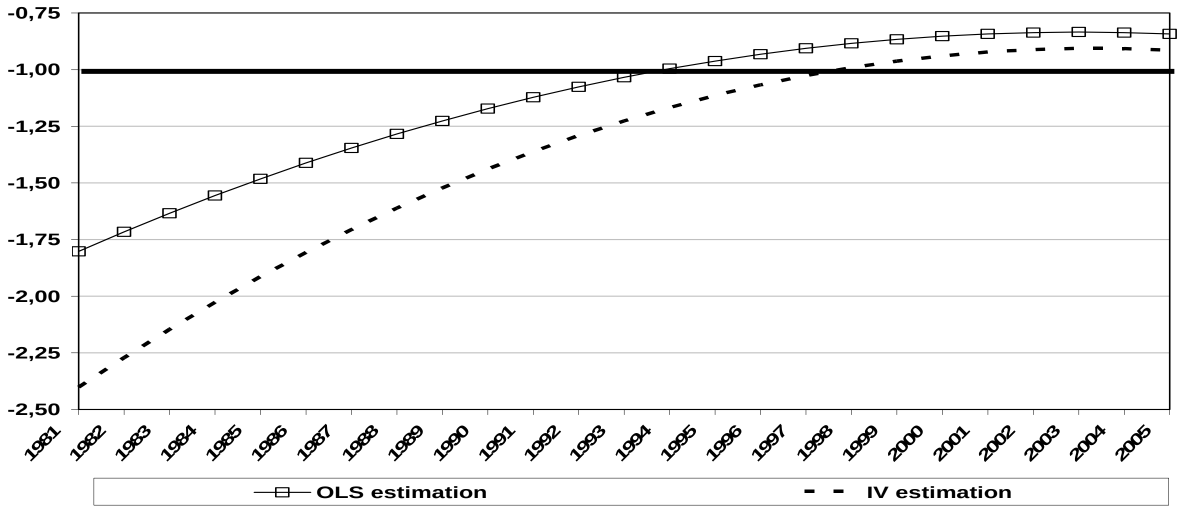

Table 1

Results from the estimation of relationship (2), under the simplifying assumptions (3) and (4)

			[1]	[2]	[3]	[4]	[5]	[6]
Market rigidity indicator			**EPL**		**ETCR**		**EPL*ETCR**	
Estimation method			**OLS**	**IV**	**OLS**	**IV**	**OLS**	**IV**
Price elasticity	**ICT**	**Cte**	-1,812**	-2,386**	-1,816**	-2,426**	-1,802**	-2,402**
			(30,13)	(19,76)	(30,72)	(20,30)	(0,06)	(0,11)
		t	0,088**	0,133**	0,083**	0,136**	0,088**	0,134**
			(10,19)	(6,17)	(9,69)	(6,36)	(0,01)	(0,02)
		t²	-0,002**	-0,003**	-0,002**	-0,003**	-0,002**	-0,003**
			(7,14)	(4,51)	(6,26)	(4,59)	(0,00)	(0,00)
	Transport equipment		-0,123**	0,157	-0,076	0,025	-0,099*	0,057
			(2,88)	(0,58)	(1,77)	(0,1)	(0,04)	(0,26)
	Other equipment		-0,120**	-0,086	-0,126**	-0,054	-0,124**	-0,044
			(2,86)	(0,53)	(3,02)	(0,35)	(0,04)	(0,16)
	Non-residential structures		0,008	-0,058*	-0,005	-0,036	0,00	-0,045
			(1,00)	(2,11)	(0,59)	(1,42)	(0,01)	(0,03)
	Labour		-0,653**	0,276	-0,730**	0,178	-0,743**	0,196
			(6,86)	(0,59)	(7,81)	(0,41)	(0,09)	(0,45)
Education	**ICT ($a5_{ICT}$)**		9,478**	7,258**	8,382**	7,078**	8,464**	6,527**
			(8,24)	(3,35)	(7,51)	(4,00)	(1,09)	(1,87)
	ICT, supp. effect. ($a5'_{ICT}$)		1,249**	1,148**	1,505**	1,438**	1,272**	1,124**
			(8,04)	(4,50)	(8,47)	(5,71)	(0,15)	-0,249
	ICT, quadratic component		-13,689**	-12,791**	-12,780**	-12,693**	-12,824**	-12,394**
			(5,78)	(3,83)	(5,54)	(4,31)	(2,298)	(2,990)
	Transport equipments		-2,038**	-0,31	-4,011**	-2,721**	-3,466**	-2,036*
			(3,76)	(0,29)	(6,61)	(2,93)	(0,555)	(0,998)
	Other equipments		-2,639**	-1,438	-3,263**	-2,090*	-2,962**	-1,765
			(4,88)	(1,53)	(5,36)	(2,17)	(0,556)	(0,937)
	Non residential structures		-0,836	-0,683	0,737	1,608	-0,122	0,505
			(1,51)	(0,67)	(1,20)	(1,56)	(0,565)	(1,002)
	Labour		-2,307**	-3,752**	-1,680**	-3,319**	-1,522**	-3,173**
			(4,19)	(3,42)	(2,66)	(2,73)	(0,576)	(1,176)
Market rigidities	**ICT ($a7_{ICT}$)**		-0,120**	-0,093*	-0,068	0,138	-0,132**	-0,063
			(3,39)	(2,06)	(0,75)	(1,02)	(0,029)	(0,042)
	ICT, add. effect ($a7'_{ICT}$)		-0,101**	-0,091**	-0,541**	-0,465**	-0,220**	-0,185**
			(8,18)	(5,54)	(8,15)	(5,83)	(0,024)	(0,031)
	Transport equipment		-0,091**	-0,082*	-0,383**	-0,359*	-0,149**	-0,138**
			(2,65)	(1,98)	(4,57)	(2,42)	(0,026)	(0,035)
	Other equipment		0,001	0,002	-0,061	-0,02	-0,043	-0,03
			(0,04)	(0,05)	(0,73)	(0,19)	(0,026)	(0,032)
	Non-residential structures		0,072*	0,072	0,440**	0,545**	0,059*	0,091**
			(2,10)	(1,74)	(5,24)	(4,93)	(0,026)	(0,033)
	Labour		0,036	0,061	0,154	0,169	0,025	0,034
			(1,04)	(1,45)	(1,87)	(1,61)	(0,025)	(0,033)
Sargan test								
Statistic				31,71		29,335		35,231
P-value				0,203		0,1353		0,1068
Davidson & MacKinnon test								
Statistic				9,745		10,838		10,583
P-value				0		0		0
R²			0,9566	0,9422	0,958	0,9468	0,9592	0,9471

Between brackets: Student t-statistics of the estimated coefficients.

**denotes parameter significance at a 1% threshold, * at a 5% threshold

List of instruments: $\Delta c_{j,k,t-1}$, $\Delta c_{j,k,t-2}$, $\Delta AGE_{j,k,t-1}$, $\Delta AGE_{j,k,t-2}$, $\Delta TUC_{j,k,t-1}$, $\Delta TUC_{j,k,t-2}$.

In order to simplify the presentation, the estimated coefficients of certain variables used in the estimations (CUR, AGE, chg, country trend, year dummy and country*product fixed-effects) are not shown in the above table.

The estimated coefficients of the rigidity indicators show that:

- Labour market rigidities (measured by the EPL indicator) always have a negative impact on ICT diffusion, this adverse effect being amplified (almost multiplied by two) above the ICT diffusion threshold (column [1] and [2]);
- Product market rigidities (measured by the ETCR indicator) have an adverse and statistically significant effect on ICT diffusion only above the diffusion threshold (column [3] and [4]);
- The interaction between both rigidity indicators has an adverse and significant effect on ICT diffusion, only above the threshold in the case of the IV estimation but also below in the case of the OLS estimation (column [5] and [6])

The product market rigidity indicator (ETCR) is broken down into 4 sub-indicators: entry barriers (ENTRY), the public ownership in the leading firm of each sector (PUB), the market share of this firm (MARKET) and the level of vertical integration (VERT). When substituting the aggregate indicator for each one of its components alternatively, the impact on ICT demand is positive and significant below the ICT diffusion threshold for each component. But above the threshold the impact is non-significant for market share (MARKET) and the level of vertical integration (VERT), whereas it is negative and significant for entry barriers (ENTRY) – these being the market rigidities that varied the most over the period – and for public ownership (PUB).

Table 2

Results from the estimation by OLS of relationship (2) with the ETCR components, under the simplifying assumptions (3) and (4)

		[1]	**[2]**	**[3]**	**[4]**
Market rigidity indicator		**ENTRY**	**PUB**	**MARKET**	**VERT**
Market Rigidities	**ICT ($a7_{ICT}$)**	0,048**	0,040**	0,055**	0,026*
		(3,25)	(4,37)	(5,12)	(2,25)
	ICT, add. effect ($a7'_{ICT}$)	-0,062**	-0,040**	-0,047**	-0,026*
		(4,29)	(4,36)	(5,52)	(2,25)
	Transport equipment	-0,044*	0,00	0,005	0,00
		(2,49)	(1,44)	(0,68)	(1,12)
	Other equipment	-0,004	0,00	-0,003	0,00
		(0,28)	(0,37)	(0,42)	(0,34)
	Non-residential structures	0,072**	-0,000*	-0,008	0,00
		(5,66)	(1,96)	(1,24)	(1,68)
	Labour	0,017	0,00	0,00	0,00
		(1,41)	(0,29)	(0,05)	(0,22)
Test $a7_{ICT}+a7'_{ICT}=0$ (p-value)		0,019	0,017	0,465	0,572
R^2		0,9468	0,9410	0,9417	0,9409

Between brackets: Student t-statistics of the estimated coefficients.

** denotes parameter significance at a 1% threshold, * at a 5% threshold

List of instruments: $\Delta c_{j,k,t-1}$, $\Delta c_{j,k,t-2}$, $\Delta AGE_{j,k,t-1}$, $\Delta AGE_{j,k,t-2}$, $\Delta TUC_{j,k,t-1}$, $\Delta TUC_{j,k,t-2}$.

These results are fully consistent with the previous studies (for instance Aghion et al., 2008). Given that, in these studies, the threshold effect could be interpreted as a “distance to frontier’ effect: the closer a country is to the frontier, the more the increase in performances, fuelled by the use of ICT, calls for new forms of product and labour market flexibilities. Rigidities also have an adverse impact on the demand for transport equipment and a positive one on the demand for non-residential structures.

As regards education, the greater the share of the population with a higher education, the greater the ICT diffusion. The impact of the level of education on ICT diffusion is particularly strong when ICT diffusion is already substantial. This is easy to interpret: the higher the level of ICT diffusion already reached, the greater the need for educated people to facilitate ICT diffusion. This result is consistent but more comprehensive than that obtained by Aghion et al. (2008). The estimates also show that, while the level of education increases ICT diffusion, it reduces (for a given volume of output) the demand for transport equipment and labour; the latter effect obviously reflects the positive impact of education on productivity.

The estimates strongly confirm the idea that the ICT diffusion gaps between the main advanced countries can largely be explained by differences in the level of education and market rigidities.

4. Final remarks

Compared with the large body of literature on ICT, this analysis provides some original results:

- the impact of the level of education and market rigidities on ICT diffusion has changed considerably over time. The correlation between ICT diffusion, positive with the level of education and negative with market rigidities, increased (in absolute terms) until the middle of the 1990s. This suggests a change in the effect of the level of education and market rigidities on ICT diffusion, this effect growing with the widespread diffusion of ICT in the different countries to stabilize at a certain diffusion threshold;
- The estimates show for each country a decrease in the price elasticity of demand for ICT. More precisely, the elasticity of substitution of ICT vis-à-vis all production factors is close to or above 2 at the beginning of the 1980s and comes close to 1 in the middle of the 2000s. This development seems to correspond to a situation where ICT diffusion, linked to improved productivity, reflects both a widening of ICT diffusion and an intensification of this diffusion. Given that the first effect is gradually subsiding while the second is still supporting ICT

growth, the overall result is a slowdown in ICT diffusion and a decrease in the price elasticity of ICT demand (in absolute terms);

- The estimates also confirm the (positive) impact of the share of the population with a higher education and of market rigidities on ICT diffusion. These effects increase with the level of ICT diffusion. These results are consistent but more comprehensive than those obtained by Aghion et al. (2008).

These results suggest that the technological revolution driven by ICT has, since the beginning of the present decade, entered a new phase where ICT diffusion no longer corresponds to a widening of the diffusion of ICT equipment. In this new phase, the level of ICT diffusion is much higher in the United States than in the other countries, especially the major countries of continental Europe. These results provide useful insights for economic policy, as they make it possible to quantify the effects to be expected, in terms of ICT diffusion, from an increase in the share of the working-age population with a higher education or from a decrease in product and labour market rigidities. The robustness of the results and, consequently, of the lessons to be drawn should be confirmed by other empirical analyses, based on industry or firm level data. Nevertheless, these results extend and complete those of previous studies and seem in keeping with intuition.

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