

What Explains the ICT Diffusion Gap Between the Major Advanced Countries? An Empirical Analysis

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ABSTRACT

Over the last few years, a large body of literature has shown that the level of information and communications technology (ICT) diffusion, and, as a result, the favorable effects of this diffusion on productivity, differ greatly between the major advanced countries, with the United States the country where ICT diffusion is strongest. This study aims to explain empirically this gap. Annual macroeconomic panel data are used for the period 1981-2005 and cover eleven OECD countries: Austria, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Spain, the United Kingdom and the United States. The estimates obtained provide insight into the factors determining ICT diffusion and the gaps in this diffusion vis-à-vis the United-States. Compared to the United States, the lower ICT diffusion in the other major advanced countries can be explained by a smaller share of the population with a higher education and/or a higher level of rigidity in labour and product markets.

IN RECENT YEARS, A LARGE BODY of literature (e.g. OECD 2003) has shown that the level of information and communications technology (ICT) diffusion, and, as a result, the favourable effects of this diffusion on productivity, differs greatly between the major advanced countries, with the United States being the country where diffusion is highest. However, because of difficulties in obtaining the relevant data, only a limited number of empirical investigations have been carried out to account for the differences in ICT diffusion between countries. These studies have found no differences in the price elasticity of demand as an explanatory factor (Cette, Lopez

and Noual, 2004 and 2005). They also show that product market regulation, employment protection legislation, and the share of the working-age population with higher education have a relatively substantial impact on ICT diffusion (Aghion *et al.*, 2009). However, the results and lessons drawn from these studies remain to be consolidated and deepened. This is the aim of this article, which summarizes the results from our longer study (Cette and Lopez, 2008).

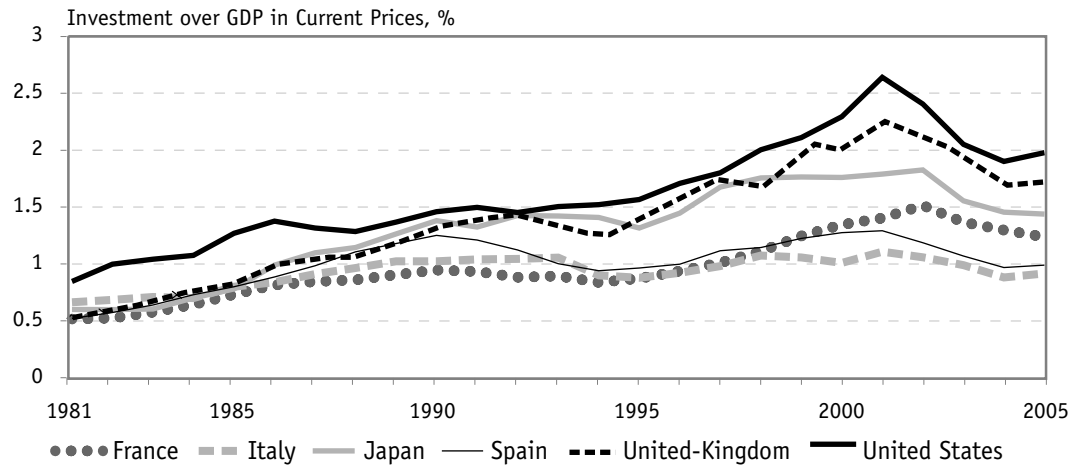
This empirical investigation uses annual macro-panel data for the 1981-2005 period from eleven OECD countries: the G-7 countries excluding Canada plus Austria, Denmark, Fin-

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Chart 1

Total Economy ICT Investment Rate, 1981-2005

For six large countries in the analysis



Source: Authors' calculations using the EU-KLEMS database (see Appendix A).

land, the Netherlands, and Spain. The initial data are mainly taken from the EU-KLEMS and OECD databases. Some variables, such as investment price indices, capital stock and the user cost of capital, are obtained from specific assumptions by country and variable; the methodology used is presented in the appendix.

The article is divided into four sections. After providing an overview of ICT diffusion in the countries under study and the main factors underlying this diffusion, we briefly present the model used to capture the demand for ICT and other factors of production. We then put forward the lessons to be drawn from the results before concluding.

ICT Diffusion: Stylized Facts
ICT Diffusion Gaps

The major advanced countries exhibit large gaps in terms of ICT diffusion manifested by the ICT investment rate, defined as the ratio of ICT investment to GDP in current prices (Chart 1) and the ICT capital coefficient, defined as the

ratio of the ICT capital stock to GDP in current prices (Chart 2). Such gaps have been reported in the literature since the early 2000s and confirmed in later research.²

Three country groups can be identified:

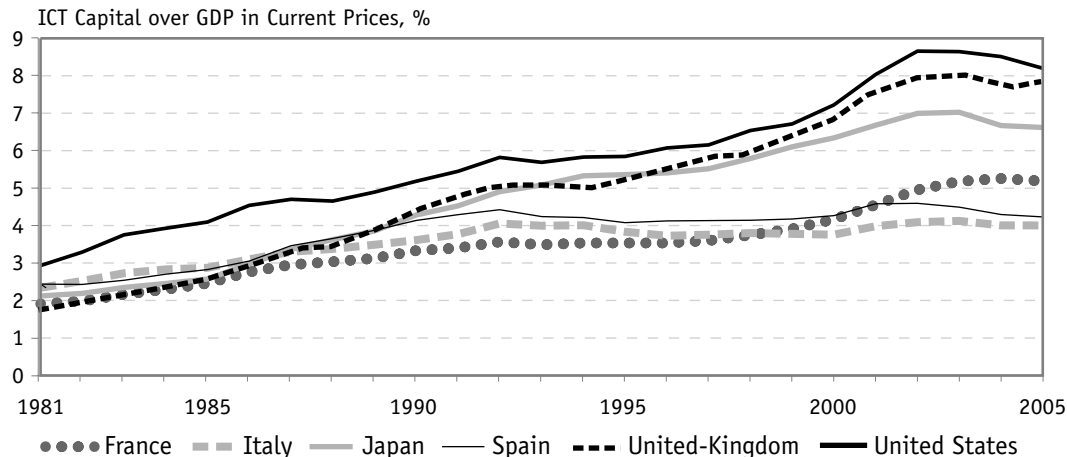
- The United States is the country with the highest level of ICT diffusion: its ICT investment rate and ICT capital coefficient stand at over 2 and 8 per cent respectively. The lead of the United States in terms of ICT diffusion, expressed by the ICT capital coefficient, can be observed as early as the start of the 1980s;
- At the other end of the spectrum, Italy, Spain, Germany, Austria, France and Finland are the countries with the lowest ICT diffusion: their ICT investment rate and ICT capital coefficient range between 1.0 per cent and 1.5 per cent and 4.0 per cent and 5.5 per cent, respectively (Chart 3);
- The intermediate group includes the Netherlands, Japan, Denmark and the United Kingdom: their ICT investment rate and

² See Schreyer (2000), Colecchia and Schreyer (2001), Pilat and Lee (2001), OECD (2002 and 2003), and van Ark *et al.* (2002a and 2002b) for the earlier studies and van Ark *et al.* (2008) for later work.

Chart 2

Total Economy ICT Capital Coefficient, 1981-2005

For six large countries in the analysis



Source: Authors' calculations using the EU-KLEMS database (see Appendix A).

ICT capital coefficient range between 1.5 per cent and 2.0 per cent and 6.0 per cent and 8.0 per cent, respectively. In this intermediate group, the situation of the United Kingdom appears to be close to that of the United States.

In all the countries except Spain and Italy, the ICT investment rate and the ICT capital coefficient rose continuously until the end of the 1990s, with a strong acceleration in the second half of this decade. In 2002, the ICT investment rate recorded a sharp fall, which continued in 2003 and 2004. In 2005, the ICT investment rate stabilized in all countries, or even increased slightly. As a result of these trends in the ICT investment rate, the ICT capital coefficient stabilized, or even posted a small decline, in the early 2000s.

The strong increase in the ICT investment rate in the second half of the 1990s followed by its decline in the period 2002-2004 can be explained in two ways. First, while the emergence of the dot-com bubble in the second half of the 1990s led to the development of ICT-using firms, the bursting of this bubble in the early 2000s inevitably resulted in a

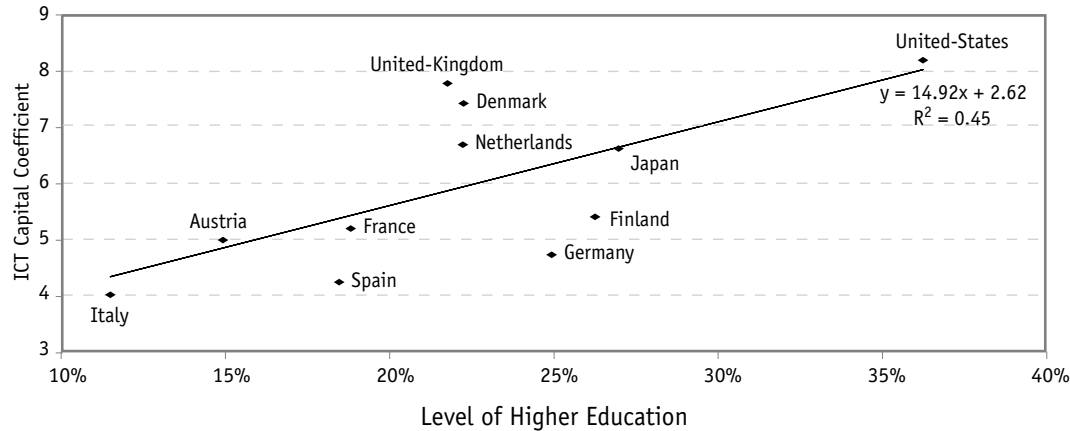
decline in the ICT investment rate. Second, ICT investment spending increased in the late 1990s due to the fear of the Y2K bug, then declined. Assuming that there was over-investment in ICT at the end of the 1990s, the corresponding ICT over-accumulation seems to be over, judging by the stabilization, and even the recent small increase, in the ICT investment rate. Because ICT has, by nature, a short lifespan, an over-accumulation can be quickly absorbed.

The stabilization — or even the small decrease — in the ICT capital coefficient in recent years suggests that the rate of advance in ICT diffusion, at least as measured by this indicator, has largely ended in advanced countries. But the extent or level of this ICT diffusion between countries is very different. In particular, the gap between the United States and other countries is substantial.

The Main Factors Underlying the Gaps in ICT Diffusion

Gust and Marquez (2000) suggest that gaps in ICT diffusion between advanced countries, and

Chart 3
Level of Education and ICT Capital Diffusion in 2005



The level of education is the share of the working-age population (25-64 years of age) with a higher education, completed or not (source OECD).

especially the European lag vis-à-vis the United States, is temporary, corresponding to a positive starting position of ICT-producing countries, and that it will gradually disappear. However, the stability — or even the widening — of the ICT diffusion gaps between Europe and the United States, over several decades, puts this approach into question.

A number of studies (a review is provided in OECD, 2003b) provide alternative explanations for the European ICT diffusion gap vis-à-vis the United States, using descriptive approaches (Antipa *et al.*, 2007) or econometric investigations (Gust and Marquez 2004, Aghion *et al.*, 2009). Two explanatory factors are often put forward: the level of education and market rigidities.

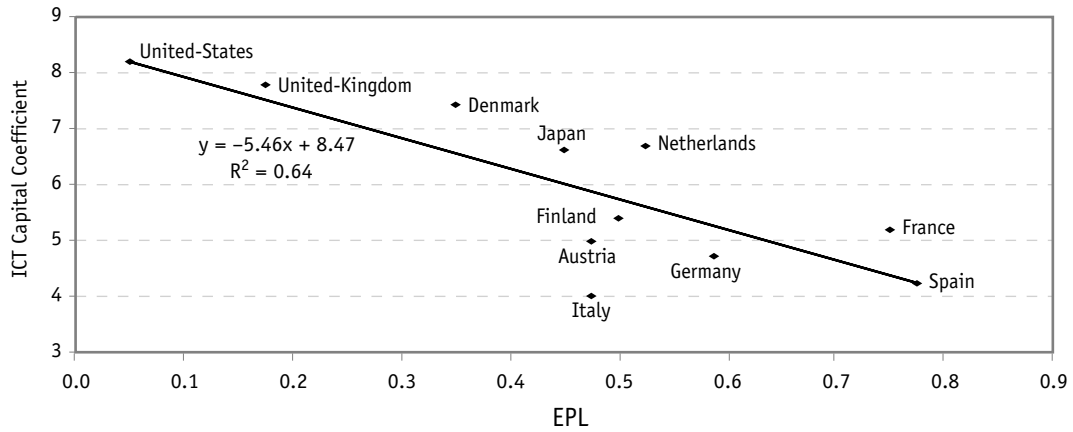
An efficient use of ICT generally requires firm reorganization and institutional flexibility, which can be restricted by excessively stringent regulations. Moreover, in product markets, rigid regulations can reduce competitive pressure and thus lower the incentives to use the most efficient production 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 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.

Charts 3, 4 and 5 confirm that ICT diffusion is positively correlated with the level of education and negatively correlated with the level of regulation in labour markets as captured by employment protection (EPL) and in product markets, as captured by regulation in energy, transport and communications (ETCR).

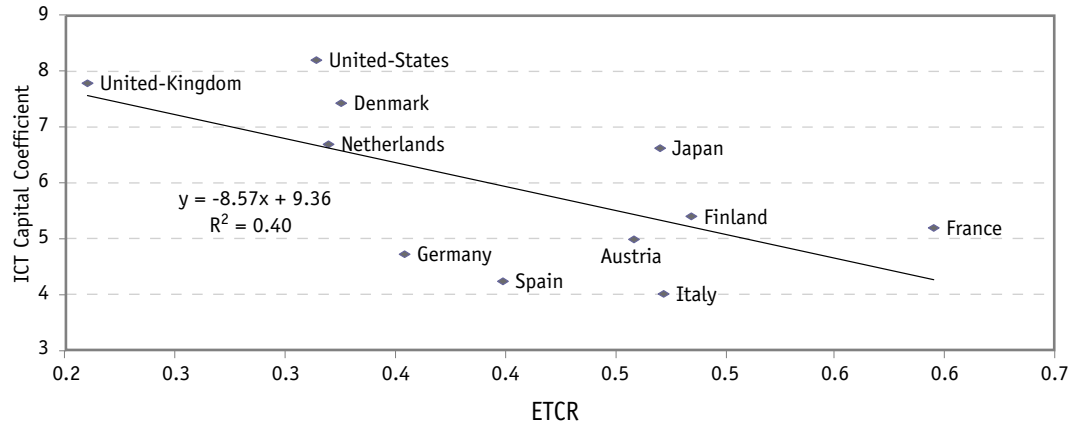
Aghion *et al.* (2009) have conducted the most sophisticated empirical investigation of ICT diffusion at the macroeconomic level for 17 countries over the 1985-2003 period. In the estimated specification, the ICT investment rate is explained by the share of the population with higher education and the function of product and labour market rigidities, these variables being possibly aggregated into a function with the distance from the technological frontier. The capacity utilization rate, which is deemed to have an impact on ICT diffusion via the accelerator effect, and, alternatively, different variables representing capital market rigidities are put

Chart 4
Labour Market Rigidities (EPL indicator) and ICT Capital Diffusion in 2005



Labour market rigidities are represented by EPL (source OECD), detailed in Appendix A.

Chart 5
Product Markets Rigidities (ETCR Indicator) and ICT Capital Diffusion in 2005



Product market rigidities are represented by ETCR (source OECD), detailed in Appendix A.

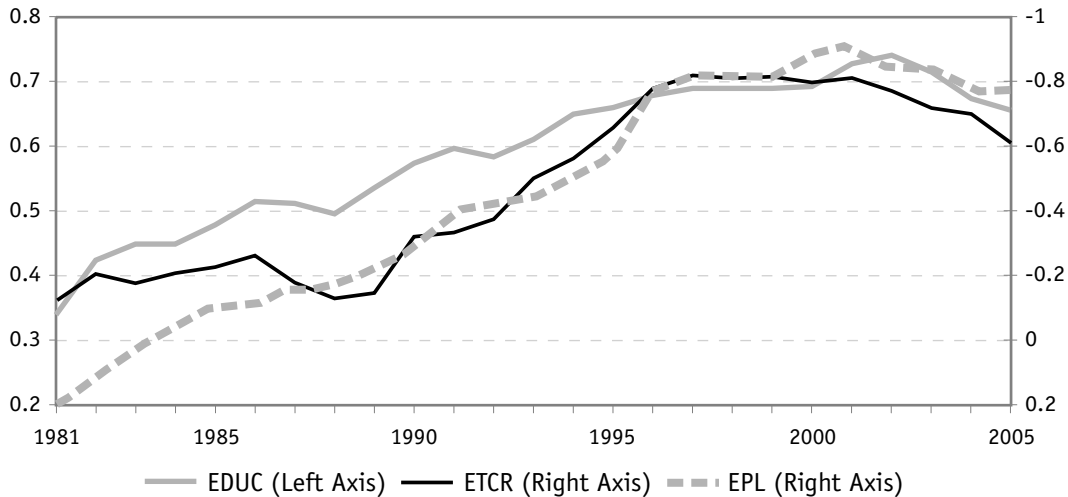
forward as explanatory variables. The main results of this analysis are the following: (i) the level of education of the working-age population does not have a significant impact on ICT diffusion in the countries far from the technological frontier. Conversely, for the countries close to the frontier, the impact is significant and positive; (ii) cross-rigidities in the product and labour markets have a significant and negative impact on ICT diffusion, this effect being stronger for countries close to the technological

frontier; (iii) the pressures on capital utilization have a significant and positive impact on ICT diffusion.

With respect to the effect of the level of education and market rigidities on ICT diffusion, one important aspect has, to our knowledge, not yet been mentioned in the literature, namely the fact that the effect has changed considerably over time. Chart 6 shows that the correlation of ICT diffusion with the level of education (positive) and with market rigidities (negative),

Chart 6

Total Economy 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.

increased (in absolute terms) over time and only stabilized in the mid 1990s. This observation suggests a discontinuity in the impact of the level of education and rigidities on ICT diffusion: it increased alongside the generalized increase in ICT diffusion in the different countries, and then stabilized at a certain threshold of ICT diffusion. This simplified specification, which assumes such a discontinuity, is used in the rest of our analysis.

The Model

The selected specification, which we shall briefly present, builds on that of Cette, Lopez and Noual (2004 and 2005).³ Given the short time dimension, we estimate a static model corresponding to a long-term relationship on the basis of a simple and partially calibrated specification of the demand for factors. Factor demand comes from a very general specification of the production function and from weak assump-

tions, mainly the local approximation of the production function using a constant elasticity of substitution (CES) and constant returns to scale.

Measurement errors such as white noise or errors corresponding to a simultaneity bias are dealt with, in the estimation, by using appropriate instrumental variables. Other measurement errors are considered in more specific ways:

- 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 could be considered to be measurement errors. Assuming that these differences are time-invariant, the corresponding measurement errors are taken into account by country-product constants.
- 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

³ See Cette and Lopez (2008) for the detailed presentation of this model.

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 account of the quality improvements in goods, especially ICT. Nevertheless, relative prices may also depend on country-specific determinants such as the exchange rate and import and export mark-up behaviour. The measurement error corresponding to these realities is captured by adding as explanatory variables the exchange rate and the average age of the equipment.

- Another source of errors stems from the fact that asset prices may not take proper account of the changes in asset performances, mainly ICT capital. Like the previous measurement errors, this type of error affects the measurement of factor cost and volume in a complex way. This measurement error is taken into consideration, at least partly, by adding the average age of the equipment to the list of explanatory variables.

The estimated factor demand equation is complemented 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). In order to take better account of the effect of the level of education on the demand for ICT capital, we use a quadratic specification for this variable. As regards market rigidities, we use the OECD indicator for employment protection legislation (EPL) for the labour market and the OECD indicator for regulation in energy, transport and communications (ETCR) for the product market.

The two indicators of market rigidities are interrelated. This is consistent with an already

large body of literature, which suggests that there is an interaction between the effects of regulations across the two markets.⁴ We tested different types of crossing. In the end, we selected the maximum function of EPL and ETCR.

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 in particular Aghion and Howitt, 2006, Aghion *et al.*, 2009). These two additional aspects are specified by introducing a threshold effect in ICT diffusion on the parameters corresponding to the impacts on factor demand of the level of education and market rigidities. The threshold used is an ICT capital coefficient of 4 per cent, but estimations made with other thresholds yield very similar results. With the actual data, the proportion of observations above this threshold of 4 per cent is 26.9 per cent over the entire 1981-2005 period, 65.5 per cent over the 1996-2005 period and 100 per cent in 2005.

The estimated model takes into consideration the different types of measurement errors and introduces the indicators of education and rigidities. In the model, the logarithm of the capital coefficient depends, for each factor and country, on: (i) the logarithm of the user cost of the factor relative to the price of all the other factors; (ii) the impact of total factor productivity (TFP); (iii) the error correction variables, i.e. the average age of the equipment for the relevant factor (except labour) and the logarithm of the exchange rate; (iv) the level of education of the working-age population (for ICT factors, the level of education squared) and the level of rigidities; (v) country-product constants; (vi) error terms assumed to be independently and identically distributed.

4 See in particular Amable and Gatti (2006); Koeniger and Vindigni (2003); Blanchard and Giavazzi (2003); Blanchard (2005); and Aghion *et al.* (2009).

It is assumed that the price elasticity of demand for each factor is identical in every country and, for non-ICT factors, time-invariant. As regards ICT, this elasticity is assumed to exhibit a simple quadratic pattern over time, identical in every country. This quadratic trend reflects the fact that ICT diffusion, linked to improved productivity, corresponds both to a widening of the 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 variability of the price elasticity of ICT demand has been documented by Oulton (2002).

TFP has three components: an annual component identical for all countries and factors; a trend specific to each country; and a cyclical component specific to each country linked to the capacity utilization rate.

What the Estimates Tell Us

Estimates were made using the instrumental variables method on panel data based on: (i) the five production factors: ICT, transport equipment, other equipment, structures and number of employees; (ii) the eleven countries for which the data comparability appeared sufficiently robust; (iii) over the 1981-2005 period which appears sufficiently robust for the different series.

The Role of Education and Rigidities

With respect to education, the greater a country's share of the population with higher education, the greater the ICT diffusion. This effect gradually declines as the level of educa-

tion rises (the coefficient on the quadratic component is negative). The impact of the level of education on ICT diffusion is greater when ICT diffusion is already important. Thus, the higher the level of ICT diffusion, the greater the need for skilled labour to facilitate ICT diffusion. This result is consistent but more comprehensive than that obtained by Aghion *et al.* (2009). 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.

With respect to market rigidities, ICT demand declines as rigidities increase. This impact is heightened when ICT diffusion is already high. This result is again consistent with that obtained by Aghion *et al.* (2009). Thus, the closer a country is to the technological frontier, the more the productivity improvements, partly driven by the use of ICT, require organizational flexibility in product and labour markets. Rigidities also have a negative impact on the demand for transport equipment but a positive impact on the demand for non-residential structures and, above the ICT diffusion threshold, on the demand for labour. This latter result is also consistent with that of Aghion *et al.* (2009), who show that rigidities have a negative effect on the productivity of the countries close to the technological frontier, unlike for those far from the frontier.

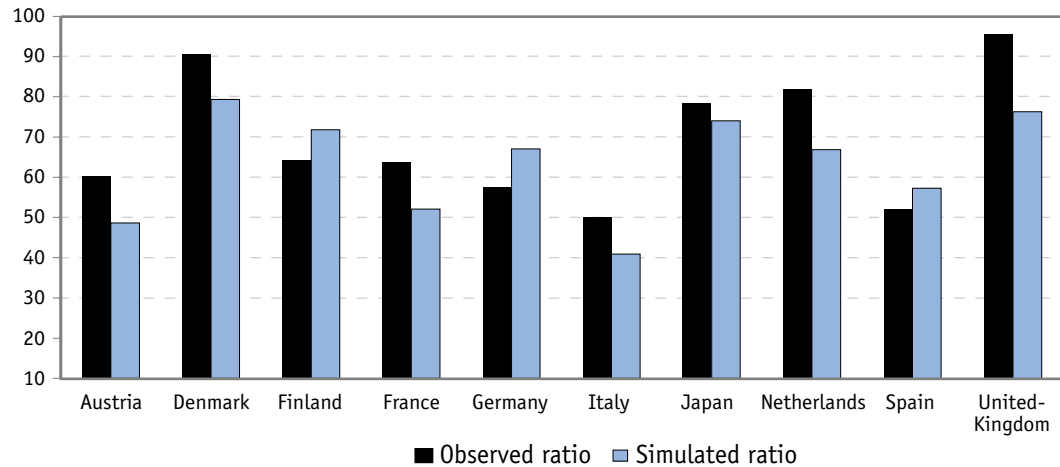
Evidence of ICT Diffusion Gaps

The estimated parameters for price elasticity, the impact of education and the impact of rigidities enable us to explain quite accurately the ICT diffusion gaps between the United States and the ten other countries in our sample (see Chart 7 for 2005).

Chart 7

ICT Diffusion in the Different Countries Relative to the United States, 2005

Ratio of the Domestic ICT Capital Coefficient to the US Coefficient (per cent)

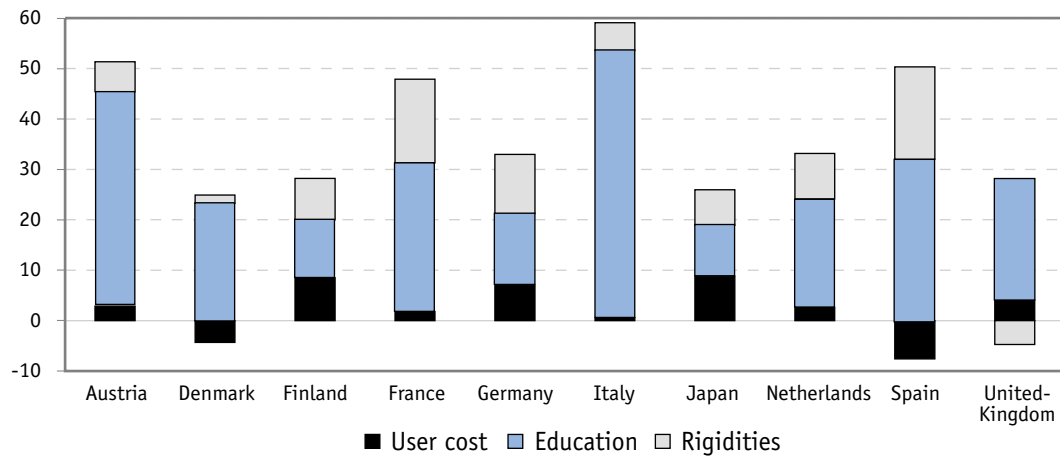


The ratios correspond to the relative level of ICT diffusion. The simulated ratios are calculated using only the estimated values based on the variables of the level of education, rigidities and user cost of ICT capital.

Chart 8

Factors Underlying the Simulated ICT Diffusion Gap vis-à-vis the United States, 2005

(points)



These contributions to the simulated ICT diffusion gap vis-à-vis the United States are calculated on the basis of estimates.

These estimates enable us to break down the simulated ICT diffusion gaps for each country vis-à-vis the United States into three contri-

butions: the effects of the differences in user costs of capital;⁵ the effects of education differences; and the effects of differences in mar-

⁵ The user cost of capital gaps can come from gaps in: (i) real interest rates; (ii) average ICT depreciation rates induced by a different structure in the three ICT components, the average life of computer equipment and software being significantly shorter than that of communication equipment.

ket rigidities. This breakdown for 2005 is shown in Chart 8. The contribution of differences in the user cost of capital is very small in all countries: less than 10 percentage points. The contribution of educational differences is the most important in all countries: from 10 points in Japan to 53 points in Italy. The contribution of rigidities varies considerably across countries: from —5 points in the United Kingdom — where market rigidities were lower than in the United States in 2005 — to 18 points in Spain, where they are relatively strong.

This breakdown of the different contributions to the ICT diffusion gap of different countries vis-à-vis the United States is, to our knowledge, relatively original in the context of the existing literature. It points out the areas where greater efforts are needed, in each country, to reduce the gap. For instance, in France, ICT diffusion is roughly 48 per cent lower than in the United States. More efforts are essentially needed in higher education (which contributes about 29 points to the gap) and, to a lesser albeit still significant extent, with respect to market rigidities (the contribution of which is about 17 points).

Conclusion

The results presented in this article give insight into the political economy of ICT diffusion. They provide a quantification of the expected effects on ICT diffusion, of an increase in the proportion of the working-age population with higher education and of a decrease in product and labour market rigidities. However, the robustness of these estimates, and accordingly their interpretations, should be strengthened by other empirical investigations, carried out using industry-level or firm-level data. Nevertheless, they extend and complete the estimates of previous analyses and seem intuitively plausible.

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Appendix

Data: Sources and Assumptions⁶

The base data come from the EU-KLEMS database of Groningen University, augmented by OECD data and data from other sources where needed. In this appendix, we present only details for variables that are based on assumptions specific to this empirical investigation. For all data expressed in real terms, the reference year is 2000. Because the constant price data from the EU-KLEMS database are at 1995 prices, they have been rebased to 2000 prices.

Investment price series are needed to calculate the volume of investment. These are calculated using US national accounts data, on the assumption that the gap relative to the GDP deflator, for every country and investment component, is the same as that in the United States, according to the method applied in Cette, Lopez and Noul (2004 and 2005).

For each of the seven components and 11 countries, the capital stock is calculated using constant price investment data derived from the perpetual inventory method by the relation: $K_t =$

$(1 - \delta) \cdot K_{t-1} + I_t$, where K_t is the volume of capital stock at the end of year t , I_t the volume of investment over the year t and δ the obsolescence rate specific to each asset but assumed to be time-invariant for each asset, and identical across countries.

The obsolescence rates are common and similar — for example — to those used by Cette, Mairesse and Kocoglu (2002), Cette, Lopez and Noul (2004 and 2005) and those used to build the EU-KLEMS database. They are 2.5 per cent per year for non-residential construction, 12.5 per cent for communication equipment, other machinery and equipment and others assets, 17.5 per cent for transport equipment and 30 per cent for computer equipment and software.

The user cost of equipment is obtained using an investor arbitrage model or, as well, an intertemporal profit maximisation model. For each of the four assets and each country, it is calculated on the basis of a common relation: $C = p_{-1} \cdot (i + \delta - \Delta \log(p))$, where p is the

⁶ See Cette and Lopez (2008) for a more detailed discussion of data sources.

investment price (whose calculation for every country and component is presented above), δ the obsolescence rate (the level of which for each product is presented above) and i the nominal interest rate. $\Delta \log n(p)$ is the variation of the natural logarithm of price p , and is an approximation of its growth rate. The nominal interest rate used, for every country, is the interest rate on long-term Treasury notes taken from the *OECD Economic Outlook*.

The level of education (EDUC) is represented by the share of the population between 25 and 64 with higher education (whether completed or not). The data come from the OECD and UNESCO Education databases compiled by Cohen and Sotro (2007). These data are decennial and are annualized for the purposes of the estimation by linear interpolation over a decade, which is probably not a strong hypothesis for a relatively stable variable.

The level of rigidities in the employment protection legislation (EPL) corresponds to the composite OECD indicator. For estimations, this indicator is divided by four in order to take on a value between zero and one. For more information see OECD (1999).

The indicator for product market regulation (ETCR) comes from the OECD 'International Regulation' database. It is obtained by aggregating four sub-indicators measuring entry barriers, public ownership, market structure (the market share of the biggest firm in each industry) and vertical integration. These indicators are built by taking account of the level of product market rigidities in seven non-manufacturing industries: gas, electricity, post, telecom, airlines, rail and road. For estimations, the ETCR indicator is divided by six in order to take on a value between zero and one. For more information see Conway and Nicoletti (2006).