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Productivity growth and technological change in Europe and the U.S.[1]

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Abstract: This paper presents an evaluation on the technological sources of labor productivity growth across European countries and the US economy for the period 1980-2004. Assets of capital are divided into those related to the information and communication technologies (ICT), and non-ICT assets. Technological progress is divided into neutral change and investment specific change. Previous exercises have aimed at ICT as a serious contributor to the upsurge of US productivity from 1995 on. Contribution to productivity growth from each type of technological progress for the US and EU-15 countries is computed using two different approaches: a growth accounting and a general equilibrium. The US and Denmark are the countries with the larger contribution from ICT-technological progress. Overall, we find that Europe is well behind the US in terms of the effects of ICT technological change.

JEL Classification: O4

Keywords: Productivity growth, Investment-specific technological change, Neutral technological change.

1 Introduction

Technological improvements in equipment have been impressive in the last two decades. Whereas there were some doubts at the beginning of the 1990s, now there is a wide consensus about the positive and significant effect of these improvements on growth and productivity. Neoclassical models predict that long-run productivity growth can only be driven by technological progress. Technology in turn can be differentiated into neutral progress and investment-specific progress. While the first of them is associated to the multifactor productivity, the second one is the amount of technology that can be acquired by using one unit of a particular asset. The amount of technology that can be transferred to productivity widely differs among the different capital assets. To this end, recent typologies and data bases recommend the use of disaggregated measures of capital, in order to disentangle the marginal effect of each investment asset.

In these new data bases (as for instance EU-KLEMS), special focus has been given to the distinction of capital assets among those related to the information and communication technologies (ICT), like computers, the internet, or software licenses, to non-ICT assets, like machinery, transport equipment or structures. As mentioned before, the quality improvements widely differ among these assets. ICT, which have spread more rapidly and bolstered productivity more effectively than earlier technologies, have had a definite impact on the economy. Numerous studies have pointed to the special role played by these technologies in the recovery of productivity growth since the mid-1990s in the United States and some European countries (see among others Colecchia and Schreyer, 2001; and Stiroh, 2002; Daveri, 2002; and Timmer, Ypma and van Ark, 2003, 2005).

This paper study the importance of the different sources of technological progress on labor productivity growth across the U.S. and some European countries during 1980-2004. We use the "Total Economy Growth Accounting" Data Base from the Groningen Growth & Development Center (GGDC), that contains information on the EU-15 and the U.S.[1] We use two different approaches to identify the *neutral progress* from the *investment-specific progress*: (*i*) the standard growth accounting decomposition and (*ii*) the calibration of a general equilibrium model. This refers to the controversy held by Solow and Jorgenson during the sixties regarding the best approach to measure the contribution of production factors to growth. This debate has been recently updated by the criticism of Greenwood, Hercowitz and Krusell (1997) to Hulten (1992), with extensions until today (see, for instance, Oulton, 2007, and Greenwood and Krusell, 2007).

As regards the *growth accounting approach*, we implement three different measures: the traditional one proposed by Solow (1956), and two other approaches that take into account the existence of investment-specific technological progress, one proposed by Jorgenson (1966) and the other proposed by Hulten (1992). Regarding the *general equilibrium approach*, we use an extension of the Greenwood, Hercowitz and Krusell (1997) model, developed in Martínez, Rodríguez and Torres (2008). We extend the Greenwood *et al.* (1997) model with investment-specific technological change in two directions. First, we consider six different types of capital assets, three of them corresponding to ICT (hardware, software and communications) and three non-ICT (constructions and structures, machinery and transport equipment). And second, we consider the existence of investment-specific technological change to all the capital assets.

We interpret this controversy as complement views of the same issue. In fact, the traditional growth accounting can be seen as a good approximation to the fluctuations of technical progress in the short-run whereas the general equilibrium approach fits better the determinants of productivity growth in the long-run.

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[1] For comparisons between the European Union and the US of productivity growth, see for instance, van Ark, Melka, Mulder, Timmer and Ypma (2002), van Ark, Inklaar and McGuckin (2003) van Ark (2005) and Timmer and van Ark (2005).

We find that neutral technological progress is the main force driving the productivity growth during the period. The contribution from non-ICT capital assets to productivity growth is negative for most of countries. ICT-technological progress contribution to productivity growth is very large in Belgium (0.56 percentage points), Denmark (0.55 percentage points) and the U.S. (0.59 percentage points), explaining around a third of total productivity growth. In the case of the US, we obtain that the contribution of only ICT-specific technological change is 35% for all the period. The lowest contributions correspond to Spain and Greece, were ICT-technological progress only contributes to total productivity growth 0.18 percentage points and 0.12 percentage points, respectively. Looking at the contribution from total investment-specific technological change, only Denmark, France, and the U.K. show similar figures to that of the U.S. economy.

The structure of the paper is as follows. Section 2 presents a growth model in which it is included six types of capital assets and the technological progress corresponding to each capital asset. Section 3 calculates the decomposition of productivity growth using the two alternative approaches. Finally, section 4 presents some conclusions.

2 The model

Following Greenwood *et al.* (1997) we use a neoclassical growth model in which two key elements are present: the existence of different types of capital and the presence of technological change specific to the production of capital. We use the model developed in Martínez *et al.* (2006) which it is an extension of the Greenwood *et al.* (1997) model, incorporating two new features. *First*, while Greenwood *et al.* (1997) disaggregate between structures and equipment capital assets, we distinguish among six different types of capital inputs. Our production function relates output with seven inputs: L is labor in hours worked; K_1 constructions and structures; K_2 transport equipment; K_3 machinery and other equipment; K_4 communication equipment; K_5 hardware; and K_6 is software. The first three types of capital are grouped into non-ICT capital inputs, whereas the remaining three ones are ICT inputs. *Second*, denote Q_i as the price of asset i in terms of the amount of which that can be purchased by one unit of output. This price reflects the current state of technology for producing each asset. Greenwood *et al.* (1997) consider that this price is constant for structures, but is allowed to vary for equipment assets. Note that, according to this definition, equipment embody both ICT and non ICT inputs.

In order to take into account the effect of taxation on capital accumulation we introduce the role of government. The government levies private consumption goods, capital income and labor income, to finance an exogenous sequence of lump-sum transfers, $\{T_t\}_{t=0}^{\infty}$. For simplicity, the government balances its budget in each period.

2.1 Households

The economy is inhabited by an infinitely lived, representative agent of household who has time-separable preferences in terms of consumption of final goods, $\{C_t\}_{t=0}^{\infty}$, and leisure, $\{O_t\}_{t=0}^{\infty}$. Preferences are represented by the following utility function:

$$\sum_{t=0}^{\infty} \beta^t \left[\phi \log C_t + (1-\phi) \log O_t\right], \tag{1}$$

where β is the discount factor and $\phi \in (0,1)$ is the participation of consumption on total income. Private consumption is denoted by C_t. Leisure is $O_t = N_t H - L_t$, where H is the number of effective hours in the year ($H = 96 \times 52 = 4992$), times population in the age of taking labor-leisure decisions (N_t), minus the aggregated number of hours worked a year ($L_t = N_t h_t$, with h_t representing annual hours worked per worker).

The budget constraint faced by the consumer says that consumption and investment cannot exceed the sum of labor and capital rental income net of taxes and lump-sum transfers:

$$(1+\tau_c) C_t + \sum_{i=1}^{6} I_{i,t} = (1-\tau_l) W_t L_t + (1-\tau_k) \sum_{i=1}^{6} R_{i,t} K_{i,t} + T_t, \tag{2}$$

where T_t is the transfer received by consumers from the government, W_t is the wage, $R_{i,t}$ is the rental price of asset type i, and τ^c, τ^l, τ^k, are the consumption tax, the labor income tax and the capital income tax, respectively.

The key point of the model is that capital holdings evolve according to:

$$\left\{K_{i,t+1} = (1-\delta_i) K_{i,t} + Q_{i,t} I_{i,t}\right\}_{i=1}^{6}, \tag{3}$$

where δ_i is the depreciation rate of asset i. Following Greenwood *et al.* (1997), $Q_{i,t}$ determines the amount of asset i than can be purchased by one unit of output, representing the current state of technology for producing capital i. In the standard neoclassical one-sector growth model $Q_{i,t} = 1$ for all t, that is, the amount of capital that can be purchased from one unit of final output is constant. Greenwood *et al.* (1997) consider two types of capital: equipment and structures, where structures can be produced from final output on a one-to-one basis but equipment are subject to investment-specific technological change. However, in our model $Q_{i,t}$ may increase or decrease over time depending on the type of capital we consider, representing technological change specific to the production of each capital. In fact, an increase in $Q_{i,t}$ lowers the average cost of producing investment goods in units of final good.

The problem faced by the consumer is to choose C_t, O_t, and I_t to maximize the utility (1):

$$\max_{(C_t,I_t,O_t)} \sum_{t=0}^{\infty} \beta^t \left[\phi \log C_t + (1-\phi) \log O_t\right], \tag{4}$$

with $O_t = N_t\overline{H} - L_t$, subject to the budget constraint (2) and the law of motion (3), given taxes (τ_c, τ_k, τ_l) and the initial conditions $\{K_{i0}\}_{i=1}^{6}$.

2.2 Firms

The problem of firms is to find optimal values for the utilization of labor and the different types of capital. The production of final output Y requires the services of labor L and six types of capital K_i, $i = 1, ...6$. The firm rents capital and employs labor in order to maximize profits at period t, taking factor prices as given. The technology is given by a constant return to scale Cobb-Douglas production function,

$$Y_t = A_t L_t^{\alpha_L} \prod_{i=1}^{6} K_{i,t}^{\alpha_i}, \tag{5}$$

where A_t is a measure of total-factor productivity and where $\{0 \leq \alpha_i \leq 1\}_{i=1}^{6}$, $\sum_{i=1}^{6} \alpha_i \leq 1$, and $\alpha_L = 1 - \sum_{i=1}^{6} \alpha_i$. Final output can be used for seven purposes: consumption or investment in six types of capital,

$$Y_t = C_t + \sum_{i=1}^{6} I_{i,t}. \tag{6}$$

Both output and investment are therefore measured in units of consumption.

2.3 Government

Finally, we consider the existence of a tax-levying government in order to take into account the effects of taxation on capital accumulation. The government taxes consumption and income from labor and capital. We assume that the government balances its budget period-by-period by returning revenues from distortionary taxes to the agents via lump-sum transfers T_t:

$$\tau^c C_t + \tau^l W_t L_t + \tau^k \sum_{i=1}^{6} R_{i,t} K_{i,t} = T_t. \tag{7}$$

2.4 Equilibrium

The first order conditions for the consumer are:

$$\begin{aligned} \phi C_t^{-1} &= \lambda_t \left(1+\tau_c\right), && (8) \\ \left(1-\phi\right) O_t^{-1} &= \lambda_t \left(1-\tau_l\right) W_t, && (9) \\ \beta \frac{Q_{i,t}}{Q_{i,t+1}} \left[\left(1-\tau_k\right) Q_{i,t+1} R_{i,t+1} + 1 - \delta_i\right] &= \frac{\lambda_t}{\lambda_{t+1}}, && (10) \end{aligned}$$

for each $i = 1, ...6$. λ_t is the Lagrange multiplier assigned to date's t restriction.

Combining (8) and (9) we obtain the condition that equates the marginal rate of substitution between consumption and leisure to the opportunity cost of one additional unit of leisure:

$$\frac{1-\phi}{\phi} \frac{C_t}{O_t} = \frac{1-\tau_l}{1+\tau_c} W_t. \tag{11}$$

Combining (10) and (8) gives

$$\frac{1}{\beta} \frac{C_{t+1}}{C_t} = \frac{Q_{i,t}}{Q_{i,t+1}} \left[\left(1-\tau_k\right) Q_{i,t+1} R_{i,t+1} + 1 - \delta_i\right], \tag{12}$$

for $i = 1, ...6$. Hence, the (inter-temporal) marginal rate of consumption equates the rates of return of the six investment assets.

The first order conditions for the firm profit maximization are given by

$$\left\{ R_{i,t} = \alpha_i \frac{Y_t}{K_{i,t}} \right\}_{i=1}^{6}, \tag{13}$$

and

$$W_t = \alpha_L \frac{Y_t}{L_t}, \tag{14}$$

that is, the firm hires capital and labor such that the marginal contribution of these factors must equate their competitive rental prices.

Additionally, the economy must satisfy the feasibility constraint:

$$C_t + \sum_{i=1}^{6} I_{i,t} = \sum_{i=1}^{6} R_{i,t} K_{i,t} + W_t L_t = Y_t. \tag{15}$$

First order conditions for the household (8), (9) and (10), together with the first order conditions of the firm (13) and (14), the budget constraint of the government (7), and the feasibility constraint of the economy (15), characterize a competitive equilibrium for the economy.

2.5 The balanced growth path

Next, we define the balanced growth path, in which the steady state growth path of the model is an equilibrium satisfying the above conditions and where all variables grow at a constant rate. The balanced growth path requires that hours per worker must be constant. Given the assumption of no unemployment, this implies that total hours worked grow by the population growth rate, which is assumed to be zero.

According to a balanced growth path, output, consumption and investment must all grow at the same rate, which is denoted by g. However, the different types of capital would grow at a different rate depending on the evolution of their relative prices. From the production function (5) the balanced growth path implies that:

$$g = g_A \prod_{i=1}^{6} g_i^{\alpha_i}, \tag{16}$$

where g_A is the steady state exogenous growth of A_t, Let us denote g_i as the steady state growth rate of capital i. Then, from the law of motion (3) we have that the growth of each capital input is given by:

$$\{g_i = \eta_i g\}_{i=1}^{6}, \tag{17}$$

with η_i being the exogenous growth rate of $Q_{i,t}$. Therefore, the long run growth rate of output can be accounted for by neutral technological progress and by increases in the capital stock. In addition, expression (17) says that the capital stock growth also depends on technological progress in the process producing the different capital goods. Therefore, it is possible to express output growth as a function of the exogenous growth rates of production technologies as:

$$g = g_A^{1/\alpha_L} \prod_{i=1}^{6} \eta_i^{\alpha_i/\alpha_L}. \tag{18}$$

Expression (18) implies that output growth can be decomposed as the weighted sum of the neutral technological progress growth and embedded technological progress, as given by $\{\eta_i\}_{i=1}^{6}$. Growth rate of each capital asset can be different, depending on the relative price of the new capital in terms of output.

Denote as $\left\{\{\rho_i, s_i\}_{i=1}^{6}, c, v\right\}$ the following steady state ratios

$$\begin{aligned} \rho_i &\equiv \left(Q_i \frac{Y}{K_i}\right)_{ss} > 0, & (19) \\ c &\equiv \left(\frac{C}{Y}\right)_{ss} \in (0,1), & (20) \\ s_i &= (1-c)\,\omega_i \equiv \left(\frac{I_i}{Y}\right)_{ss} \in (0,1), & (21) \\ \psi &\equiv \left(\frac{L}{NH}\right)_{ss} = \left(\frac{h}{4992}\right)_{ss} \in (0,1), & (22) \end{aligned}$$

where the subscript ss denotes its steady-state reference. Notice that s_i in (21) refers to the investment rate of asset i, while ω_i is its portfolio weight, such that $\sum_{i=1}^{6} \omega_i = 1$. The total investment-saving rate is given by $(1-c)$.

The balanced growth path can finally be characterized by the following set of equations:

$$\begin{aligned} &\left\{g\beta^{-1} = \eta_i^{-1}\left[(1-\tau_k)\,\alpha_i\rho_i + 1 - \delta_i\right]\right\}_{i=1}^{6}, & (23) \\ &\left\{\eta_i g = \rho_i s_i + 1 - \delta_i\right\}_{i=1}^{6}, & (24) \end{aligned}$$

and

$$\begin{aligned} 1 &= \alpha_L + \sum_{i=1}^{6} \alpha_i. & (25) \\ c &= \alpha_L \frac{\phi}{1-\phi} \frac{1-\tau_l}{1+\tau_c}\left(\psi^{-1} - 1\right), & (26) \end{aligned}$$

For calibrating the model, we need an additional equation that fixes the after-tax return rate of capital to some value. The right hand side of expression (23) is the real (after-tax) rate of return on asset i, that in equilibrium should equal the intertemporal marginal rate of substitution of consumption, as given by g/β. Expressions (23), as well as its corresponding first order condition (12), implies an arbitrage condition that imposes that the return of the different assets must be equal to g/β. Following Greenwood *et al.* (1997, 2000) we will use an after tax rate of return of 7% rate for all countries,

$$g\beta^{-1} = 1.07. \tag{27}$$

In similar calibrations, Pakko (2005) uses a rate of 6% for the U.S. and Bakhshi and Larsen (2005) use a rate of return of 5.3% for the U.K. economy. Expression (27) is also a non arbitrage condition under international free capital mobility.

2.6 Data and Parameters

Expressions from (23) to (27) define a system of fifteen equations. As usual, we will estimate part of the parameters in the model in order to have a complete system of equations. First, using a data set, the following set of parameters will be estimated

$$\left\{g, \psi, \alpha_L, \tau^c, \tau^k, \tau^l, \{\eta_i, \delta_i, \omega_i\}_{i=1}^{6}\right\}. \tag{28}$$

Second, using the nonlinear system of fifteen equations from (23) to (27), we will solve for the following fifteen unknowns

$$\left\{\{\alpha_i, \rho_i\}_{i=1}^{6}, c, \beta, \phi\right\}. \tag{29}$$

From the Groningen Growth & Development Center (GGDC) "Total Economy Growth Accounting" Data Base[2] we retrieve data on GDP, (nominal and real) investment, cost shares, capital assets and labor in hours worked from 1980 to 2004 for the fifteen countries of the EU-15 and for the US economy. Luxemburg is excluded in our analysis. Capital and investment series are disaggregated into 6 assets. Non-ICT series have been grouped into three assets: machinery and other equipment, transport equipment and constructions and structures; whereas ICT series have been aggregated into three assets: hardware, communication equipment and software. This data base suffices to calculate most of the parameters in (28).

In order to calculate the tax rates, not provided in the GGDC data base, a complementary set of data has been used. In this paper we use effective

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[2] See Timmer, Ypma and van Ark (2003): `http://www.ggdc.net/dseries/totecon.html`

average tax rates, that we borrow from Boscá, García and Taguas (2005), following the methodology proposed by Mendoza, Razin and Tesar (1994) to estimate effective average tax rates for OECD countries for the period 1964-2001. This set provides realistic measures of tax rates, useful to take into account the distortionary effects of taxes, specially on capital accumulation. To compute tax rates averages, we select the period 1980-2001.

The estimated values of (28) are reported in table 1, divided into four panels. Productivity growth is calculated as $g = T^{-1} \sum_t y_t / y_{t-1}$, where y_t is the GDP per hour worked.

As regards the *relative price changes* $\{\eta_i\}_{i=1}^{6}$, prices Q_{it} represent the amount of asset i that can be purchased by one unit of output at time t. We consider the following series as proxy for Q_{it}

$$Q_{it} = \frac{P_t}{q_{it}}, \tag{30}$$

where P_t is the GDP deflator price (taken from IMF-IFS), and q_{it} is the implicit deflator of asset i is calculated as the ratio of nominal to real investment in asset i. The second panel of table 1 reports the average price changes of the six assets through 1980-2004, $\eta_i = T^{-1} \sum_t Q_{i,t} / Q_{i,t-1}$. Price variations η_i are similar across countries. For transport equipment, however, there are five countries whose price evolution exhibits a differentiated pattern (Spain, Ireland, Italy, Portugal and Sweden): the change in this price exceeds 1 per cent. The change in the price of non ICT equipment is almost 0 per cent on average. Importantly, the amount of hardware equipment that can be purchased by one unit of output has increased by 16.25% per year from 1980 to 2004. This increase is of about 3.5 per cent per year for both communication equipment and software. Implicit technological change, as measured by the evolution of the Q_i, is therefore stronger in the ICT equipment.

For the rates of depreciation, we take the estimation given in van Ark *et al.* (2003, p. 23-24) as a central moment, and adjust it using the GGDC data base series on the stock of capital i and gross formation of fixed capital. These estimates are stable across years and very similar across countries, as shown in table 3. Structures depreciate by 2.8 per cent a year. This rate contrasts with that assumed by Greenwood *et al.* (1997) of 5.6%. The rates of depreciation of ICT equipment are high, specially the software, 42%: a software license fully depreciates in about two years. This time length is four years for hardware equipment.

The last panel of table 1 finally reports the investment weights averaged over 1980-2004. Structures receive the highest weight, going from a minimum of 39 per cent in Belgium up to a 57 per cent in Spain and Belgium. The assets of the new economy have had a minor relevance on the composition of this physical portfolio.

[**Table 1 here**]

3 Technological sources of productivity growth

In this section we estimate the sources of productivity growth using two methodologies adopted in the literature: the growth accounting view and the general equilibrium view. In turn, within the first one, we consider three alternative approaches: the standard growth accounting decomposition, due to Solow (1956), and two decompositions that take into account the quality improvement in the capital assets, one proposed by Jorgenson (1966) and the other by Hulten (1992). The general equilibrium view uses the model developed in Section 2 of this paper, which is an extension of the model used by Greenwood, Hercowitz and Krusell (1997). We follow the terminology of Cummins and Violante (2002) which define the first approach as the "traditional growth accounting" and the second as "equilibrium growth accounting".

The debate about the correct approach to quantify the contribution of technological progress for growth was initiated by Solow (1960) versus Jorgenson (1966). Both authors introduce the concept of "embodied" technological change but using different frameworks. The difference is that Solow (1960) assumes "embodied" technological change but only in the production of investment goods, whereas Jorgenson (1966) assumes that it also affects output. A review of the Solow-Jorgenson controversy can be found in Hercowitz (1998).

The recent revival of the Solow-Jorgenson controversy had been hosted by Hulten (1992) versus Greenwood *et al.* (1997). This debate has its continuity in Oulton (2007) versus Greenwood and Krusell (2007). Greenwood and Krusell (2007) show that traditional growth accounting and equilibrium growth accounting report very different findings concerning the empirical importance of investment-specific technological progress for the growth process, being the second approach preferred to the first one. The reason is that whereas the use of a general equilibrium model can isolate the technological progress from other sources of output growth as capital accumulation, the traditional growth accounting cannot. Output growth derives from both technological progress and capital accumulation. Traditional growth accounting quantify the importance of both components in growth as independent one from the other. The problem is that capital accumulation is affected by technological progress. So, in reality traditional growth accounting is not able to quantify the importance of technological change given that it is not possible to know the proportion of capital accumulation due to technological progress. Only a fully articulated general equilibrium model can do that. As pointed out by Hercowitz (1998) if technological change is "disembodied", it affects output independently on capital accumulation. On the opposite site, Oulton (2007) claims that the general equilibrium growth model with embodied technological change is a particular case of the Jorgenson's approach, where the concept of investment-specific technological change is closely related to the concept of Total Factor Productivity, where TFP growths at different rates in a two-sector model. In the same line that Greenwood and Krusell (2007) arguments, Cummins and Violante (2002) pointed out that the main disadvantage of traditional or statistical growth accounting is that is does not isolate the underlaying sources of capital accumulation. By contrast, a general equilibrium model can solve the optimal investment behavior as a function of the underlying sources of growth.

3.1 Three growth accounting approaches

Traditionally, the most standard method to study the determinants of productivity growth has been the growth accounting approach, which obtains the contribution of (neutral) technical progress as a residual after controlling for the growth rates and output shares of production factors (Solow, 1957). This simple methodology, widely used, is flexible enough to take account not only the contribution of the traditional inputs but also for distinguishing between neutral and investment-specific technological change. In this subsection, we report the results obtained from carrying out three versions of the traditional growth accounting.

The first approach is the traditional simple growth decomposition, initially due to Solow (1956), does not control for the changes in the prices of capital assets, that is, for the embedded technological progress, and assumed constant returns to scale:

$$\ln(g) = \underbrace{\gamma_{A,S}}_{\text{Neutral}} + \sum_{i=1}^{6} \underbrace{v_i \left(\gamma_{K_i} - \gamma_L \right)}_{\text{Accumulation}} \tag{31}$$

where γ_χ is the growth rate of χ and $\gamma_{A,S}$ is the change in neutral technological progress (total factor productivity, TFP, or Solow residual). In these exercises, as a measure of productivity growth we use that reported in table 2 as $\gamma_Y - \gamma_L = \ln(g)$. Productivity growth is decomposed in two different elements: total factor productivity growth and the contribution from the growth in the capital/labor ratio. v_i is the elasticity of output with respect to capital asset i, that can be measured as the ratio of the marginal product to average product. This ratio can be computed as the share of compensation of asset i over total compensation, including the labor costs. Note that the elasticity of substitution between the factors employed to produce output is not assumed to be one. Instead, the Cobb-Douglas production function of previous section does assume it.

Particularly, as regards the cost shares, the GGDC data base follows the recommendations of OECD (2001) for constructing the series of capital assets, which are based on the concept of *capital services*. The idea is to capture the productive services embedded into the stock of capital. This concept of productive capital can be seen as a volume index of capital services. The expression driving the concept of capital services for the asset i is as follows:

$$VCS_{it} = \mu_{it} K_{it}, \tag{32}$$

where μ_{it} is, in turn, the nominal usage cost of capital. Call RE_t the remuneration of employees. Then, cost shares are given by the following expressions:

$$\begin{aligned} v_{L,t} &= \frac{RE_t}{RE_t + \sum_{i=1}^{6} VCS_{it}}, & (33) \\ v_{i,t} &= \frac{VCS_{it}}{RE_t + \sum_{i=1}^{6} VCS_{it}}. & (34) \end{aligned}$$

These cost shares are therefor used in growth accounting decompositions for weighting the contribution of the different inputs to output growth and productivity growth, as guided by theoretical foundations. For calibration purposes, we will use average values of the labor cost share as an estimator of $v_i = T^{-1} \sum_t v_{i,t}$. Note that our measure of the labor cost share is equivalent to $\alpha_L = T^{-1} \sum_t v_{L,t}$. However, while the cost ratios v_i are computed using the series of inputs compensation, the values of technological parameters $\{\alpha_i\}_{i=1}^{6}$ are calibrated using the balanced growth equilibrium expressions from (23) to (27). Also note that

$$\alpha_L = 1 - \sum_{i=1}^{6} v_i = 1 - \sum_{i=1}^{6} \alpha_i.$$

The other two approaches take into account the existence of investment-specific technological change. The second one is due to Jorgenson (1966), where productivity growth is decomposed as:

$$\ln(g) = \underbrace{\gamma_{A,J}}_{\text{Neutral}} + \sum_{i=1}^{6} \underbrace{v_i\left(\gamma_{K_i} - \gamma_L\right)}_{\text{Accumulation}} + \sum_{i=1}^{6} \underbrace{z_i \ln(\eta_i)}_{\text{Implicit}}, \tag{35}$$

where $\gamma_{A,J}$ is the change in neutral technological progress as defined by Jorgenson (1966) and z_i is the ratio of nominal investment in asset i to nominal GDP. The last term of the above expression can be interpreted as a measure of implicit technical change. In our case, we tale the values of η_i reported in table 1.

The third decomposition approach is due to Hulten (1992):

$$\ln(g) = \underbrace{\gamma_{A,H}}_{\text{Neutral}} + \sum_{i=1}^{6} \underbrace{v_i\left(\gamma_{K_i} - \gamma_L\right)}_{\text{Accumulation}} + \sum_{i=1}^{6} \underbrace{v_i \ln(\eta_i)}_{\text{Implicit}} \tag{36}$$

where $\gamma_{A,H}$ is the change in neutral technological progress as defined by Hulten (1992). As in the Jorgenson's decomposition, it is considered a measure of implicit technical change. The last two terms of (36) and (35) can be interpreted as measures of implicit technological change. Note that the difference between both of them lies in using the output share of capital assets, v_i, or the investment ratio, s_i, as a way of weighting the growth of capital input prices Q_i. Note finally that the central term in expressions, that collects the effect of capital-to-labor ratio accumulation, is common in the three expressions (31), (35) and (36), and renders an identical value.

The contributions of both types of technical progress and capital deepening to the productivity growth in the EU-15 and U.S. are reported in Table 2 according to these three approaches. The first panel in this table reports observed productivity, $\ln(g)$, and the three measures of total factor productivity, the Solow-traditional approach $\gamma_{A,S}$, the extended Jorgenson's approach $\gamma_{A,J}$, and that proposed by Hulten, $\gamma_{A,H}$. The second panel reports calculation of the effect of capital deepening on productivity, a measure that is common to the three approaches. Next , the following two panels report the contribution on implicit technological change to productivity growth according to Jorgenson's and Hulten's views. Finally, in the last panel of the table, we calculate the weights of the different contributions to productivity growth. For the sake of brevity, we present the contribution of the capital inputs aggregated into three assets: constructions, non-ICT equipment and ICT equipment.

A major result which can be seen is that the contribution of technical progress is quite sensitive to the approach followed. Obviously, the impact of neutral change is higher under the Solow's (1956) method as long as total factor productivity is computed as a residual that neglects the effects from the implicit technological progress[3]. Comparing the approach of Jorgenson to that of Hulten, considering the prices of capital inputs, neutral technical change is always higher under Jorgenson's view, where the investment ratio is used as weighting factor of capital assets prices. This is quite reasonable as long as the Jorgenson's approach only recognizes the existence of embedded technological progress in the new capital assets through investment, while the latter considers the investment-specific technical change through the output share of capital inputs over final output.

The growth of neutral technical change is distributed across countries without following a well-defined pattern with respect to the intensity in the use of ICT. Regardless the differences coming from the approach, it seems to be clear that the relative contribution of neutral technical change does not depend on whether the country is ICT-intensive user or not. Relatively similar countries in terms of ICT development such as the UK and the US show significant differences by comparing the effects of neutral technological progress on productivity growth using the two approaches which control for the prices of capital assets. Indeed, the percentage of productivity growth explained by neutral change is 10 points higher (taking Jorgenson's view) and over 15 points (on the basis of Hulten's approach) in the UK than in the US. By contrast, quite different economies such as Sweden and Spain have a similar effect of neutral technical change on productivity growth (in any case less different than the comparison between the UK and the US), both measured according to the traditional approach by Solow and the more elaborated contribution of Hulten.

The differences between countries with heterogenous levels of ICT penetration rather come from the comparison between subperiods. Our results (not reported here but available upon request) show how, in general, the countries with a higher development of the "New Economy" (the US, Sweden, the UK and Finland) usually experienced a poor contribution of neutral technological growth to the dynamics of productivity at the beginning of the sample, specially when they are compared to the economies where the new technologies are not widely extended (Spain, Italy, Portugal and, in a sense, the Netherlands). Obviously, many factors could be behind this fact but it

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[3] Belgium and Finland are two exceptions due to their particular investment ratios and output shares and their dynamics of capital assets accumulations as well.

is reasonable to think that the introduction of ICT uses to generate adjustment and transitional cost (Samaniego, 2006). Indeed, the magnitude of the technological revolution related to ICT is huge enough to suffer organizational costs at level plant. This issue does not matter when the use of ICT is quite smaller. As time goes by, these negative effects of ICT on efficiency are assimilated and the new equipment begin to develop their productive potential. That may be one of the reason why ICT-intensive countries experience a significant contribution of neutral technical change to productivity growth over the last years of the sample (1995-2004).

[**Table 2 here**]

3.2 The equilibrium growth accounting approach

Next, the different sources of long-run productivity growth is calibrated using the general equilibrium approach. The contribution to growth from each production factor technological progress and the contribution to growth from neutral technological change have been calculated following Greenwood, Hercowitz and Krusell (1997) approach. In order to compare the approaches expressed in (31), (35) and (36), we use a log-linear version of expression (18)

$$\ln(g_{GE}) = \underbrace{\frac{\ln(g_A)}{\alpha_L}}_{\text{Neutral}} + \sum_{i=1}^{6} \underbrace{\frac{\alpha_i}{\alpha_L}\ln(\eta_i)}_{\text{Implicit}}, \tag{37}$$

with

$$\ln(g_A) = \ln(g) - \sum_{i=1}^{6} \alpha_i \left(\gamma_{K_i} - \gamma_L\right).$$

where $\ln(g_{GE})$ is the productivity growth rate calibrated by the model that needs not coincide with the observed rate $\ln(g)$. Therefore, $\ln(g_A)$ is now the growth rate of total factor productivity, which is proportional to the neutral change by α_L, the elasticity of output with respect to labor.

Table 4 summarizes the results. The first panel of it, presents observed and calibrated productivity as well as the neutral technological change. The second panel reports the technological change implicit in the six capital assets under consideration. The following panel calculates how much the neutral change and the implicit change account to explain the productivity growth. In the following and subsequent panels, we report the calibration of some relevant parameters (β, $1-c$, and $\{\alpha_i\}_{i=1}^{6}$). In view of this table, we remark the following results. The contribution of neutral technological progress dominates that of the implicit technological progress. The lowest contribution of neutral technological change corresponds to Italy (48% of total growth). This contribution is 65% in the U.S. This result contrasts with that of obtained by Greenwood *et al.* (1997) where the neutral change accounts for a 42%, thereby dominated by the implicit change, and a 58% of productivity growth can be attributed to implicit technological change during the period 1954-1990. However, our exercise should be compared with caution with the one by Greenwood *et al.* (1997), as the sample period is different, and the disaggregation of capital is also different[4]. For the rest of countries, contribution from neutral technological change appears very large (above 70%). Therefore, for most of the countries, we find that neutral technological progress explain a very large fraction of productivity growth during this subperiod.

Average productivity growth during the period 1980-2004 ranges from the 4.22% of Ireland to the 1.26% of the Netherlands. However, most of countries show an average productivity growth during the period of around 2%. Our calibrated growth rates are slightly different, given that we calibrated the balanced growth path for each country, which is unlikely to be the same than the actual one. Calibrated average productivity growth varies from 4.84% of Ireland, to the 0.92% of Greece. Differences between the productivity growth from the data and the steady state approximation are negligible (the highest discrepancy is for Ireland, where observed and calibrated productivity only differ by 0.62%).

During the period 1980-2004 no important differences are observed between the behavior of the US economy versus the European economies in terms of labor productivity growth. The US average productivity growth were 1.83% where the average of productivity growth in Europe was 2.12%. The data evince, however, that some European countries as the Netherlands, Italy and Spain, have a relatively low productivity growth from the mid of the nineties on.

ICT-technological progress contribution to productivity growth is very large in Belgium (0.56 percentage points), Denmark (0.55 percentage points) and the U.S. (0.59 percentage points), explaining around a third of total productivity growth. In the case of the US, we obtain that the contribution of only ICT-specific technological change is 28% of total labor productivity growth for all the period. The lowest contribution from the ICT corresponds

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[4] Although, Martínez, Rodríguez and Torres (2008b) show that the aggregation in capital assets do not seem a significant issue by comparing the results of Greenwood, Hercowitz and Krusel (1997) with ours.

to Ireland, where it only accounts for a fraction of 6% of productivity growth (6% = 0.29/4.84). Also Greece, Spain and France show relative low contribution from ICT (0.12%, 0.18% and 0.24% respectively). Contribution from ICT-specific technological change in UK is around 32% of total labor productivity growth. Bakhshi and Larsen (2005) in a similar analysis for the UK for the period 1976-1998 obtained that ICT-specific technological was around 20-30% of total labor productivity growth.

The main difference in our results with respect to previous literature relays on the contribution of non-ICT technological change to productivity growth. It is important to note that in our specification of non-ICT capital it is included the structures. By assumption, the contribution from non-ICT technological change to productivity growth is zero in previous work (see Greenwood *et al.* (1997), Bakhshi and Larsen (2005), among others). However, as Fisher (2003) shows, the relative price of nonresidential structures changes through time. Therefore, implicit technological change associated to structures is included in total implicit technological change from non-ICT capital. As a results, contribution to growth for non-ICT specific technological change is negative for Austria, Belgium, Finland, Germany, Ireland, the Netherlands and Sweden.

The largest contributions from investment-specific technological change correspond to the U.K., the U.S. and Denmark, 0.80%, 0.73%, 0.61%, respectively. For the remaining countries, contributions fall between the 0.08 percentage points of Finland to the 0.58 percentage points of Italy.

How different are these results in comparison with those corresponding to the traditional growth accounting approaches? Can a reasonable explanation be drawn regarding these discrepancies? Certainly, a major difference arises when the two approaches are compared: both types of technical progress have higher contributions to productivity growth with the general equilibrium approach than under the standard growth accounting exercises. The reason of this is related to the different dimensions of economic growth on which both approaches focus. Indeed, the traditional growth accounting methods can be interpreted as a good approximation for explaining the short-term fluctuations of technical progress and output. In fact, they consider capital deepening as one of the forces driving the productivity growth. In the case of the general equilibrium approach, the analysis pays attention upon the long-term view, with the economy placed on its balanced growth path. In the steady-state, the only reason for capital accumulation is the presence of (neutral or embedded) technical progress. This is the only condition for increasing the marginal productivity of capital endlessly. Consequently, under a long-term perspective, only controlling for the growth of technical change is enough for having a complete description of the sources of productivity growth.

[**Table 3 here**]

4 Concluding remarks

The recent experiences of US and some European countries show that ICT investment encourages economic growth and labor productivity. However, the European Union as a whole are considerably lagged with respect to the US economy in the use of ICT at all economic levels. Since the early eighties, US economy has doubled European investment in ICT. As a way to fill this gap, Lisbon Strategy and the initiative *i2010* collected a number of policy recommendations in order to make significant advances on this issue. Additionally, world-wide recognized experts like Prof. Dale Jorgenson have claimed that the impact of ICT is sensitive to existing degree of liberalization in the market for factors, goods and services (see El País June 4th 2006). This is a remarkable difference between the US and the EU economy in terms of productivity. Therefore, the use of new technologies should be viewed as an instrument for reversing productivity slowdown but properly combined with other policy tools concerning the liberalization of markets.

This paper investigates the importance of different sources of technological progress in explaining productivity growth in Europe and the US. Two different approaches had been used to quantify the contribution of technological change to productivity growth: a traditional growth accounting and a general equilibrium method. Whereas the first approach is a good approximation to the fluctuation of technological progress in the short-run, the second approach can isolate the underlying sources for capital accumulation and it is a better approximation for the determinants of productivity growth in the long-run. The main conclusion that we obtain is that the EU member countries fell well behind the US with respect to the effects from ICT technological change. Only Denmark and in some extend, also Belgium, show important contributions to productivity growth from ICT technological progress. Therefore, it seems that the goal of the so-called Lisbon Strategy, i.e., the European Union to become by 2010 the most dynamic and competitive knowledge-based economy in the world, is far away from reality.

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Table 1: Parameters, period 1980-2004

	Austria	**Belgium**	**Denmark**	**Finland**	**France**	**Germany**	**Greece**	**Ireland**	**Italy**	**Netherl.**	**Portugal**	**Spain**	**Sweden**	**U.K.**	**U.S.A.**
Productivity growth, g	1.019	1.020	1.022	1.028	1.023	1.024	1.012	1.043	1.015	1.014	1.021	1.018	1.020	1.024	1.019
Fraction of hours worked, v	0.327	0.331	0.307	0.337	0.308	0.308	0.388	0.366	0.330	0.283	0.365	0.370	0.313	0.338	0.370
Labor income share, α_L	0.651	0.709	0.676	0.684	0.671	0.697	0.766	0.644	0.661	0.698	0.698	0.734	0.706	0.688	0.706
Consumption tax rate, τ_C	0.151	0.127	0.198	0.177	0.139	0.113	0.133	0.173	0.107	0.135	0.137	0.096	0.143	0.126	0.047
Capital income tax rate, τ_K	0.206	0.276	0.435	0.299	0.270	0.242	0.100	0.116	0.281	0.236	0.184	0.190	0.363	0.322	0.330
Labor income tax rate, τ_L	0.426	0.443	0.379	0.418	0.428	0.359	0.348	0.323	0.389	0.447	0.243	0.321	0.513	0.244	0.230
Price changes across $\{\eta_i\}$															
Costructions, η_1	1.004	1.009	1.002	0.997	1.006	1.008	1.003	0.993	0.997	1.002	1.004	0.999	0.998	1.016	1.001
Transport equipment, η_2	1.001	1.006	0.992	1.001	1.013	0.995	1.011	1.014	1.005	1.006	1.017	1.013	1.015	1.004	1.008
Machinery equipment, η_3	0.992	0.968	1.005	0.985	1.016	0.986	1.011	1.004	1.017	0.983	0.995	1.006	0.999	1.003	1.009
Communication equip., η_4	1.035	1.034	1.037	1.030	1.044	1.034	1.030	1.027	1.047	1.035	1.029	1.036	1.032	1.033	1.038
Hardware, η_5	1.163	1.162	1.165	1.158	1.173	1.162	1.157	1.150	1.177	1.164	1.156	1.164	1.160	1.160	1.167
Software, η_6	1.041	1.040	1.037	1.036	1.040	1.040	1.036	1.030	1.033	1.042	1.034	1.035	1.038	1.039	1.044
Depreciation rates $\{\delta_i\}$															
Costructions, δ_1	0.027	0.028	0.028	0.028	0.028	0.028	0.027	0.027	0.028	0.028	0.026	0.027	0.028	0.027	0.028
Transport equipment, δ_2	0.188	0.188	0.188	0.191	0.186	0.190	0.182	0.182	0.187	0.187	0.185	0.187	0.184	0.189	0.188
Machinery equipment, δ_3	0.132	0.132	0.130	0.133	0.130	0.133	0.129	0.132	0.130	0.132	0.132	0.130	0.132	0.132	0.130
Communication equip., δ_4	0.111	0.106	0.111	0.091	0.109	0.113	0.106	0.094	0.108	0.112	0.104	0.106	0.111	0.107	0.109
Hardware, δ_5	0.241	0.243	0.243	0.256	0.237	0.246	0.220	0.215	0.238	0.240	0.251	0.241	0.243	0.233	0.242
Software, δ_6	0.408	0.426	0.418	0.431	0.422	0.426	0.394	0.429	0.420	0.427	0.433	0.420	0.418	0.407	0.419
Investment weights $\{\omega_i\}$															
Costructions, ω_1	0.446	0.395	0.423	0.442	0.504	0.418	0.541	0.439	0.364	0.461	0.385	0.577	0.382	0.381	0.361
Transport equipment, ω_2	0.120	0.145	0.130	0.094	0.110	0.126	0.144	0.218	0.133	0.152	0.134	0.102	0.075	0.118	0.111
Machinery equipment, ω_3	0.316	0.281	0.278	0.294	0.296	0.318	0.223	0.264	0.363	0.253	0.359	0.221	0.347	0.341	0.295
Communication equip., ω_4	0.049	0.035	0.019	0.046	0.032	0.045	0.048	0.020	0.062	0.013	0.038	0.030	0.039	0.031	0.071
Hardware, ω_5	0.046	0.103	0.083	0.035	0.024	0.053	0.031	0.036	0.041	0.061	0.071	0.035	0.075	0.068	0.086
Software, ω_6	0.024	0.041	0.066	0.089	0.034	0.041	0.013	0.023	0.037	0.060	0.012	0.034	0.082	0.062	0.076

Table 2: Growth Accounting Decompositions

	Austria	**Belgium**	**Denmark**	**Finland**	**France**	**Germany**	**Greece**	**Ireland**	**Italy**	**Nether.**	**Portugal**	**Spain**	**Sweden**	**U.K.**	**U.S.A.**
Productivity, *ln(g)* (a)	1.88%	2.00%	2.16%	2.72%	2.27%	2.37%	1.15%	4.23%	1.44%	1.36%	2.08%	1.73%	1.97%	2.35%	1.83%
Total Factor Productivity															
Solow ($\gamma_{A,S}$)	0.73%	0.97%	0.76%	1.85%	0.91%	1.37%	0.49%	3.04%	0.37%	0.73%	1.15%	0.73%	0.96%	1.27%	0.88%
Hulten ($\gamma_{A,H}$)	0.44%	0.54%	0.26%	1.80%	0.45%	1.06%	0.28%	2.97%	-0.01%	0.48%	0.90%	0.48%	0.62%	0.75%	0.27%
Jorgenson ($\gamma_{A,J}$)	0.58%	0.77%	0.49%	1.79%	0.67%	1.24%	0.31%	2.96%	0.12%	0.58%	0.93%	0.55%	0.74%	1.00%	0.54%
Capital contribution (b = b1+b2+b3)	1.15%	1.03%	1.39%	0.87%	1.36%	1.00%	0.66%	1.18%	1.07%	0.63%	0.93%	1.00%	1.00%	1.07%	0.95%
Constructions (b1)	0.08%	-0.02%	0.11%	-0.08%	0.30%	0.05%	0.11%	0.01%	0.23%	-0.04%	-0.14%	0.10%	0.06%	0.09%	0.06%
Non-ICT (b2)	0.65%	0.34%	0.58%	0.50%	0.75%	0.49%	0.35%	0.90%	0.45%	0.25%	0.77%	0.59%	0.34%	0.45%	0.17%
ICT (b3)	0.43%	0.71%	0.70%	0.45%	0.31%	0.46%	0.20%	0.27%	0.39%	0.42%	0.30%	0.30%	0.60%	0.53%	0.71%
Implicit change-Hulten (c = c1+c2+c3)	0.29%	0.43%	0.51%	0.05%	0.47%	0.32%	0.21%	0.08%	0.38%	0.24%	0.25%	0.25%	0.34%	0.52%	0.61%
Constructions (c1)	-0.08%	-0.23%	0.03%	-0.14%	0.12%	-0.12%	0.04%	0.02%	0.17%	-0.11%	-0.08%	0.03%	-0.02%	0.00%	0.07%
Non-ICT (c2)	0.08%	0.14%	0.00%	-0.05%	0.16%	0.10%	0.07%	-0.09%	-0.04%	0.05%	0.10%	0.02%	-0.01%	0.23%	0.03%
ICT (c3)	0.29%	0.52%	0.47%	0.25%	0.19%	0.33%	0.10%	0.15%	0.25%	0.30%	0.23%	0.19%	0.37%	0.29%	0.51%
Implicit change-Jorgenson (d = d1+d2+d3)	0.14%	0.20%	0.27%	0.06%	0.25%	0.14%	0.18%	0.09%	0.25%	0.15%	0.22%	0.18%	0.23%	0.27%	0.34%
Constructions (d1)	-0.04%	-0.14%	0.02%	-0.08%	0.07%	-0.07%	0.03%	0.01%	0.09%	-0.07%	-0.04%	0.02%	-0.01%	0.00%	0.04%
Non-ICT (d2)	0.03%	0.07%	0.00%	-0.02%	0.07%	0.04%	0.05%	-0.01%	-0.01%	0.03%	0.06%	0.02%	0.00%	0.08%	0.02%
ICT (d3)	0.16%	0.28%	0.26%	0.16%	0.10%	0.17%	0.10%	0.09%	0.16%	0.19%	0.19%	0.14%	0.23%	0.19%	0.28%
Importance of Capital Accummulation (b/a)	61%	52%	65%	32%	60%	42%	58%	28%	74%	47%	45%	58%	51%	46%	52%
Importance of Neutral Change															
Solow ($\gamma_{A,S}$/a)	39%	48%	35%	68%	40%	58%	42%	72%	26%	53%	55%	42%	49%	54%	48%
Hulten ($\gamma_{A,H}$/a)	23%	27%	12%	66%	20%	45%	24%	70%	-1%	36%	43%	28%	32%	32%	15%
Jorgenson ($\gamma_{A,J}$/a)	31%	38%	23%	66%	29%	52%	27%	70%	9%	43%	45%	32%	37%	43%	30%
Importance of Implicit Change															
Solow (0/a)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hulten (c/a)	16%	22%	24%	2%	21%	13%	18%	2%	26%	18%	12%	14%	17%	22%	33%
Jorgenson (d/a)	8%	10%	13%	2%	11%	6%	16%	2%	17%	11%	10%	10%	12%	12%	19%

Table 2 (continued): Growth Accounting Decompositions

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Nether.	Portugal	Spain	Sweden	U.K.	U.S.A.
Cost shares $\{v_i\}$															
Constructions, v_1	0.189	0.146	0.167	0.163	0.208	0.157	0.148	0.199	0.178	0.183	0.114	0.160	0.145	0.155	0.140
Transport equipment, v_2	0.031	0.031	0.032	0.025	0.026	0.028	0.027	0.053	0.031	0.030	0.033	0.026	0.016	0.029	0.025
Machinery equipment, v_3	0.095	0.069	0.080	0.092	0.074	0.082	0.045	0.085	0.099	0.061	0.131	0.057	0.091	0.096	0.074
Communication equip., v_4	0.014	0.007	0.005	0.007	0.007	0.011	0.008	0.005	0.014	0.003	0.008	0.007	0.009	0.006	0.015
Hardware, v_5	0.015	0.032	0.027	0.011	0.008	0.018	0.005	0.009	0.010	0.017	0.014	0.010	0.020	0.016	0.026
Software, v_6	0.004	0.007	0.012	0.017	0.006	0.007	0.002	0.004	0.007	0.009	0.002	0.007	0.014	0.010	0.013
Investment rates $\{z_i\}$															
Constructions, z_1	0.053	0.044	0.046	0.049	0.046	0.049	0.035	0.038	0.055	0.039	0.060	0.040	0.053	0.048	0.044
Transport equipment, z_2	0.020	0.022	0.021	0.016	0.017	0.019	0.023	0.031	0.020	0.024	0.022	0.019	0.012	0.017	0.016
Machinery equipment, z_3	0.074	0.061	0.069	0.074	0.079	0.064	0.086	0.062	0.055	0.072	0.063	0.105	0.058	0.054	0.053
Communication equip., z_4	0.008	0.016	0.014	0.006	0.004	0.008	0.005	0.005	0.006	0.010	0.012	0.006	0.012	0.010	0.013
Hardware, z_5	0.008	0.005	0.003	0.007	0.005	0.007	0.008	0.003	0.009	0.002	0.006	0.006	0.006	0.004	0.010
Software, z_6	0.004	0.006	0.011	0.015	0.005	0.006	0.002	0.003	0.005	0.009	0.002	0.006	0.013	0.009	0.012

Table 3: General Equilibrium Decomposition

	Austria	**Belgium**	**Denmark**	**Finland**	**France**	**Germany**	**Greece**	**Ireland**	**Italy**	**Nether.**	**Portugal**	**Spain**	**Sweden**	**U.K.**	**U.S.A.**
Observed productivity *ln(g)*	1.88%	2.00%	2.16%	2.72%	2.27%	2.37%	1.15%	4.23%	1.44%	1.36%	2.08%	1.73%	1.97%	2.35%	1.83%
Calibrated productivity (a=b+c)	1.56%	1.96%	1.84%	2.63%	2.05%	2.42%	0.92%	4.84%	1.11%	1.39%	1.70%	1.26%	1.82%	2.51%	2.10%
Neutral change (b)	1.19%	1.56%	1.23%	2.56%	1.38%	2.08%	0.66%	4.60%	0.54%	1.14%	1.25%	1.04%	1.39%	1.71%	1.37%
Implicit change (c = d+e)	0.37%	0.40%	0.61%	0.08%	0.67%	0.33%	0.26%	0.24%	0.58%	0.26%	0.45%	0.22%	0.43%	0.80%	0.73%
Non-ICT (d=d1+d2+d3)	0.00%	-0.15%	0.05%	-0.26%	0.43%	-0.03%	0.13%	-0.05%	0.19%	-0.08%	0.07%	0.05%	-0.03%	0.32%	0.14%
Constructions (d1)	0.12%	0.17%	0.05%	-0.08%	0.18%	0.16%	0.06%	-0.22%	-0.08%	0.04%	0.08%	-0.02%	-0.04%	0.30%	0.02%
Transport equipment (d2)	0.00%	0.03%	-0.04%	0.00%	0.06%	-0.02%	0.03%	0.14%	0.02%	0.03%	0.07%	0.03%	0.04%	0.02%	0.03%
Machinery equipment (d3)	-0.12%	-0.35%	0.05%	-0.18%	0.19%	-0.17%	0.04%	0.03%	0.25%	-0.15%	-0.08%	0.03%	-0.02%	0.01%	0.10%
ICT (e = e1+e2+e3)	0.37%	0.56%	0.55%	0.34%	0.24%	0.37%	0.12%	0.29%	0.38%	0.34%	0.38%	0.18%	0.46%	0.48%	0.59%
Communication equip. (e1)	0.07%	0.04%	0.03%	0.05%	0.06%	0.06%	0.03%	0.03%	0.12%	0.01%	0.04%	0.03%	0.04%	0.04%	0.09%
Hardware (e2)	0.26%	0.47%	0.44%	0.18%	0.14%	0.26%	0.08%	0.23%	0.23%	0.26%	0.32%	0.12%	0.33%	0.36%	0.40%
Software (e3)	0.03%	0.05%	0.08%	0.11%	0.05%	0.05%	0.01%	0.03%	0.04%	0.07%	0.01%	0.03%	0.09%	0.08%	0.10%
Neutral change (b/a)	76%	79%	67%	97%	67%	86%	72%	95%	48%	82%	73%	82%	76%	68%	65%
Implicit change (c/a)	24%	21%	33%	3%	33%	14%	28%	5%	52%	18%	27%	18%	24%	32%	35%
Time discount rate, β	0.9523	0.9535	0.9550	0.9604	0.9560	0.9570	0.9453	0.9749	0.9481	0.9474	0.9542	0.9509	0.9532	0.9568	0.9518
Investment rate, 1-c	0.1714	0.1386	0.1192	0.1495	0.1559	0.1558	0.1103	0.2496	0.1428	0.1303	0.1603	0.1185	0.1187	0.1494	0.1262
Technology parameters $\{\alpha_i\}$															
Constructions, α_1	0.193	0.142	0.173	0.170	0.197	0.152	0.159	0.177	0.174	0.181	0.148	0.187	0.148	0.143	0.142
Transport equipment, α_2	0.032	0.034	0.034	0.024	0.028	0.031	0.023	0.068	0.033	0.033	0.032	0.019	0.017	0.032	0.026
Machinery equipment, α_3	0.092	0.075	0.077	0.081	0.081	0.086	0.038	0.086	0.097	0.062	0.094	0.043	0.086	0.097	0.074
Communication equip., α_4	0.014	0.009	0.005	0.013	0.009	0.012	0.008	0.007	0.017	0.003	0.010	0.006	0.010	0.009	0.018
Hardware, α_5	0.011	0.022	0.020	0.008	0.006	0.012	0.004	0.011	0.009	0.012	0.016	0.006	0.016	0.017	0.019
Software, α_6	0.006	0.009	0.015	0.021	0.008	0.009	0.002	0.007	0.008	0.011	0.003	0.006	0.017	0.015	0.016

Figure 1: **Evolution of the Q –prices in the U.S.A., 1980-2004**