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PRODUCTIVITY GROWTH AND TECHNOLOGICAL CHANGE IN EUROPE AND US

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RESUMEN

En este trabajo se presenta una evaluación de las causas tecnológicas que afectan al crecimiento de la productividad en los países europeos y en Estados Unidos en el período 1980-2004. El progreso tecnológico se clasifica entre cambios neutrales y cambios específicos de la inversión. La contribución al crecimiento de la productividad de cada uno de los cambios tecnológicos se calcula con el enfoque de contabilidad del crecimiento y con un enfoque de equilibrio general. En cuanto a la contribución del cambio tecnológico neutral, se observa que las tecnologías de la información y de la comunicación son las que más contribuyen a través de los cambios tecnológicos implícitos que producen. Además, producen más efecto en las tasas de crecimiento de la productividad. En particular la mayor contribución proviene del equipamiento informático.

Clasificación JEL: O41, O47.
Palabras Clave: Crecimiento de la productividad, Cambio tecnológico específico de la inversión, Cambio tecnológico neutral.

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ABSTRACT

This paper presents an evaluation on the technological sources of productivity growth across European countries and the U.S. for the period 1980-2004. Technological progress is divided into neutral change and investment specific change. Contribution to productivity growth from each type of technological progress is computed using a growth accounting approach and a general equilibrium approach. Concerning the growth accounting view, the neutral change dominates the effect from the implicit change, and the ICT assets provide most of the implicit technological change. Regarding the general equilibrium approach, ICT assets (specially the hardware equipment) also respond for most of the implicit change affecting productivity growth.

JEL Classification: O41, O47.
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 effects 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 output. In this sense, 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, 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, and 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 out 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).

This paper studies the importance of the different sources of technological progress on labor productivity growth across the U.S. and some European countries during 1980-2004. For this purpose, 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] Two different approaches are used 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 was retaken by the criticism of Greenwood, Hercowitz and Krusell (1997) to Hulten (1992), with extensions until today (see, for instance, Oulton, 2007 *versus* Greenwood and Krusell, 2007).

As regards the *growth accounting approach*, we implement in turn three

[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).

different measures: the traditional one proposed by Solow (1956) plus 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). Concerning the *general equilibrium approach*, we use an extension of the Greenwood, Hercowitz and Krusell (1997) model, developed in Martínez, Rodríguez and Torres (2008). We first 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 take into account the existence of investment-specific technological change to all the capital assets.

The controversy between the *growth accounting approach* and the *general equilibrium approach* can be interpreted 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.

Regardless the approach, we find that the contribution of neutral technological progress to the productivity growth overcomes that of implicit change. Using the growth accounting view, the neutral change dominates the effect from the implicit change. Capital deepening also accounts for an important fraction of productivity growth, with the exceptions of Finland, Germany and Ireland. Both according to Hulten's view and Jorgenson's view, the ICT assets provide most of the implicit technological change in these economies. The contribution from non-ICT capital assets to productivity growth is negative or negligible for the majority of countries. Regarding the general equilibrium approach, ICT assets, specially the hardware equipment, respond for most of the implicit change. 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 over one quarter of their productivity growth. These are three intensive users of the ICT assets. The lowest contributions correspond to Spain and Greece, where ICT-technological progress only contributes to productivity growth 0.18 and 0.12 percentage points, respectively.

The structure of the paper is as follows. Section 2 presents the 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.* (2008) that extends the model of the Greenwood *et al.* (1997) model in two directions. *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), by contrast, consider that this price is constant for structures, but is allowed to vary for equipment assets. Note that, according to their definition, equipment include 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 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:

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

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:

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

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, L_t, and I_t to maximize the utility (1):

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

subject to the budget constraint (2) and the law of motion (3), given taxes (τ_c, τ_k, τ_l) and the initial conditions $\{K_{i,0}\}_{i=1}^{6}$.

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,

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

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:

$$\phi C_t^{-1} = \lambda_t (1 + \tau_c), \tag{8}$$

$$(1 - \phi) O_t^{-1} = \lambda_t (1 - \tau_l) W_t, \tag{9}$$

$$\beta \frac{Q_{i,t}}{Q_{i,t+1}} [(1 - \tau_k) Q_{i,t+1} R_{i,t+1} + 1 - \delta_i] = \frac{\lambda_t}{\lambda_{t+1}}, \tag{10}$$

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

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

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

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 $Q_{i,t}$. 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 $\left\{\{\rho_i, s_i\}_{i=1}^6, c, \psi\right\}$ the following steady state ratios

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

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) 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 EU-15 countries and for the U.S. 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).

The estimated values of (28) are reported in table 1, divided into four panels. Productivity growth is collected in the first row of this table and is calculated as $g = T^{-1}\sum_t y_t/y_{t-1}$, where y_t is the GDP per hour worked. With the exception of Ireland, that according to the GGDC evinces an impressively high rate of productivity growth, 4.3%, for the rest of the countries this rate is limited to the interval $0.014 \leq \ln(g) \leq 0.024$.

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

The following row collects the fraction of hours worked, ψ. The highest fractions are found for the Greece, Ireland, Spain and the U.S., while the lowest ones are for Denmark, France and the Netherlands. This fraction in the major European economies are well below that of the U.S. This fact is also illustrated in Blanchard (2004) and Prescott (2004).

The average labor cost shares provided by the GGDC data base is used as an estimator of α_L, presented in the third row of table 1. These shares are consistent with those provided by Gollin (2002), who estimates that the income share should be within the $[0.65, 0.80]$ interval in a wide set of countries under consideration.

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 borrow from Boscá, García and Taguas (2005) their estimates of effective average tax rates, who follow the methodology of Mendoza, Razin and Tesar (1994), for OECD countries for the period 1964-2001. To compute tax rates averages, we select the period 1980-2001. With the exceptions of Denmark, the U.K. and the U.S., the respective governments levy higher taxes on the labor income than on the capital income.

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 consumption price index (taken from IMF-IFS, line 64, 2000 base year), and q_{it} is the implicit deflator of asset i, which 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 implicit technological change, as measured by the evolution of the Q_i, is stronger in the ICT equipment: for hardware is 16.25%, and for communication and software it is about 3.5 per cent per year. As an illustration, figure 1 depicts the series of the levels of $Q_{i,t}$ for the U.S. economy, 1980-2004. There are moderately long swings in the implicit change for structures that tend to revert to 1. There is an upward continuous trend for the $Q_{i,t}$ of transport equipment and machinery. The series for the three ICT assets are also positively sloped, mainly the one of hardware equipment.

For the rates of depreciation, we take the estimation given in van Ark, Inklaar and McGukin (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, which 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%.

The last panel of table 1 finally reports the investment weights averaged over 1980-2004, ω_i. Using the GGDC data base, these weights represent the ratio of nominal investment in asset i to nominal GDP. In all countries, structures receive the highest weight, going from a minimum of 36 per cent in Italy and the U.S. up to a 57 per cent in Spain. Note that the implicit technological change in structures is nearly zero. The assets of the new economy have had a minor relevance on the composition of this physical portfolio. However, there are six countries that could be considered as intensive users of ICT assets: the U.S. invests a 23% of its portfolio on these assets; this is followed by Sweden, Denmark, Belgium and the U.K. The sum of these weights is only 14% for Germany.

[**Table 1 and figure 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, we consider three alternative growth accounting approaches: the standard growth accounting decomposition, due to Solow (1956) plus two decompositions that take explicit account of 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. We follow the terminology of Cummins and Violante (2002) which define the first approach as the *traditional growth accounting* and the second one 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 using different frameworks. The difference is that while Solow (1960) assumes *embodied* technological change only in the production of investment goods, 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 though they were independent from each other. The problem is that capital accumulation is affected by technological progress. Hence, traditional growth accounting is not able to quantify the importance of technological change given that it is not possible to verify 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 from 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. Within the lines proposed by Greenwood and Krusell (2007), Cummins and Violante (2002) pointed out that the main drawback of the traditional growth accounting view is that is does not isolate the underlying 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

In this subsection, we report the results obtained from carrying out three versions of the traditional growth accounting. The first approach is the growth accounting approach, which obtains the contribution of (neutral) technical progress residually after controlling for the growth rates and output shares of production factors (Solow, 1956 and 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. This approach, however, does not control for changes in the prices of the capital assets and assumes constant returns to scale. Given this view, productivity growth can be decomposed as:

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

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 our 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 to 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. The Cobb-Douglas production function of previous section does assume it.

Particularly, 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. The cost shares are given by the following expressions:

$$v_{L,t} = \frac{RE_t}{RE_t + \sum_{i=1}^{6} VCS_{it}}, \tag{33}$$

$$v_{i,t} = \frac{VCS_{it}}{RE_t + \sum_{i=1}^{6} VCS_{it}}. \tag{34}$$

These cost shares are used in growth accounting decompositions for weighting the contribution of the different inputs to output growth and productivity growth, as guided by theoretical foundations. 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. Note that portfolio weights ω_i in table 1 are related to the investment rates as $\omega_i = z_i / \sum_i z_i$.The last term of (35) is a measure of the contribution from implicit technical change. In our case, we take 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 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, z_i, as a way of weighting the growth of capital input prices Q_i. Note finally that the central term that collects the effect of capital-to-labor ratio accumulation, is common in the three expressions (31), (35) and (36), and must render 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, v_i, and the investment rates, z_i. For the sake of brevity, we present the contribution of the capital inputs aggregated into three assets: constructions, non-ICT equipment and ICT equipment.

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. When the prices of the capital inputs are taken into consideration, neutral technical change is 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 this approach only recognizes the existence of embedded technological progress in the new capital assets through investment, while the later 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 an intensive user of the ICT or not. Relatively similar countries in terms of ICT development such as the U.K. 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, Hulten's view and Jorgenson's view. Indeed, the percentage of productivity growth explained by neutral change is 13 points higher (taking Jorgenson's view) and over 17 points (on the basis of Hulten's approach) in the U.K. than in the U.S. 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 U.K. and the U.S.), 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 U.S., Sweden, the U.K. 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 is reasonable to think that the introduction of ICT generates adjustment costs (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 start developing 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 of section 2, following Greenwood *et* *al.* (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 3 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 panels we report the calibration of some relevant parameters (β, $1-c$, and $\{\alpha_i\}_{i=1}^{6}$). Note that these calibrated technological parameters $\{\alpha_i\}_{i=1}^{6}$ are similar to the cost shares $\{v_i\}_{i=1}^{6}$ in table 2. For the U.S., those shares corresponding to the ICT capital are higher than the remaining countries, which reflects higher investment effort in these assets. Using a log-linear version of the model, the last panel of table 3 presents some statistical moments of productivity growth to check how the model fits the observations: standard deviations and the correlation coefficient between observed growth and the growth rate predicted by the model. We take the series A_t, and $\{Q_i\}_{i=1}^{6}$ as exogenous from 1980 to 2004. In general, the model produces slightly smoother series of productivity growth, as standard deviations of the observed series are higher than those motivated by the model (due probably to the log-linearization). Yet the correlation coefficients, with the exception of the U.K., are between 0.70 and 0.95. We thereby conclude that the approximation given by the model is accurate. As an illustration, figure 2 plots the series of productivity growth for the U.S. economy (the correlation coefficient is 0.75). Note that the model reproduces and leads the recovery of productivity growth after 1995. This fact is well documented in other works like Timmer and van Ark (2005). The main peaks of the observed series are replicated by the model.

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 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, the disaggregation of capital, and the data set are different. 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 1.3% of the Netherlands. However, most of the countries show an average productivity growth during the period of around 2%. Our calibrated growth rates are slightly different 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 differ by 0.62%).

During the period 1980-2004 no important differences are observed between the behavior of the U.S. economy versus the European economies in terms of labor productivity growth. The U.S. average productivity growth were 1.83%, while 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 since the mid of the nineties.

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. 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 quarter of total productivity growth. In the case of the U.S., we obtain that the contribution of only ICT-specific technological change is 28% of labor productivity growth for all the period. The lowest contribution from the ICT corresponds 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 U.K. is around 32% of total labor productivity growth. Bakhshi and Larsen (2005) in a similar analysis for the U.K. 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 structures are included in our specification of non-ICT capital. 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 non residential structures changes through time. Therefore, implicit technological change associated to structures is included in total implicit technological change from non-ICT capital. As a result, contribution to growth for non-ICT specific technological change is negative for Belgium, Finland, Germany, Ireland, the Netherlands and Sweden.

How different are these results in comparison with those corresponding to the traditional growth accounting approaches? 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. 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 and figure 2 here**]

4 Concluding remarks

The recent experiences of the U.S. 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 U.S. economy in the use of ICT at all economic levels. Since the early eighties, the U.S. economy has doubled European investment in ICT. As a way to fill this gap, the Lisbon Strategy and the initiative *i2010* collected a number of policy recommendations in order to make significant advances on this issue. Therefore, the use of new technologies should be viewed as an instrument for reversing productivity slowdown but properly combined with other policy tools.

This paper investigates the importance of different sources of technological progress in explaining productivity growth in Europe and the U.S.. 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.

Regarding the traditional growth accounting methodology, we have seen that the contribution of neutral technical change on productivity growth is not distributed across countries following a clear pattern. Particularly, we have shown that the relative magnitude of this source of growth does not depend on whether the country is an intensive user of ICT assets or not. If subperiods were considered, things would be different and a significant correlation between neutral technological progress and intensity in the use of ICT would be found. Moreover, regardless the approach followed within this growth accounting exercise (Hulten versus Jorgenson), it happens that the relative importance of neutral technical change is higher than the implicit technical change.

Under the equilibrium growth accounting approach, the contribution of neutral technical change also dominates that of the implicit technological progress. As can be expected, the implicit technological change linked to ICT assets is more powerful than that coming from non-ICT inputs, with the exceptions of France and Greece. Even for some countries (Belgium, Finland, Germany, Ireland, Netherlands and Sweden) the implicit technical progress of non-ICT assets appears as a negative contributor to productivity growth.

The main conclusion that we obtain is that the E.U. member countries fall well behind the U.S. with respect to the effects from ICT technological change. Only two rather small economies, Denmark and Belgium, show important contributions to productivity growth from ICT technological revolution. 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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Figure 1: **Evolution of the** Q **–prices in the U.S.A., 1980-2004**

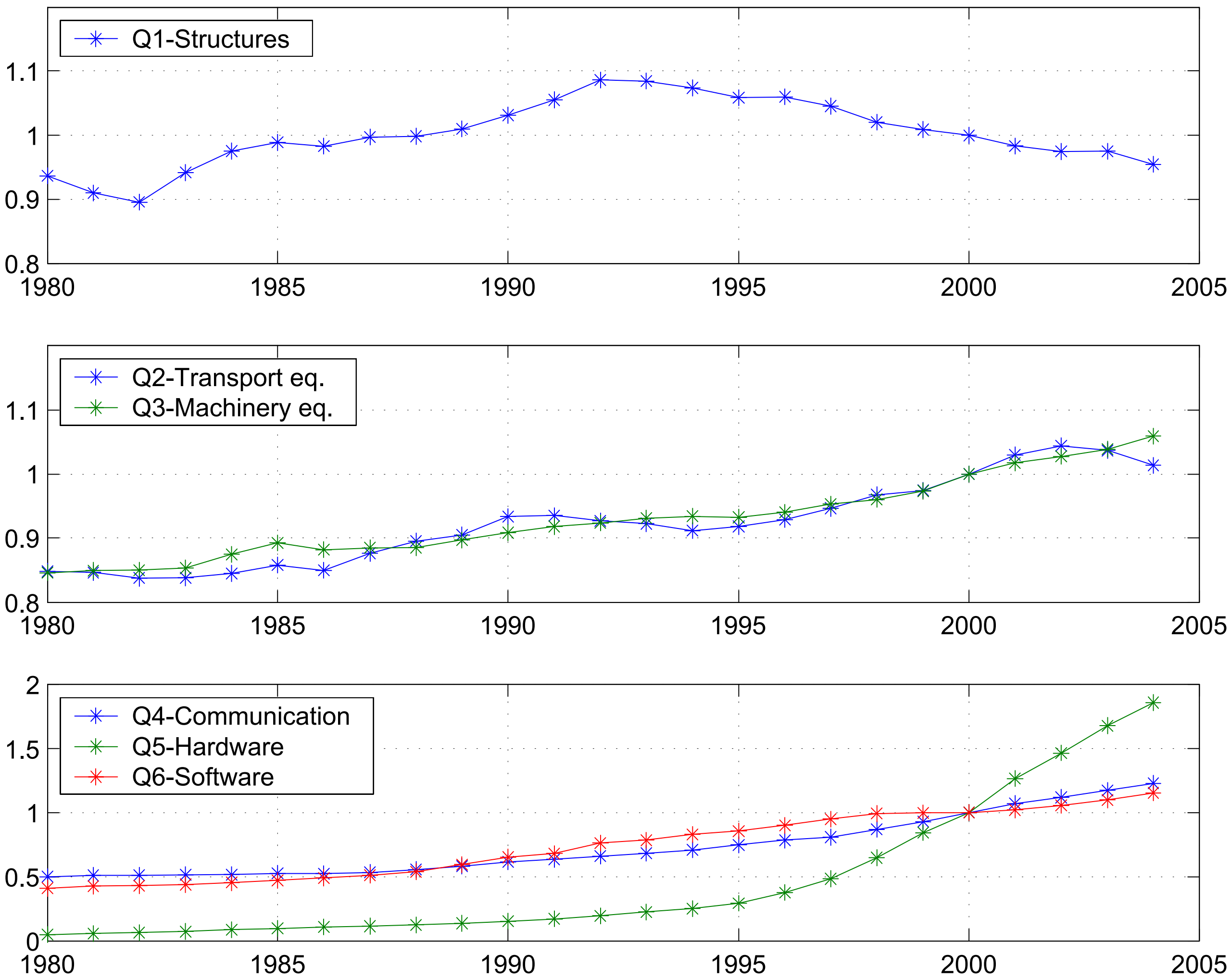

Figure 2: Productivity growth in the U.S.A., 1980-2004

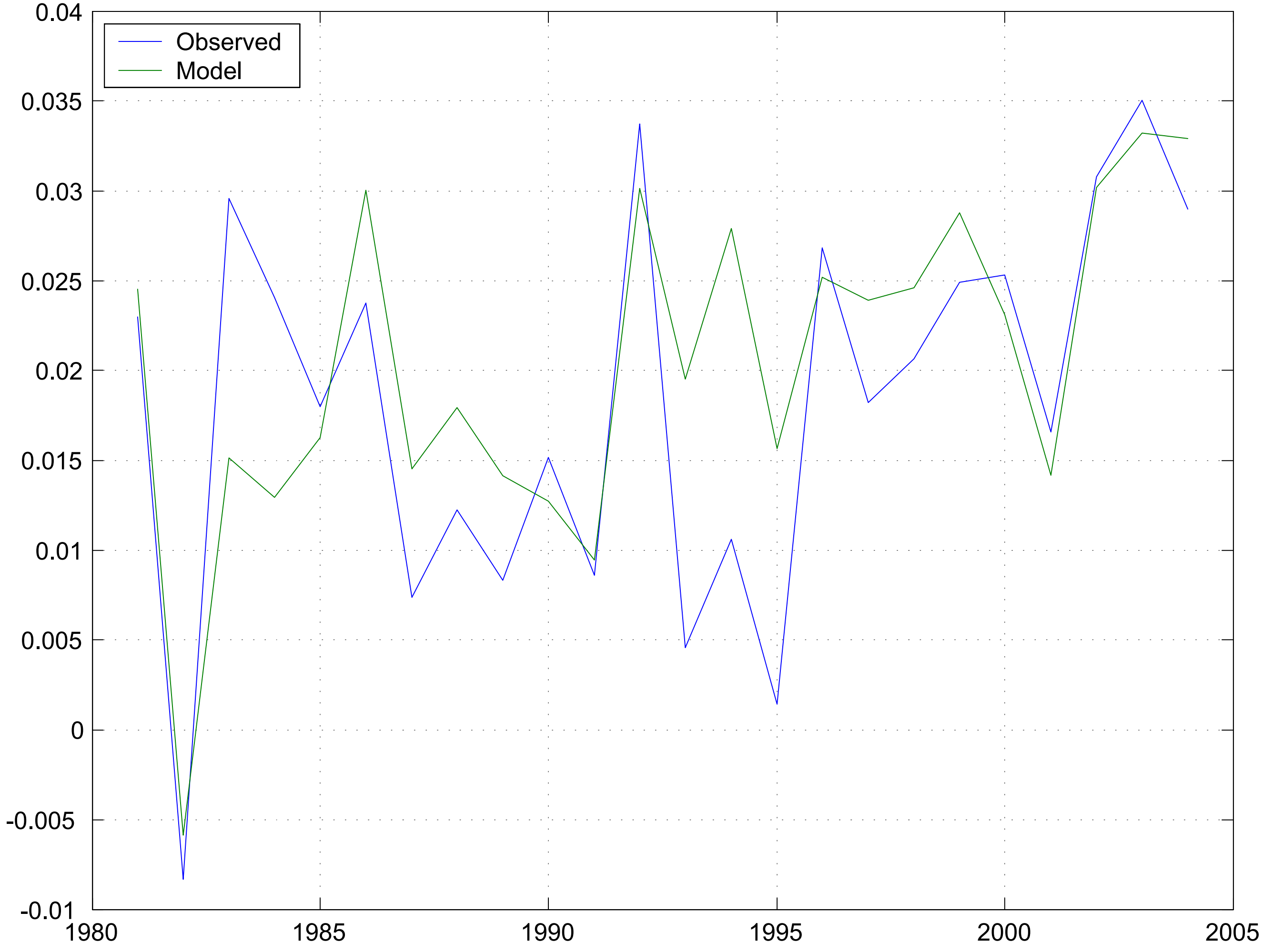

Table 1: Parameters, period 1980-2004

	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, ψ	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 $\{\eta_i\}$															
Constructions, 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 $\{\delta_i\}$															
Constructions, 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 $\{\omega_i\}$															
Constructions, 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%
Neutral Change (or TFP)															
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)	0,59%	0,28%	0,52%	0,50%	0,66%	0,44%	0,27%	0,67%	0,36%	0,20%	0,65%	0,55%	0,27%	0,44%	0,15%
Non-ICT (b2)	0,14%	0,05%	0,18%	-0,08%	0,39%	0,10%	0,20%	0,24%	0,33%	0,02%	-0,02%	0,14%	0,13%	0,11%	0,09%
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%	0,12%	0,03%	-0,05%	0,13%	0,12%	0,04%	-0,16%	-0,06%	0,03%	0,05%	-0,01%	-0,03%	0,22%	0,01%
Non-ICT (c2)	-0,08%	-0,21%	0,01%	-0,14%	0,15%	-0,13%	0,07%	0,09%	0,18%	-0,09%	-0,03%	0,07%	0,00%	0,01%	0,09%
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)	0,03%	0,05%	0,01%	-0,02%	0,05%	0,05%	0,02%	-0,05%	-0,02%	0,01%	0,03%	-0,01%	-0,01%	0,08%	0,00%
Non-ICT (d2)	-0,04%	-0,13%	0,00%	-0,08%	0,10%	-0,08%	0,06%	0,05%	0,10%	-0,05%	0,00%	0,05%	0,01%	0,01%	0,05%
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.	Portuga	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 $\ln(g_{GE})$ (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 $\ln(g_A)/(1-\alpha_L)$ (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
Model *versus* observations, 1980-2004															
Standard deviation (Observed)	0,021	0,016	0,020	0,017	0,015	0,016	0,031	0,023	0,016	0,020	0,028	0,019	0,012	0,012	0,011
Standard deviation (Model)	0,013	0,013	0,012	0,019	0,012	0,012	0,027	0,024	0,011	0,013	0,025	0,013	0,015	0,021	0,009
Correlation coeff. (Model vs Observed)	0,892	0,776	0,774	0,704	0,825	0,908	0,946	0,712	0,668	0,758	0,718	0,788	0,567	0,303	0,751