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Technological sources of productivity growth in Japan, the U.S. and Germany: What makes the difference?*

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Resumen

En este artículo se trata de analizar las contribuciones de las tecnologías de la información y la comunicación (TIC) al crecimiento económico y la productividad del trabajo en tres economías: Japón, Alemania y Estados Unidos. Se utiliza un modelo de equilibrio general dinámico para cuantificar la contribución al crecimiento de la productividad en los tres países con distintos progresos tecnológicos. Los resultados muestran que la contribución de los activos TIC es de alrededor del 40 por ciento en Japón y Alemania, mientras que en Estados Unidos esta contribución es del 65 por ciento. La fuente de crecimiento es el progreso tecnológico neutral en Japón y Alemania, mientras que en Estados Unidos es progreso tecnológico es más específico de la inversión, principalmente asociado a los activos TIC.

Clasificación JEL: O3; O4.
Palabras Clave: Crecimiento de la productividad, cambio tecnológico específico de la inversión, cambio tecnológico neutral, tecnologías de la información y la comunicación.

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Abstract

This paper studies the contribution of Information and Communication Technologies (ICT) on economic growth and labor productivity across the three leading economies in the world: Japan, Germany and the US. We use a dynamic general equilibrium growth model with investment-specific technological change to quantify the contribution to productivity growth in the three countries from different technological progress. We find that contribution to productivity growth due to ICT capital assets is about 0.40 percentage points for Japan and Germany, whereas it is about 0.65 percentage points in the case of the US. Neutral technological change is the main source of productivity growth in Japan and Germany. For the US, the main source of productivity growth derives from investment-specific technological change, mainly associated to ICT.

JEL classification: O3; O4.
Keywords: Productivity growth; Investment-specific technological change; Neutral technological change; Information and communication technology.

Abstract. This paper studies the contribution of Information and Communication Technologies (ICT) on economic growth and labor productivity across the three leading economies in the world: Japan, Germany and the US. We use a dynamic general equilibrium growth model with investment-specific technological change to quantify the contribution to productivity growth in the three countries from different technological progress. We find that contribution to productivity growth due to ICT capital assets is about 0.40 percentage points for Japan and Germany, whereas it is about 0.65 percentage points in the case of the US. Neutral technological change is the main source of productivity growth in Japan and Germany. For the US, the main source of productivity growth derives from investment-specific technological change, mainly associated to ICT.

JEL classification: O3; O4.

Keywords: Productivity growth; Investment-specific technological change; Neutral technological change; Information and communication technology.

1 Introduction

In this paper we investigate the contribution of different sources of technological progress to productivity growth in three leading world economies, i.e., Japan, Germany and the United States. According to the neoclassical growth model, long run productivity growth can only be driven by the state of technology. Here we adopt the view that the progress of technology can be due to two complementary sources: 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 physical capital asset.

Implicit technology can widely vary from one to another asset. Indeed recent typologies recommend using disaggregated measures of capital, as for instance, structures and equipment. Equipment are in turn divided into information and communication technologies (ICT) equipment -hardware, software and communication networks-, and non-ICT equipment -machinery, transport equipment, etc. The amount of technology incorporated in a computer, for instance, is much higher than that in an non-ICT asset. As pointed out by Jorgenson (2002), this technological progress can be observed in improvements in performance, rather than a decline in the nominal price of the capital assets. In nominal terms, the price of a personal computer has changed very little in the last decade. But in real terms, when quality is also controlled for (in terms of processing units), the decrease goes beyond the 25 per cent by year.[1] The decay in the price in the rest of capital assets has been moderately smaller but also reflects an implicit technological progress. Thereby, both the acquisition prices and the rental prices of capital equipment have been reducing in the last fifteen years.

Several recent studies have stressed the importance of the ICT on economy as a key factor behind the upsurge in the United States productivity after 1995 (see Collechia and Schreyer 2001; Stiroh 2002; Jorgenson, 2002, among others). As regards Europe, indexes show that E.U. countries fall well below the United States in terms of ICT penetration (see for instance Daveri, 2000; and Timmer and van Ark, 2005). Whereas there exist a huge literature for the case of the US economy, the literature is relatively scarce for the cases of Japan and Germany. In the case of the European economies a relevant analysis is Inklaar, McGukin and van Ark (2003), which show that total factor productivity growth in Germany since the mid 1990s has been much slower than in the US, especially in market services. Additionally, Inklaar, Timmer and van Ark (2006) show that TFP growth in ICT-intensive industries in the EU countries since 1995 has been much lower than in the US.[2]

Of particular interest is the case of Japan. Hayashi and Prescott (2002) calibrate a simple neoclassical growth model of the Japanese economy showing that the economic downturn during the 1990s can be explained by a slowdown in Total Factor Productivity (TFP). Braun and Shioji (2007) have extended the analysis of Hayashi and Prescott (2002) and found that economic growth in the "lost decade" was mainly due to investment-specific technological change. Additionally, Jorgenson and Motohashi (2005) study the role of ICT on economic growth in Japan and the United States. They show that the contribution of ICT to economic growth in Japan after 1995 was similar to that of the US, and that more than half of Japanese output growth from the mid 1990s can be attributed to information technology. These authors conducted a simulation exercise on potential output growth in Japan and the US until 2013. They obtained that economic growth in Japan will continue to lag behind the US but that labor productivity growth in both economies will be similar.

In this paper we investigate the contribution of different sources of tech-

[1] Jorgenson (2002), for instance, pointed out that a 2005 typical personal computer is 140 times as fast compared with the typical personal computer in 1990.

[2] Martínez, Rodríguez and Torres (2008b), using the Groningen Economic Growth Accounting Database, analyze the contribution of ICT to productivity growth in the European countries and the US, showing that the contribution of ICT in Germany is much lower than that in the US.

nological progress to productivity growth in three leading economies, Japan, Germany and the United States, for the period 1977-2005. We use a dynamic general equilibrium growth model calibrated with data from the EU-KLEMS database. Sources of technological change to productivity are decomposed into neutral and implicit change from different capital assets. Capital is disaggregated into three assets: structures, non-ICT equipment and ICT equipment. Fukao and Miyagawa (2007) also use the EU-KLEMS database and make a comparison between Japan and the mayor EU countries and the US. As in the mayor European countries, also Japan experienced a slowdown in TFP growth after 1995 of a similar magnitude.

The comparison of productivity growth contribution from technological progress across these three countries is particularly interesting for several reasons. First, they are the three leading economies in the world and their dynamics are taken as a reference of the overall world economic moment. Second, the economic performance has been different in each of these three country, especially during the last decade. As we will see, while the Japanese economy has experienced a slowdown in the growth of its productivity during the nineties, the U.S. economy has evinced an upsurge of productivity ever since, while German productivity growth has evolved within a more stable pattern. As shown by Fukao and Miyagawa (2007), real GDP growth in Japan during the period 1995-2004 did not exceed 1%, much lower than the 3.3% of output growth in the period 1973-1995. This sharply contrast with the evolution of the European economies and specially with the performance of the US economy. Third, it is expected that ICT plays a key role in the economic growth as in these economies the ratio of ICT capital on total capital is high. Therefore, it seems to be very important to quantify how considerable this contribution is.

Our results show some important differences in the performance of these three economies. We find that neutral technological change is the driving source of productivity in Japan and Germany, accounting for about 75% of its growth. For the US economy, the main source of productivity derives from investment-specific technological change, mainly associated to ICT. The contribution to average productivity growth from implicit technological change is around 0.5 percentage points for Japan and Germany whereas it is about 0.75 percentage points for the US. The main finding of the paper is that the importance of ICT technological progress in explaining productivity growth shows considerable differences across countries. ICT technological progress contribution to average productivity growth is about 0.36 percentage points for Germany, around 0.42 percentage points for Japan and 0.62 percentage points for the US.

Finally, we study the effects of the four different technological change in the short-run. Whereas a neutral technological shocks has a positive impact on productivity growth, specific technological shock to structures and non-ICT equipment have a negative impact on productivity growth. This is provoked by the fact that a specific technological shock has a positive impact on hours worked. Additionally, specific technological shocks also have a negative impact on consumption growth and a positive impact on investment growth. Nevertheless, we obtain that most of the variability of productivity in the short-run can be attributed to neutral shocks.

The structure of the paper is as follows. In Section 2 we present a theoretical growth model with embodied technological progress and the characterization of its balanced growth path. Section 3 presents a description of the data set and the calibration exercise. Section 4 presents the estimation of the contribution of each type of technological change to labor productivity growth in the long-run. Section 5 focus on the effects of different technological shocks in the short-run. Finally, Section 6 presents some concluding remarks.

2 The model

Following Greenwood, Hercowitz and Krusell (1997) we use a dynamic general equilibrium 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 each type of capital. We use a simplification of the model developed in Martínez, Rodríguez and Torres (2008a) which, in turn, 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, we distinguish among three different types of capital inputs. Output is therefore produced as a combination from four inputs: L is labor in hours worked; K_{str} non residential structures; K_{nict} non-ICT equipment and K_{ict} ICT equipment. *Second*, denote $Q_{i,t}$ as the amount of asset i that can be purchased by one unit of output at time t. This price reflects the current state of technology for producing each capital asset. Greenwood *et al.* (1997) consider that this price is constant for structures, but is allowed to vary for equipment assets. In our model, we consider the existence of technological progress for the three capital assets.

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:

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

where β is the discount factor and $\gamma \in (0,1)$ 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:

$$\begin{aligned} & (1+\tau^c)\, C_t + I_{str,t} + I_{nict,t} + I_{ict,t} \\ = & \left(1-\tau^l\right) W_t L_t + \left(1-\tau^k\right)\left(R_{str,t} K_{str,t} + R_{nict,t} K_{nict,t} + R_{ict,t} K_{ict,t}\right) \\ & + T_t \end{aligned} \tag{2}$$

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:

$$K_{i,t+1} = (1-\delta_i)\, K_{i,t} + Q_{i,t} I_{i,t}, \tag{3}$$

where δ_i is the depreciation rate of asset $i \in \{str, nict, ict\}$. $Q_{i,t}$ 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. 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):

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

with $O_t = N_t\overline{H} - L_t$, subject to the budget constraint (2) and the law of motion (3), given taxes $\left\{\tau^c, \tau^k, \tau^l\right\}$ and the initial conditions K_{i0}, for $i \in \{str, nict, ict\}$.

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 the services of three types of capital K_i, $i \in \{str, nict, ict\}$. 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,

$$Y_t = A_t L_t^{\alpha_L} K_{str,t}^{\alpha_{str}} K_{nict,t}^{\alpha_{nict}} K_{ict,t}^{\alpha_{ict}} \tag{5}$$

where A_t is total factor productivity and where $0 \leq \alpha_i < 1$, $i \in \{str, nict, ict\}$, and

$$\begin{aligned} \alpha_{str} + \alpha_{nict} + \alpha_{ict} &< 1, \\ \alpha_L + \alpha_{str} + \alpha_{nict} + \alpha_{ict} &= 1. \end{aligned}$$

Final output can be used for four purposes: consumption or investment in three types of capital,

$$Y_t = C_t + I_{str,t} + I_{nict,t} + I_{ict,t} \tag{6}$$

Both output and investment are 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:

$$\tau^c C_t + \tau^l W_t L_t + \tau^k \left(R_{str,t} K_{str,t} + R_{nict,t} K_{nict,t} + R_{ict,t} K_{ict,t}\right) = T_t. \tag{7}$$

2.4 Equilibrium

The first order conditions for the consumer are:

$$\frac{\gamma}{C_t} = \lambda_t (1 + \tau_c), \tag{8}$$

$$\frac{1-\gamma}{N_t H - L_t} = \lambda_t (1 - \tau_l) W_t, \tag{9}$$

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

for each $i \in \{str, nict, ict\}$. 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:

$$\frac{1-\gamma}{\gamma} \frac{C_t}{N_t H - L_t} = \frac{1-\tau_l}{1+\tau_c} W_t. \tag{11}$$

Combining (10) and (8) gives

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

for $i \in \{str, nict, ict\}$. Hence, the (inter-temporal) marginal rate of consumption equates the after-tax rates of return of the three investment assets.

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

$$R_{i,t} = \alpha_i \frac{Y_t}{K_{i,t}}, \tag{13}$$

for $i \in \{str, nict, ict\}$, 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:

$$\begin{aligned} & C_t + I_{str,t} + I_{nict,t} + I_{ict,t} \\ = \; & R_{str,t} K_{str,t} + R_{nict,t} K_{nict,t} + R_{ict,t} K_{ict,t} + W_t L_t = Y_t \end{aligned} \tag{15}$$

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:

$$g = g_A g_{str}^{\alpha_{str}} g_{nict}^{\alpha_{nict}} g_{ict}^{\alpha_{ict}}, \tag{16}$$

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 $i \in \{str, nict, ict\}$. Then, from the law of motion (3) we have that the growth of each capital input is given by:

$$g_i = \eta_i g, \tag{17}$$

with η_i being the exogenous growth rate of $Q_{i,t}$, $i \in \{str, nict, ict\}$. 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:

$$g = \underbrace{g_A^{1/\alpha_L}}_{\text{Neutral change}} \times \underbrace{\eta_{str}^{\alpha_{str}/\alpha_L} \eta_{nict}^{\alpha_{nict}/\alpha_L} \eta_{ict}^{\alpha_{ict}/\alpha_L}}_{\text{Implicit change}}. \tag{18}$$

Expression (18) implies that the log of output growth can be decomposed as weighted sum of the neutral technological progress growth and implicit technological progress, as given by η_i for $i \in \{str, nict, ict\}$. Growth rate of each capital asset can be different, depending on the relative price of the new capital in terms of output.

Define the following steady state ratios

$$\rho_i \equiv \left(Q_i \frac{Y}{K_i}\right)_{ss}, \tag{19}$$

$$c \equiv \left(\frac{C}{Y}\right)_{ss}, \tag{20}$$

$$\omega_i (1-c) = s_i \equiv \left(\frac{I_i}{Y}\right)_{ss}, \tag{21}$$

$$v \equiv \left(\frac{L}{NH}\right)_{ss} = \left(\frac{h}{4992}\right)_{ss} \in (0,1), \tag{22}$$

where the subscript ss denotes the steady state reference. Using these ratios, the balanced growth path can be characterized as

$$g/\beta = \eta_i^{-1} \left[(1-\tau_k)\,\alpha_i \rho_i + 1 - \delta_i\right], \tag{23}$$

$$\eta_i g = \rho_i s_i + 1 - \delta_i, \tag{24}$$

for $i \in \{str, nict, ict\}$ and

$$1 = c + s_{str} + s_{nict} + s_{ict}, \tag{25}$$

$$1 = \alpha_L + \alpha_{str} + \alpha_{nict} + \alpha_{ict}. \tag{26}$$

$$c = \alpha_L \frac{\gamma}{1-\gamma} \frac{1-\tau_l}{1+\tau_c} \left(v^{-1} - 1\right), \tag{27}$$

3 Data and parameters

From the EU-KLEMS Database[3] we retrieve (nominal and real) series of gross output, investment, compensation of inputs, capital assets and labor in hours worked for Japan, the US and Germany.[4] We use observations from 1977 to 2005 for the three countries. Data are available from 1970 to 1990 only for West Germany, and from 1991 to 2005 for reunified Germany. We use data of West Germany to construct series of prices (implicit deflators) for investment assets and for 1977-1990. EU-KLEMS also provides complete series of gross output and total hours worked in Germany from 1970 to 2005. As regards series of capital, we calculate growth rates of the different assets from 1977 to 1990 using data from West Germany. These series are then

[3] See `http://www.euklems.net/`

[4] Fukao and Miyagawa (2007) also use the EU-KLEMS Database to analyze the sources of productivity growth across Japan, the U.S. and the European countries.

linked to the growth rates from 1991 to 2005 using the data from reunified Germany.

A Törnqvist index has been used to construct aggregate series of Non-ICT and ICT (capital and investment) series, that takes account of the variation in relative prices of assets. For all the cases, the aggregated capital stock and their implicit deflators are computed. Non-ICT series are the aggregation of machinery and other equipment, transport equipment and other assets. ICT series are the aggregation of hardware, communication equipment and software. Structures only include non-residential constructions, that is, residential capital has been excluded throughout this analysis.

Table 1 presents average labor productivity growth rates for several periods. Labor is measured in hours worked. On average for the period 1977-2005, according to EU-KLEMS data, the Japanese economy evinces the highest productivity growth rate with 2.90%. This is followed by Germany with 2.32% and the U.S. with 1.44%. The evolution of productivity over time has a different lecture: it is decreasing in Japan, increasing in the US and (reasonably) stable in Germany. The Japanese growth rate is now almost a half during 2000-2005 as relative to the nineties, while the US growth rate is just the double. However, average productivity growth in Japan during the period 2000-2005 is similar to the US productivity growth and higher than in Germany. This upsurge in the U.S. productivity has been associated to the use of ICT assets (see, among others, Jorgenson and Stiroh, 2000, and Jorgenson, 2001). Indeed some studies have highlighted that the higher the ICT deepening within a sector or an economy, the higher its productivity (see Oliner and Sichel, 2000, and Baily and Lawrence, 2001). As regards the Japanese rates, a similar (more dramatic) contraction is also documented in Hayashi and Prescott (2002), using growth per person aged 20-69, instead of hours worked.

In order to conduct the calibration of the model we need to assign values to the following set of parameters

$$\Omega = \left\{ g, v, \alpha_L, \{\delta_i, s_i, \eta_i\}_{i \in \{str, nict, ict\}}, \tau^c, \tau^l, \tau^k \right\}. \tag{28}$$

Table 2 shows the selected values for this set of parameters. The first row presents figures for the (gross) productivity growth, g, for the three countries, and are backed by the results in table 1. In the case of Germany, this first order moment is calculated for the period 1991-2005. Note notwithstanding that the this figure is almost identical to the one in table 1 using observations from 1977 to 2005. Following is the fraction of hours worked over total hours, $v = h/4992$. This fraction goes from 29% in Germany to 36% in Japan and the U.S. In the case of Japan, this ratio has been decreasing from 0.425 in 1977, up to a stable value of 0.35 in the mid of the nineties (see Hayashi and Prescott, 2002). This decrease is concerned with institutional reforms in the labor market, that have limited the workweek since the late eighties. For the case of the US, this ratio is very stable using the EU-KLEMS data. Greenwood *et al.* (1997, 2000) use instead a value of $v = 0.24$ for the US.

As regards the cost shares, the EU-KLEMS data base also provides estimated series of labor compensation and capital compensation that allow to construct an estimate of the labor cost share parameter α_L, as the ratio of labor compensation over total costs. The compensation to the services from residential capital has been excluded. These cost shares α_L are between two thirds and three quarters. For the cases of the US and Germany, 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. Particularly, for the US economy, Gollin estimates a band of [0.664, 0.773], that catches our prior guess of $\alpha_L = 0.7248$. This value is reasonably close to $\alpha_L = 0.7$ as proposed by Greenwood et al. (1997, 2000) or Pakko (2005) in similar calibrations. However, for the case of Japan, Gollin's estimate is [0.692, 0.727], while we use a value of $\alpha_L = 0.6387$, using the EU-KLEMS data set. Hayashi and Prescott (2002) estimate a value $\alpha_L = 0.638$, using data from national accounts and Input-Output matrices, which is exactly equal to the value we use.

Depreciation rates are estimated using the three aggregated series of capital. These estimates are similar but not identical across countries, as shown in table 2. Given that we are using aggregate series of capital, the weights within the portfolio of these physical assets differ from one to another country. This produces different estimates of the depreciation rate.[5] Structures depreciate by 2.8% a year on average. This rate contrasts with that assumed by Greenwood *et al.* (1997) of 5.6%. The rates of depreciation are much higher in the case of the of ICT equipment, [18%,22%], and the one of non-ICT assets, around 12%.

Table 2 also reports the investment weights as the ratio of nominal investment in asset i over total nominal investment expenditure that we label by ω_i. According to the notation in (21) and (25), note that $s_i = (1-c)\,\omega_i$, and $\sum_i \omega_i = 1$. Non-ICT assets have the highest weight, specially in Japan

[5] Depreciation rates provided by EU-KLEMS are the same for all countries but can vary depending on the sector. These are: [2.3%, 5.1%] for non residential structures; [9.2%, 22.9%] for transport equipment; [9.4%, 14.9%] for other machinery and other assets; 31.5% for hardware and software; and 11.5% for communication networks.

and Germany, 47%. The US economy has invested about a 25% from total nominal investment in ICT assets. This weight is sensibly higher than those of Japan and Germany, 15%.

Prices Q_{it} represent the amount of asset i that can be purchased by one unit of output at time t, $Q_{it} = P_t/q_{it}$, where P_t is the implicit deflator of gross output, and q_{it} is the implicit deflator of asset i calculated as the ratio of nominal to real investment. Table 2 reports the average gross price changes of the three assets for the three countries:

$$\eta_i = T^{-1} \sum_t Q_{it}/Q_{it-1}.$$

Price variations η_i are similar in the US and Germany. Greenwood *et al.* (1997) assume that the price of structures moves according to the price index of durable goods. In our case, this prices fluctuates by 0.17% in the US and Germany, but has a negative decay in Japan, -0.4%. The change in the price of non ICT equipment is 0.4% per cent in the US and Germany. In the case of Japan, this variation is 1%. Finally, the amount of ICT equipment that can be purchased by one unit of output has increased by 9% per year in the US and Germany, and 6.3% per year in Japan. Implicit technological change, as measured by the evolution of the Q_i, is thereby stronger of the ICT equipment.

The evolution of the levels of the $Q'_{i,t}s$ are depicted in figure 1 (base year is 1995). As can be observed, the implicit change for structures shows moderately long swings around one, which is the assumption used by Greenwood *et al.* (1997) and Bakhshi and Larsen (2005). The implicit change for non-ICT equipment shows a slightly upward trend. Finally, we also observe a significant upward trend in the case of the implicit change of ICT equipment at an accelerate rate, mainly due to implicit change associated to hardware equipment.

Finally, in order to take into account the distortionary effects of taxes, particularly on capital accumulation, realistic measures of tax rates are needed. In this paper we use the effective average tax rates, estimated by Boscá, García and Taguas (2008), who follow the methodology proposed by Mendoza, Razin and Tesar (1994). To that end, table 2 presents average values for the period 1980-2001. Tax structure is similar in Japan and the US, where labor income taxes are higher than capital income taxes. In Germany, the consumption tax rates doubles those of Japan and the US, but the labor income tax is higher that the capital income tax.

3.1 Model evaluation

In order to evaluate the empirical relevance of our model, simulated productivity growth are compared to the observed productivity growth year-by-year. Figure 2 plots the observed productivity growth and the calibrated one derived from the model for the three countries. We use series of $Q_{i,t}$ and the total factor productivity A_t as exogenous. As we can observe, the calibrated model makes an impressive very good job in explaining movements in labor productivity growth. This means that our model is able to replicate non only long-run behavior of productivity growth in the three countries, but also short-run fluctuations in labor productivity growth. The correlation coefficients of the observed productivity growths and those generated by the model are 0.8693 for Japan, 0.8722 for the US, and 0.8542 for Germany. For the US economy we observe some important differences in the period 1981-1985, with observed productivity growth larger than the predicted one.

Therefore, we conclude that the model replicates the empirical figures reasonably well, despite it is built in terms of the steady state, thus, from a long-run perspective. However, results presented in figure 2 show that the model can also replicate productivity growth behavior in the short-run.

4 Long-run analysis

In this section the contribution of investment-specific technological progress long-run productivity growth is calibrated. We follow the approach proposed by Greenwood *et al.* (1997), but incorporating the new elements included in our model: neutral technological progress and investment-specific technological progress from the three capital assets considered. Therefore, we can decompose long-run productivity growth into four different technological factors.

This calculation is given by expression (18), that relates the long run productivity growth to both neutral progress and investment specific technological progress. On the other hand, we exploit the system of nine steady state equations composed by (23) to (27) to solve for the following nine unknowns

$$\left\{ \{\alpha_i, \rho_i\}_{i \in \{str, nict, ict\}}, c, \beta, \gamma \right\}, \tag{29}$$

given the set of parameters Ω given in (28) as reported in table 2. Once technological parameters α_i, $i \in \{str, nict, ict\}$, are calibrated, we use the series of output, capital and labor in hours worked to calculate residually the total factor productivity. This gives an estimation of the neutral change that, added to the specific change, produces a calibrated value of productivity growth according to (18).

Notice that table 2 proposes a vector of investment weights for the portfolio of physical assets, ω_i. The investment-saving rate on asset i would be given by $s_i = (1 - c)\,\omega_i$, and the total investment-saving rate is $(1 - c)$. In order to calibrate the steady state value of this rate, we need an additional equation that fixes the after-tax return rate of capital to some value. This can be done by using equation (23). The right hand side of this expression is the real (after-tax) rate of return on asset $i \in \{str, nict, ict\}$, that in equilibrium should equal the stationary marginal rate of substitution between future and present consumption, as given by g/β. Expression (23) is therefore an arbitrage condition that imposes that the return of the different assets must be equal to g/β. For example, Greenwood *et al.* (1997, 2000) use a 7% rate, $g/\beta = 1.07$ for their long run analysis, and a 4% rate, $g/\beta = 1.04$, for their short run analysis. Pakko (2005) uses a rate of 6%. Hayashi and Prescott (2002) calculate that the after tax rate of return has decreased from 6.1% in the eighties until 4.2% at the end of the nineties. Bakhshi and Larsen (2005) use an after tax real rate of return of 5.3% for the UK economy. In this paper, in order to overcome the uncertainty associated to this rate, we will calibrate the parameters of the model in (29) for an interval of the after tax return rates going from 4% to 7%, and calibrate a stationary saving rate consistent with these values.

Tables 3, 4 and 5 summarize the results obtained from the calibrated decomposition exercise for the three countries.

Japan. Results are reported in table 3. The calibrated value of productivity growth is reasonably close to the observed one and seems to be robust to the assumed after tax return rate on capital. Neutral change produces increases in productivity between 1.51 and 1.58 percentage points, while implicit technological change produces changes from 0.65 to 0.55 percentage points. Therefore, neutral technological change account for a fraction of around 80% of productivity growth. The remaining 20% is accounted for the investment-specific technological change. ICT equipment provide most of this contribution, from 0.49 to 0.43 percentage points, whereas contribution from non-ICT equipment provide around 0.20 percentage points. It is important to note that the contribution from structures is negative, around -0.2 percentage points. This results from the fact that relative prices of structures decreased in Japan during the sample period.[6] The calibrated

[6] Martínez, Rodríguez and Torres (2008b) also find negative contribution from struc-

saving rate moves within an interval from 15.5% to 20.0%. Estimated technological parameters are also provided in the subsequent lines of the table. Hayashi and Prescott (2002) estimate a discount factor for Japan $\beta = 0.976$ and Hayashi and Nomura (2005) use a value of 0.964. Our benchmark model produces this same discount factor when the after tax discount rate of 6-7%, with a stationary investment rate of 15-17%.

Miyagawa, Ito and Harada (2004) study the contribution of IT investment to productivity growth in Japan at an industry level. These authors decompose labor productivity growth into intra-sectoral capital deepening, efficiency effects of capital deepening, efficiency effects of labor shifts, and intra-sectoral TFP growth, showing that the productivity slowdown in the 1990s was caused by the reduction in the efficiency effects of labor shifts. Shinjo and Zhang (2003), estimating the marginal Tobin's q-ratios of IT capital, show the existence of an overinvestment in IT capital relative to non-IT capital in the US, but the opposite in the case of Japan. Tokui, Inui and Kim (2008) analyze embodied technological progress in the Japanese economy using firm-level data. These authors estimate a production function with several control variables accounting for technological progress, obtaining that the average rate of technological progress embodied in machinery and equipment is between 0.2 and 0.4 percent.

U.S.A. Results are reported in table 4. The calibrated value of productivity growth is again nearby the observed one and robust to the assumed after tax return rate on capital. Productivity growth is now dominated by the investment specific technological change, mainly due to the contribution of the technology embedded in the ICT assets, 0.70. This ICT contribution widely exceeds that of the neutral change. Neutral technological change contribution to productivity growth is between 0.32 and 0.47 percentage points. Therefore, the implicit technical change account for a fraction between 70% and 60% of the total productivity growth. This is in line with the 58% result provided by Greenwood *et al.* (1997). The contribution of structures is very low, 0.03 percentage points. This results is also in line with the one in Greenwood *et al.* (1997) as they assume that the contribution of structures to productivity growth is zero, given the assumption of no technological progress associated to this capital asset. The contribution to productivity growth from non-ICT equipment is around 0.05 percentage points. The saving rate moves within an interval from 14.2% to 11.2%. Greenwood *et al.* (1997) propose a discount factor for the US of $\beta = 0.97$, and an investment rate of 11.4%. Like in the case of Japan, our exercise produces this rates

tures in the case of some European countries.

when the after tax discount rate is assumed to be 6-7%. Not surprisingly, the technological change decomposition replicates the 58% result given by Greenwood et al. (1997) for a different period.

Germany. Results are finally reported in table 5. The calibrated value of productivity growth fits the observed one. Productivity growth is now dominated by the neutral technological change as in the case of Japan. Neutral change produces increases in productivity of around 1.85 percentage points. Therefore, the neutral technical change account for a fraction of 80% of total productivity growth with implicit technical change accounting for the rest. The contribution of ICT equipment is between 0.36 and 0.41 percentage points. Contribution from non-ICT equipment is about 0.07 percentage points whereas contribution from structures is of 0.02 percentage points. These results are very similar to the ones obtained for the US. The saving rate moves within an interval from 13.2% to 16.7%. Fernández de Córdoba and Kehoe (2000) and Bems and Hartelius (2006) estimate values for the German discount factor of 0.95-0.96. Again, our exercise produces this rates when the after tax discount rate is assumed to be between 6% and 7%.

In view of these tables, there are four results that we would like to highlight. *First*, neutral technological change dominates productivity growth in Japan, 70%, and Germany, 80%, while investment specific technological change accounts for a fraction of 60% of the US productivity growth. This implies that the sources of long run productivity growth are very different in the US economy as compared with the Japanese and the German economies. It is important to note the differences in the average productivity growth across countries during the sample period (see table 1). Average productivity growth is higher in Japan and Germany than in the US. The contribution to productivity growth from implicit technological change is around 0.45 percentage points for Japan, 0.5 percentage points for Germany and 0.75 percentage points for the U.S. Another difference is found in the contribution from neutral technological change. In this case we obtain a value of 1.71 percentage points for Japan, 1.85 percentage points for Germany and only a value of 0.4 percentage points for the U.S. This factor accounts for an important fraction of productivity growth in Japan and Germany with respect to the US economy during the sample period.

Second, technology embedded in the ICT assets are the main source of the specific change. With only ICT investment-specific technological change, productivity growth would have increased by 0.41% in Japan, 0.46% in Germany and 0.71% in the US. Table 1 reported that productivity growth is declining in Japan, increasing in the US and stable in Germany, and table

2 reported that the US has invested in ICT assets more than Japan and Germany have done, while the amount of technology implicit in the ICT assets is the highest one, as measured by the $\eta_i' s$, $i \in \{str, nict, ict\}$. This supports other results that make the ICT responsible of the upsurge in the US productivity growth during the nineties.

Third, the contribution to productivity growth from "traditional" non-ICT equipment shows dramatic differences across countries. Whereas this contribution is about 0.06 percentage points for the US and Germany, in the case of Japan this figure is 0.25 percentage points. This implies that technological change associate to non-ICT equipment is much larger in the Japanese economy than in the other two countries, being an important factor explaining the larger productivity growth in Japan as compared with Germany and the US.

Finally, when we compare our exercise with other calibrations, we see that the model demands an after tax return rate of about 6-7% for all countries, a result consistent with a non-arbitrage condition under international free capital mobility.

A conclusion derived from the previous results seems to indicate that the US is the leading economy in the new information and communication era. However, if we pay attention at the contribution from total (ICT and non-ICT) investment-specific technological change, during the period 1977-2005, Japan have been the leading country. Average contribution to productivity growth from specific-technological change have been of about 1.5 percentage points for Japan, 0.75 points for the US and 0.5 points for Germany. On the other hand, Japan have been the country with the larger average productivity growth during the period. Yet, in order to study how specific technological change has evolved over time, we repeat the previous analysis by splitting the sample period into two periods, 1977-1990 and 1991-2005, using an after-tax rate of return of 6.5% for the three countries. Results are summarized in table 6. Our results are consistent with the ones presented by Fukao and Miyagawa (2007) for the three countries. These authors show that the US has experienced a very rapid increases in ICT capital after 1995. On the contrary, ICT capital in Japan in 2004 were less than twice as high as their 1995 level. Jorgenson and Motohashi (2005) show that the contribution of IT capital in Japan declined during the first half of the 1990s, but rebounded strongly after 1995. In our case, ICT contribution to productivity growth remains constant, on average, between the periods 1977-1995 and 1995-2005.

In the US we obtain that ICT contribution to productivity growth is similar in both sub-periods, about 0.62 percentage points. Jorgenson and

Motohashi (2005) using a traditional growth accounting obtained that the contribution from ICT to output growth is larger in the second subperiod compared with the first one. Non-ICT contribution increases, from a 0.01 to 0.13 percentage points. However, contribution from investment-specific technological change decreases in the second subperiod for the US. This result is affected by the negative contribution of structures. Whereas average contribution from structures is close to zero for the whole period, we find important differences across time. In fact, whereas in the period 1977-1995 average contribution is 0.16 percentages points, contribution from structures is negative (-0.2 percentage points) during the period 1995-2005.

Neutral technological change is the main source of productivity growth for the three countries and about 75-80% of total productivity growth is due to this source of technological change during 1995-2005. Comparing both subperiods of time, we obtain that neutral technological change contribution to productivity growth decreases in Japan, increases in the US and remains almost constant in Germany. This is consistent with the results obtained by Hayashi and Prescott (2002) in which low productivity growth in Japan in the 1990s is associated to the reduction in total factor productivity growth. Average neutral technological change contribution is negative in the US economy during the period 1977-1995. This result is produced by the first years of the sample period, in which TFP growth was negative. However, recovery of TFP growth has been very remarkable during the period 1995-2005.

5 Short-run analysis

In this section we analyze the quantitative effects of cyclical fluctuations both from neutral and investment-specific technological shocks. Whereas neutral technological shocks have been extensively studied in the literature, the model developed in the previous sections allows us to study the effect of three additional types of investment-specific technological shocks. That is, we can study the effects of technological shocks to the three types of capita assets under consideration (structures, non-ICT equipment and ICT equipment. For instance, it is possible to quantify the effect of a shock to equipment as compared with a shock to structures.

We assume that the stochastic structure governing the evolution of the implicit technological shocks is given by

$$
\begin{aligned}
\ln Q_{i,t} &= a_i + \ln(\eta_i) t + u_{i,t}, \\
u_{i,t} &= \rho_i u_{i,t-1} + \varepsilon_{i,t} \\
\varepsilon_{i,t} &\sim iid\mathcal{N}\left(0, \sigma_i^2\right).
\end{aligned} \tag{30}
$$

with $0 < \rho_i < 1$, for $i \in \{str, nict, ict\}$. This means that this process is the sum of a trend and a cycle. The fundamental shock $\varepsilon_{i,t}$ has a transitory impact on the level of the cyclical component $u_{i,t}$, whose persistency is given by ρ_i The long run growth rate of $Q_{i,t}$ is $\ln \eta_i$. Analogously the process for the neutral technological change is:

$$
\begin{aligned}
\ln A_t &= a_A + \ln(g_A) t + u_{A,t}. \\
u_{A,t} &= \rho_A u_{A,t-1} + \varepsilon_{A,t}, \\
\varepsilon_{A,t} &\sim iid\mathcal{N}\left(0, \sigma_A^2\right).
\end{aligned} \tag{31}
$$

We also assume that these shocks are orthogonal $E(\varepsilon_{i,t}\varepsilon_{j,t}) = 0$, for any $i, j \in \{str, nict, ict, A\}$ and $i \neq j$. These processes are filtered and written as

$$
\begin{aligned}
\ln Q_{i,t} &= \gamma_{i,0} + \gamma_{i,1} t + \rho_i \ln Q_{i,t-1} + \varepsilon_{i,t}, \\
\text{with } \gamma_{i,0} &= (1 - \rho_i) a_i + \rho_i \ln(\eta_i), \\
\gamma_{i,1} &= (1 - \rho_i) \ln(\eta_i), \\
&\quad \text{given } \ln(\eta_i),
\end{aligned} \tag{32}
$$

The process for the neutral technological change has an analogous obvious representation. A value for $\{\alpha_i, \rho_i, \sigma_i\}$ is obtained using a maximum likelihood estimator. Results are shown in table 7.[7]

We next study how these shocks affect the economy around the balance growth path, using the impulse response functions from a log-linear version of previous model. The neutral shock, $\varepsilon_{A,t}$, has a direct immediate impact on output by raising the total factor productivity A_t. Its short-run effect on consumption is always positive due to the income effect. A non neutral shock affects the after-tax real rate of return that implies an intertemporal substitution in consumption from (12), and a substitution between consumption

[7] Greenwood *et al.* (2000) for the US economy estimate a parameter of 0.64 for equipment technological change. Pakko (2005), using a similar model for the US, estimates a parameter of 0.945 for the neutral technological change and a value of 0.941 for the equipment technological change, very similar to our estimates.

and leisure. Output is therefore affected in the current period through the impact on labor supply and on saving decisions.

Instead, a non neutral shock in asset $i \in \{str, nict, ict\}$ only affects the marginal product of i. This induces a substitution in the portfolio of assets: a higher investment in asset i and a disinvestment in the remaining ones. The net effect on total savings depends on the substitution effect and the portfolio composition. Savings also increase due to the rise in returns to labor and the increases in labor supply (or a reduction in leisure). In the following and subsequent periods, a positive non-neutral shock in asset $i \in \{str, nict, ict\}$ impulses the marginal product of own and the remaining factors in the production function, which implies the existence of a complementary effect.

Labor productivity therefore increases in response to a neutral shock (output increases more than hours worked). But a non neutral shock can have a negative immediate impact on productivity. In response to a non neutral shock in $i \in \{str, nict, ict\}$, there is an increase in investment in asset i and in total investment that produces a decrease in consumption. Given the wage, leisure must also decrease. This produces a rise in hours worked. Note that $\alpha_L < 1$ is the elasticity of output with respect to labor. A one percent increase in the amount of hours worked produces a less than proportional increase on output of α_L percent.[8]

Figures 3 to 5 plot the impulse response of productivity growth, consumption growth and investment growth, respectively, in response to a 1% increase in the four shocks. In the impulse response figures, steady state productivity growth have been normalized to zero. So, the figures show deviations of variables growth rates with respect to the steady state.

In the three economies under consideration, labor productivity increases in response to a positive neutral technological shock. The highest (positive) impact occurs in the first period and declines thereafter. The immediate response is similar in the three countries: labor productivity growth increases by 0.75 percentage points in response to a 1% neutral shock. Specific technological shocks have a negative impact effect on productivity growth, showing a hump-shaped impulse response. A technological shock to structures has a negative impact on productivity, according to the previous arguments. Only a few periods afterwards the effect turns out positive, given that the effect of this shock on labor is larger than on output. In quantitative terms, the larger negative impact is observed for the Japanese economy. A technologi-

[8] Miyagawa, Sakuragawa and Takizawa (2006) using a VAR approach with Japanese firm-level data find that a positive technology shock results in a reduction of labor input on impact indicating the existence of an adjustment cost of investment.

cal shock to non-ICT equipment also has a negative impact on productivity but it becomes positive thereafter. The short run effect of an ICT shock on productivity is also negative but negligible. Concerning the persistency of these shocks, all shocks have a cumulative positive effect on productivity in the medium and the long term.

Figure 4 presents the impulse-response for consumption growth. Consumption growth increases in response to a positive neutral shock. However, non neutral shocks induce a suddenly decrease in consumption growth, provoked by the positive impact on investment growth but the effect turns out positive afterwards, showing also a hump-shaped impulse-response. Again the larger effects correspond to a technological shock to structures while the effect of a technological shocks to ICT equipment is negligible.

Figure 5 shows the impulse-responses for investment growth. For each country we compute four impulse-response functions, corresponding to (the growth rates of) structures, non-ICT equipment, ICT equipment and total investment, in terms of the four technological shocks. Neutral technological shock provokes an immediate positive response of total investment growth above the steady state growth rate but thereafter the effect turns out negative for some period with a total investment growth rate below the steady state value. A similar qualitative effect of neutral technological shocks is observed with respect to structures investment growth but of lesser quantitative importance. However, structures technological shocks has a very positive impact effect on structures investment growth but in the next period the effect becomes negative as structures investment growth lower than its steady state growth value. A non-ICT technological shock has a negative impact effect on structures investment growth

The most interesting result is the response of ICT equipment investment growth and non-ICT equipment investment growth. On the one, the immediate impact of a shock on asset i moves decisions to invest in this asset: the weight in the portfolio of asset i increases and decreases the weight of the remaining ones. However, this effect revert in the next period, indicating that the different capital assets are complementaries in the short-run, in spite of the rivalry existing among different capital assets in the investment process. On the other hand, a structures technological shock has important effects on equipment, both ICT and non-ICT, investment growth. In fact, a positive structures technological shock has an immediate negative effect on investment growth in both ICT and non-ICT equipment indicating the existence of a substitution effect which provokes a reallocation in the portfolio assets. On the other hand, the effect of a non-ICT technological shock on ICT equipment investment growth and the effect of a ICT technological shock on non-ICT equipment investment growth, are in both cases negligible. This implies that there is no substitution effect between the two types of capital equipment given a specific shock to each one. Finally, a neutral technological shock has a very small effect on ICT and non-ICT equipment investment growth.

Finally, table 8 reports the variance decomposition of productivity, consumption and investment. It is worth mentioning that most in the variability of productivity, around 90% for the three countries, is accounted for by the neutral shock in the short run. In the medium and long-run, neutral shock is the responsible of about 80% of productivity variability in the US and about 75% in Germany. In Japan, the non neutral shocks account for a fraction of a 40% of this variance in the medium and the long term.[9] As regards consumption and saving decisions, most of this variability is due to the shock to structures. Note that this shock has been usually neglected in another similar analysis (i.e. $Q_{str,1} = 1$ constant for all period). The variability of ICT investment is mainly guided by shocks to the ICT, whereas variability of non-ICT investment is explained by a shock to both structures and non-ICT technical change. Total investment variability is mainly explained by neutral technological shocks and shocks to structures.

6 Concluding remarks

This paper investigates the contribution of different sources of technological progress to productivity growth in three leading world economies, i.e., Japan, Germany and the United States. We use a dynamic general equilibrium growth model with investment-specific technological progress, which allows to decompose productivity growth in four different technology progress sources: neutral technological change and three different investment-specific technological change, associated to three different capital assets: structures, non-ICT equipment and ICT.

The results obtained from the calibration of the model suggests that, in the long-run, the sources of productivity growth are different across the three countries. Investment-specific technological change is more important in the US than in Japan and, specially, than in Germany. This differences is mainly due to the technological progress associated to ICT capital assets, more intensive in the US than in the other two economies. On the

[9] Braun and Shioji (2007) estimate a SVAR model showing that investment-specific technological shocks are at least as important as neutral technology shocks in Japan's business cycles.

other hand, contribution from neutral technological change is much more important in Japan and Germany, than in the US. This factor is the main responsible of the larger productivity growth showed by the Japanese and German economies, as compared with the US economy. However, the contribution to productivity growth from ICT capital is much larger in the US than in Japan and Germany. Additionally, we obtain that "traditional" non-ICT capital technological progress plays an important role in the Japanese productivity growth, whereas its contribution in Germany and the US is very low.

Our results seems to provide an "optimistic" rather than a "pessimistic" view of the Japanese economy, showing a similar behavior to the German economy. Those results are consistent with the projections of Jorgenson and Motohashi (2005) in which labor productivity growth will be similar for Japan and the US, but with output growth larger in the US, due to the slower growth in labor input in the Japanese economy.

Finally, we show how the different technology shocks induce different responses of the economy. Particularly of interest is that a technological shock in non-ICT equipment and structures moves labor productivity and consumption growth downward their balanced growth paths. Technological shocks specific to each capital asset change the portfolio weight of the economy. We find a high degree of substitution between structures and equipment, whereas we find a high degree of complementarity between ICT equipment and non-ICT equipment in the investment decision process.

References

[1] Baily, M. and Lawrence, R. (2001): Do We Have a New E-Conomy?, *American Economic Review,* 91, 308-312.

[2] Bems, R. and K.J. Hartelius (2006): Trade deficits in the Baltic States: How long will the party last?, *Review of Economic Dynamics,* 9, pp. 179-209.

[3] Boscá, J., García, J. and Taguas, D. (2008): Taxation in the OECD: 1965-2004, Working Paper, Misterio de Economía y Hacienda, Spain.

[4] Braun, R. and Shioji, E. (2007): Investment specific technological changes in Japan, *Seoul Journal of Economics*, 20, n. 1.

[5] Cummins, J.G. and Violante, G. L. (2002): Investment-specific technical change in the US (1947-2000): Measurement and macroeconomic consequences, *Review of Economic Dynamics*, 5, 243-284.

[6] Fernández de Córdoba, G. and T. Kehoe (2000): Capital flows and real exchange rate fluctuations following Spain's entry into the European Community. *Journal of International Economics,* 51, 49-78.

[7] Fukao, K. and Miyagawa, T. (2007): Productivity in Japan, the US, and the mayor EU economies: Is Japan falling behind? *RIETI Discussion Paper Series* 07-E-046.

[8] Gollin, D. (2002): Getting Income Shares Right. *Journal of Political Economy*, 110, pp. 458-474.

[9] Greenwood, J., Hercowitz, Z. and Krusell, P. (1997): Long-run implication of investment-specific technological change, *American Economic Review,* 87, 342-362.

[10] Greenwood, J., Hercowitz, Z. and Krusell, P. (2000): The role of investment-specific technological change in the business cycle, *European Economic Review,* 44, 91-115.

[11] Hayashi, F. and Prescott, E. (2002): The 1990s in Japan: A lost decade, *Review of Economic Dynamics*, 5, 206-235.

[12] Inklaar, R., McGuckin, R. and van Ark, B. (2003): ICT and productivity in Europe and the United States: Where do the differences come from? *Economics Program Working Paper Series*, n. 03-05, The Conference Board, New York.

[13] Inklaar, R., Timmer, and van Ark, B. (2005): ICT and productivity in Europe and the United States. Where the differences come from?, *The Conference Board EPWP* 03-05.

[14] Jorgenson, D. W. (2001): Information Technology and the US Economy, *American Economic Review,* 91, 1-32.

[15] Jorgenson, D. (2002): *Economic growth in the information age.* MIT Press, Cambridge.

[16] Jorgenson, D. and Motohashi, K. (2005): Information technology and the Japanese economy. *Journal of the Japanese and International Economies*, 19, 460-481.

[17] Jorgenson, D. and Stiroh, K. J. (2000): Raising the Speed Limit: U.S. Economic Growth in the Information Age, *Brooking Papers on Economic Activity,* 1, 125-211.

[18] Martínez, D., J. Rodríguez and Torres, J.L. (2008a): The productivity paradox and the new economy: The Spanish case. Forthcoming in *The Journal of Macroeconomics*, 30, 1169-1186.

[19] Martínez, D., J. Rodríguez and Torres, J.L. (2008b): Productivity growth and technological change in Europe and the US, Mimeo.

[20] Mendoza, E., Razin, A., and Tesar, L. (1994): Effective tax rates in macroeconomics. Cross-country estimated of tax rates on factor incomes and consumption, *Journal of Monetary Economics,* 34, 297-323.

[21] Miyagawa, T., Ito, Y., and Harada, N. (2004): The IT revolution and productivity growth in Japan. *Journal of the Japanese and International Economies*, 18, 362-389.

[22] Miyagawa, T., Sakuragawa, Y., and Takizawa, M. (2006): The impact of technology shocks on the Japanese business cycle- An empirical analysis based on the industry data, *Japan and the World Economy*, 18, 401-417.

[23] Oliner, S. and Sichel, D. (2000): The resurgence on growth in the late 1990s: Is information technology the story?, *Journal of Economic Perspectives,* 14, 3-22.

[24] Pakko, Michael R. (2005): Changing Technology Trends, Transition Dynamics, and Growth Accounting, *The B.E. Journal of Macroeconomics, Contributions,* 5(1), Article 12.

[25] Shinjo, K. and Zhang, X. (2003): Productivity analysis of IT capital stock: The USA-Japan comparison. *Journal of the Japanese and International Economies*, 17, 81-100.

[26] Sonobe, T. and Otsuka, K. (2001): A new decomposition approach to growth accounting: derivation of the formula and its application to prewar Japan. *Japan and the World Economy*, 12, 1-14.

[27] Timmer, M. and van Ark, B. (2005): Does information and communication technology drive EU-US productivity growth differentials?, *Oxford Economic Papers,* 57, 693-716.

[28] Tokui, J., Inui, T. and Kim. Y. (2008): Embodied technological progress and productivity slowdown in Japan, *RIETI Discussion Paper Series* 08-E-017.

[29] Vijselaar, F. W. and Albers, R. M. (2002): New Technologies and Productivity Growth in the Euro Area, *ECB Working Papers* No. 122.

Table 1: Productivity growth rates 1977-2005

	Japan	**U.S.A.**	**Germany**
1977-1980	4.09	-0.26	2.91
1980-1990	3.79	0.95	2.17
1990-2000	2.24	2.07	2.88
2000-2005	2.08	2.10	1.44
1977-2005	2.90	1.44	2.37

Table 2: Parameters values

	Japan	**U.S.A.**	**Germany**
g	1.0302	1.0144	1.0237
v	0.3530	0.3660	0.2998
α_L	0.6387	0.7248	0.7412
δ_{str}	0.0286	0.0277	0.0310
δ_{nict}	0.1261	0.1284	0.1259
δ_{ict}	0.2209	0.1933	0.1813
ω_{str}	0.3747	0.3545	0.3783
ω_{nict}	0.4795	0.3930	0.4717
ω_{ict}	0.1458	0.2525	0.1500
η_{str}	0.9917	1.0017	1.0017
η_{nict}	1.0073	1.0043	1.0046
η_{ict}	1.0674	1.0916	1.0914
τ^c	0.0510	0.0470	0.1130
τ^l	0.2510	0.2300	0.3390
τ^k	0.3850	0.3300	0.2420

Table 3: Japan, 1977-2005

After tax return rate, $(g/\beta - 1) \times 100$	**4%**	**5%**	**6%**	**7%**
Observed productivity, g	2.97	2.97	2.97	2.97
Calibrated productivity, (a)+(b)	2.13	2.13	2.13	2.12
Neutral change (a)	1.63	1.68	1.71	1.75
Implicit change (b)=(b1)+(b2)+(b3)	0.50	0.45	0.41	0.38
Structures (b1)	-0.19	-0.20	-0.21	-0.22
NICT equipment (b2)	0.19	0.18	0.18	0.17
ICT equipment (b3)	0.49	0.47	0.45	0.43
Discount factor, β	0.9906	0.9811	0.9719	0.9628
Investment rate	20.08	18.29	16.79	15.52
Cost shares				
Structures, α_{str}	0.1461	0.1551	0.1626	0.1690
NICT equipment, α_{nict}	0.1660	0.1600	0.1550	0.1507
ICT equipment, α_{ict}	0.0492	0.0462	0.0438	0.0417
Decomposition of technological change				
Neutral	76.53	78.76	80.63	82.23
Implicit	23.47	21.24	19.37	17.77

Table 4: U.S.A., 1977-2005

After tax return rate, $(g/\beta - 1) \times 100$	**4%**	**5%**	**6%**	**7%**
Observed productivity, g	1.43	1.43	1.43	1.43
Calibrated productivity, (a)+(b)	1.11	1.13	1.15	1.16
Neutral change (a)	0.32	0.38	0.42	0.47
Implicit change (b)=(b1)+(b2)+(b3)	0.79	0.75	0.72	0.70
Structures (b1)	0.03	0.03	0.03	0.03
NICT equipment (b2)	0.06	0.05	0.05	0.05
ICT equipment (b3)	0.70	0.67	0.64	0.61
Discount factor, β	0.9754	0.9661	0.9570	0.9481
Investment rate	14.19	13.02	12.02	11.17
Cost shares				
Structures, α_{str}	0.1190	0.1249	0.1299	0.1342
NICT equipment, α_{nict}	0.0978	0.0949	0.0925	0.0904
ICT equipment, α_{ict}	0.0584	0.0554	0.0528	0.0506
Decomposition of technological change				
Neutral	28.98	33.49	37.18	40.27
Implicit	71.01	66.51	62.81	59.72

Table 5: Germany, 1977-2005

After tax return rate, $(g/\beta - 1) \times 100$	**4%**	**5%**	**6%**	**7%**
Observed productivity, g	2.37	2.37	2.37	2.37
Calibrated productivity, (a)+(b)	2.31	2.31	2.31	2.31
Neutral change (a)	1.80	1.82	1.84	1.86
Implicit change (b)=(b1)+(b2)+(b3)	0.51	0.48	0.47	0.45
Structures (b1)	0.02	0.02	0.02	0.03
NICT equipment (b2)	0.07	0.07	0.07	0.06
ICT equipment (b3)	0.41	0.39	0.37	0.36
Discount factor, β	0.9839	0.9745	0.9653	0.9563
Investment rate	16.70	15.34	14.19	13.19
Cost shares				
Structures, α_{str}	0.1084	0.1132	0.1174	0.1210
NICT equipment, α_{nict}	0.1153	0.1122	0.1095	0.1072
ICT equipment, α_{ict}	0.0351	0.0333	0.0319	0.0306
Decomposition of technological change				
Neutral	77.98	78.90	79.69	80.37
Implicit	22.01	21.09	20.30	19.63

Table 6: Contribution to growth, 1977-1995 versus 1995-2005

	Japan		USA		Germany	
	77-95	95-05	77-95	95-05	77-95	95-05
Observed productivity, g	3.41	2.19	0.92	2.28	2.68	2.28
Calibrated productivity, (a)+(b)	2.43	1.55	0.50	2.22	2.46	2.44
Neutral change (a)	2.06	1.17	-0.28	1.67	2.08	1.94
Implicit change (b=b1+b2+b3)	0.37	0.37	0.79	0.55	0.37	0.51
Structures (b1)	-0.27	-0.14	0.16	-0.20	-0.16	0.09
NICT equipment (b2)	0.21	0.10	0.01	0.13	0.20	0.04
ICT equipment (b3)	0.43	0.42	0.62	0.62	0.34	0.38
Percentage						
Neutral	0.85	0.76	-	0.75	0.85	0.79
Implicit	0.15	0.24	-	0.25	0.15	0.21

Table 7: Estimation of parameters

	Japan	**U.S.A.**	**Germany**
ρ_{str}	0.9030	0.9726	0.8419
σ_{str}	0.0195	0.0180	0.0096
ρ_{nict}	0.9461	0.9221	0.9495
σ_{nict}	0.0162	0.0104	0.0102
ρ_{ict}	0.9388	0.8472	0.3871
σ_{ict}	0.0478	0.0274	0.0186
ρ_{A}	0.8522	0.9478	0.7239
σ_{A}	0.0154	0.0142	0.0087

Table 8: Forecast error variance decomposition

	Japan				USA				Germany			
	ε_{str}	ε_{nict}	ε_{ict}	ε_A	ε_{str}	ε_{nict}	ε_{ict}	ε_A	ε_{str}	ε_{nict}	ε_{ict}	ε_A
Time						Productivity						
1	12.16	0.16	0.00	87.67	7.56	0.04	0.00	92.40	8.31	0.29	0.00	91.40
5	13.67	18.93	9.31	58.09	11.03	3.21	4.68	81.08	10.18	11.67	3.44	74.72
10	13.56	19.28	9.58	57.57	11.96	3.23	4.63	80.18	10.17	11.76	3.37	74.70
50	13.58	19.11	9.53	57.78	11.83	3.18	4.55	80.44	10.22	11.74	3.35	74.69
						Consumption						
1	83.79	1.13	0.00	15.08	77.95	0.38	0.01	21.66	74.26	2.58	0.04	23.12
5	67.95	8.80	3.33	19.91	65.78	1.59	1.27	31.36	65.05	8.73	1.00	22.22
10	66.47	9.91	3.98	19.63	65.67	1.68	1.30	31.35	67.14	9.20	0.98	22.68
50	65.85	9.87	4.04	20.24	64.75	1.66	1.28	32.30	66.82	9.18	0.97	23.02
						Structures investment						
1	65.08	27.34	2.55	5.02	82.21	8.12	2.16	7.51	67.77	23.02	1.50	7.71
5	61.64	32.03	3.57	2.76	80.37	11.14	3.72	4.77	63.86	28.24	2.91	4.99
10	61.62	32.03	3.57	2.79	80.33	11.13	3.72	4.82	63.85	28.24	2.91	5.01
50	61.61	32.03	3.57	2.79	80.32	11.13	3.72	4.83	63.85	28.24	2.91	5.01
						Non-ICT investment						
1	49.21	50.58	0.00	0.20	69.52	29.84	0.01	0.64	46.49	53.07	0.02	0.42
5	50.57	49.30	0.01	0.12	70.62	28.98	0.04	0.36	48.50	51.16	0.06	0.27
10	50.57	49.30	0.01	0.12	70.62	28.98	0.04	0.36	48.50	51.16	0.06	0.28
50	50.57	49.30	0.01	0.12	70.61	28.98	0.04	0.36	48.50	51.16	0.06	0.28
						ICT investment						
1	11.29	0.00	88.68	0.03	27.58	0.03	72.15	0.25	13.53	0.12	86.31	0.04
5	11.18	0.01	88.80	0.02	26.72	0.05	73.08	0.15	10.64	0.13	89.21	0.02
10	11.18	0.01	88.80	0.02	26.72	0.05	73.08	0.15	10.64	0.13	89.21	0.02
50	11.18	0.01	88.80	0.02	26.72	0.05	73.08	0.15	10.64	0.13	89.21	0.02
						Total investment						
1	39.32	0.59	0.00	60.09	50.76	0.29	0.01	48.94	39.61	1.55	0.02	58.81
5	49.17	9.88	5.73	35.21	56.78	1.68	3.28	38.26	44.86	4.96	2.47	47.41
10	48.91	9.90	5.73	35.46	56.58	1.70	3.29	38.44	44.77	5.00	2.46	47.76
50	48.89	9.91	5.73	35.47	56.56	1.70	3.28	38.46	44.77	5.01	2.46	47.76