The Devil is in the Details: Capital Stock Estimation and Aggregate Productivity Growth—An Application to the Spanish Economy *

Francisco-Javier Escribá-Pérez[a], María-José Murgui-García[b] and José-Ramón Ruiz-Tamarit[c]

Abstract:

The variables that contribute to explaining the major puzzles and paradoxes in macroeconomics and economic growth literature always appear related, directly or indirectly, to capital stock and depreciation. Depreciation defined in a narrow sense refers only to physical wear and tear, but in a broader sense, it also includes economic deterioration and obsolescence. In this study, we explore the link between these two depreciation concepts, the capital deepening and total factor productivity (TFP) growth. We propose a double growth accounting framework that allows us to establish a relationship between variables in statistical terms and variables in economic terms. Then, with Spanish data for 1964–2015, we first analyze the role played by capital intensity and TFP in explaining the evolution of labor productivity. The results are substantially different depending on whether we use statistical or economic measures of capital and depreciation. Second, we focus on the paradox of productivity, concluding that the apparent absence of a positive correlation between investment in information and communication technology and the TFP growth rate may be due to the delay effect associated with such investment combined with the statistical under-estimation of true economic depreciation.

Keywords: Capital, Depreciation, ICT, Slowdown, TFP.

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[a] Department of Economic Analysis, Universitat de València (Spain).

[b] Corresponding author. Department of Economic Analysis, Universitat de València (Spain). Address: Facultat d'Economia, Av. dels Tarongers s/n, 46022 València, España. Tel.: (+) 34 96 3828779; Fax: (+) 34 96 3828249; maria.j.murgui@uv.es

[c] Department of Economic Analysis, Universitat de València (Spain) and Department of Economics IRES, Université Catholique de Louvain (Belgium); ramon.ruiz@uv.es

1. Introduction

Labor productivity growth is widely recognized as the direct source of sustained long-run growth. It is therefore responsible for the improvements in well-being that societies in developed countries have enjoyed since the second half of the 20th century. Nevertheless, during the last fifty years, the evolution of labor productivity has experienced significant slowdowns and accelerations; the interest researchers have placed in these movements attests to their relevance. However, despite the efforts made, there are still some puzzles and unresolved paradoxes when it comes to explaining such ups and downs.

The story of labor productivity is a story of two fundamental indicators associated with economic growth: the dynamics of capital deepening and technological change. The former requires measuring capital stock, and the latter is computed residually as the total factor productivity (TFP) growth rate. We can therefore identify capital depreciation as a key variable that connects capital-labor ratio and TFP growth rates. Thus, depreciation emerges as one of the most important factors behind the declines and advances observed in labor productivity growth.

Solow (1957) describes the growth accounting technique that is today the most common method for calculating TFP growth. This method of measuring productivity involves comparing trends in output and inputs. Consequently, accounting exercises could generate sizeable biases if output and/or input services are measured inaccurately.[1] In fact, given that no satisfactory explanation has yet been found for the persistent productivity slowdown observed since the early 1970s in the United States and other industrialized countries, many researchers have been reviewing the data looking for possible errors in measuring output and inputs.[2]

In the context of multi-factor productivity estimations, capital depreciation, which too often has been treated as an irrelevant aggregate in macroeconomics, becomes important because how we measure it plays a major role in measuring both capital stock and TFP growth. According to the perpetual inventory method (PIM), the current capital stock is the result of adding up gross investment flow and subtracting the flow of capital depreciation. Many studies, such as Feldstein and Rothschild (1974), Nickell (1975), Hulten and Wykoff (1981), Hulten (1990), Jorgenson (1996), and Bitros and Flytzanis (2016), claim that depreciation should be considered an economic decision that depends endogenously on market conditions. However, since Jorgenson (1963), growth

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[1] Solow's original work also included some theoretical assumptions that, if violated, would contribute to the mismeasurement of TFP growth. These assumptions are that all inputs adjust instantly to their optimal levels, there are constant returns to scale, there are no external factors, and the economy is perfectly competitive. Several authors have since questioned their validity, considering the effects of quasi-fixed and external inputs, non-constant returns to scale, a variable degree of capacity utilization, or imperfect competition, allowing them to propose alternative measures of TFP growth using the primal approach (Basu et al., 2006) as well as the dual approach (Morrison and Schwartz, 1996).

[2] Baily (1981) considered the US productivity slowdown a consequence of poorly measuring the services of capital, and suggested using the economic value of capital stock computed as Tobin's average q.

accounting exercises have traditionally assumed that the useful life of capital goods is exogenously determined by technological parameters, and depreciation is therefore calculated at a constant exponential rate. This approach to depreciation correctly accounts for physical deterioration (wear and tear or simple efficiency losses caused by aging and the regular and constant use of capital), but not economic deterioration and obsolescence. Given that the latter two are very important for an encompassing capital measurement, the constant rate of depreciation associated with the proportionality hypothesis raises the question as to whether TFP growth measurements are therefore biased.

There are two methodological approaches that allow integrating economic deterioration and obsolescence into capital theory. The first focuses on retirements, scrapping, and withdrawals. It uses vintage capital models and emphasizes the fact that machines are replaced by new equipment that increases capital efficiency. The second endogenizes depreciation by introducing the mechanisms of capital maintenance, depreciation-in-use, and technical progress into the basic model of the optimizing firm with cost of capital adjustments. In both cases, we find the rate of depreciation is no longer an exogenous and constant parameter, but a decision variable that may increase or decrease depending on the prevailing economic conditions. We should therefore expect a negative relationship between the depreciation rate and the process of capital deepening, but a positive relationship between the depreciation rate and TFP growth.

Musso (2004, 2006) and Mukoyama (2008) analyze the above propositions in the context of a vintage capital model and prove that any distortion in the measurement of capital stock may cause a substantial bias in measuring TFP growth. These authors perform numerical exercises, calibrating model parameters and assigning different values to the depreciation rate. They find the higher the depreciation rate, the lower the mismeasurement of TFP growth, allowing them to account for much of the observed slowdown in labor productivity since the 1970s. Escribá-Pérez et al. (2018, 2019), in the context of an extension of the conventional model of the firm that admits the existence of a well-defined capital stock, prove that the economic value of depreciation and capital stock are poorly measured when we use the PIM to compute them and assume the hypothesis of proportionality.

In this study, we go further and explore the theoretical relationship between the depreciation rate and the TFP growth rate. The economic and statistical values of capital, as well as the corresponding depreciation rates, are introduced to analyze whether the new measures in economic terms can help explain two of the main unresolved issues in the empirical literature concerning productivity and growth: the role of TFP growth measurement in explaining the labor productivity puzzles and the role of obsolescence in explaining the paradox of productivity that traditionally focused on information and communications technology (ICT). Thus, a double exercise of Solow’s growth accounting is possible, allowing for an interesting comparison. By decomposing twofold the aggregate output growth and labor productivity growth, depending on the different measures of TFP growth and capital deepening, we can obtain the relationship between these variables and the two different measures of depreciation. One is technical and exogenous, representing wear and tear, and the other comes about endogenously, including economic deterioration and obsolescence.

We present our empirical exercises using the available data for the non-financial business sector of the Spanish economy from 1964 to 2015. We analyze the role played by capital intensity and TFP in explaining labor productivity growth. We find a significantly different explanation depending on whether statistical or economic measures are considered. Consequently, the periods of TFP growth and stagnation are also different. Moreover, given the great relevance of the capital stock growth rate in this setting and that the depreciation rate is fundamental for measuring capital stock, if the depreciation rate is not properly measured, all the remaining computations will be biased. To put it another way, an underestimation (overestimation) of depreciation brings about an overestimation (underestimation) of capital growth, and this in turn leads to an underestimation (overestimation) of TFP growth.

Another issue we address in this study is the role of ICT in explaining the recent evolution of labor productivity and TFP. It is commonly accepted that investment in ICT and the TFP growth rate are highly correlated. However, when we use the statistical measures of depreciation and capital stock, it is difficult to recognize this positive link, given the negative TFP growth rates observed during the ICT investment boom. Empirical studies have observed an acceleration of investment in ICT in Spain during the second half of the 1990s. Our results allow us to observe its impact on TFP statistics, with a certain delay, since 2002 and before the start of the Great Recession. We also identify the mechanism by which the effects of ICT are transmitted to the economic system. The computer revolution speeds up the process of capital substitution associated with technological change. This technological change is incorporated by investing in new and more productive equipment, which triggers economic deterioration and obsolescence. This greater obsolescence, which should be reflected in higher rates of economic depreciation, is barely recorded by official agencies whose measure of depreciation is statistical and strictly captures physical deterioration.

This paper is organized as follows. Section 2 presents a double growth accounting framework in which the relationship between the TFP growth rates and depreciation rates is established. Section 3 uses data from the Spanish economy to provide two sets of results to explain productivity growth, depending on whether a statistical or economic measure is used in the computations. Section 4 analyzes the Spanish paradox of productivity. Section 5 concludes.

2. Depreciation and TFP growth.

In this section we first refer back to the results of a standard growth accounting exercise. Consider first income per capita growth rate as expressed in the following sum of the labor productivity growth rate, employment rate and participation rate

$$\hat{y} = \hat{Y} - \hat{N} = \widehat{\left(\frac{Y}{L}\right)} + \widehat{\left(\frac{L}{H}\right)} + \widehat{\left(\frac{H}{N}\right)}. \tag{1}$$

The involved variables are income per capita y, aggregate output Y, population N, employment L and, labor supply H. Moreover, aggregate output is obtained according to the production function

$$Y = A\,F(L, K), \tag{2}$$

where A is a variable that represents the technological level or total factor productivity and K is the physical capital stock.

The employment and participation rates are bounded and range between zero and one. Moreover, in the long-run they are expected to be stationary, and neither is therefore expected to contribute to the long-run growth of per capita income. Then, from a long-run point of view only the labor productivity growth rate matters when explaining the economy's rate of growth.

As usual, we assume that i) function $F(\cdot)$ is homogeneous of degree one in all of its determinants taken simultaneously, and ii) factor prices are determined in competitive markets according to the marginalist theory of distribution, $W/p = w = \partial Y/\partial L$ and $C/p = c = \partial Y/\partial K$, where W represents the nominal wage and $C = p^k(r + \delta + \xi)$ is the nominal rental price of capital that depends on the price of investment goods p^k, the real interest rate r, the depreciation rate δ and other components such as the risk premium or taxes, which we will group together in parameter ξ. Therefore, we get $\Pi_K + \Pi_L = 1$, being $\Pi_K = cK/Y$ the capital share and $\Pi_L = wL/Y$ the labor share. Finally, from the production function, after substituting and rearranging terms, we find

$$\widehat{\left(\frac{Y}{L}\right)} = \hat{A} + \Pi_K \widehat{\left(\frac{K}{L}\right)} = \hat{A} + c\,\frac{\widehat{\left(\frac{K}{L}\right)}}{\frac{Y}{K}} \cdot \tag{3}$$

We have already mentioned the importance of the labor productivity growth rate for understanding the sustained long-run growth of the economy. Now, equation (3) shows how it depends on the TFP growth rate, as well as on a second term where the capital deepening rate appears multiplied by the capital share. The term $\hat{A}$, which represents production function shifts that increase TFP, is usually unknown but it can be calculated as a residual, $\hat{A} = \hat{Y} - \Pi_L\hat{L} - \Pi_K\hat{K}$.

These outcomes deserve a new inspection because we are now dealing with two different series of capital stock, each resulting from a different measure of depreciation: statistical and economic. In the Appendix we provide a description of the algebraic procedures to get the traditional statistical and the new economic measures of both the depreciation rate and the capital stock. First, the statistical measure of capital (K) comes from the combination of Jorgenson's theorem of proportionality with the mechanics of the perpetual inventory method. This statistical measurement of depreciation (δ) means that the only loss in the value of the assets taken into account is the loss due to ageing and the regular use of assets. Consequently, it is ignored the role of variable utilization, maintenance and embodied technical progress. Instead, the economic measure of capital (K^*) is computed sequentially together with the economic depreciation rate (δ^*). An algorithmic strategy that, using market-valued variables like prices, investment and profits, allows for an endogenous calculation of capital stock. This economic measure of capital stock is a good approximation to the productive capital stock from which a proportional stream of capital services is deduced. The corresponding market-based measure of depreciation becomes then a good representation of the whole processes of deterioration, both physical and economic, and obsolescence that affect capital assets. Consequently, the depreciation rate is subject to important changes under the influence of conventional economic forces.

When we use the economic measure of capital stock, K^*, instead of the statistical measure, K, we get an alternative specification of the production process

$$Y = A^* F(L, K^*). \tag{4}$$

This means that, whatever the value of output and employment, any change in the capital stock measure will be fully absorbed by the residual TFP. In this case, equation (3) can be rewritten as

$$\widehat{\left(\frac{Y}{L}\right)} = \widehat{A^*} + \mathit{\Pi}_{K^*} \widehat{\left(\frac{K^*}{L}\right)} = \widehat{A^*} + c^* \frac{\widehat{\left(\frac{K^*}{L}\right)}}{\frac{Y}{K^*}}, \tag{5}$$

where $\mathit{\Pi}_{K^*} + \mathit{\Pi}_{L^*} = 1$, $\mathit{\Pi}_{K^*} = \frac{c^* K^*}{Y}$, and $c^* = A^* \frac{\partial F(L,K^*)}{\partial K^*} = \frac{p^k}{p}(r + \delta^* + \xi)$.

In the standard growth accounting exercise there is only one capital stock involved, and the corresponding capital share is computed as a long-run constant, usually approached by its sample average value.[3] However, we are interested in explaining labor productivity and TFP cyclical features. Then, given that each of the two capital series leads to a different expression for the capital share, and their values are different for each sub-period considered in the analysis, equations (3) and (5) can be combined as in the following expression

$$\widehat{TFP^*} - \widehat{TFP} = \widehat{\left(\frac{A^*}{A}\right)} = \Pi_K \left(\frac{\widehat{K}}{L}\right) - \Pi_{K^*} \left(\frac{\widehat{K^*}}{L}\right). \tag{6}$$

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[3] See the seminal contributions of Solow (1957) and Denison (1962).

This expression shows the relationship between the TFP growth rates obtained using each of the capital stocks. Moreover, from (8) and (9) as given in the Appendix, we get, respectively, $\widehat{K} = \frac{I^G}{K} - \delta$ and $\widehat{K^*} = \frac{I^G}{K^*} - \delta^*$, where I^G represents the gross investment. Therefore, the difference between the rates of growth of the two TFP measures can be rewritten in terms of the ratios that represent the main flows in the capital accumulation processes

$$\widehat{TFP^*} - \widehat{TFP} = \Pi_{K^*}\,(\delta^* - \delta) + \Pi_K\left[\frac{I^G}{K} - \frac{I^G}{K^*}\right] + \left(\delta - \frac{I^G}{K^*} + \widehat{L}\right)(\Pi_{K^*} - \Pi_K). \qquad (7)$$

This difference is proportional to: i) the difference between the economic and statistical depreciation rates, ii) the difference between the two (gross) investment rates, and iii) it also depends on the dynamic differences between the two capital shares. In fact, the second term in the right-hand side of the previous equation depends mainly on the difference between the two capitals. Accordingly, the larger economic depreciation rate with respect to the statistical rate, and the larger economic capital stock with respect to the statistical one, the greater the difference between economic and statistical TFP growth rates. This means that, the depreciation rate measure has a direct impact on the residual TFP growth measure, while the capital stock measure has only an indirect influence because it plays the role of a scale effect. The last term on the right-hand side of equation (7) says that the difference between the economic and statistical capital shares has a positive effect on the difference between economic and statistical TFP growth rates if and only if the statistical depreciation rate is greater than the sum of the economic depreciation rate and the rate of growth of the economic capital stock in per capita terms.

3. Productivity growth in Spain

With the help of the proposed accounting framework, we now focus on the results for the non-financial business sector of the Spanish economy during 1964–2015.[4] The data used to perform the growth accounting exercises were taken from the National Accounts.[5]

First, we divide the entire period into seven sub-periods according to the evolution of output growth. The figures for the whole period are shown in the first column of Table

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[4] The non-financial business sector is defined as total activities in the economy excluding the financial intermediation sector, real estate, and non-market services.

[5] The Spanish regional database BD.MORES (see De Bustos et al., 2008) is compiled by the Budget General Directorate of the Spanish Ministry of Finance and is available at:

https://www.sepg.pap.hacienda.gob.es/sitios/sepg/es-ES/Presupuestos/DocumentacionEstadisticas/Documentacion/paginas/basesdatosestudiosregionales.aspx

1; output and labor productivity grow at average values above 2% and both capital stocks grow at similar rates above 3%. The different sub-periods we analyze correspond to periods of expansion and recession in the Spanish economy as shown in Figure 1.[6]

The first sub-period, 1964–1973, was a time of expansion; the labor productivity growth rate increased rapidly at an average of over 6%, as shown in Table 1. This strong increase was accompanied by a rise in both output and labor growth, although the latter was minimal. The next sub-period, 1974–1985, was recessionary and saw a slowdown in labor productivity, which fell to an average rate of 2.9%. This was accompanied by a decrease in both employment and output growth.

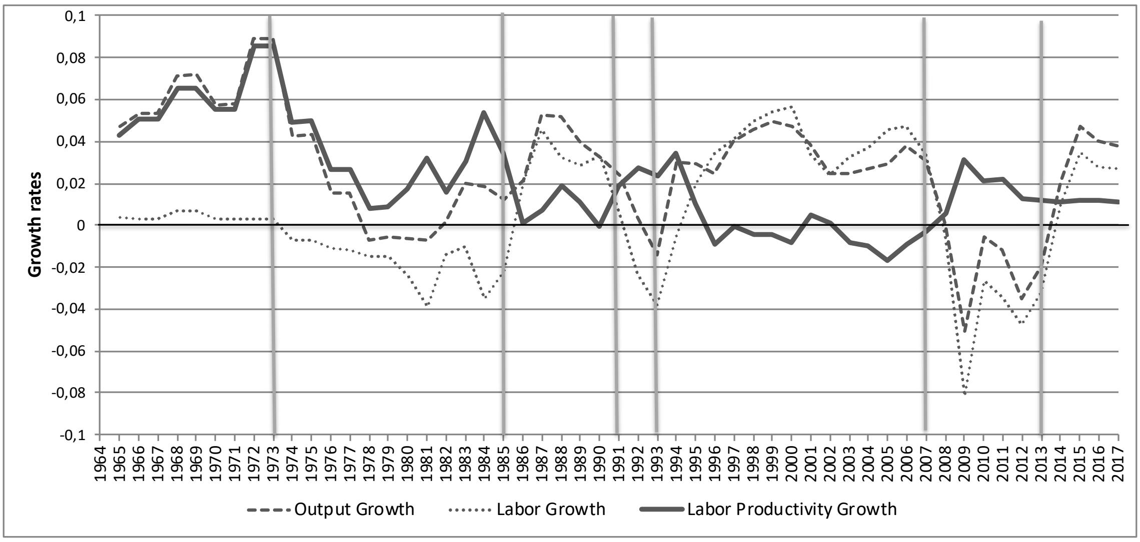

Figure 1. Output, labor, and productivity growth. Spanish non-financial business sector. Source: National Accounts and authors' elaboration

The sub-periods 1986–1991 and 1994–2007 were times of expansion; in both cases, these sub-periods experienced a slowdown in labor productivity, with average rates falling to 0.9% and -0.2%, respectively. This weak and even negative growth was accompanied by a sharp rise in employment. Then, in the two-year sub-period 1992–1993 and the final sub-period 2008–2013, both of which saw economic crises, we observe a strong recovery in labor productivity growth with values above 2.5% and 1.7%, respectively. This was accompanied by a sharp decline in employment, with rates that fell to average values of -3.1% in 1992–1993 and -3.8% in the years of the Great Recession. Therefore, for the Spanish economy, we observe a persistent trade-off between the

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[6] From 2014 onward, a new period of economic recovery began. During these years, the Spanish economy experienced a strong increase in both production (3.65%) and employment (2.50%), but not in labor productivity (1.16%). In this section, however, we do not provide a detailed analysis of the most recent years due to the provisional nature of some data and the unavailability of other data.

evolution of labor productivity and the evolution of employment from the mid-1970s to the present day.

Table 1. Spanish non-financial business sector growth rates. Values in percentages

	Whole sample	**Sub-periods**					
	1964–2015	**1964–1973**	**1974–1985**	**1986–1991**	**1992–1993**	**1994–2007**	**2008–2013**
Output ($\hat{Y}$)	2.68	6.55	1.18	3.69	-0.52	3.43	-2.03
Labor ($\hat{L}$)	0.49	0.38	-1.75	2.75	-3.05	3.60	-3.78
Labor Productivity ($\widehat{Y/L}$)	2.19	6.17	2.93	0.94	2.53	-0.17	1.75
Statistical Capital ($\hat{K}$)	3.68	5.46	3.50	4.26	2.90	4.07	1.03
Economic Capital ($\widehat{K^*}$)	3.34	7.33	0.24	7.67	2.29	3.49	0.14

Source: Authors' elaboration from official statistics and Escribá-Pérez et al., 2018.

The evolution of labor productivity growth shown in Table 1 can be interpreted following the evolution of its major components: i) the TFP growth rate and ii) the capital intensity growth rate. Nevertheless, the decomposition can also be carried out using equation (3) or (5). This twofold decomposition depends on which of the two different capital stock measures—statistical or economic—was used to calculate the variables that appear in the equations. This is not purely and simply a zero-sum arithmetic exercise without significance but conforms the basis for interpreting and explaining the facts linked to Spanish economic growth over the last 50 years.

In Figure 2, we illustrate the evolution of economic and statistical depreciation rate estimated for the non-financial business sector of the Spanish economy from 1964 to 2015. As can be observed, the economic depreciation rate fluctuates around the statistical depreciation rate, describing a trajectory in differences that is apparently stationary in the long term. In consequence, the economic capital stock also fluctuates around the statistic capital stock, as it is shown in Figure 3 where we show the evolution of the different measures of capital stocks for the non-financial business sector for 1964-2015. Nevertheless, fluctuations in the capital stock are less pronounced because of the cumulative nature of this variable. It must be remarked here that differences between the two depreciation rates are the result of either greater or lesser destruction of capital in different periods, which are not recorded in the official statistics. Thus, when the latter underestimate depreciation, they are overestimating capital growth, which in turn leads to an underestimation of TFP growth, and vice versa.

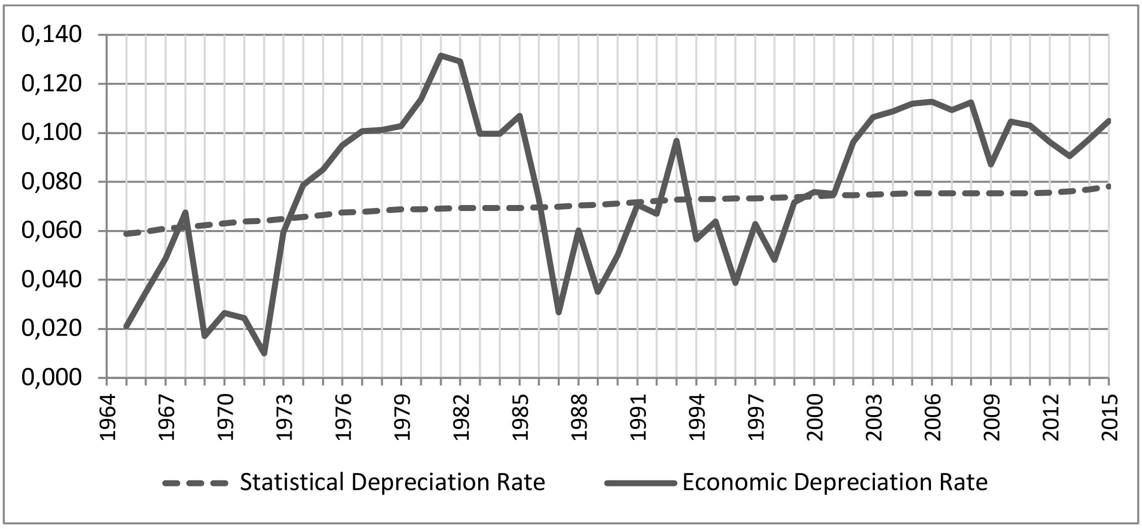

Figure 2. Economic and statistical depreciation rate: Spanish non-financial business sector, 1965–2015. Source: Escribá-Pérez et al. (2018) and authors' elaboration.

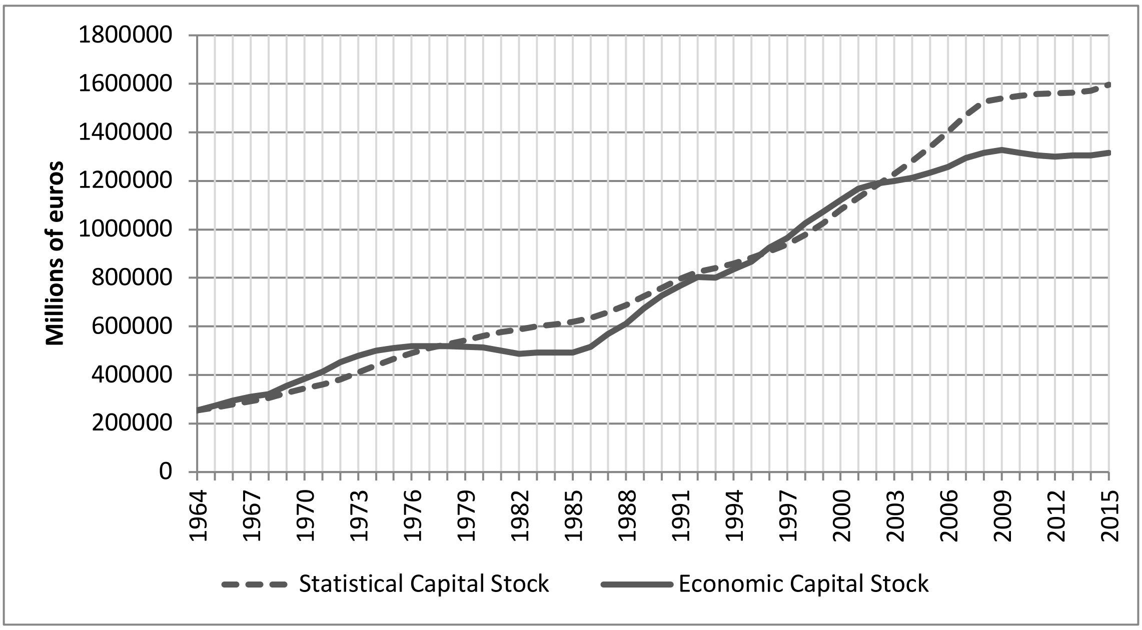

Figure 3. Economic and statistical capital stock: Spanish non-financial business sector, 1964–2015. Source: Escribá-Pérez et al. (2018) and authors' elaboration.

Table 2 summarizes the changes in labor productivity, TFP, capital intensity, and depreciation rates over the period analyzed. In the columns on the right-hand side of the table, we show their contributions to the average labor productivity slowdown or acceleration. From sub-period 1964–1973 to sub-period 1974–1985, labor productivity underwent a significant slowdown, with its growth rate falling by 3.2 percentage points. Using standard statistical measures, this is basically explained by the sharp fall in the TFP growth rate shown in column [8] of Table 2. However, when the economic measures are used, we find an alternative explanation for the slowdown, which is twofold and involves not only the fall in TFP* growth but also the sharp decrease in capital intensity growth. Behind the latter, we can identify the impact of a greater and increasing economic depreciation rate in the second half of the 1970s, as shown at the bottom of column [3] and in Figure 2. This represents the effect of obsolescence due to the rise in oil prices in an economy with enormous energy dependence and far-reaching industrial reconversion plans. We can also see, using equation (7), how the difference between the two TFP growth rates is positive in the 1974–1985 sub-period, mainly due to the difference between the depreciation rates (the statistical depreciation rate is lower than the economic depreciation rate), as seen in Figure 4. In fact, the underestimation of depreciation in this sub-period becomes an underestimation of TFP growth $\left(\widehat{TFP} < \widehat{TFP^*}\right)$.

From 1974–1985 to 1986–1991, labor productivity underwent another slowdown, as can be seen in column [9] of Table 2. We call this downfall, in which 2.0 percentage points were lost, the second slowdown to highlight a major difference with the experience in the U.S. economy where the growth rate remained almost constant. It is actually a continuation of the process that started earlier. However, certain major differences may be found with respect to the previous sub-period as regards the evolution of the variables underlying the labor productivity growth rate. These differences do affect the way we interpret the causes of this slowdown deepening. In fact, if we use the statistical measures, the slowdown can be explained almost exclusively by the decrease in the capital intensity growth rate (-1.4%). When we use the economic measures, however, we obtain a substantially different explanation for the stagnation of labor productivity. Here we identify a double effect pushing in opposite directions: a decrease in the TFP* growth rate (-2.7%) and an increase in the capital intensity growth rate (0.7%). Behind the latter is a lower economic depreciation rate, which is the result of two opposite forces in the economic deterioration: the strength of maintenance expenditures dominates on the impetus of a higher capacity utilization rate. Figure 4 shows that the difference between the growth rates of the two TFP measures is negative in sub-period 1986–1991; the overestimation of depreciation $(\delta > \delta^*)$ becomes an overestimation of TFP growth $\left(\widehat{TFP} > \widehat{TFP^*}\right)$.

Table 2. Labor productivity growth and its components. Spanish non-financial business sector. Values in percentages.

	Whole sample	**Sub-periods**										
	1964–2015	**1964–1973**	**1974–1985**	**1986–1991**	**1992–1993**	**1994–2007**	**2008–2013**	**Slowdown in 1974–85 relative to 1964–73**	**Slowdown in 1986–91 relative to 1974–85**	**Acceleration in 1992–93 relative to 1986–91**	**Slowdown in 1994–2007 relative to 1992–93**	**Acceleration in 2008–13 relative to 1994–07**
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
Labor Productivity Growth	2.19	6.17	2.93	0.94	2.53	-0.17	1.75	-3.24	-1.99	1.59	-2.70	1.92
$\widehat{TFP}$ *Contribution*	0.94	3.80	0.99	0.37	0.53	-0.35	-0.15	-2.81	-0.62	0.17	-0.89	0.20
$\widehat{K/L}$	3.19	5.08	5.26	1.51	5.95	0.47	4.81	0.17	-3.74	4.44	-5.48	4.34
$\widehat{K/L}$ *Contribution*	1.25	2.37	1.94	0.57	1.99	0.18	1.89	-0.43	-1.37	1.42	-1.82	1.72
$\boldsymbol{\widehat{TFP^{*}}}$ ***Contribution***	**1.08**	**3.00**	**2.11**	**-0.59**	**0.72**	**-0.13**	**0.27**	**-0.88**	**-2.70**	**1.31**	**-0.85**	**0.41**
$\boldsymbol{\widehat{K^{*}/L}}$	**2.84**	**6.95**	**1.99**	**4.92**	**5.34**	**-0.11**	**3.92**	**-4.95**	**2.93**	**0.42**	**-5.45**	**4.02**
$\boldsymbol{\widehat{K^{*}/L}}$ ***Contribution***	**1.11**	**3.17**	**0.82**	**1.53**	**1.81**	**-0.04**	**1.47**	**-2.36**	**0.72**	**0.28**	**-1.85**	**1.52**
$\boldsymbol{\delta^{*}}$	**7,78**	**3.44**	**10.36**	**5.26**	**8.19**	**8.13**	**9.90**					
δ	7,05	6.21	6.83	7.06	7.25	7.42	7.56					

Source: Authors' elaboration from official statistics and Escribá-Pérez et al., 2018

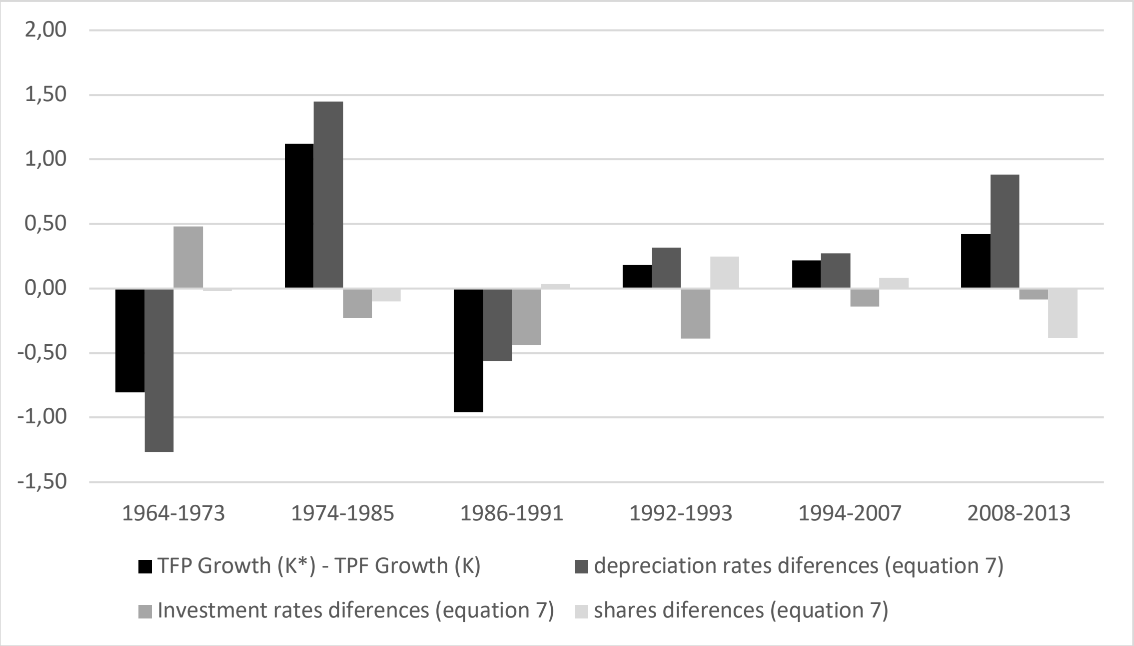

Figure 4. Differences in TFP growth measures and components. Source: Authors' elaboration.

From sub-period 1986–1991 to sub-period 1992–1993, there is a relative acceleration in labor productivity, during which its growth rate increased by 1.6 percentage points, as shown in column [10] of Table 2. The return of labor productivity to the growth path during this short period of two years, accompanied by sharp employment destruction, is primarily explained by strong growth in capital intensity (4.4%) when we use the statistical capital stock measure. When we use the economic capital stock measure, however, the return to a significantly positive labor productivity growth rate is explained by the increase in the TFP* growth rate (1.31%). Economic depreciation was greater than statistical depreciation in a period with enormous destruction of small and medium enterprises. Again, the underestimation of depreciation in this sub-period ($\delta^* > \delta$) is transformed into underestimating TFP growth.

As column [11] of Table 2 shows, from sub-period 1992–1993 to sub-period 1994–2007, the Spanish economy again underwent a slowdown in the labor productivity growth rate, which declines 2.7 percentage points. This was later partially recovered as it moved from sub-period 1994–2007 to sub-period 2008–2013, with the growth rate increasing by 1.9 percentage points (column [12]). Although these movements are in opposite directions, the explanations for both can be found in the evolution of the same underlying variable: the rhythm of creation and destruction of employment and the consequent fall and rise in the capital intensity growth rate. Furthermore, contrary to what we saw earlier, there are no major differences in how these changes are explained depending on whether we use the statistical or economic capital stock measurement. The third slowdown experienced by the Spanish economy over the final years analyzed is due

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to a powerful wave of job creation. The TFP growth rates obtained with both capital stocks fall by approximately 0.9 percentage points, and the corresponding capital intensity growth rates fall by approximately 5.5 percentage points. However, as shown in the next section, once this last period of expansion (1994–2007) is analyzed in greater detail, a substantial difference in depreciation rates can be seen from the early 2000s, in connection with the ICT investment boom.

The final movement is associated with the Great Recession. In Spain, this brought with it a drastic loss of employment, which by itself practically explains the huge acceleration in labor productivity.[7] The TFP growth contribution obtained with either of the two capital stocks rises in parallel, by 0.2 and 0.4 percentage points, respectively, and the corresponding contributions of capital intensity growth rise by 1.7 and 1.5 percentage points, respectively.

4. Depreciation and the Spanish productivity paradox

Judging by what we have seen so far, the most striking Spanish result is the slowdown in the labor productivity growth rate in sub-period 1994–2007, with a negative average value of -0.17%. Although similar to what happened in the rest of the European Union, this result is at odds with what happened in the United States from the beginning of the 1990s, where there is a recovery in labor productivity represented by an increased and high positive growth rate. In the case of the US economy, there has been much debate regarding the importance of ICT in overcoming the productivity slowdown observed from the early 1970s. Indeed, since Solow first raised the idea of a *productivity paradox*,[8] many contributions have attempted to provide an explanation (Brynjolfsson and Yang, 1996), but it continues to be a controversial issue, as shown in Acemoglu et al. (2014). Nevertheless, many authors have seen the mid-nineties increase in the labor productivity growth rate as the delayed resolution of the Solow paradox, associating such a recovery with the wave of ICT investments deployed from the mid-seventies.

There is less extensive literature on this issue in the Spanish economy, and it has only recently become a subject of discussion. Hence, we consider the role that ICT investment might have played in explaining the Spanish growth process during the final stages of the period under study. First, Mas and Quesada (2005) report that from 1964 to the mid-1980s, this type of investment was negligible. It then began to take off and, after the brief stagnation of 1991–1993, continued until the telecom crisis at the beginning of the new millennium. Therefore, we can take it as proven that, between 1995 and 2000,

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[7] For the crisis period 2008–2012, Hospido and Moreno-Galbis (2015) use balance sheet information from a sample of Spanish manufacturing and services companies to point out that labor productivity is also affected by the behavior of TFP. The authors find a positive link between TFP and certain composition effects associated with the proportion of temporary workers and the weight of exporting firms facing international competition, which contribute significantly to the recent improvement in labor productivity.

[8] According to Solow (1987): "the fact that what everyone feels to have been a technological revolution ... has been accompanied everywhere ... by a slowing down of productivity growth, not by a step up. You can see the computer age everywhere but in the productivity statistics."

there was a boom in investment in hardware and software in parallel with a sharp decline in hardware prices.

Looking at the statistics, it seems the expected positive effect of such a high investment in ICT is not present because of the negative growth in labor productivity observed during the sub-period 1994–2007. However, we cannot be sure of this because the dynamics of labor productivity in this period, as well as in the following sub-period 2008–2013, are driven mainly by huge changes in employment. Consequently, the impact of large investments in ICT, if any, could be hidden by the atypical behavior of the labor productivity growth rate in Spain. We therefore need to inspect the dynamic behavior of its two components: TFP and capital intensity. It must be remarked that the relative weight of these variables depends on which capital stock measure we use to calculate them.

The commonly accepted view is that ICT investment should be accompanied by high TFP growth rate values. However, this does not correspond with the real fact of the low values recorded for this rate when it is calculated using statistical capital stock. In the sub-period 1994–2007, there was a sharp fall in the TFP growth rate in Spain, which had an annual average value of -0.35%. Even if we use the economic capital stock measure, we still obtain a negative value of -0.13%, as shown in column [6] in Table 2. This fall was also a general feature in Europe at the time, but not in the US, where the TFP growth rate increased, although less than expected by those who were relying on the benefits of the *New Economy*. According to Stiroh (1998), it is not necessarily true that more and better computers should accelerate TFP. The computer revolution can be characterized by: i) a computer-producing sector that is subject to fundamental technological changes, and ii) the remaining computer-using sectors that, induced by falling prices, undertake a deep capital substitution process. Although the former implies the production function shifts that increase TFP, the change is small and has no significant impact on the aggregate. The latter, meanwhile, could imply movements along the production function, as well as shifts associated with the investment-specific embodied technical progress.

In what follows, we focus on the relationship between investment in ICT and the TFP growth rate when we use economic rather than statistical measures for both depreciation and capital. We pay special attention to the central role played by depreciation in this issue because of its direct connection to any capital substitution process.

Our hypothesis is that generalized investment in ICT and the introduction of new and improved ICT in most of the new investment capital goods exert an important indirect effect on the residual TFP growth rate. Recall that according to (6), $\widehat{TFP^*} > \widehat{TFP}$ if and only if $\Pi_K\left(\widehat{K/L}\right) > \Pi_{K^*}\left(\widehat{K^*/L}\right)$. Consequently, for a given labor productivity growth rate, the underlying explanatory contribution of the TFP growth rate is conditioned by the contribution of capital intensity and, therefore, by what measure of capital stock we use in our calculations. Moreover, this measure greatly depends on the magnitude of depreciation. Since the computer revolution implies the addition of more productive equipment to the capital stock, we would expect an accompanying process of strong capital goods substitution (Jorgenson and Stiroh, 1999; Whelan, 2002). In other words, we expect to see a huge stream of economic deterioration and obsolescence that is not recorded in the statistical measures of capital stock and depreciation.

The expansion of ICT investment that began around 1995 in Spain and increased the share of such items in total investment to more than 10% by 2004 does not provide clear evidence to support the hypothesis during the second half of the 1990s. This is probably due to the fact that it is too soon to observe its effects. If we consider that the acceleration in ICT investment was gradual and requires complementary investment in learning, human capital, and some restructuring of the productive organization, there might be a certain time lag before the process of input substitution takes off.[9] It is therefore absolutely reasonable that the effect of ICT investment on the rate of depreciation becomes visible after a certain delay. Using the economic measures of capital and depreciation for Spain, we can identify a second episode of higher and increasing depreciation rates in the statistics for 2002–2007. Consequently, we inspect the complete data set corresponding to this time interval prior to the start of the Great Recession in 2008.

Table 3. Growth and productivity in 2002–2007. Values in percentages

$\hat{Y}$		2.9	
$\hat{L}$		3.7	
$\widehat{Y/L}$		-0.8	
$\hat{K}$	4.5	$\boldsymbol{\widehat{K}^*}$	1.7
$\widehat{K/L}$	0.8	$\boldsymbol{\widehat{K^*/L}}$	-2.0
$\Pi_K \cdot \widehat{K/L}$	0.3	$\Pi_{K^*} \cdot \boldsymbol{\widehat{K^*/L}}$	-0.9
δ	7.5	$\boldsymbol{\delta^*}$	10.8
$\widehat{TFP}$	-1.1	$\boldsymbol{\widehat{TFP}^*}$	0.1

Source: Authors' elaboration from official statistics and Escribá-Pérez et al., 2018.

As the figures in Table 3 show, the high rate of employment growth is almost responsible for the negative labor productivity growth rate. However, taking a closer look at the contributions of its components, we can compare those measured in economic terms with those measured in statistical terms. Then, we find a positive but not too high capital stock growth rate, an important depreciation rate of nearly 11%, which represents a strong process of economic deterioration and obsolescence,[10] and a TFP growth rate that is low but still positive. It must be remarked that, in Spain during the period under inspection, those six years just before the Great Recession sharply contrast with the preceding years

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[9] The idea that the measured consequences of investment in ICT need time to become visible in the macroeconomic aggregates was also put forward by Mas and Quesada (2006) and Martínez et al. (2008).

[10] Given that this period of strong economic growth represents an expansive phase of the business cycle, a higher rate of productive capacity utilization is also expected. Therefore, greater depreciation due to economic deterioration appears in our records combined with the greater depreciation caused by obsolescence.

that make up the long wave of expansion experienced from 1994 onwards. According to the correlations identified in the Appendix, we can point to some observed facts, such as lesser investment strength, the relatively low values of real interest rates, and the Tobin's q-ratio, or acceleration of the real flow of distributed profits, as the key factors that explain the particularly high economic depreciation rate values during these years.

This is just the accounting growth picture that is summarized in the referenced literature: the computer revolution accompanied by relatively swift price declines, huge investments in equipment with embodied ICT, and, after a reasonable delay, a strong obsolescence process affecting old capital goods. The technological revolution shows then the expected production function shifts and the corresponding TFP growth.

5. Conclusions

In this study, we analyze the relevance of depreciation in growth processes. We conclude that when a constant depreciation rate is assumed in measuring capital, economic deterioration and obsolescence are not properly recorded, causing a sizeable mismeasurement of capital stock. Thus, the underestimation or overestimation of depreciation is transformed into underestimation or overestimation of TFP growth. Our database corresponds to the Spanish economy from 1964 to 2015. We use two pairs of series for the depreciation rate and capital stock, which give us two different data sets for the growth rates of the capital-labor ratio and TFP. One is the statistical measure obtained according to the OECD recommendations, while the alternative is an economic measure computed endogenously according to economic agents' decisions. The latter uses market-valued variables like prices, investment, and profits.

In this context, we show how capital deepening and TFP play different roles in explaining growth over the past fifty years. While the slowdown in labor productivity between 1975 and 1985 has traditionally been explained in terms of the decline in the TFP growth rate, our results point to increased depreciation, mainly due to obsolescence. Capital destruction in economic terms is so high that it reduces the capital-labor growth rate by an amount that goes well beyond any statistical measurement. Nevertheless, we must conclude in the opposite direction when analyzing the slowdown experienced between 1986–1991. Then, economic depreciation was smaller than that implicit in official statistics, probably due to higher equipment maintenance and repair. Therefore, while the traditional explanation was given in terms of the fall in the rate of capital deepening, our results highlight the fall in the TFP growth rate, which decreased by much more than recorded in conventional estimates.

We have also studied the Spanish paradox of productivity, and propose a non-trivial feasible explanation. The issue concerns the true impact of investment in ICT on labor productivity and TFP dynamics in Spain since the mid-1990s. Apart from the specific agreement with the literature that emphasizes the idea that the economy experiences the effects of ICT investment with a delay, our explanation shows notable differences. Most of such literature concentrates on the secondary requirements that supposedly encourage the diffusion of a technological revolution: lower adoption costs, higher rates of penetration and use of new ICT, better qualifications and training of the labor force, new organizational forms, larger firm sizes, more flexible employment legislation, and a friendlier environment for firms and business. Instead, we focus on the relevance of depreciation and the corresponding capital substitution process as the main channels whereby any technical change materializes.

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Appendix: Two measures of capital stock and the depreciation rate.

Here we provide a quick revision of the traditional statistical and the new economic measures of the depreciation rate and thus of capital stock. The availability and quality of data series for production inputs determine the results concerning the residual variable TFP in growth accounting exercises. Although there is no widespread debate regarding labor input and a consensus dictates how it should be measured, there have been significant discrepancies and contradictory approaches as regards the way in which the series of physical capital stock should be obtained. Even so, a certain agreement on the measurement of capital has been reached among empirical and theoretical economists. It involves the use of both Jorgenson's theorem of proportionality, which states that the depreciation of capital goods is proportional to the capital stock, and the mechanics of the PIM, which is widely used to estimate capital stock series and studies according to the accumulation equation

$$K_t = I_t^G + (1 - \delta_t)K_{t-1}. \tag{8}$$

The dynamics of capital stock depends on investment and depreciation flows. There are no fundamental problems involved in the measurement of the gross investment flow, I_t^G, since it represents the acquisition of new capital goods according to explicit transactions that are market-observable transactions. However, the case of the depreciation flow is different because economic transactions related to capital depreciation activities are basically unobservable.

In order to measure depreciation and provide useful data series, the most common practice has for years consisted of assigning accounting values based on assumptions about the mathematical functional form of the survival (retirement) profile, the efficiency profile according to age, and the age-price profile of an asset or cohort of assets. Hence the measure of capital stock is a statistical measure because depreciation is estimated under arbitrary assumptions about the parameters that characterize the previous functions. The statistical measurement of depreciation implies that the only loss in the value of the assets taken into account is the loss experienced as they age. Consequently, because it is ignored the role of utilization, maintenance and embodied technical progress, depreciation is treated more as a technical necessity than as a result of economic decisions.

In such a context, accuracy in implementing the perpetual inventory method depends on the choice of the asset retirement distribution. A survival profile is required in order for the retirement process to be modeled, and a key parameter in this process is the average service life. Although a subject of debate, it is usual to assume fixed service lives and one ad hoc pattern for retirements (one-hoss-shay, linear, or a bell-shaped function like Winfrey, Weibull and lognormal distributions). The age-efficiency function is also assumed to be fixed, with several possible shapes (hyperbolic, linear or geometric profiles). In coherence with the above, the age-price function is also taken as fixed and can be of the straight-line type, with prices falling by a constant amount each period, or of the geometric type, with prices falling by a constant rate each period.

In the search for a measure of the depreciation flow, different combinations of retirement patterns with age-efficiency patterns or with age-price patterns are admitted for the purposes of achieving the goal. The functional form of these interconnected statistical functions is important when it comes to determining the functional form of the depreciation pattern, the parameters of which are taken mainly from empirical studies (company accounts, statistical surveys and second-hand asset price records exploited using econometric methods). However, the more recent OECD recommendations imply the explicit recognition that the geometric depreciation pattern is the most suitable approximation to the loss in value of assets as they age. Now the usual method employed to estimate the depreciation rate is the well-known double-declining balance method, as summarized in the expression $\delta_i = 2/\bar{T}_i$, where $\bar{T}_i$ is the average service life for assets of type *i*. According to this method, the measurement of depreciation is directly associated with the fixed average service life of the different assets.

In short, the measurement of capital according to the perpetual inventory method depends on a statistical measure of depreciation, which implies that the variability observed in the implicit depreciation rate δ_t mainly reflects changes in the composition of the capital stock.

Alternatively, we have the economic measure of capital stock. This is different in nature from the statistical measure above and also provides different results. In a recent paper Escribá-Pérez et al. (2018) revisits the intertemporal behavior of firms in a perfectly competitive environment. It represents a generalization of Hayashi's (1982) paper because the investment-related adjustment costs function is complemented with a function incorporating maintenance and repair expenditures. The latter allows the depreciation rate to be considered an endogenous control variable together with investment. The control problem consists in choosing the optimal investment and depreciation that maximize the present discounted value of cash-flow. This problem has a single state variable, so it is subject to one dynamic constraint that expresses the accumulation process of capital stock,

$$K_t^* = I_t^G + (1 - \delta_t^*)K_{t-1}^*. \tag{9}$$

In fact, the economic measurement of capital (K_t^*) and depreciation (δ_t^*) translates to the empirics the fundamental assumptions of the purest neoclassical theory of capital, which suggests measuring aggregate capital at equilibrium in terms of value. Following Hayashi's work, we can associate the economic value of the capital stock along the optimal equilibrium path, to the market value of the firm, V_t^*, by introducing the financial market measure of Tobin's q ratio. Moreover, under the usual assumptions of competitive markets and static expectations we get

$$q_t = \frac{V_t^*}{p_t^K K_t^*} = \frac{B_t^*}{r_t p_t^K K_t^*} = \frac{B_t^G - \delta_t^* p_t^K K_{t-1}^*}{r_t p_t^K K_t^*}. \tag{10}$$

This contribution integrates market prices like the real interest rate (r_t) and the price of investment goods (p_t^K), and profitability indicators like distributed profits (net profits B_t^* or gross profits B_t^G) and the observable Tobin's q_t, into the evaluation process (Escribá-Pérez et al., 2019). The only data needed from official sources are price variables and the value of flows such as gross investment and gross distributed profits. Finally, from a known initial value of capital stock, equations (9) and (10) can be used sequentially to obtain the series of depreciation rate δ_t^* and capital stock K_t^*. According to this algorithmic system of equations we can identify a set of correlations between the independent variables mentioned above and the two endogenous ones. First, intensive investment expenditures will increase the capital stock but reduce the depreciation rate. Second, higher levels of distributed profits are associated with higher values of the depreciation rate and lower values of the capital stock. Finally, smaller values of Tobin's q ratio and real interest rates are correlated with higher depreciation rates and a smaller capital stock.