INVESTMENT AND GROWTH IN EUROPE DURING THE GOLDEN AGE

Antonio Cubil
Mª Teresa Sanchis

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Investment and growth in Europe during the Golden Age[*]

Antonio Cubel, Mª Teresa Sanchis

Universidad de Valencia, Spain

Corresponding autor
Antonio Cubel
Facultad de Economía
Universidad de Valencia
Campus dels Tarongers
Avda. Dels Tarongers s/n
46022 Valencia (Spain)

Phone number: + 34 963828244
Fax: +34 963828249
E-mail addres; Antonio.Cubel@uv.es

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Abstract

This paper analyzes investment decision determinants in a sample of nine European countries plus USA and Canada during the Golden Age, using time series information on the user cost of capital. The results support the view that the exceptional conditions of economic stability that converged in Europe during those years favoured investment and growth. We estimate the Hall and Jorgenson equation for aggregate capital formation and for machinery and equipment investment through the Arellano and Bond's Generalised Method of Moments (GMM) in first-differences.

JEL CODE: N10, N14, E22, O16

KEY WORDS: investment, relative prices, user cost of capital, growth, GMM

1. Introduction

The two decades after the II World War represent a stage of unprecedented growth in Europe's economic history, with GDP growth in western European countries averaging 4.1%[1] and the highest level of convergence in history. Assessing underlying factors in this transformation is undoubtedly an interesting issue in Economic History. A wide variety of explanations have been offered for the remarkable behaviour of Western economies during the Golden Age[2]. Pioneer works on growth accounting emphasised the advances in total factor productivity[3], while Keynesian works stressed the expansion of added demand. Aspects of demand expansion have been analysed as economic stability, the expansion of international trade[4], the role of the new international order[5], the development of the welfare state or the effect of rapid structural change[6].

More recently, the new growth theory has rescued the relevance of investment in physical and human capital[7] as a way to embody new technology. From this point of view, it is considered that in post-war Europe exceptional circumstances generated demand stability and promoted investment in physical and human capital[8]. In general, the thrust of theoretical evidence and stylised facts for European countries, confirms that the increase in the investment rate, and in particular in machinery and equipment investment, was

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[1] Maddison (1995)

[2] A review of the causes of growth during the Golden Age can be found in Crafts and Toniolo (1996), Temin (1997), Toniolo (1998).

[3] In this line were the pioneer works of Kendrick (1961) and Denison (1967), Christensen, Jorgenson y Lau (1971, 1973). More recent approaches are Maddison (1987, 1991) for a wide simple of countries and Jorgenson, Gollop y Fraumeni (1987) for the United States.

[4] Ben David (1993) find a strong link between the timing of trade and income convergence among countries in Europe..

[5] Eichengreen (1996) . Boltho (1982) stands out the role of monetary stability under the Bretton Woods system.

[6] Temin (2002) considers the reallocation of employment from agriculture to industry as a key determinant of growth.

[7] Levine y Renelt (1992) stands out the role of the differences in the investment behaviour of nations for the explanation of income differences between countries.

[8] Eichengreen (1996). Toniolo (1998).

relevant[9]. The increased investment rate meant that the huge growth potential offered by the technological backwardness of European countries with respect to the United States[10] could be realised.

As Williamson noted, market integration could be responsible for the spurt on investment through convergence on the cost of capital goods. It is a well-known fact that relative prices of capital goods[11] are a significant variable which negatively affect investment rates and growth. So the integration of capital goods market could be considered a relevant factor in the explanation of growth and income convergence in European countries during the Golden Age. We consider that it is not only goods market integration but financial market integration that boosted investment in all the countries in this period. In this paper we use a variable that synthesizes the conditions in the real and financial markets: the user cost of capital. More specifically, per capita income growth depends upon capital accumulation, accumulation depends upon investment and the investment decision depends upon the user cost of capital. In this paper, therefore, we will break down user cost into its two main components, the relative price component and the non price component, in order to distinguish the effect of capital goods market integration and the effect of the convergence in financial markets on investment and growth.

We will do that by using new data on the user cost of capital and the investment rate and analyzing the annual evolution of these variables between 1950-1973 and by estimating an approximation to the traditional Hall and Jorgenson's investment equation. Traditional attempts to model investment using time series methods have for the most part

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[9] Levine and Renelt (1992) showed that relative backwardness and investment in machinery and equipment are the only consistently robust variables in econometric literature, irrespective of the sample size and period analyzed.

[10] Crafts and Toniolo (1996), chapter 1, highlight the relevance of technological "catching-up" for explaining post-war European investment as did initially Abramovitz (1986). Temple and Voth (1998) outlined that higher levels of human capital lower the cost of adopting advanced techniques.

[11] Easterly(1993), Jones(1994), point out the relative price of capital as an explanatory factor for low investment rates in less developed countries and attributed it to distortions in relative prices provoked by economic policy.

been unsuccessful[12]. At best, only a limited role has been found for the real cost of capital and the overall fit of investment equations is invariably poor. Recent works on investment decisions, however, suggest that real investment becomes more sensitive to changes in the cost of capital when relative capital prices lead user cost. This seems to occur when the price component of the cost experiences a sharp decline due to technical change or to changes in market conditions[13] . A disaggregated approach which models investment in separate kinds of capital goods has been found to explain investment behaviour better. Taking into account these results, we will distinguish between aggregate investment and machinery and equipment investment, which is the component of overall investment most directly related to productivity growth[14] and goods markets integration.

The article is organized as follows. In the *second* section, we describe some stylized facts, and some measures of convergence on investment rates, the real user cost of capital and its main components. In the *third* section we present the theoretical foundations of the user cost of capital formula and the Hall and Jorgenson investment theoretical model. In the *fourth* section, we estimate econometrically the relationship between investment rates and the accelerator, the user cost of capital and its two main components using a GMM in "first differences" estimation for panel data. We finish with some concluding remarks.

2. Stylized facts

2.1. Investment rate and its composition.

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[12] Oliner, Rudebustch and Sichel (1995).

[13] For the investment boom of the 1990s some authors have arrived at this conclusion. Tevlin and Whelan (2000) for computers in United States and Baksshi and Thompson (2003) for United Kingdom.

[14] There are two additional reasons for focusing on aggregation. First, several authors (De Long and Summers (1991), De Long (1992)) demonstrated that machinery investment has a wider impact on income per capita growth than aggregate capital goods. Second, more recently several authors have stressed that aggregation biases could explain the failure of time series investment equations, Caballero (1999), Bakhshi and Oulton (2003).

We have constructed annual series of investment and its components[15], as well as the user cost of capital for diverse European countries, the USA and Canada for the period 1950-75 based on OECD figures. These series are expressed at internationally comparative levels, taking as reference unit the Purchasing Power Parities of the United Nations International Comparative Programme. *Appendix 1* contains a detailed description of the data.

Since 1950 until the first oil shock a clear phase of expansion in capital formation can be identified. In the fifties, the process of capital formation was influenced by the need to rebuild the capital stocks in countries that suffered the most damage during the Second World War. The relatively higher ratio of investment to GDP in continental Europe with respect to the United States and the United Kingdom and Canada is explained by this fact.

On average, the investment rate increased along the twenty-five year period, 1950-1975, at around 4.5 percentage points, although huge differences can be appreciated among countries. F*igure 1* show that expansion was positive in all European countries, those with lower initial income levels such as Spain, Portugal, Ireland and Greece registering the highest increases. Meanwhile the reverse happened in the most advanced countries such as the United States, Canada and the United Kingdom whose investment rate decreased in absolute terms at the end of the period.

When the recovery phase after the Second World War finished, Western economies continued to grow quickly. In the sixties, the rate of investment remained at the higher level reached at the end of the fifties in most countries and continued to expand in the less advanced European countries such as Spain, Greece, Portugal and Ireland. Meanwhile some advanced countries such as the United Kingdom and France experienced a more pronounced increase in their investment rates than in the fifties.

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[15] We have not broken down aggregate investment into its two component, machinery and structures because for some countries of the sample we have no reference on investment in structures or on prices, specially for the fifties. For this reason in the rest of the article we talk of machinery investment and aggregate investment.

F*igure 2* shows the share of machinery and equipment investment in GDP. The most significant fact is the sharp convergence in investment rate among the sample countries due to two factors. First, investment rates in Germany and Norway doubled between 1950-1970 but experienced a decline at the end of the sixties. And second, the remaining countries maintained an upward trend throughout the whole period. The positive slope was more pronounced in the countries which came from the lowest investment rates at the beginning of the period. It is interesting to highlight the route Germany took to recover its economy after the war because it devoted most of its investment effort to increase and modernize its machinery and equipment capital stock. Comparison of *figures 1* and *2* reveals that convergence in investment rates was more clear for machinery and equipment investment than for the aggregate and made this kind of investment a central force in explaining income per capita convergence in Europe.

Different works have insisted on the existence of a narrow correlation between growth and the increase in the investment rate in GDP during the fifties and sixties. We have tried to validate this relationship through an econometric exercise by regressing GDP per capita growth on investment in machinery, the initial level of GDP per capita (to capture the possible convergence of the follower countries to the technological leaders), the population growth rate (to pick up the requirement of an increasing capital stock) and the investment share of non residential construction over GDP (to control the increase in productivity caused by capital accumulation other than capital goods) .

The main results of this equation are presented in *table 1*. These results confirm the robustness of the relationship between GDP per capita growth and investment. An increase in the standard deviation of aggregate investment will cause an increase of 0.45% in the GDP per capita growth rate. If we break it down into investment components, we find that machinery and equipment still has a stronger relationship with GDP growth than aggregate investment, because an increase in standard deviation causes an increase in GDP per capita growth rate of 0.6%[16].

Table 1

Investment and GDP growth

	(1)	(2)	(3)	(4)
Ln intitial GDP per capita	- 0.01621	-0.01611	-0.0176	-0.01637
	(-11.16)	(-11.21)	(-12.41)	(-12.05)
Population growth		0.0008		
		(0.0042)		
Machinery and equipment	0.1992	0.1939	0.1941	
	(4.89)	(4.28)	(4.69)	
Non residential construction			0.1236	
			(3.05)	
Investment total				0.1142
				(16.24)
Constant	0.14791		0.1549	0.1418
	(11.02)		(11.80)	(11.24)
Observations	45	45	45	45
R^2	0.84	0.85	0.86	0.93
	(0.48)	(0.46)	(0.47)	(0.52)

Summary Statistic: Mean and standard deviation (in parentheses)			
GDP growth	0.0.076	Population growth	0.0066
	(0.01359)		(0.00502)
LN initial GDP per capita	8.32099	Equipment	0.08994
	(0.5753)		(0.03050)
Non residential construction	0.04370	Aggregate investment	0.22628
	(0.01595)		(0.0398)

Notes: The dependent variable is GDP per capita growth rate. Estimation by GMM. R^2 not corrected in parentheses.

16 These results are similar to those obtained by Temple and Voth (1998) for more developed countries, and to the results of De Long and Summers (1992).

Figure 1. Ratio of Gross Fixed Capital Formation to GDP in PPP

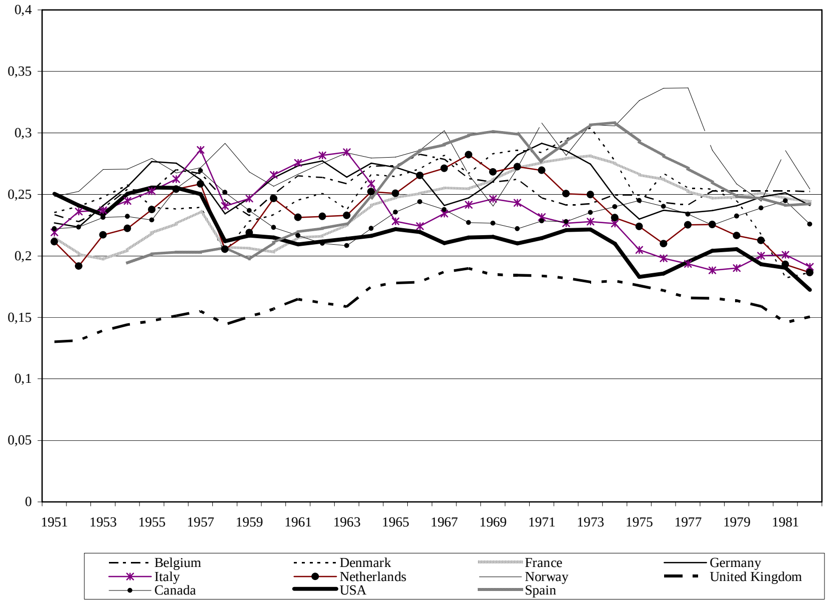
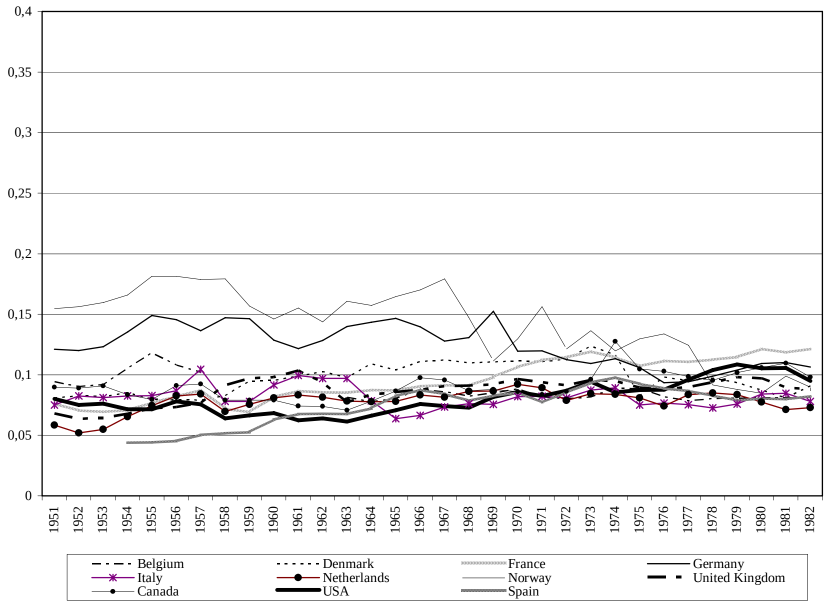


Figure 2. Ratio of Machinery and equipment investment to GDP in PPP



Source: OCDE Historical Statistics

2.2. The user cost of capital

Recently many studies have established a robust link between the relative price of capital and economic growth. Jones (1994) for example, uses data underlying the Penn World Tables to argue that "an increase in the relative price of machinery reduces capital accumulation and therefore reduces the growth rate of the economy"[17]. However, in this relationship a decisive link has been lost. The substitution of the cost of capital by the relative price of capital could be an omission that matters. The user cost of capital is determined by a combination of conditions in financial capital markets and in capital goods markets. As has been expressed in the Hall-Jorgenson formula[18], the user cost expression is derived under profit maximisation using capital accumulation identity and the assumption of no adjustment cost:

$$W = \int_0^{\infty} e^{-rt} R(t) d(t) \quad [1]$$

[1]

Where r is the interest rate and R the net income defined as,

$$R = pQ - sL - qI$$

[2]

Where p is the price of output, s the salary, q the price of capital, Q the output, L represents the quantity of labour and I the investment rate. The maximization of net value under the conditions of a neoclassical production function and the restriction that capital stock growth is equal to investment less depreciation leads to conditions of marginal productivity,

[17] Jones (1994), p. 372.
[18] Jorgenson (1963) and Hall and Jorgenson (1967).

$$\frac{\partial Q}{\partial L} = \frac{s}{p}$$

[3]

$$\frac{\partial Q}{\partial K} = \frac{c}{p} = \frac{q(r+\delta) - \dot{q}}{p} = P_t(R_t + \delta - \frac{\dot{P}_t}{P_t})$$

[4]

Where *equation 4* represents the Standard Hall-Jorgenson rental rate formula, where P_t is the price of capital relative to the price of output, R_t is the real interest rate, δ is the depreciation rate.

In *figures 2* and *3* we have represented the user cost of capital for aggregate investment and for machinery and equipment investment. The user cost of capital is expressed in international comparative levels as is described in *appendix 1*. The information contained in the figures suggests three facts: 1) refers to the relationship between income per capita and the cost of capital, 2) the decreasing trend followed by machinery and equipment costs along the sixties and 3) the convergence in the cost of capital among the sample countries.

In figures 2 and 3 it is easy to identify a negative association between income level and the user cost of machinery. This relationship was predictable since the price component of the cost is the main determinant of user cost and there is a negative relationship between the relative price of capital and income per capita level[19]. Accordingly, it can be observed that the lowest costs correspond to the most developed country, United States, while the highest costs were reached in the less developed countries of Europe, and in particular Spain where in 1954 costs doubled the average sample cost of the sample and quadrupled that of the United States. The negative association between income per capita and the cost of capital is less clear for aggregate capital goods, because this kind of

[19] Urrutia and Restuccia (2001).

investment has a very significant non tradable component in the form of construction services[20] whose prices tend to be higher in upper level income countries. So the inverse relationship between income level and relative prices that we observe in the case of machinery tends to mask for the aggregate.

The second fact to highlight refers to common trends in the cost of capital of the different countries since the beginning of the sixties. It is important to outline the high volatility of the costs of capital in some countries throughout the fifties. In most of them volatility is determined by highly volatile long term interest rates due to the readjustment in monetary markets after the war. This was followed by a progressive convergence to the lowest capital cost of the United States, especially in the case of machinery and equipment. At the end of the sixties the period of convergence to the lowest level of the leader seems to stop. Since then, the cost series follow an upward trend jointly with the United States.

Expressed in logs, the cost of capital is the sum of two series, the relative price of capital and the non-price component. If we look within specific categories of capital goods, the two components of the cost seem to have very different properties. The relative price of equipment has a very persistent downward trend in most of the countries throughout the whole period. The non price component for both, the aggregate and machinery, has an upward trend for most of the period and countries (see table 2).

[20] Burstein, Neves and Rebelo (2004) document four basic facts about investment goods and investment prices, including the high nontradable component of the investment goods in the form of construction services that affect the prices of investment goods.

Figure 3 User cost of capital goods

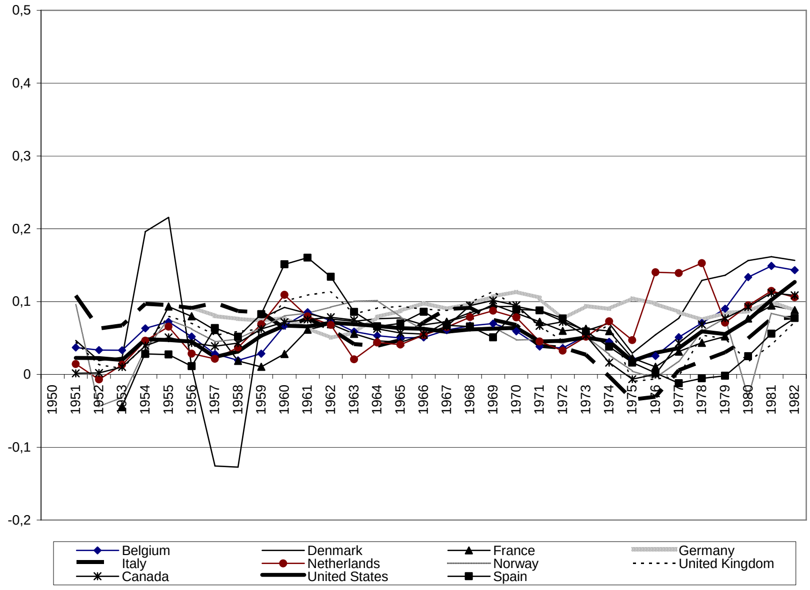
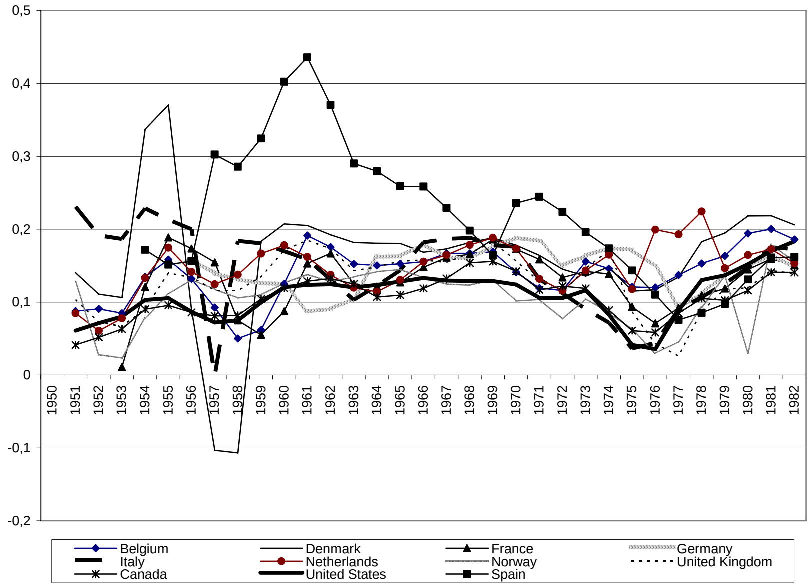


Figure 4 User cost of machinery and equipment



Source: See text

Throughout the sixties, the pattern of declining relative prices for equipment came not only from technological innovations in equipment industries[21], but in particular, from Europe's vigorous openness to foreign trade and market integration[22]. At the beginning of the fifties all countries have higher machinery and equipment relative prices than the United States.

In contrast, long-run real interest rates will be related to the marginal productivity of capital, which will be a stationary variable in any general equilibrium model. From the mid fifties onwards, European real long term interest rates recover their secular convergence[23]. Some countries like Spain and France even experienced a decrease in absolute terms in their nominal interest rates. This evolution of interest rates seems to be a consequence of the commitment to exchange rate stability in the international monetary system. The zeal to keep this commitment helped to control inflation rates in the post war period and with it to reduce differentials in interest rates with respect to the United States. This would be positive, without any doubt, for investment in Europe. But in the second stage, once the European interest rates stabilized around the North American level there was a tendency to increase in nominal terms in parallel with the United States. Interest rates grew on average at 4.01% in 1965-1973 against the lower rate of 1.78% in the previous period, 1951-1965, as a consequence of increasing instability in the international monetary system due to loss of confidence in the dollar.

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[21] Hulten (1992).

[22] Eaton and Kortum(2001) modelize the relationship between relative prices of capital goods and the development of trade in capital goods. They demonstrate that less developed countries import capital goods from a selected bulk of more advanced countries and that the imported goods tends to reduce the relative price of capital in less developed countries.

[23] Taylor and Obsfeld (2004);

Table 2

Break down of user cost of capital determinants

(Average rates of cumulative annual growth, in %)

	1951-1965				
	Equipment			Other capital goods	
	Non price component	Relative price	User cost	Relative price	User cost
Spain	-3,12	-0,57	-2,12	0,88	1,73
Italy	0,91	-1,05	-0,69	0,52	1,51
France	-1,53	-0,06	-0,63	0,18	-0,39
Denmark	2,59	-0,91	0,05	2,21	7,22
Netherlands	2,52	0,30	1,09	1,40	1,77
Germany	0,06	1,41	1,44	2,16	2,97
Belgium	2,42	0,62	1,47	1,58	2,76
USA	3,59	0,75	1,64	-0,04	1,35
Norway	4,37	0,62	1,79	1,61	2,63
United Kingdom	4,30	0,44	1,84	1,20	2,09
Canada	3,47	1,27	2,28	-1,08	-1,83
Average	1,78	0,26	0,74	0,96	1,98
	1965-1973				
	Non-price	Relative price	User cost	Relative price	User cost
Netherlands	4,45	-2,56	-0,86	2,45	3,21
Spain	3,23	-1,56	-0,03	2,90	5,43
Denmark	5,26	-2,35	0,06	0,50	2,77
France	5,76	-1,99	0,22	0,28	1,93
Canada	4,76	-1,56	0,22	1,86	2,22
Belgium	1,82	-0,47	0,27	2,20	3,97
Germany	3,73	-1,28	0,35	-0,14	0,83
USA	5,17	-1,34	0,36	2,58	5,49
Norway	2,73	-0,47	0,49	0,70	2,53
Italy	0,84	0,57	0,93	1,27	3,02
United Kingdom	6,33	-0,15	2,69	1,16	2,74
Average	4,01	-1,20	0,43	1,43	3,10

Note: As non price component we take the nominal interest rate.

If we break down the variance of the cost as the sum of the variance of relative prices, the variance of the non-price component minus twice the covariance between the two components. The break down shows that only in those countries with a rapid decline in relative prices for equipment can this component on its own explain most of the change in the cost. Meanwhile for aggregate capital goods the evolution of the user cost of capital is mainly explained by the evolution in the non-price component.

These differences are also reflected in the different convergence trend followed by any of the two components. In *figures 5* and *6* we represent the coefficient of variation for the cost of capital, for its two components, as well as for long term nominal interest rate. It can be observed that there was a convergence in the cost of capital among countries in both kinds of investment goods that was lead jointly by convergence in relative prices and in the non-price component.

Although we can stress that convergence was sharper in the machinery and equipment case. After 1970, increased dispersion in both the aggregate and the machinery was caused by the increasing dispersion in the non-price component, specially in interest rates.

We can conclude that integration in financial markets and trade liberalization after the war enabled European countries to benefit from high stability and convergence in the cost of capital. This process took place especially in the sixties, while the previous decade represents a progressive change towards new conditions of stability.

Figure 5 Dispersion in the user cost of capital and its components

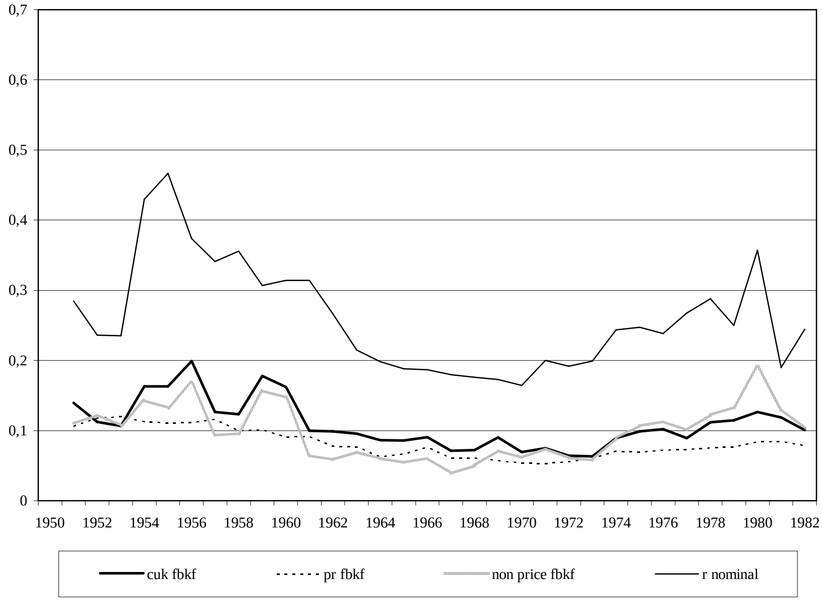
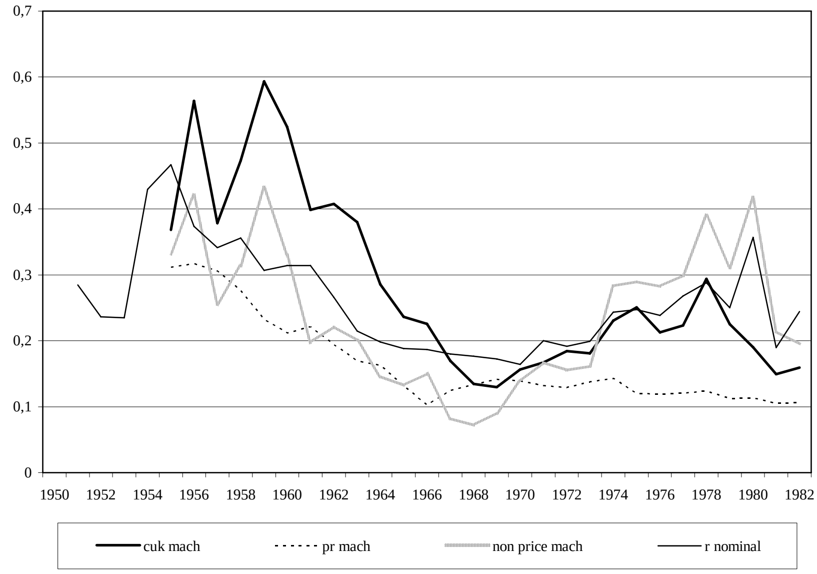


Figure 6 Dispersion in the user cost of machinery and its components



Source: See appendix 1.

3. The user cost of capital in a traditional investment model

Chirinko(1993) in a comprehensive survey on investment models, suggests that in the empirical works investment is more sensitive to quantity variables (output or sales) than to price variables, which tend to have only modest effects. This could contradict the common results obtained in the literature on economic growth that find a relevant role for prices in investment behaviour. Aggregate models invariably find little or no role for the real user cost of capital, so they understate the positive effects of falls in the relative prices of equipment on investment[24].

Traditional models of investment start with a theory relating optimal frictionless capital stock, K_t^*, to production technology and factor prices. If firms could costless adjust capital stock, they would always set $K_t=K_t^*$. However, the sluggish behaviour of capital stock suggests that there are costs associated with adjustment. The traditional neoclassical Keynesian investment models used simple ad hoc specifications of the effects of adjustment costs, the most common being the partial adjustment approach, which assumed that firms move part of the way towards their optimal frictionless stock each period. Formulating this relationship in terms of capital stock and using lower case letters to denote the log of variables, the partial adjustment equation is,

$$\Delta k = (1-\lambda)(k^*_{t-1} - k_{t-1})$$

[5]

Which can be re-written as:

$$k_t = \lambda k_{t-1} + (1-\lambda)k_t^*$$

[6]

Applying repeated substitution to equation (2) gives an equivalent representation for the capital stock, this time as an infinite distributed lag function of past k_t^*'s:

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[24] Bakhshi, Oulton and Thompson. (2003).

$$k_t = \sum_{r=0}^{\infty}(1-\lambda)\lambda^r k_{t-r}^* = \sum_{r=0}^{\infty}\gamma_r k_{t-r}^*$$

[7]

This has been turned into an empirical investment equation by taking the following steps. First, the infinite distributed lag suggested by the partial adjustment theory is replaced with a finite approximation, usually about 8 to 12 quarters. Second, the equation is differenced to turn it into a net investment equation:

$$\Delta k_t = \sum_{r=0}^{N}\gamma_r \Delta k_{t-r}^* + \varepsilon_t$$

[8]

This equation is operationalized by assuming a form for k_t^*. Specifying a CES production function, K_t^* is proportional to Y_t/C_t^{σ}, where Y_t is output, C_t is the cost of capital, and σ is the elasticity of substitution between capital and labour. Taking logs of K^* we obtain

$$\Delta k_t = \sum_{r=0}^{N}\gamma_r \Delta y_{t-r} - \sigma\sum_{r=0}^{N}\gamma_r \Delta c_{t-r} + \varepsilon_t$$

[9]

Since $\sum_{r=0}^{\infty}\gamma_r = 1$, the sum of the coefficients on output should approximately equal one while the coefficients on the cost of capital should sum to the elasticity of substitution, σ. These sums have an intuitive interpretation since they describe the predicted long-run response of capital stock to permanent unit shocks to output and the cost of capital. This approach only describes the determination of capital stock in terms of net investment. When the interest variable is gross investment, which includes both the change in capital stock and the replacement of depreciated capital, most empirical models assume a constant average rate of depreciation and estimate an equation for gross investment. In this case, approximating the log-difference of the capital stock with the growth rate, we get

$$\Delta k_t \approx \frac{\Delta K_t}{K_{t-1}} = \frac{I_t}{K_{t-1}} - \delta$$

[10]

Where δ is the depreciation rate. This gives an equation for gross investment

$$\frac{I_t}{K_{t-1}} = \delta + \sum_{r=0}^{N} \gamma_r \Delta y_{t-r} - \sigma \sum_{r=0}^{N} \gamma_r \Delta c_{t-r} + \varepsilon_t$$

[11]

In the presence of adjustment costs, the actual capital stock will not adjust immediately to the desired level, we therefore augmented *[11]* by the lagged dependent variable,

$$\frac{I_t}{K_{t-1}} = \delta + \sum_{\gamma=0}^{N} \gamma_r \frac{I_{t-1}}{K_{t-2}} + \sum_{r=0}^{N} \gamma_r \Delta y_{t-r} - \sigma \sum_{r=0}^{N} \gamma_r \Delta c_{t-r} + \varepsilon_t$$

[12]

The increase in *GDP* in t is taken as a proxy for Δy that represents the increase in demand expected by investors[25]. We have calculated annual data on the user cost of capital for every country from 1950 to 1973 at international comparative levels as described in *appendix 1*. The main problem in constructing the variables for estimating *equation 12* was to obtain time series of capital for every country throughout the whole period. For this reason we have taken a shortcut that consists in taking *(I/Y)* as a proxy for *(I/K)*. Several growth accounting studies, including that of Mankiw, Romer and Weil(1992) use a formulation of the production relationship that replaces capital stock growth with an approximation based on its steady-state relationship with investment as a share of GDP. The change in capital stock is given by

$$\Delta K = I - dK$$

[13]

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[25] This choice can be rationalized on the ground that investment observed at time *t* was planned at time *t-1* on the basis of demand expected at time *t* by fully rational investors.

Dividing through by K and assuming a steady-state constant value *(γ)* for the inverse of the capital-output ratio allows the capital stock rate of change of the capital stock *(K)* to be measured by investment rate ($i=I/Y$). The use of the investment rate has an obvious advantage. It avoids the measurement problems introduced by the choice of an initial capital stock and an assumed rate of depreciation. And in any case, the assumption of a constant capital-output ratio seems particularly reasonable for studying the growth experiences of countries with similar characteristics. Bosworth and Collins (2003) show that there is very little correlation between the change in capital stock and the mean investment rate in a sample of 85 countries, even over a period as long as forty years.

$$\Delta \ln K = i\gamma - d$$

[14]

So the basic regressions we run can be rewritten as:

$$\log(I/Y)_t = a + \sum b_s \log(I/Y)_{t-s} + \sum c_s \Delta \log(Y)_{t-s} - \sum d_s \Delta \log c_{t-s} + u_t$$

[15]

Previous empirical implementations of this model have found that it provides a fairly good description of the cyclical behaviour of investment.

4. Econometric modelling

We estimate the investment equation formula, equation *[15]*, for aggregate investment as well as for machinery and equipment investment. We have data only on N=11 countries and T=23 years and we will manage this set of data as a panel, although we were aware that the *n* dimension of the panel is too small. The desire of exploiting panel data has the motivation of controlling unobserved time invariant heterogeneity. It is clear that omitting individual effects and using pooled OLS to estimate the parameters of equation *[15]* would yield biased and inconsistent estimates owing to the correlations between the error term and the lagged dependent variable.

$$\Delta i_t = \alpha_0 + \alpha_1 \Delta i_{t-1} + \alpha_2 \Delta\Delta c_{it} + \Delta\Delta y_{it} + \varepsilon_t - \varepsilon_{t-1}$$

A standard procedure to overcome this problem in dynamic panels (Anderson and Hsiao(1981)) is to wipe out the individual effects by means of a first difference transformation. Notice that if the errors at levels are serially uncorrelated, the errors in differences are moving average of order MA(1). If the errors are MA(k) the disturbances in differences are MA(k+1). Thus the differenced errors are correlated with some of the values of the lagged dependent variables and inconsistent estimation of the parameters in equation *[15]* requires instrumental variables methods. The GMM estimator proposed by Arellano and Bond(1991) is adopted.

The basic idea is to write the regression equation as a dynamic data model, take first differences to remove unobserved time invariant country specific effects and then instrument the right hand side variables in the first differenced equations using levels of the series lagged two periods or more, under the assumption that the time-unvarying disturbances in the original levels equations are not serially correlated.

In studying a dynamic equation this procedure have important advantages over other estimation methods. First, estimates will no longer be biased by any omitted variables that are constant over time (unobserved country specific or fixed effects). Secondly, the use of instrumental variables allows parameters to be estimated consistently in models which include endogenous right-hand side variables, such as lagged instruments. Finally, the use of instruments potentially allows consistent estimation even in the presence of measurement errors.

So we transform our estimation equation by taking first-differences in order to eliminate unobserved individual country effects that are a source of inconsistency in the estimates.

$$\Delta i_t = \alpha_0 + \alpha_1 \Delta i_{t-1} + \alpha_2 \Delta\Delta c_{it} + \Delta\Delta y_{it} + \varepsilon_t - \varepsilon_{t-1}$$

[16]

Then, as instruments for the variables that are correlated with the error term (lagged dependent variable and other endogenous variables, such as the increase in demand) we use the lagged levels of the observed series, i_{t-3} to instrument for (i_{t-1}-i_{t-2}) and y_{t-2} to instrument for (y_t-y_{t-1}). The original estimator of Arellano and Bond (1991) makes use of all possible lags from *t-2*.. We limit our instruments to lags *t-2* to *t-7* for two reasons. First, the decision to include a large number of instruments must be tempered by the use of a small sample. In this respect, generally these additional instruments may render important gains in efficiency, but may also be infeasible and inappropriate in panels with a small cross-sectional dimension, since the number of instruments would by far exceed the number of observations. When the time series are persistent and the number of time series observations is small, the first-differenced GMM is poorly behaved. The reason is that, under these conditions, lagged levels of the variables are only weak instruments for subsequent first-differences. Second, as shown by Arellano and Bover (1995) for a given small-sample cross-section dimension, the use of too many instruments might lead to *overfitting bias* and reduce the power of the Sargan test to detect any instrument invalidity. To limit this problem, we use a minimal set of instruments. In addition, by using levels of the dependent variable lagged by one additional period to instrument for the first-differenced term- the first instrument for y_{t-1}-y_{t-2} is y_{t-3}- we account for the potential presence of measurement errors (Blundell and Bond (1998)).

The consistency of these estimators relies on the validity of the instruments and on the absence of first-order autocorrelation in the errors (ε_t) (second-order autocorrelation in the errors of the first-differenced equation), $E(\Delta\varepsilon_t, \Delta\varepsilon_{t-2})=0$. Arellano and Bond (1991) present specification tests for instruments validity. The first is a Sargan test for over-identifying restrictions, which tests for the overall validity of the instruments, implying the absence of correlation between the instruments and the error term. The second tests for the null hypothesis of the absence of second-order serial correlation in the residuals of the first-differenced equation.

We will consider the results of applying GMM to estimation of the Jorgenson and Hall investment equation. The one-step and the two-step GMM estimators are asymptotically equivalent for the first-differenced estimator. Otherwise, the two-step estimator is more efficient, and this is always true for the system GMM. Temple and Bond show that in finite samples efficiency gain is typically small and the two-step GMM estimator has the disadvantage of converging to its asymptotic distribution relatively slowly. In finite sample, the asymptotic standard errors associated with the two-step GMM estimators can be seriously biased downwards, and thus form an unreliable guide for inference. With this in mind, we prefer to report the results of the one-step, with standard errors that are only asymptotically robust to heteroscedasticity but have also been found to be more reliable for finite sample inference[26].

The proposed estimators have good properties in asymptotic terms. Nevertheless, in finite samples, GMM estimation techniques have been found to produce poor results. Kiviet´s solution (1995) is to use a corrected LSDV estimator that is efficient in comparison with the established consistent estimation methods. However, Judson and Owen (1999), show that GMM is a good alternative to a LSDV corrected. We have implemented all this techniques in appendix 2 and we have no encountered large differences in the coefficients.

The results from estimating *equation [16]* using annual data are reported in *tables 2* and *3* for two basic specifications: with the user cost of capital or with its two components. In general, the instruments used appear to be valid on the basis of the Sargan test, while the results of the autocorrelation tests do not indicate major problems concerning the existence of second-order correlation that would lead to inconsistent estimates.

[26] Blundell and Bond (2001).

We begin with a regression between the ratio of investment in physical capital to (*ratiofbk*f) the rate of growth of GDP (*Ggdp*) and the rate of growth of the user cost of capital (*gcuk*). In this regression, GDP rate of growth enters with the expected sign and is significant at the 1% confidence level. Growth in the user cost of capital, however, enters with the wrong sign and is not significant. These results remain unchanged when we include country dummies and when we use different specifications of the cost of capital.. The estimate of 0.8 for the lagged investment ratio implies relatively slow adjustment. The coefficient on GDP growth rate implies that a 10 % increase in the growth rate would increase the ratio of investment in physical capital by 4-5%. These results agree with those obtained with the accelerator-style models that previous studies have found best fit the data[27]. However the mentioned studies do not find any role for user cost of capital.

This result is not surprising. Recent research has shown that aggregate economic models fail to explain the investment boom in the second half of the nineties. This appears to reflect two factors. First aggregate models do not capture the increase in replacement investment associated with compositional shifts in capital stock towards short-lived assets, such as machinery or, more recently, computers. Second, aggregate models invariably find little or no role to the user cost of capital, so they understate the positive effects of falls in the relative price of certain type of investment goods.[28]

To test the influence of the relative price of capital on investment, we break down the user cost of capital into its price (*prel*) and non-price (*nonprice*) components in the second column of *table 3*. The estimated coefficient of each variable point to a similar negative effect but only the impact of the relative price of capital on the ratio of investment in physical capital to GDP is statistically significant.

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[27] Chirinko (1993), Oliner, Rudebusch and Sichel (1995)
[28] Herbet (2001), Bakhshi, Oulton and Thompson (2003), Tevlin and Whelan (2003)

In contrast with the results for the aggregate, when we focus only on machinery and equipment, investment is sensitive to the cost of capital. The estimate of 0.7 for the lagged investment ratio implies relatively slow adjustment, but the ratio depends less on previous periods than on the aggregate, as we expected. The coefficient on output is significantly positive at 10% and the coefficient on the cost of capital is negative as expected but small.

As in the aggregate we test the influence of price and non price components of the cost of capital. As in previous estimates, relative price of capital is highly significant, but the non-price component is not, suggesting that the influence of the cost of capital on investment is driven mainly by the evolution of prices.

Our results are in line with recent works on investment decisions in the 1990s, which suggest that real investment becomes more sensitive to changes in the user cost of capital when the relative prices of capital lead the user cost. If the price component of the user cost of capital experiences a steep decline due to technical progress or to changes in market conditions, this component will be the leading force in the cost of capital[29]. In this case, the cost of capital would tend to be significant in explaining investment. Aggregate models usually find little or no role for the real user cost, so do not pick up the strong effects of relative price declines on investment in those groups of capital goods more sensitive to technological progress[30], such as machinery and equipment in our period of analysis. In our analysis the disaggregated approach allows us to assess that user cost of capital became significant in explaining investment only when the decline of relative prices was strong and could overweight the upward trend in the non-price component. This

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[29] For example for the investment boom of the 1990s in most advanced countries, like United States, traditional aggregate econometric models completely fail to capture the magnitude of investment when investment became more sensitive to the cost of capital, they show that aggregate models do not capture the increase in replacement investment associated with compositional shifts in capital stock towards high depreciation assets, like computers.

[30] This was the case for computers in the United States in the 1990's Tevlin and Whelan (2003), and in the United Kingdom, Bakhshi, Oulton and Thompson (2003).

effect was only observed in the case of machinery and equipment for most countries in the sample, but not for the aggregate. The upward trend in the non-price component, however, was mainly driven by the general increase in long term interest rates.

In the period analyzed Europe invested heavily in machinery and equipment that embodied new technology. The diffusion of this effect was favoured by trade liberalization across Europe. So, there was an important compositional change in investment towards machinery and equipment other than capital goods.

Table 3. Estimation of Investment Share Equation for Aggregate Investment

	GMM	GMM
Parameter Estimates		
Ratiofbkf	0.82934***	0.84628***
	(0.05528)	(0.05394)
Ggdp	0.52517***	0.53305***
	(0.08805)	(0.08336)
Gcuk	.02332	
	(0.02637)	
Relprice		-0.1905***
		(0.05893)
Nonprice		-0.00188
		(0.00183)
Specification Test		
Sargan-test	214.94	212.13
	(0.4691)	(0.5233)
AR(2) test	-1.52	-1.53
	(0.1278)	(0.1267)
Obs	221	

Notes: The dependent variable is the ratio of investment to the GDP. One, two and three asterisks indicate rejection of the null hypothesis at 10%, 5% and 1% respectively. Ratio of investment to GDP lagged differences are instrumented by the level lagged three periods for robustness in the presence of measurement errors. Likewise, GDP is considered an endogenous variable and is instrumented by the level lagged two periods. AR(2) test is a test for the presence of second-order correlation in the error structure. All standard errors are robust.

Table 4. Estimation of Investment Share Equation for Machinery and Equipment Investment

	GMM	GMM
Parameter Estimates		
Ratioequip	0.72635***	0.71609***
	(0.59786)	(0.05581)
Ggdp	0.1304494*	0.0971443
	(0.074472)	(0.0715572)
Gcuk	-0.06782*	
	(0.37558)	
Relprice		-0.17572***
		(0.04482)
nonprice		0.04884
		(0.04924)
Specification Test		
Sargan-test	231.09	231.14
	(0.2012)	(0.1881)
AR(2) test	-1.83*	-1.78*
	(0.067)	(0.075)
Obs	221	221

Notes: The dependent variable is the ratio of investment in machinery and equipment to the GDP. One, two and three asterisks indicate rejection of the null hypothesis at 10%, 5% and 1% respectively. Ratio of investment in machinery and equipment to GDP lagged differences are instrumented by the level lagged three periods for robustness in the presence of measurement errors. Likewise, GDP is considered an endogenous variable and is instrumented by the level lagged two periods. AR(2) test is a test for the presence of second-order correlation in the error structure. All standard errors are robust.

5. Conclusions

During the last decade a fairly wide consensus in the literature on economic growth has emerged about the factors that determine differences in income levels between countries. One of the most significant factors is investment rate differences: It has been observed a positive association between income levels and investment rates. In this work we present the increase in investment share in GDP as a central variable in explaining growth and convergence in income levels in Europe during the Golden Age. We find a positive cross-country relationship between equipment investment and growth in per capita income in Europe and also for the aggregate.

With this evidence in mind, throughout the paper we have tried to answer three questions. First, did the exceptional circumstances that concurred in Europe during the post-war period favour convergence in investment rates and through which channel did they operate? We have based our analysis upon a simple model in which investment depends on changes in the real user cost of capital, changes in aggregate demand and previous investment share level. Although previous works on economic growth have focused on the relative prices of capital, in this research we have selected the user cost of capital as a representative variable for summing up the exceptional conditions in financial and goods markets of capital that could favour investment. We have found that convergence in the investment rates observed in Europe during the Golden Age had its counterpart in convergence in the user cost of capital goods.

Second, what determines convergence in the user cost? We have broken down the user cost of capital into two components, a relative price component and a non-price component. The reduction in the dispersion of the user cost was jointly driven by relative price convergence and by nominal interest rates convergence. Both variables reflect the exceptional frame of international relations developed in Western countries in the two decades after World War II. Integration in financial markets and trade liberalization after the war favoured high demand stability and convergence in the cost of capital. This process took place mainly in the sixties, while the previous decade was one of change towards new conditions.

Third, how much convergence in the cost components did affect the investment share? Disaggregation seems to matter in explaining the role of the cost of capital in investment. Our results are in line with recent works on investment decisions in the 1990s, which suggest that real investment becomes more sensitive to changes in the user cost when the relative prices of capital leads the user cost. In our analysis the disaggregated approach allows us to assess that user cost of capital becomes significant in explaining investment only when the decline of relative prices is strong and able to overweight the upward trend in the non-price component. This effect was only observed in the case of machinery and equipment but not for the aggregate. In the aggregate case we have found little or no role for the real user cost, while we have found a negative coefficient for machinery and equipment.

As in other works investment in machinery and equipment seems significant in explaining growth and sensitive to the conditions in international markets that benefited every country involved in an integration process. Our results renew the underlying claim in De Long and Summers' work about the role of trade policies in exogenously determining equipment investment.

APPENDIX 1. Constructing the user cost of capital and machinery and equipment by countries in comparative levels, 1950-1975

The annual series of the user cost of capital expressed in international prices have been constructed for each country taking as reference 1980 purchasing power parities of the International Comparisons Programme (ICP) of the United Nations. The objective of the ICP is to facilitate international comparisons of the real product and to establish purchasing power parities between currencies in different countries. They have been used as basic reference in the Penn World Tables (PWT)[31].

The information contained in the Penn World Tables, although widely used by other authors[32] to analyse the relation between the relative prices of capital and economic growth, was insufficient to cover the objectives of this work. First, the PWT only provide data from 1960 on and does not cover the previous decade. Second, its level of disaggregation does not allow analyzing investment in machinery and equipment. And by the other hand, in the present work we wanted to turn aside attention from the relative price of capital to its user cost, which is the variable of reference in the theoretical models on investment and that allows us, in addition, to emphasize the effect of financial market integration on post-war investment.

In order to take care of all these aims, we have constructed annual series of the user cost of capital goods, and its main components, such as investment in machinery and equipment and non-residential construction, for 11 OECD countries from 1950 to 1973. The countries included in the sample are Germany, Austria, Belgium, Canada, Denmark, The United States, Spain, France, Great Britain, Netherlands, Italy and Norway. First we assembled annual series of prices from OECD statistics. Second, we used the benchmark data from the ICP for 1980 to build a comparable estimate of the relative prices of capital

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[31] Kravis, Heston and Summers (1982)

[32] De Long and Summers (1982), Jones (1994), Restuccia and Urrutia (2001), Collins and Williamson (2001)

goods. Third, we constructed annual series of relative prices of capital goods and its components by backward discounting the annual variation rates of the implicit price indexes for investment and consumption, extracted from the National Accounts of each country. The prices of capital have been expressed in relation to those of consumption, and not with respect to GDP because investment is a component of this one.

We tried to establish the benchmark year as near as possible to the initial year of the period, with the intention of reducing bias derived from the problem of the index numbers, but finally we had to use 1980 because the previous benchmarks (1970 and 1975) included a small number of countries.

After constructing the annual series of the relative prices of capital goods expressed in comparative levels internationally we proceed to elaborate the user cost of capital. The expression that gathers the user cost of capital has been derived in the previous section:

$$\frac{\partial Q}{\partial K} = \frac{c}{p} = \frac{q(r+\delta) - \dot{q}}{p} = P_t(R_t + \delta - \frac{\dot{P}_t}{P_t})$$

[4]

where *c/p* it is the user cost of capital, *P* the price of replacement of the capital assets expressed in relation to the prices of consumption, *R* is the real long term interest rate, δ the rate of physical depreciation, and the last term represents the revaluation of capital assets. The nominal interest rate was obtained for each country from the International Financial Statistics of the International Monetary Fund. The same rate of depreciation was applied to all the countries. We considered a depreciation rate of 0.10 for the equipment and of 0.5 for the aggregate.

APPENDIX 2

The controversy about the best technique to estimate a dynamic panel data model, as the one we have estimated in section 4, has taken us to make an exercise to verify the robustness of the results. As it has been said, our dataset have a time dimension far larger and an individual (country) dimension far smaller than the typical microeconomic panel. Following Judson and Owen (1999), we use several different techniques for estimating dynamic models with panel characteristic. Our goal is to asses the validity of the results obtained.

We consider four estimates: a typical OLS estimator, the usual LSDV, a Kiviet's corrected LSDV estimator and Arellano and Bond one-step estimator. These are the usual choices in the literature. Table A.1 show the result of the estimation when the dependent variable is the ratio of investment to output. The common features of all the estimations are: 1) GDP growth is the main determinant of the growth of the investment ratio. Its coefficient is between 0.49 and 0.56; (2) in all the cases, the price variable is not significant; (3) when the user cost of capital is replaced by its two components, the evolution of the relative prices appears significant in all the cases, with a coefficient between -0.18 and -0.21; (4) the evolution of the financial components of the user cost of capital is, in all the cases, non-significant.

When we substitute the investment ratio for the share of investment in machinery and equipment on output, price variables turn significant in every estimate as we have seen in the text. The common features of all the estimations are: (1) GDP growth is significant in the determination of the investment ratio with a value for the parameter 0.12-0.18. The higher value is, as expected, for the OLS estimate; (2) the price variable turns significant, with a value for the coefficient low and negative from -0.06 to -0.08; (3) when we decompose the user cost of capital is its two components, the financial component turns non-significant, but the relative prices maintain its significance.

The results that we have obtained in this exercise reinforce the confidence that we have in the fitness of the values of the estimators used in the text.

TABLE A.1. ESTIMATES FOR THE INVESTMENT RATIO

	OLS	LSDV	LSDVC	GMM	OLS	LSDV	LSDVC	GMM
Lagged	0.9644691	0.8269474	0.8902325	0.82934	0.9663147	0.8410479	0.9009567	0.84628
Ratiofbkf	(0.0087237)	(0.0378779)	(0.044787)	(0.05528)	(0.0084578)	(0.0366435)	(0.0427638)	(0.05394)
Ggdp	0.5646029	0.4944097	0.4933078	0.52517	0.5535208	0.4991647	0.4938152	0.53305
	(0.835244)	(0.0825113)	(0.0874499)	(0.08805)	(0.0820267)	(0.0811326)	(0.0878259)	(0.08336)
Gcuk	-0.0086902	0.0225491	0.017922	0.02332				
	(0.0349159)	(0.0366099)	(0.0387505)	(0.02637)				
Gprel					-0.2170443	-0.1871799	-0.1918781	-0.1905
					(0.0767565)	(0.0785317)	(0.0748725)	(0.05893)
Gnonprice					-0.001588	-0.0016112	-0.001605	-0.00188
					(0.0017417	(0.0025109)	(0.002568)	(0.00183)
Sargan				214.94				212.13
				(0.4691)				(0.5233)
AR(2)				-1.52				-1.53
				(0.1278)				(0.1267)
N				221				221

TABLE A.2 ESTIMATES FOR THE EQUIPMENT RATIO

	OLS	LSDV	LSDVC	GMM(AB)	OLS	LSDV	LSDVC	GMM
Lagged	0.9740146	0.7446658	0.8210628	0.72635	0.9742123	0.7316917	0.8015814	0.71609
Ratioequip	(0.0156029)	(0.0604009)	(0.0553298)	(0.059786)	(0.152569)	(0.0457073)	(0.0543748)	(0.05581)
Ggdp	0.1814311	0.1289112	0.1217858	0.1304494	0.1477957	0.0949386	0.0912089	0.0971443
	(0.0609116)	(0.0650248)	(0.0671571)	(0.074472)	(0.0594981)	(0.0612003)	(0.0672097)	(0.0715572)
Gcuk	-0.0851237	-0.075846	-0.0757979	-0.06782				
	(0.0441292)	(0.0418172)	(0.0349765)	(0.037558)				
Gprel					-0.1831174	-0.1850143	-0.1825993	-0.17572
					(0.0638706)	(0.0429049)	(0.0407567)	(0.04482)
Gnonprice					0.0264386	0.0477012	0.0448034	0.04884
					(0.048014)	(0.455717)	(0.0517633)	(0.04924)
Sargan				231.09				227.86
				(0.2012)				(0.2387)
AR(2)				-1.83				-1.79
				(0.067)				(0.073)
N				221				221

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