The determinants of capital deepening: evidence for the U.S., Japan, Spain and Canada.*

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Abstract

Capital deepening is a crucial variable in macroeconomics. However, it is generally taken as an input –in most growth accounting exercises, for example– and little or no effort is devoted to the empirical assessment of its determinants. This paper intends to fill this void by developing a model in which capital deepening depends on both supply and demand-side determinants. This model is estimated for economies with different trajectories of capital deepening –the U.S. and Canada, with relatively flat paths, and Japan and Spain, with steep paths– and both sets of determinants are shown to be relevant in these countries. We also find the incidence of the supply-side determinants to be stable and largely independent of the business cycle, while the impact of the demand-side determinants is specially strong during expansions. Additionally, we provide new estimates of the elasticity of substitution between production factors. These results may help to enlighten the design of economic growth and labour market policies.

JEL Classification: E22, E24, O40, E32.

Keywords: Capital deepening, Capacity utilisation rate, Employment, Biased technical change, Elasticity of substitution.

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1 Introduction

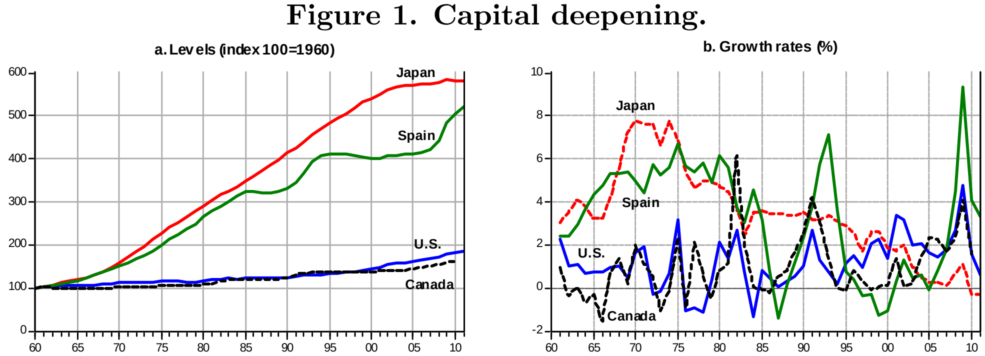
Capital deepening (i.e. capital stock over employment ratio) plays a central role in economic growth models. The role of capital stock in the labour market is the object of an important controversy and the capital-labour degree of substitutability is the key factor. While mainstream economists hold the view that capital stock plays no role in shaping unemployment –for example, Layard, Nickell, and Jackman (1991) and subsequent literature–, several studies have found it crucial in OECD economies (e.g. Rowthorn 1999, Stockhammer and Klär 2011, Karanassou and Sala 2010 and Arestis *et al.* 2007).

Moreover, capital deepening is generally taken as an input in economic growth and no effort is devoted to the empirical assessment of its determinants. Madsen (2010), for example, points out that a problem associated with the traditional growth accounting framework is the lack of information about the factors responsible for capital deepening. This paper intends to fill this void by providing evidence on the behaviour of the determinants of capital deepening along several decades in four OECD countries with diverse institutional settings and economic realities such as the United States, Japan, Spain and Canada.

A natural point of departure of our analysis is the model developed by Antràs (2004), where demand equations for labour and capital are combined into a single expression accounting for the supply-side determinants of capital deepening (namely, cost of production factors and biased technical change). To this simple setup we add, following Andrés *et al.* (1990a, 1990b), Fagnart *et al.* (1999) and others, the possibility that actual demand does not meet its expected value. In such case, firms' are likely to react by adjusting their use of the production factors to this conjuncture, either by hiring or firing workers, by changing the rate of capacity utilisation, or both. This creates a transmission channel by which the demand-side conditions affect investment and hiring/firing decisions or, in other words, by which capital deepening may also depend on demand-side factors.

We present a model of factor demand with consideration for demand-side forces in the hiring of labour and capital services. This model is tested in four countries with substantial economic heterogeneity among them. In terms of capital deepening, the economic differences can be seen in Figure 1, depicting the trajectories of the ratio of capital stock over employment.

Figure 1. Capital deepening.



The process of capital deepening has been specially intense in Japan, where in the 1960-2011 period the amount of capital stock per employee has grown almost sixfold, and Spain, where it has grown fivefold. In contrast, it has grown less than twofold in both Anglo-Saxon countries (Figure 1a). The origin of these differences is to be found in the very dynamic process of capital deepening linked to the industrialisation process that Japan and Spain experienced in the 1960s and 1970s. Note that the evolution in Japan is fast and relatively constant until the last decade of the sample, while in Spain the evolution of the capital stock per employee had two downturns of flat-path evolution in the late 1980s and in the 1995-2005 period.

As Figure 1b shows, it was in the 1960s and 1970s when the growth rates of capital stock per employee was much higher in Japan and Spain, and it is in last decades that these growth rates have converged to the relatively stable lower rates of the U.S. and Canada. This convergence has two exceptions easily found in Figure 1b in the case of Spain.

The contrasted patterns in the evolution of capital deepening call for an empirical analysis of its determinants. We estimate a capital deepening equation derived from a simple theoretical setting with the inclusion of controls suggested by, for example, Madsen (2010). The main issue tackled in this paper is to what extent supply-side or demand-side determinants are the crucial driving forces of the capital deepening process in each of these four economies. We also examine the role of these driving forces of capital deepening across the different business cycle phases (recession or expansion).

In this way, our paper contributes to the literature in three main dimensions. First of all, in developing a model in which capital accumulation depends both on supply-side and demand-side factors. Second, in providing an empirical account of the determinants of capital deepening from a wider than usual perspective that, accordingly, controls for demand-side constraints. Third, in assessing the relative influence of these determinants in expansions and contractions across countries. Finally, even if it is not the main target of our analysis, the empirical equations yield updated estimates of the elasticity of substitution between capital and labour.

As expected, our estimated dynamic equations characterize capital deepening as a sluggish process, with persistence coefficients in the 0.80-0.94 interval in most cases. Relative factor costs, which is an approximation to the net return to capital investment, is highly relevant in the U.S., Japan and Spain and less so in Canada, with similar albeit low sensitivity across countries (lower than 0.1, in absolute value). The higher is the user cost of capital relative to labour cost, the slower the process of capital deepening. In turn, we also find the relative intensity in the use of factors, which is the central demand-side variable, as a strongly relevant determinant across countries. In particular, the higher is the rate of capacity utilisation relative to the employment rate (that is, the more intense is the use of the capital factor relative to labour), the quicker the process of capital deepening. In this case the U.S. and Spain are the most sensitive countries, followed by Canada. Also, the results verify biased technical change in the U.S., Spain and Canada and, as predicted by economic theory, corporate taxation shows a robust decelerating role on capital deepening.

Regarding the relevance of the central supply- and demand-side determinants, we find the former robust across business cycle phases. That is, its quantitative impact is stable across expansions and recessions, and scarcely sensitive to the economic conjuncture. In contrast, the relative intensity in the use of the production factors has a robust positive impact in expansions, but is less relevant in economic downturns. This result should come as no surprise since, after all, the dependent variable in our analysis is a combination of the production factors and, therefore, we are implicitly evaluating changes in the production function. Nevertheless, the different intensity of the demand-side determinant across the business cycle does not deny the relevance of its role and could help, along the following lines, the design of some policy measures.

If demand-side factors are more influential in expansions, it would seem advisable to promote the process of capital deepening more intensively in expansions by way, for example, of less countercyclical public policies than traditionally implemented. On the supply-side, our finding also calls for a careful design of policies affecting firms' decisions on investment and hiring. The reason is that these policies crucially affect the procyclical behavior of the ratio between the rates of capacity utilisation and (the use of) employment, since in economic expansions the capacity utilisation rate tends to increase proportionally more than the employment rate, probably because in the very short run it is less costly to use already installed capacity than to hire new workers. From this point of view, the design and implementation of labour market reforms should be closely connected to investment policies, a conclusion already obtained in Sala and Silva (2011) in their analysis of labour productivity.

The rest of this Chapter is structured as follows. Section 2 presents the analytical framework. Section 3 shows the empirical model and results. Section 4 explores the relative influence of the determinants of capital deepening across business cycle phases. Finally, section 5 concludes.

2 Analytical framework

From the New Economy framework that includes endogenous changes in total factor productivity in growth accounting (e.g. Aghion and Howitt, 2007), Madsen (2010) adds a new critique. He argues that it is through capital deepening that there is no common knowledge about the determinants of capital deepening. It is traditionally taken as an input of macroeconomic growth analysis but no real effort has been devoted to the identification of its determinants. In his own words, "a problem associated with the traditional growth accounting framework is that it does not give any information about factors that are responsible for capital deepening." (Madsen, 2010, p. 641). Furthermore, he warns about an endogeneity bias in the growth accounting when not acknowledging the endogenous nature of capital accumulation

In order to tackle this issue we take as a starting point the factor demands in Antràs (2004) and include demand-side considerations to the analysis of capital deepening.

2.1 Factor demands

We consider an economy with n identical firms that supply a homogeneous good. These firms acquire inputs in competitive markets and face a cost W per labour unit and CC of capital use.

Each firm has a Constant Elasticity of Substitution (CES) production technology:

$$Y_t = \left[\theta(A_t^N N_t)^{-\beta} + (1-\theta)\left(A_t^K K_t\right)^{-\beta}\right]^{-1/\beta}, \tag{1}$$

where Y is output, N is employment, K is capital stock, A^N is an index of labour-augmenting efficiency (proxying Harrod-neutral technological change), A^K is an index of capital-augmenting efficiency (proxying Solow-neutral technological change), and θ and β are parameters. θ represents the factor share ($0 < \theta < 1$). The constant elasticity of substitution is $\sigma = \frac{1}{1+\beta}$ and the coefficient β is the degree of substitutability. For example, the Cobb-Douglas technology of production is an extreme case of perfect substitution, when $\beta = 0$ and, therefore, $\sigma = 1$, which means indifference between factors (implying that capital investment does not generate any net employment). When this restriction is relaxed, we allow for $\beta \neq 0$ and $\sigma \neq 1$, then variations in capital investment may affect unemployment dynamics.

We assume that biased technological progress grows at constant rates for each factor, following Antràs (2004) and León-Ledesma *et al.* (2010) among others. Therefore, $A_t^N = A_0^N e^{\lambda_N . tr}$ and $A_t^K = A_0^K e^{\lambda_K . tr}$, where A_0^N and A_0^K are the initial values of the technological progress parameters, λ_N and λ_K stand for their respective constant growth rates of technological progress, and tr is a time trend.

Profit maximization in a perfectly competitive environment yields expressions for the factor demands (as a proportion of total output) that log-linearized can be written as

$$\log(K_t/Y_t) = \alpha_K - \sigma \log(CC_t/P_t) - (1-\sigma)\lambda_K tr \tag{2}$$

$$\log(N_t/Y_t) = \alpha_N - \sigma \log(W_t/P_t) - (1-\sigma)\lambda_N tr, \tag{3}$$

where CC, W, and P are prices: CC is the user cost of capital, W is the labour cost, and P is the aggregate price of goods and services. Also, $\alpha_K = \sigma \log(1-\theta) + (\sigma - 1)\log A_0^K$ and $\alpha_N = \sigma \log \theta + (\sigma - 1) \log A_0^N$ are constants, and note that $\frac{\beta}{1+\beta} = 1 - \sigma$. Subtraction of equation (3) from equation (2) yields the following specification for capital deepening:

$$\log(K_t/N_t) = \alpha_3 + \sigma \log(W_t/CC_t) + (1-\sigma)(\lambda_N - \lambda_K)tr. \tag{4}$$

Equation (4) is standard. According to this simple model, capital deepening depends on two supply-side factors: (i) the relative cost of labour and capital; and (ii) the bias in technological change. The coefficient on the first variable provides an estimate of the elasticity of substitution, whereas the coefficient on the second variable will inform –given the value of $\hat{\sigma}$– on whether labour-augmenting efficiency grows faster or lower than capital-augmenting efficiency. Acemoglu (2007) argues that despite the large literature dedicated to the understanding of technical progress, the determinants of the direction of the bias of technological change are yet not fully explained. He argues that technical change is not neutral, it benefits some factors of production and it may affect the compensation of others. His argument is that an increase in the abundance of a factor always induces a change in technology that is absolutely biased towards this factor, and a technology is absolutely biased towards a factor if it increases its marginal product (i.e. unit cost in a competitive context).

In this simple model, the implicit assumption is that capital deepening is shaped exclusively by the aforementioned supply-side determinants. In the following section we consider, in the context of this theoretical model, the possibility of demand-side factors in the acceleration of capital deepening.

2.2 Demand-side considerations

To the basic capital deepening equation derived from factor demands we include demand-side forces proxied by the degree of capital utilisation. Nakajima (2005) includes demand-side shocks and imperfect competition in the final good to a general-equilibrium model market that replicates U.S. business cycles better than the real business cycle model. The main factor for this achievement is the acknowledgement of the cyclical nature of installed capital utilisation. Also Fagnart *et al.* (1999) argue that idle capacity, or underutilisation of total installed productive capacity (explained largely by uncertainty at the time of investment choices) has been acknowledged by researchers in order to model business cycles more precisely.

Therefore we relax the perfect competition in the final good and assume that firms have some degree of market power. They maximise profits based on an expectation of the stochastic demand (Y^E). This uncertainty about aggregate demand will allow for demand-side considerations since it shapes firms' investment decisions (Fagnart *et al.*, 1999; Bond and Jenkinson, 2000). In contrast to the standard maximisation problem, this model allows for *ex post* rationing of factor utilisation. Hence, firms maximise profits subject to their expectation of demand on the period t, but once the realisation of the random (and unexpected) shocks that determine the demand are known, the utilisation rate of installed capacity and labour demand are adjusted accordingly in $t+1$ (since productive capacity is rigid in the short run, firms adjust the degree of utilisation).

In the style of Fagnart *et al.* (1999), the mechanism is that firms use a putty-clay kind of technology, in the sense that capital and labour are substitutes *ex ante*. But *ex post*, when idiosyncratic shock are known, and the capacity choices were already made, firms can adjust the utilisation intensity of production factors by hiring or firing workers and by deciding the level of installed capacity utilisation in order to face actual demand. At that stage, production factors may be thought as complements to achieve a certain level of production. Note that investment decisions and capacity choices are made *ex ante* (with uncertainty on demand) and *ex post* only factor utilisation intensity is adjusted in accordance to the gap between expected and actual demand.

The realisation of the demand that firms face depends mainly on two factors: the price level (chosen by firms) and random shocks. The expected demand that firms consider in their profit maximisation problem is the expected value of this realisation. This idea is expressed analytically in (5). Firms produce (and decide the factor demand) accordingly to their expectation of the market demand (Y), which is a function of the price (P), and an idiosyncratic (stochastic) shocks term (φ) with zero mean and a constant standard deviation greater than zero.

$$Y_t^E = E_{t-1}\left[Y_t(P_t,\varphi)\right] \tag{5}$$

Under these assumptions, the problem of the firm is a standard monopolistic competition case, and can be expressed as the following profit-maximisation problem, where π stands for the firms' profit function.

$$\max\ \pi\left(K_t, N_t, P_t\right) = P_t Y_t^E - W_t N_t - CC_t K_t$$

subject to:

$$Y_t^E = E_{t_{-1}}\left[\theta(A_0^N e^{\lambda_N.tr} N_t)^{-\beta} + (1-\theta)\left(A_0^K e^{\lambda_K.tr} K_t\right)^{-\beta}\right]^{-1/\beta}$$

Recall that $A_0^N e^{\lambda_N.tr} = A_t^N$ and $A_0^K e^{\lambda_K.tr} = A_t^K$ are the index of constant growth factor efficiency.

Operating from the first order conditions of this problem, we obtain the optimal factor utilisation in relation to the production of the firm as an inverse relation of each factor's cost, that is, the individual factor demands.

$$\frac{K_t}{Y_t^E} = (1-\theta)^\sigma \left(\frac{CC_t}{P_t}\right)^{-\sigma} (A_0^K e^{\lambda_K.tr})^{\frac{-\beta}{1+\beta}} \tag{6}$$

$$\frac{N_t}{Y_t^E} = \theta^\sigma \left(\frac{W_t}{P_t}\right)^{-\sigma} (A_0^N e^{\lambda_N.tr})^{\frac{-\beta}{1+\beta}} \tag{7}$$

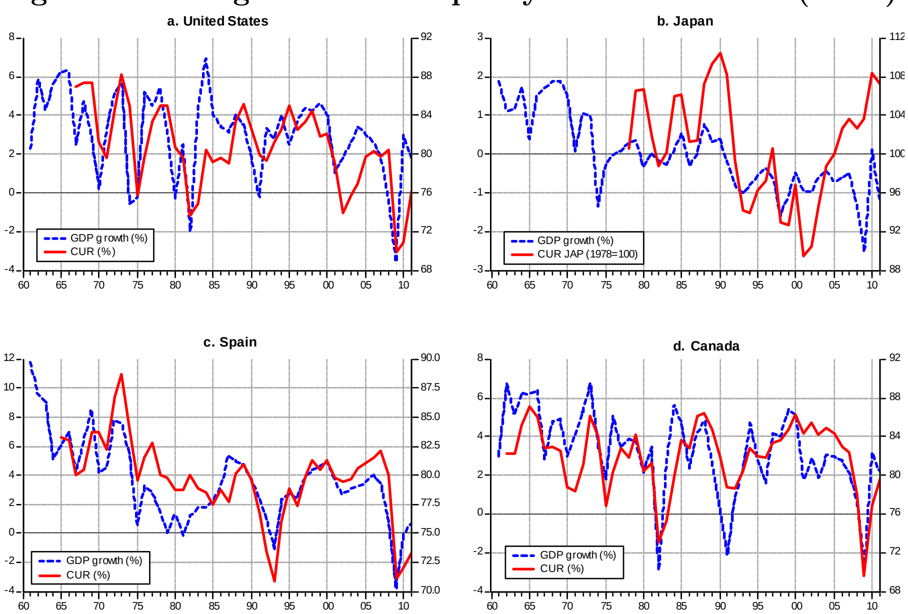
Recall that each firm maximizes profits subject to their expected demand for goods (Y^E). Thus far, with perfect information and no uncertainty on demand, the log-linearisation of (6) and (7) would be equivalent to (2) and (3) respectively. With the aggregation of the n firms, we can replace the expected value with the potential aggregate demand ($\hat{Y}$). Also, we add the ratio $\frac{Y_t}{Y_t}(=1)$, of the actual value of production (Y_t) on the left-hand side in both equations. The following expressions result:

$$\frac{K_t}{Y_t} = (1-\theta)^\sigma \left(\frac{CC_t}{P_t}\right)^{-\sigma} (A_0^K e^{\lambda_K.tr})^{\frac{-\beta}{1+\beta}} \frac{\widehat{Y}_t}{Y_t} \tag{8}$$

$$\frac{N_t}{Y_t} = \theta^\sigma \left(\frac{W_t}{P_t}\right)^{-\sigma} (A_0^N e^{\lambda_N.tr})^{\frac{-\beta}{1+\beta}} \frac{\widehat{Y}_t}{Y_t} \tag{9}$$

The last term in both equations is the $\frac{\widehat{Y}_t}{Y_t}$ ratio. It expresses the gap between, on one hand, the actual aggregate production (Y), and on the other, the potential aggregate demand ($\hat{Y}$). This ratio expresses the gap between the potential production of the firm with no foreseen restrictions about demand, and the actual production once factor demands have been adjusted *ex post*. This gap is directly related to the gap between total installed production capacity and the rate of utilisation by the firms. Then, the degree of capacity utilisation can be used as a proxy for this ratio. The $\frac{\widehat{Y}_t}{Y_t}$ ratio is the transmission channel for business cycles (Nakajima 2005, Fagnart *et al.* 1999), as the degree of capacity utilisation rate, because of the correspondence between the fact that production is responsive to aggregate demand *ex post,* and installed capacity is rigid in the short run. Figure 3 shows how that the growth rate of GDP (as an approximation to the cyclical component of output) and the capacity utilisation rate (CUR) have a similar evolution (Graff and Sturm, 2012). Moreover, the output gap is a natural empirical proxy of demand-side forces (Stimel, 2010).

Figure 3. GDP growth and Capacity Utilisation Rate (CUR).



This line of reasoning is also presented in Andrés *et al.* (1990a) and Graff and Sturm (2012), who approximate the $\frac{\hat{Y}_t}{Y_t}$ ratio with the CUR, which represents the adjustment between total installed capacity and its degree of utilisation. Further studies that support the approximation of the business cycle with the information provided by the capacity utilisation rate are, for example, Fagnart *et al.* (1999), Planas *et al.* (2012) and Price (1995). Following the relation shown by Figure 3, they argue that the ratio $\frac{\hat{Y}_t}{Y_t}$ can be proxied by a growing function of CUR because firms invest in capacity with an expectation of potential demand and then use this capacity with the intensity required by actual demand (what we call *ex post* rationing). Then, (8) can be expressed as (10). Following the same reasoning, as CUR works for the demand of capital services, we replace the unobservable $\frac{\hat{Y}_t}{Y_t}$ ratio in equation (9) with the employment rate

(NR, total employment over working-age population), which is a proxy to the factor utilisation intensity in the case of labour, as shown in (11).

In sum, we re-write the demand for factors as:

$$\frac{K_t}{Y_t} = (1-\theta)^{\sigma}\left(\frac{CC_t}{P_t}\right)^{-\sigma}(A_0^K e^{\lambda_K.tr})^{\frac{-\beta}{1+\beta}}.h(CUR_t) \tag{10}$$

$$\frac{N_t}{Y_t} = \theta^{\sigma}\left(\frac{W_t}{P_t}\right)^{-\sigma}(A_0^N e^{\lambda_N.tr})^{\frac{-\beta}{1+\beta}}.h(NR_t), \tag{11}$$

where $h(\cdot)$ is a growing function. The next step is to log-linearize expressions (11) and (12). The result is as follows[1]:

$$\log\left(\frac{K_t}{Y_t}\right) = \alpha_K - \sigma\log\left(\frac{CC_t}{P_t}\right) - (1-\sigma)\lambda_K.tr + \gamma_K.\log\left(CUR_t\right) \tag{12}$$

$$\log\left(\frac{N_t}{Y_t}\right) = \alpha_N - \sigma\log\left(\frac{W_t}{P_t}\right) - (1-\sigma)\lambda_N.tr + \gamma_N.\log\left(NR_t\right), \tag{13}$$

where again $\alpha_K = \sigma\log(1-\theta) - (1-\sigma)\log A_0^K$ and $\alpha_N = \sigma\log\theta - (1-\sigma)\log A_0^N$ are constants, and $\frac{\beta}{1+\beta} = 1-\sigma$. Note that the only difference between expressions (12) and (13) and standard equations (2) and (3) is that the perfect competition assumption only takes into account supply-side determinants of factor demand. But when flexibilising this framework, the assumption of stochastic demand allows for *ex post* rationing of factor utilisation and provides room for demand-side forces in factor utilisation equations.

Combing (12) and (13), we can express capital deepening as in (14), which is the base equation for our empirical model.

$$k_t - n_t = \beta_0 + \beta_1(cc_t - w_t) + \beta_2(cur_t - nr_t) + \beta_3.tr, \tag{14}$$

where $k_t = \log(K_t)$, $n_t = \log(N_t)$, $w_t = \log\left(W_t\right)$, $cc_t = \log\left(CC_t\right)$, $nr_t = \log(NR_t)$ and $cur_t = \log(CUR_t)$. $\beta_0 = \alpha_K - \alpha_N$ is a constant, and tr represents a time trend. The coefficient β_1 is associated to the relative cost of production factors and a negative sign is expected. In other words, when the wedge between cost of factors ($cc - w$) increases, and capital becomes relatively more costly in relation to labour, a deceleration of capital deepening is expected. Moreover, it corresponds to the σ of the theoretical model, which represents the constant elasticity of substitution between capital and labour.

The coefficient β_2 is associated to the role of the relative utilisation intensity of production factors in the determination of capital deepening, and a positive sign is expected. In this case, when the wedge between the utilisation intensity of factors ($cur - nr$) increases, an acceleration

[1] We assume that $h(\cdot)$ is so that $log[h(\cdot)]$ results a linear fuction.

in capital deepening is expected which represents the transmission channel of demand-side forces. Finally, the coefficient $\beta_3 = (1-\sigma).(\lambda_N - \lambda_K)$ measures the non-symetrical growth of efficiency specific to each production factor (i.e. the bias in technological change between production factors). Then, if the estimation of β_3 throws a positive value, and σ is assumed to be less than 1, this indicates that labor-augmenting efficiency grows faster than capital-augmenting efficiency. The opposite would result from a negative value. Note that in the standard Cobb-Douglas case ($\sigma = 1$) this measure is not possible.

2.3 Empirical model

We extend the benchmark model by incorporating one extra consideration. Madsen (2010), Bond and Jenkinson (2000) and Edgerton (2010) explain how corporate taxation has a deceleration effect on capital deepening since it is a disincentive to firm-level investment. We thus believe important to include fiscality through direct taxes on businesses. With this extension, equation (15) states the benchmark of our empirical model. Thus the main difference between (15) and the standard point of departure expressed in (4) is to allow for demand-side determinants of capital deepening, and direct taxes on business.

$$kd_t = \widehat{\beta_0} + \widehat{\phi_1} kd_{t-1} + \widehat{\phi_2}\Delta kd_{t-1} + \widehat{\beta_1}(cc_t - w_t) + \widehat{\beta_2}(cur_t - nr_t) + \widehat{\beta_3}.tr + \widehat{\beta_4}.\tau_t + \varepsilon_t, \qquad (15)$$

where $kd = k - n$, τ represents fiscality (direct taxes on businesses) and ε_t represents a typical error term with zero mean and constant standard deviation.

First of all, the estimated equation is dynamic since the process of capital deepening is of a dynamic nature by definition. The factor-demand adjustment allowed in the model calls for a measure of the degree of persistence of capital deepening.

Decisions to invest in new capacity are influenced by the cost and availability of capital and the target rates of return sought by firms and financial institutions. The dependence on bank loans is an important factor limiting expansion and the user cost of capital is a crucial factor in the expected net return to investment by firms. As predicted by economic theory, we expect a negative effect of higher user cost of capital (relative to labour cost) on capital deepening. That is, an increase in the cost of capital services, relative to the real wage (labour cost), has a decelerating effect on capital deepening. Hence, we expect a negative-sign estimated coefficient associated to the relative cost of production factors ($cc - w$). From this coefficient it is possible to provide calculations of the elasticity of substitution between factors (Antràs, 2004).

Firm's decisions to expand capacity through investment are based to a large extent on their assessment of their future sales, which we realistically assume to be uncertain. Managers are naturally cautious about overestimating future sales, as the penalty for doing so tend to be much greater than for losing potential business by failing to expand (Smith, 1996). In our model, the capacity utilisation rate is a proxy for the perception of the firm of the economic reality, which reflects on its expectations on aggregate demand. Since the expansion of capacity drives investment, we expect a positive effect on capital deepening of higher capacity utilisation rate. A higher use intensity of installed capacity, relative to labour force use intensity (reflected by the employment rate), accelerates the process of capital deepening. Therefore, we expect a positive-sign estimated coefficient associated to relative factor utilisation ($cur - nr$).

In the theoretical framework of capital deepening presented above, the relative utilisation intensity of production factors is the main channel of transmission of demand-side forces into capital per worker growth. Nevertheless, there are other proxies of demand-side forces among the empirical literature. In order to verify the robustness of these demand-side forces we explore the fitness to the model of alternative proxies of demand. Namely, these are the cyclical component of: total hours worked, private consumption and the labour income share. For example, Stimel (2010)'s choices for aggregate demand proxy closely relate to the aforementioned[2]. The idea behind the cycle of hours worked or the labour income share (also the wage-productivity gap) is analogous to the use of the capacity utilisation rate in the sense that they provide information about the demand of production factors by firms, decision made with expectation on sales. Deviations from the trend in those variables is a proxy for the economic conjuncture. In the case of private consumption, it is similar to the use of the output gap, but with higher emphasis in the cyclic deviation of consumption of goods and services by households, which affect directly the demand expectations of firms and therefore the factor demand (and capital deepening) according to our model. That said, and in order to verify the robustness of the demand-side effect on capital deepening dynamics, we use these alternative empirical approximations to aggregate demand in further specifications of our model.

As explained before, the presence of a time trend allows the model to capture the degree of bias in technological change. Given the assumption of constant rates of technical progress, our estimations provide information on the differences between the labour-augmenting and capital-augmenting efficiency growth rates.

In this paper, capital deepening is calculated as the log ratio of capital stock and employment. The source of capital data is the net capital stock (total economy) at constant prices series from the AMECO database (European Commission). Total employment series, as all other variables (except for capacity utilisation rate), where extracted from OECD Economic Outlook 91 (2012).

The user cost of capital is essentially constructed as in Andrés *et al.* (1990a), $cc = \log\left[\frac{p^i}{p}.(i + \delta - \pi^i)\right]$, with times series on interest rates (i), and GDP and investment deflators (P and P^i, respectively). The depreciation rate, δ, is assumed to be constant and equal to 0.1. Also, π^i is the inflation of investment and is constructed as the growth rate of P^i. The real wage is the log of the ratio between total compensation of employees and the GDP deflator.

On the relative factor utilisation side, the capacity utilisation rate is extracted from national statistics bureaus and the employment rate is constructed as the log ratio between employment and working-age population. The fiscal variable is the log of direct taxes on businesses ratio of GDP (on Spain, however, we use indirect taxes).

[2] His choices are the unemployment rate, the deviations from trend of GDP, and the labour cost per unit of manufacturing output.

2.4 Estimation results

Next, we present the estimation results for specification (15). The estimation methodology is the contrast of individual-country OLS and instrumental variables 2SLS estimations in order to rule out endogeneity bias. Table 2 shows the results.

The results in Table 2 show that, regarding the degree of persistence of capital deepening, the four countries can be subdivided in two subgroups: one of them with lagged dependent variables displaying high coefficients that range around 0.9 (U.S. and Japan), and a second group with moderated persistence expressed in a first lag coefficient estimation that ranges between 0.6 and 0.8 (Spain and Canada). This staggered dynamic structure may be associated with the fact that capital stock is difficult to adjust in the short run.

Table 2: Main results.

	OLS				**IV-2SLS***			
	U.S.	JAP	SPA	CAN	U.S.	JAP	SPA	CAN
Intercept $\left(\widehat{\beta}_0\right)$	-0.884	0.752	0.928	-4.805	-1.085	-0.108	0.714	2.864
	(-3.2)	(0.7)	(2.2)	(2.7)	(-2.6)	(-0.04)	(1.9)	(1.5)
First Lag $\left(\widehat{\phi_1}\right)$	0.938	0.909	0.779	0.550	0.929	0.944	0.802	0.658
kd_{t-1}	(33.1)	(12.6)	(13.6)	(1.8)	(23.9)	(5.9)	(10.6)	(4.8)
RFC $\left(\widehat{\beta}_1\right)$	-0.009	-0.020	-0.021	-0.024	-0.014	-0.032	-0.045	-0.095
$cc - w$	(-2.5)	(-2.7)	(-1.8)	(-1.5)	(-1.8)	(-2.1)	(-2.5)	(-1.5)
RFU $\left(\widehat{\beta}_2\right)$	0.206	0.056	0.228	0.126	0.240	0.079	0.211	0.211
$cur - nr$	(8.4)	(3.2)	(3.2)	(2.0)	(7.1)	(1.7)	(2.0)	(1.2)
Trend $\left(\widehat{\beta}_3\right)$	0.002	0.007	0.007	0.006	0.002	0.005	0.007	0.005
tr	(4.6)	(1.4)	(4.4)	(1.5)	(4.0)	(0.5)	(2.8)	(3.0)
Taxation $\left(\widehat{\beta}_4\right)$	-0.034	-0.018	-0.114	-0.035	-0.046	-0.020	-0.131	-0.036
τ	(-5.7)	(-4.4)	(-4.5)	(-1.5)	(-4.9)	(-2.1)	(-4.3)	(-1.8)
LL	164.0	141.2	134.7	124.8	–	–	–	–
Sample	69-11	81-11	70-11	71-10	69-11	81-11	70-11	71-10

Note: RFC = Relative Factor Cost, RFU = Relative Factor Utilisation.
LL = Log-likelihood. t-statistics in parenthesis.
*Instruments in all cases are lags of regressors
(plus the lagged GDP growth rate in Spain).

The relative cost of production factors, appears as a relevant factor across specifications, with a negative sign coefficient. The estimated coefficients (that can be also interpreted as short-run elasticities) range from -0.01 to -0.10, which would mean that the short-run effect of a 10% increase in the relative cost of factors (i.e. the distance between capital user costs and the real wage) seems not decelerate capital deepening in more than a 1%. The U.S. is the least sensitive to this relative factor cost decelerating effect with a lower estimated coefficient than the other three countries.

The model we develop in this paper contributes to the literature, on the other hand, by adding as a main difference to the standard model the impact of the relative utilisation intensity of production factors as a determinant of capital deepening. The evidence of its role is quite robust. The estimated coefficients are positive and their values range from 0.06 to 0.24 and they show, in general, high statistical significance[3]. Japan is the least sensitive to this demand-side force, while the other three countries have similar estimated coefficients in the 0.20-0.24 range.

The results in Table 2 also present a relevant role for the time trends, which in our analytical framework proxy for constant biased technological progress. The estimated coefficients are positive, implying that labour efficiency grows at a higher rate than capital efficiency (i.e., $\lambda_N > \lambda_K$), certifying the possible existence of biased technological change. When the elasticity of substitution between factors in the case of Spain is probably higher than the unity, meaning that capital efficiency may be growing at a higher rate than labour efficiency (i.e., $\lambda_N < \lambda_K$). In the case of Japan, the bias is not significant probably meaning that both growth rates are similar.

Finally, direct taxes on businesses (indirect taxes in Spain) have a robust high significance in all specifications. These results imply that reductions in corporate taxation (as a percentage of GDP) may have an immediate short-run effect of increasing capital deepening and this effect would remain and be more intensive in the long-run because, as already discussed, capital deepening is a dynamic sluggish process.

The Durbin-Wu-Hausman test performed on the comparison between regressions by OLS and instrumental variables 2SLS rules out endogeneity bias. The null hypothesis cannot be rejected in any case (all p-values are higher than 0.10, see Annex). The usual misspecification tests can also be found in the Annex (error term autocorrelation, homoskedasticity and normal distribution) where it can be seen that all the regular assumptions of the least squares model can be hold at the 95% confidence level.

2.5 Elasticity of substitution between capital and labour

Table 3 shows the elasticity of substitution between factors implied in our empirical specifications and, alternatively, in specifications with the cyclical component of hours worked as a demand-side transmission channel instead of the relative factor utilisation.

Recent literature has been providing empirical evidence that suggests that the elasticity

[3] The only exception is the IV specification for Canada.

of substitution between factors is significantly lower than one in the U.S., rejecting the Cobb-Douglas assumption of aggregate production (i.e., unitary elasticity). Also these empirical results have shown to be heterogeneous with high deviation across studies. Among the most reputed methodologies is the estimation of an expression of capital deepening derived from factor demands (e.g. Antràs, 2004) which we follow in this section.

For example, Chirinko (2008) surveys different computations and finds, for the case of the U.S., that Tevlin and Whelan (2003) find a 0.18 elasticity of substitution through aggregate investment, whilst Antràs (2004) with consideration of biased technical change finds values between 0.55 up to 0.95. Klump *et al.* (2007) also present a broad range of estimated values.

Table 3. Elasticities of substitution.

	Basic Model		Alternative	
	OLS	*IV*	*OLS*	*IV*
	I	**II**	**III**	**IV**
U.S.	0.15	0.20	0.36	0.44
JAPAN	0.22	0.57	0.48	0.13
SPAIN	0.10	0.20	0.27	1.20
CANADA	0.05	0.28	0.07	0.27

With that said, the implied elasticities of substitution between factors in our empirical specifications of capital deepening for the U.S. (mainly in the 0.2-0.4 range) fall inside the values considered by the related literature. Although Chirinko (2008) finds a σ between 0.4 and 0.6, and both León-Ledesma et al. (2010) and Klump *et al.* (2007) present values in the 0.5-0.7 range, it is highly relevant to stress that Chirinko *et al.* (2011) indicate that an elasticity estimated with time series data at annual frequencies will tend to be lower. They present the results in Chirinko *et al.* (1999) as an example, where the estimation of the elasticity of substitution is rather low, around 0.25.

In the case of Japan, previous studies find elasticities in the range between 0.2 and 0.4 (Rowthorn 1999, Klump *et al.* 2011) and our results range a higher deviation from aproximately 0.2 and 0.6. These results are very sensible to the specification, its control variables and instruments.

Previous research for the case of Spain points to higher-than-one estimations of the elasticity of substitution between factors (Raurich *et al.*, 2012). In that sense specification IV shows the most realistic value (1.20)[4]. The elasticity for Canada seems to be around 0.3 which is the result provided by instrumental variable specification that control for potential endogeneity.

[4] Rowthorn (1999) finds lower than 0.5 elasticities of substitution for Spain but with a very different approach than Raurich *et al.* (2012).

Therefore, we globaly choose specification IV for our computation of the elasticity of substitution. In all, it arises that the Cobb-Douglas technology is not a truthful representation of aggregate production, since the actual elasticity of substitution is very likely to be significantly different than one. This assumption implies neutrality of capital stock on unemployment, since with elasticity of substitution equal to one, capital accumulation would not affect long-run labour market outcomes (e.g. Layard, Nickell and Jackman, 1991). Differently, our results are in accordance with the results presented in studies like Rowthorn (1999), Chirinko (2008) and Antràs (2004), that is, substitutability between capital and labour is not a one-to-one proportion.

The inaccuracy in some of our computations of the elasticity of substitution between labour and capital is due to two main reasons. First, in our model, there is imperfect competition in the product market but we assume perfect competition in factor markets, and that is why we calculate the elasticity through the coefficient associated to relative factor cost (i.e., it is assumed that relative factor costs equal relative marginal productivities). Although this is a common practice in previous literature, it might be inaccurate, since Raurich *et al.* (2012) find a relevant price markup for the U.S. and Spain where the marginal product of labour equals the wage rate times a markup. Second, as León-Ledesma *et al.* (2010) explain, single-equation estimates of the elasticity of substitution tend to have more problems in identification than three-equation systems (production and factor demands) and the assumptions on technological change do affect the elasticity estimates.

3 The determinants of capital deepening and the business cycle

In this section we take a step further in our analysis. Factor demand is quite dependent on the economic conjuncture and therefore business cycle dynamics may affect capital deepening determination. Hence, we intend to identify how the roles of the main determinants in the model of capital deepening could vary along the different phases of business cycles.

In the theoretical background for the determination of capital deepening we include the consideration of demand-side forces, and the empirical results back up this contribution by showing strong positive influence of a demand-side proxy (relative factor utilisation) in capital deepening, alongside a negative effect of relative factor costs. Thus, the analysis of these effects across the phases of the business cycles provides an additional tool for the analysis. We study the intensity of these effects according to our empirical model.

To that end, we identify the GDP cycles in each country up to 2009. The NBER's definition of a whole business cycle is the period between one trough and the next one. Following this definition, we identify the troughs and peaks in GDP cycles by detrending the series with the commonly used Hodrick-Prescott filter. The identification of peaks and troughs leads consequently to the identification of expansive and recessive periods for each country, as enumerated in Table 4 (see Annex). This identification can be seen graphically in Figure 4 (see Annex), where recessive periods appear shadowed over the Hodrick-Prescott filtered GDP series (at constant prices).

Once these expansive and recessive periods have been identified, we can associate the outcome of our empirical model with each expansion and recession. We use the OLS estimation of the main model and associate the output of the empirical model with the expansive and recessive periods in each country. The same is done with the observations of relative factor cost ($cc - w$) and relative factor utilisation intensity ($cur - nr$). Next, we calculate the average value of the capital deepening fitted-values (the outcome of the model), relative factor cost and relative factor utilisation intensity, in each of the time periods identified in Figure 4 and Table 4. As a result, we get a series of average values of the main variables and estimation outcome during each expansive and recessive period in all four countries in the sample. With these series we elaborate four scatter plots: the normalised average values of estimated capital deepening and each one of its determinants, both in expansions and recessions. The result is shown in Figure 5.

From the plots in Figure 5, it arises that in both recessions and expansions the relation between capital deepening and the relative user cost of production factors ($cc - w$) is clearly negative (correlation coefficients are -0.49 in recessive periods and -0.45 in expansive periods). Therefore, the first observation is that supply-side factors are important determinants of capital deepening homogeneously all over the business cycle.

On the other hand, demand-side determinants of capital deepening (namely, the relative utilisation rate of production factors) do not show such a consistent behavior. Albeit in our specifications the $cur - nr$ variable is associated to a positive and significative coefficient, the scatter graph of expansive periods shows, as expected, a positive correlation of capital deepening and $cur - nr$ (correlation coefficient of 0.54). In turn, a practical absence of relevant correlation is found in the recessive periods (correlation coefficient of 0.10). This evidence suggests that demand-side factors may not have an homogeneous role in determining capital deepening in both parts of the business cycle. They have a positive and robust effect in capital deepening during expansive periods, but this effect does not seem to be relevant during economic recessions.

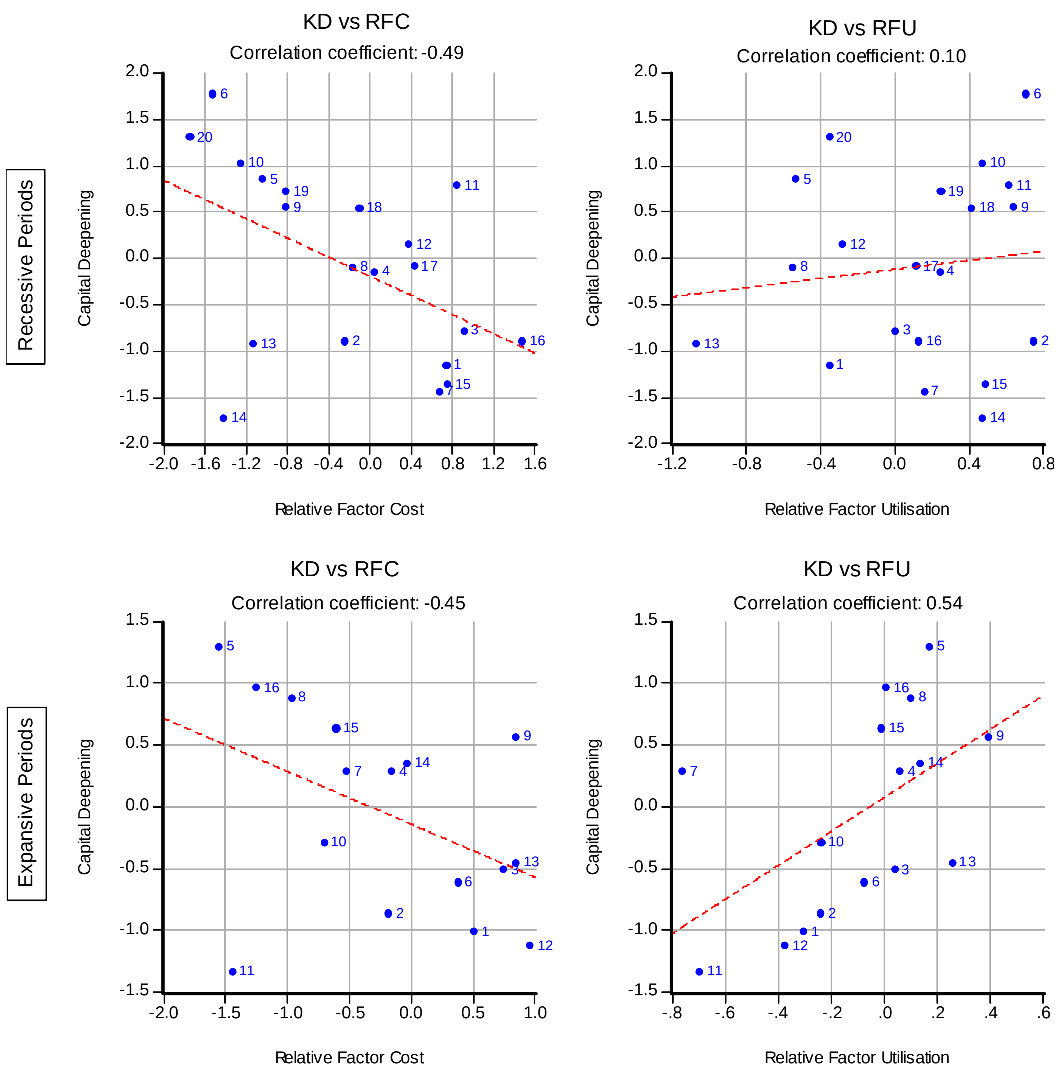
These observations that arise from the general results in Figure 5 can be even intensified if one outlier observation is excluded from the analysis. In Figure 6 we show the same plots but with the exclusion of one observation in both recessive periods cases and in the relative factor cost plot in expansive periods (recall that in the case of relative factor utilisation plot in expansive periods there is no clear correlation[5]). The correlation coefficient of capital deepening vs relative factor cost is in this case becomes -0.72 in recessive periods (instead of -0.45), -0.68 in expansive periods (instead of -0.49) and capital deepening vs relative factor utilisation in expansive periods is 0.73 (instead of 0.54).

The bottom line is that relative factor cost growth has a deceleration effect on capital deepening across the business cycle, whilst the growth in capacity utilisation relative to the employment

[5] These outliers are: in Recessive periods, KD vs RFC: observation 14 (Spain 2006-2009). In Expansive periods, KD vs RFC: observation 11 (Spain 2002-2006); and KD vs RFU: observation 7 (Japan 1994-1997).

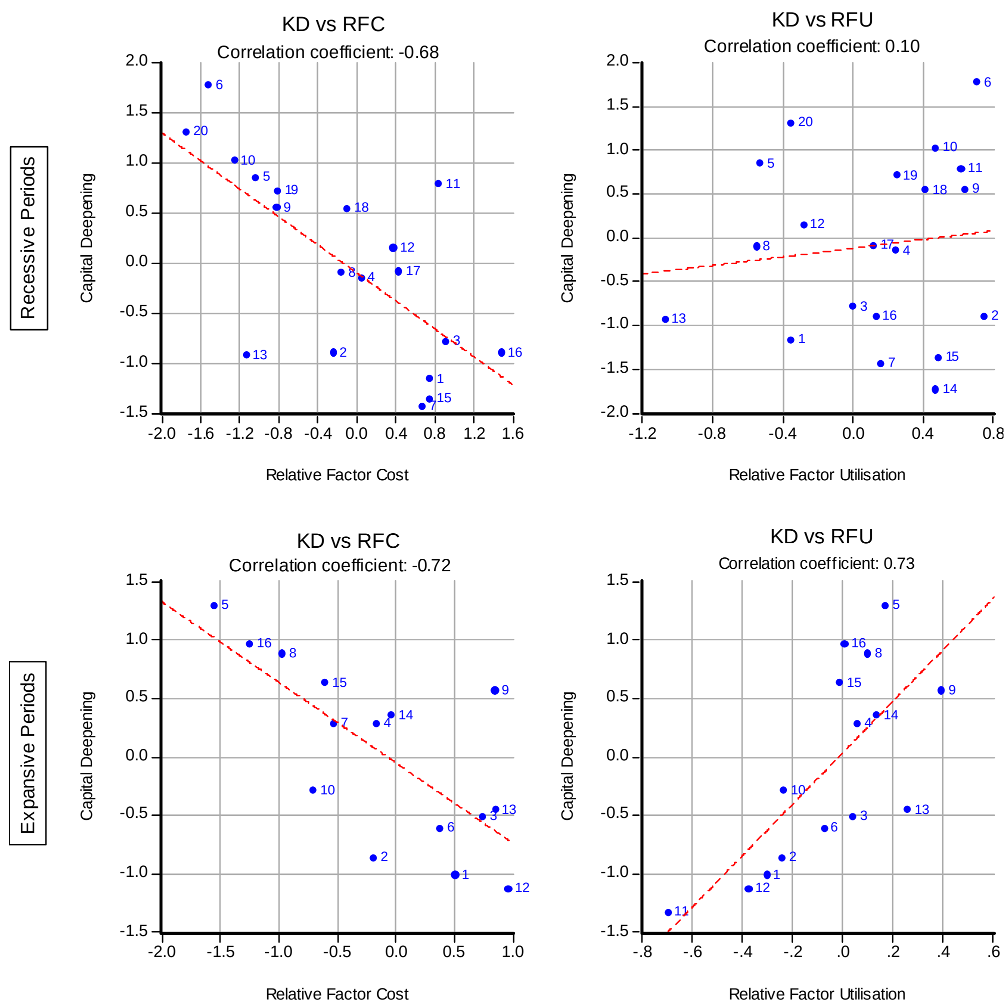
rate accelerates the accumulation of capital per worker specially during expansions, when this transmission channel is more efficient.

Figure 5. Determinants of capital deepening across business cycles.



A possible reason for this observed fact is that in strong recessive periods, employment falls with a much higher volatility than does capital stock, and we thus observe a growth in capital per worker during these strong recessions (see, for example, in Figure 2, in the U.S., the proportional fall of capital stock and employment around the oil crisis, at the beginning of the 1980s and the beginning of the 1990s). But aggregate demand also falls during recessions. Therefore, in these periods, the demand-side determinants fall as the capital deepening may increase (since employment falls deeper than capital), generating a circumstantial negative correlation of demand-side variables and capital deepening. That is a possible reason why we observe, globally, a net absence of correlation of capital deepening and relative factor utilisation in recessive periods. Also, the capital growth rate is smooth and homogeneous along the sample (it decreases in Japan), while the CUR adjusts to the business cycle and that is why it is a proxy for the conjuncture perception of firms. So in recessions, the capacity utilisation rate contracts with demand while the growth rate of capital does not change so suddenly.

Figure 6. Determinants of capital deepening across business cycle (one outlier excluded).



So this observed behaviour of demand-side variables may be an argument for the central (and unique) role of supply-side variables in most capital deepening models. We find that the role of the latter on the evolution of capital-per-woker is stable and homogenous along the business cycle, while maybe demand-side forces have an inconclusive effect during recessions. Nevertheless, the role of demand-side forces in capital deepening is statistically robust and highly relevant, although the demand transmission channel appears to be relatively more efective during expansions.

4 Concluding remarks

In this paper we focus on a generally unattended issue: the determination of capital deepening. Usually, the capital-per-worker ratio is used only as an input in growth accounting and the empirical assessment of its determinants has been a rather neglected topic. We present an analytical setting that includes demand-side considerations to the single-equation capital deepening model based only on supply-side factors *à la* Antràs (2004). From this setting, we estimate an empirical model of the determination of capital deepening as a function of supply- and demand-side determinants.

The main supply-side determinant of capital deepening, the relative cost of production factors, presents a robust role in decelerating capital-per-worker growth that does not depend on the phases of the business cycle. The specifications also show a relevant presence of biased technological change in the U.S., Spain and Canada.

But the main distinctive feature of our model, besides the empirical concern about the determinants of capital deepening, is the introduction of demand-side constraints through the role of uncertainty about demand (a main factor in investment). The main demand-side determinant in our empirical model, the relative use intensity of production factors, shows a robust accelerative effect of capital deepening on the specifications of the benchmark model, with estimated coefficients that range among higher values than the former case, up to 0.24. Furthermore, we also corroborate the relevance of this demand-side transmission channel by estimating the same model with three alternative proxies of demand in every country in our sample. Albeit these generally significant coefficients across our specifications, the relative use intensity of production factors shows mainly a strong role in accelerating capital deepening on economic expansions, and a weaker or rather indeterminate role during recessions. According to these results, public policy can be more efficient if designed to be more procyclical, increasing intervention on expansive periods, since our results show that demand-side channels are more effective during expansions.

On a different note, we provide actualized calculations of the elasticity of substitution between production factors. Our results, in tune with recent contributions, shows that the elasticity is certainly different than one (in contrast to the Cobb-Douglas production hypothesis). We find rather low values which implies that in the long-run capital accumulation generates a much less than proportional reduction in employment. Following this finding, long-run unemployment could be reduced by investment policies. This is an important fact to bear in mind while designing labour market reforms.

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5 Annex

5.1 Durbin-Wu-Hausman test results for Table 2.

U.S.	Japan	Spain	Canada
0.17	0.11	0.31	0.15

Note: p-values for J-stat.

5.2 Misspecification tests.

SC = Lagrange multipliers test for serial correlation of residuals
HET = White test for Heteroskedasticity
NOR = Jarque-Bera test for Normality
ARCH = Autoregressive Conditional Heteroskedasticity
a = number of coefficients in estimated equation (intercept not included)
JB = Jarque-Bera Statistic

Misspecification tests (Table 2)

	USA		**JAPAN**		**SPAIN**		**CANADA**	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
SC $[\chi^2(1)]$	0.69	0.13	0.84	0.76	0.85	0.07	0.26	0.07
HET $[\chi^2(a)]$	0.58	0.54	0.20	0.14	0.80	0.38	0.25	0.38
ARCH $[\chi^2(1)]$	0.11	0.40	0.61	0.70	0.44	0.78	0.51	0.43
NOR $[JB]$	0.38	0.41	0.63	0.26	0.15	0.95	0.05	0.55

The values shown represen the *p-value* for each test.
All hypothesis hold at a 95% confidence level.

5.3 Business cycle identification: expansions and recessions in each country.

Table 4. Business Cycle identification.

Expansive Periods				Recessive Periods			
US	**1**	1971	1973	US	**1**	1966	1971
	2	1975	1979		**2**	1973	1975
	3	1982	1989		**3**	1979	1982
	4	1995	2000		**4**	1989	1995
	5	2003	2007		**5**	2000	2003
JAP	**6**	1987	1991		**6**	2007	2009
	7	1994	1997	JAP	**7**	1979	1987
	8	1999	2007		**8**	1991	1994
SPA	**9**	1981	1987		**9**	1997	1999
	10	1993	2000		**10**	2007	2009
	11	2002	2006	SPA	**11**	1976	1981
CAN	**12**	1975	1981		**12**	1987	1993
	13	1982	1988		**13**	2000	2002
	14	1991	1994		**14**	2006	2009
	15	1996	1999	CAN	**15**	1973	1975
	16	2001	2006		**16**	1981	1982
					17	1988	1991
					18	1999	2001
					19	2006	2009

Figure 4. Recessive and Expansive periods (Hodrick-Prescott filtered GDP).