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A Q-MODEL OF LABOUR DEMAND

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This paper studies the demand for labour using a Q model in which labour and capital entail adjustment costs. The estimates are based on an unbalanced panel of Spanish firms over the period 1989-96. The corresponding Q variable for labour is significant in explaining hiring rates. Its estimated coefficient varies across sectors in a way that suggests that the use of temporary labour is more widespread in economic sectors that incur smaller costs of adjusting labour due to the specific characteristics of their technology and economic activity. Interaction effects between investment and labour demands are also observed in their adjustment costs.

Keywords: Q model, adjustment costs, labour demand, panel data.

(*JEL* J23, J32, E22)

1. Introduction

Investment models like the Q model typically assume that the cost that firms incur when they adjust the capital stock to their desired level exceeds the purchase price; i.e. capital is a quasi-fixed factor. Nevertheless, these models often regard labour as a variable input that can be adjusted to the firms' needs perfectly and instantaneously, despite the fact that the adjustment of the firms' staff also entails some costs.

The purpose of this paper is to study the adjustment costs that firms incur when they change their level of employment. I extend a Q model

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to the demand for labour, assuming that both capital and labour factors entail adjustment costs to firms. My approach is similar to that of Bond and Cummins (2000) and Bond and Van Reenen (2003), who model firms that demand a variable labour input and multiple quasi-fixed capital factors (instead of one homogeneous quasi-fixed capital factor). The model presented here differs from those studies in that labour is not a variable input, but a quasi-fixed factor; there are only two production factors, capital and labour, whose adjustment processes cause some costs for the firms. Moreover, the adjustment costs specified here allow for the possibility of interaction effects between the demands for different inputs, not considered by Bond and Cummins (2000) or Bond and Van Reenen (2003). The empirical analysis is done using a panel of 107 Spanish firms that were quoted on the stock exchange over the period 1987-97. This sample comes from the *Central de Balances del Banco de España* (Central Balance Sheet Office, hereafter, CBSO).

Previous research addressing labour adjustment costs can be found in Pindyck and Rotemberg (1983) and Shapiro (1986). These authors estimate first order conditions of a model under dynamic capital and labour demands using aggregate data for the manufacturing sector. Moreover, Bentolila and Saint-Paul (1992) also analyse both the adjustment costs and the demand for labour in Spain using micro data from the CBSO. They consider two types of workers that differ in their contract length, so there are workers that enjoy a permanent contract and workers with fixed-term contracts. Other authors, like Sanz Gómez (1994) and Alonso-Borrego (1998), estimate first-order conditions for labour demands using Spanish data and distinguishing between permanent skilled and unskilled workers. These studies using Spanish data usually find an inertia in the demands for labour inputs; the adjustment process towards the level desired by the firm is slow, input demands do not change instantaneously. These authors also observe that labour demands are interrelated to each other due to the existence of labour adjustment costs. However, these studies do not analyse capital adjustment costs nor cross-adjustment effects between the demands for capital and labour, as done in this paper.

The main contribution of this paper is to examine the relationship between the firm's market value and labour demand using a Q model and to study the firms' costs of adjusting the quasi-fixed factors, capital and labour, jointly using this Q model. This is done not only by taking into account the presence of adjustment costs in the demands for capital and labour, but also considering the interrelation between both input demands in the adjustment costs, without imposing any explicit functional form of the production function.

The main findings are that the ratio of the firm's market value to the existing labour's tax-adjusted costs (the corresponding Q variable of labour factor) explains the rate of hiring workers. The estimates suggest the presence of capital and labour adjustment costs that depend on the firm's plant and staff sizes. When the mean firm invests and hires new workers at the rates of 5%, the marginal adjustment costs of capital and labour seem to account for 5.53% of the previous-period capital stock and 0.38% of the wage bill paid for the previous staff, respectively. The estimates are also consistent with the presence of important interaction effects between the demands for both production factors on the adjustment costs. The estimates are validated with the fact that in the industries that have smaller labour adjustment costs the use of temporary workers is more widespread.

The rest of this paper is organised as follows. Section 2 presents the theoretical model, Section 3 describes the main features of the data, the econometric issues, and the estimation results. Finally, Section 4 summarises the main conclusions of the paper.

2. The model

In the Q models of investment, average q plays the role of a proxy of the marginal q. Hayashi (1982) proved that there is an identity between marginal q and average q under the assumptions of perfect competition and homogeneity of degree 1 of both the production and the adjustment cost functions. In a model of two quasi-fixed factors, under the same assumptions, there is no longer an identity between both variables. As in Tobin's Q investment model, there is a neoclassical model that is equivalent to the Q model described in this paper, under the presence of adjustment costs in both investment and labour hiring.

2.1 Model assumptions

Six assumptions are made to develop the Q model of labour demand. First, the firm's shareholders are risk-neutral, thus the firm's goal is to maximise the expected present value of its profits, i.e. the market value of its debt and equities. The firm's financing decisions and the choice of whether to issue shares or bonds are not taken into account. This allows me to avoid the asymmetric information problems that arise from the coexistence of both sources of financing.

Second, firms only need two production factors: capital, which is owned by firms, and labour, which is the number of workers employed every period.[1] The use of each input in firm i in period t is indicated by K_{it} and L_{it}, respectively. Third, the production function, $F(K_{it},\ L_{it})$, is assumed to have constant returns to scale. The fourth assumption is the presence of perfect competition in all markets in which firms perform; i.e. firms behave as price-takers in all output and input markets.

Fifth, the firms' tax-adjusted profits are taken into account in a way similar to Alonso-Borrego and Bentolila (1994), Cummins, Hassett and Hubbard (1994) and Estrada and Vallés (1998): I consider the corporate tax rate τ_t, the investment tax credit at rate h_t, and the expected present value, z_{it}, of the depreciation allowances permitted by the taxation system on each unit of the new capital in the current and future periods. The present value of these tax savings is indicated by Γ_{it} as follows:

$$\Gamma_{it} = h_t + \tau_t z_{it} \qquad [1]$$

The effective price of the capital goods is $P_{it}^K\,(1 - h_t - \tau_t z_{it})$; the purchase price, P_{it}^K, is corrected by: firstly, $P_{it}^K h_t$, the investment tax credit on the purchase price of the investment good. And secondly, $P_{it}^K z_{it}$ is the expected present value of the depreciation allowances on the purchase price of the new capital stock. The Spanish taxation system allows firms to deduct depreciation from their profits for the corporation tax, thus the tax savings due to this item is $\tau_t P_{it}^K z_{it}$.[2]

[1] An additional input, such as the consumption of raw materials, may be introduced in the model, without changing the functional form of the demands for quasi-fixed factors. The consumption of raw materials is considered a variable factor that can be adjusted to the firms' needs perfectly and instantaneously. For the sake of simplicity, this third type of input is left out of both the production and the net revenue functions.

[2] In the empirical analysis, the stock of capital is formed by the aggregation of several types of capital goods that have different systems of depreciation allowances. The expected present value of the depreciation allowances permitted by the taxation system, z_{it}, is obtained using the formulae provided by González-Páramo (1991). The data related to the Spanish taxation system are obtained every year from the books written by Albi and García-Ariznavarrete (1987-97).

Finally, the adjustment cost function is restricted to be homogeneous of degree one, convex, additive and separable into labour and capital as follows:

$$G(I_{it}, H_{it}, K_{it-1}, L_{it-1}) = \frac{b_L}{2}\left[\frac{H_{it}}{L_{it-1}} - a_L\right]^2 \frac{W_{it}}{P_{it}} L_{it-1} + \\ + \frac{b_K}{2}\left[\frac{I_{it}}{K_{it-1}} - a_K\right]^2 K_{it-1} + c_L \frac{H_{it}}{L_{it-1}} \frac{I_{it}}{K_{it-1}} \frac{W_{it}}{P_{it}} L_{it-1} + c_K \frac{H_{it}}{L_{it-1}} \frac{I_{it}}{K_{it-1}} K_{it-1} \quad [2]$$

The model assumes that the adjustment costs, $G(I_{it}, H_{it}, K_{it-1}, L_{it-1})$, are in terms of foregone production and depend on the investment and the labour hiring of firm i in period t, I_{it} and H_{it}, respectively, and on the capital stock and the staff held in the previous period, K_{it-1} and L_{it-1}, respectively. The adjustment costs represent a decrease in the firms' output due to the rearrangement of the production process after a change in the use of both inputs. Labour hiring is measured in terms of the net change in the number of workers in the firm's staff; the firm hires and increases the staff if H_{it} is positive, and decreases the number of workers if H_{it} is negative. The terms W_{it} and P_{it} indicate the wage of each worker and the firm's output price in period t, respectively. As the capital stock is expressed in terms of production units, the real wage, $\frac{W_{it}}{P_{it}}$, converts the number of workers employed in the previous period into production units; in this way, the adjustment cost function is defined in terms of production units.

The parameters, b_L and b_K, reflect the importance of the costs of adjusting the demand for each input, and $b_L > 0$ and $b_K > 0$ if the marginal adjustment costs are increasing in the size of the adjustment, H_{it} and I_{it}. The parameters, a_L and a_K, are thought to be the hiring and investment rates that do not cause any adjustment costs for the firm other than those produced by interaction effects between both demands (if $c_L \neq 0$ and $c_K \neq 0$). The two cross-product terms between hiring and investment rates reflect the existence of these interaction effects. The parameters, c_L and c_K, capture how the costs of adjusting capital and labour depend on the interaction between the demands for both inputs (investment and hiring rates) and on the existing levels of employment and capital stock in the previous period, respectively. This is due to the fact that the disruptions to production may be different according to both the sizes of the plant and the staff and the speed of adjusting both inputs. The case in which c_L and c_K are equal to zero is quite usual in the literature, whereby it will be also considered in the empirical specifications.

In contrast to the presence of a fixed adjustment cost, the convexity of the adjustment cost function implies that the process of adjusting both inputs is slow.[3] Despite being a quadratic function, the adjustment costs are asymmetric depending on whether the firm invests or disinvests (and depending on whether it hires or dismisses workers), even if $c_L = c_K = 0$. The costs of increasing and decreasing the same amount of capital (or labour) will differ depending on the sign of the parameter a_K (or a_L). The signs of the parameters, a_K and a_L, give information about what is more expensive for the firm, whether to invest or disinvest, and whether to hire or dismiss. For example, if $c_L = c_K = 0$ and $a_L > 0$, the adjustment costs will be larger when firms dismiss x employees ($H_{it} = -x$) than when they hire x workers ($H_{it} = x$). In that case, adjustment costs are asymmetric, and dismissals are more expensive than hiring workers.

The after-tax net revenue function takes the following form, considering the adjustment costs as foregone production and taking them away from the output level:

$$\begin{aligned} &\Pi_t(K_{it}, K_{it-1}, L_{it}, L_{it-1}, I_{it}, H_{it}) = \\ &= (1-\tau_t)\{P_{it}\left[F(K_{it}, L_{it}) - G(I_{it}, H_{it}, K_{it-1}, L_{it-1})\right] - W_{it}L_{it}\} - \\ &\quad - P^K_{it}(1-\Gamma_{it})I_{it} \end{aligned} \quad [3]$$

Finally, the empirical analysis encounters two important limitations in this CBSO data sample. The first is the lack of a measure of the gross change in the firm's staff. I only observe the average number of permanent and temporary workers that the firm employs every year, so I can only construct net hiring rates. Therefore, the adjustment cost function in equation [2] does not account for gross costs of adjusting labour, only net costs, such as those caused by disruptions to production (inexperience of new workers, readjustment of the production planning, etc.). However, given the same net employment change, the gross costs of adjusting labour may differ greatly in terms of firing

[3] It would have been more realistic to include a constant term in the adjustment cost function, which reflects the presence of a lumpy fixed cost when the firm changes its level of employment:

$$C(H_{it}) = \begin{cases} k \; if \;\; |H_{it}| > 0 \\ 0 \; if \;\; H_{it} = 0 \end{cases}$$

Different specifications of the adjustment cost function are discussed by Hamermesh (1993).

costs, disruptions to production, and search and training costs depending on the number of new employees hired, workers fired and those who leave the firm voluntarily.[4]

The second data limitation is that the small sample size makes it impossible to study either the substitution of permanent workers for temporary ones or the heterogeneity in the adjustment costs of different types of labour depending on their contract length or skill.[5] Instead, labour is regarded as a homogeneous input in order to estimate the model properly using my small sample size of firms. Otherwise, the number of explanatory variables involved in the equations for the hiring and investment rates in a model with more than two quasi-fixed factors would be very large relative to the number of firms in the sample.

2.2 Factor equations

The firm's optimization problem is as follows:

$$\max_{\{K_{it+s},L_{it+s},I_{it+s},H_{it+s}\}_{s=0}^{\infty}}$$

$$V_{it} = E_t\left[\sum_{s=0}^{\infty}\rho_{t+s}\Pi_{t+s}(K_{it+s}, K_{it+s-1}, L_{it+s}, L_{it+s-1}, I_{it+s}, H_{it+s})\right]$$

$$\text{s.t.}\quad K_{it+s} = (1-\delta)K_{it+s-1} + I_{it+s} \qquad (\lambda_{it+s})$$

$$L_{it+s} = L_{it+s-1} + H_{it+s} \qquad (\mu_{it+s}) \qquad [4]$$

The firm's market value is represented by V_{it}; $E_t(\cdot)$ is the expectation operator conditional on the information available in period t; ρ_{t+s} is the discount factor between periods t and $t+s$; δ reflects the depreciation rate of investment goods; λ_{it+s} and μ_{it+s} are Lagrange multipliers associated with each constraint. The first constraint describes the path of the capital stock over time, and the second shows that the staff in one period is formed by the staff held in the previous period plus the number of employees hired in net terms in that period.[6]

[4] On the contrary, I_{it} is the firms' gross investment that includes the amount spent on replacing the capital stock depreciated at a fixed rate. Therefore, the adjustment costs of capital are in gross terms, and the model assumes that the depreciated capital does not cause any adjustment costs other than those of gross investment.

[5] This substitution process may involve a big change in the composition of the labour demand, without varying the level of employment, when permanent workers are replaced by temporary ones.

[6] Given that gross employment changes are not observed, I do not consider the existence of a quit rate of workers, γ, as follows: $L_{it} = (1-\gamma)\,L_{it-1} + H_{it}$.

Two of the four first-order conditions, corresponding to investment and hiring, are:

$$\lambda_{it} = (1-\tau_t)P_{it}\frac{\partial G}{\partial I_{it}} + P_{it}^K(1-\Gamma_{it}) \quad [5]$$

$$\mu_{it} = (1-\tau_t)P_{it}\frac{\partial G}{\partial H_{it}} \quad [6]$$

In equilibrium, firms invest and hire workers until the marginal value of one additional unit of capital and labour is equal to its corresponding marginal cost. The marginal cost consists of both the marginal adjustment cost and the tax-adjusted purchase price of the capital good.

In investment models, the ratio of the firm's total market value to the replacement cost of the capital stock is known as Tobin's q. Tobin (1969) suggested that the investment rate is a function of q, and Hayashi (1982) proves that Tobin's q theory is consistent with a neoclassical investment model with adjustment costs. In these models, firms decide to invest in capital goods until the market value of one additional unit of capital is equal to its marginal cost (like in equation [5]). Following Hayashi (1982), Tobin's marginal q can be defined as the ratio of the market value of one additional unit of capital to its replacement cost: $q_{it} = \frac{\lambda_{it}}{P_{it}^K}$.

As the investment Q model finds a relationship between the investment rate and marginal q, the model described in this paper seeks another relationship between the hiring rate, $h_{it} = \frac{H_{it}}{L_{it-1}}$, and the corresponding marginal q of labour. Similarly, I define labour's marginal q as the ratio of the marginal value of one additional unit of labour (in this model a worker) to the labour cost:

$$q_{L,it} = \frac{\mu_{it}}{W_{it}} \quad [7]$$

The major difference between the definitions of Tobin's marginal q and labour's marginal q is that in Tobin's marginal q the replacement cost of capital is the purchase price, and in labour's marginal q the ratio is constructed using the one-period labour cost, W_{it}. This is due to the different nature of each factor: the unit of capital is owned by firms and is not rented, but firms pay returns to the labour factor every period. Using the definition in equation [7] and the first-order condition in equation [6], I find the following relationship between the net hiring rate and labour's marginal q:

$$h_{it} = a_L + \frac{1}{b_L}\frac{\mu_{it}}{(1-\tau_t)W_{it}} = a_L + \frac{1}{b_L}\frac{q_{L,it}}{(1-\tau_t)} \qquad [8]$$

This equation shows that the higher the ratio of the marginal value to the labour cost is, the more willing the firm will be to hire another employee. In neoclassical investment models, Hayashi (1982) states that in empirical work marginal q is not observable, but a proxy can be used, average q, which is the ratio of the market value of the existing capital to its replacement cost, $q^a_{it} = \frac{V_{it}}{P^K_{it}(1-\delta)K_{it-1}}$. Hayashi (1982) proved that, under certain assumptions, there is an equality between marginal q and average q when capital is the only factor that causes adjustment costs. The assumptions needed for this identity to hold are both perfect competition in all markets and constant returns to scale in the production and adjustment cost functions.[7]

In this paper, I search for the relationship between labour's unobserved marginal q, $q_{L,it}$, and a proxy for it, $q^a_{L,it}$, so that I can estimate the hiring rate equation that arises from this model (equation [8]) and recover the estimates of the structural parameters of the adjustment cost function. In accordance with the definition of labour's marginal q, labour's average q is the ratio of the firm's market value to the cost of replacing the staff inherited from the previous period:[8]

$$q^a_{L,it} = \frac{V_{it}}{W_{it}L_{it-1}} \qquad [9]$$

Bond and Cummins (2000) and Bond and Van Reenen (2003) state that, under the same assumptions made by Hayashi (1982), there is no longer equality between marginal q and average q due to the existence of more than one quasi-fixed capital factors. In this paper, to obtain the relationship between the net hiring rate and the proxy of labour's marginal q, I follow a similar approach to that carried out to obtain the

[7] Hayashi (1982) also obtained the relationship between marginal q and average q when firms are price-maker in their output markets, although there is no equality between them.

[8] If gross hiring data were available for the sample period, average q of labour factor should be defined taking into account the rate, γ, at which workers quit their job voluntarily, as follows:

$$q^a_{L,it} = \frac{V_{it}}{W_{it}(1-\gamma)L_{it-1}}$$

investment rate equation in the studies mentioned above. To simplify notation, I define the following variables: w_{it} is the real wage, $\frac{W_{it}}{P_{it}}$; p_{it}^{K} the tax-adjusted relative price of capital and labour, $\frac{P_{it}^{K}(1-\Gamma_{it})}{(1-\tau_t)W_{it}}$; k_{it} the ratio of capital stock to labour, $\frac{K_{it}}{L_{it}}$; and f_{it} is the investment rate, $\frac{I_{it}}{K_{it-1}}$. I obtain the following equation for the net hiring rate, h_{it}:[9]

$$h_{it} = \alpha_0 + \alpha_1 \overline{q}_{L,it} + \alpha_2 (f_{it} \frac{k_{it-1}}{w_{it}}) + \alpha_3 \frac{k_{it-1}}{w_{it}} + \alpha_4 (p_{it}^{K} k_{it-1}) + + \alpha_5 f_{it} + \alpha_6 (h_{it} \frac{k_{it-1}}{w_{it}}); \quad [10]$$

where

$$\alpha_0 = \frac{a_L b_L}{b_L + c_L (1-\delta)}; \ \alpha_1 = \frac{1}{b_L + c_L (1-\delta)}; \ \alpha_2 = -\frac{b_K (1-\delta) + c_K}{b_L + c_L (1-\delta)};$$
$$\alpha_3 = \frac{a_K b_K (1-\delta)}{b_L + c_L (1-\delta)}; \ \alpha_4 = -\frac{(1-\delta)}{b_L + c_L (1-\delta)}; \ \alpha_5 = -\frac{c_L}{b_L + c_L (1-\delta)};$$
$$\alpha_6 = -\frac{c_K (1-\delta)}{b_L + c_L (1-\delta)};$$

The market value to the tax-adjusted cost of the existing labour, $\overline{q}_{L,it} = \frac{V_{it}}{(1-\tau_t)W_{it}L_{it-1}} = \frac{q_{L,it}^{a}}{(1-\tau_t)}$, plays the role of the Q variable in investment models; $\overline{q}_{L,it}$ is the tax-adjusted average q of labour. Once again, the functional form of $\overline{q}_{L,it}$ differs from Q variable due to the different nature of capital and labour: workers receive earnings for their hours of work every period, and capital stock is acquired and owned by the firm. The parameters, α_0 to α_6, of the hiring rate equation are related to the parameters of the adjustment cost function as indicated

[9] Given the model assumptions, manipulating the first-order conditions for I_{it}, H_{it}, K_{it}, and L_{it} and taking into account that the after-tax net revenue function obeys Euler's law, I arrive at the following expression:

$$\lambda_{it} (1-\delta) K_{it-1} + \mu_{it} L_{it-1} = V_{it}$$

Using this expression and equations [5] and [6], I obtain the equations for the hiring rate and the investment rate implied by the model described in this paper.

in equation [10]. The investment rate equation, f_{it}, that arises from this model is as follows:

$$f_{it}=\gamma_0+\gamma_1 Q_{it}+\gamma_2\left(h_{it}\frac{w_{it}}{k_{it-1}}\right)+\gamma_3 h_{it}+\gamma_4\frac{w_{it}}{k_{it-1}}+\gamma_5\left(f_{it}\frac{w_{it}}{k_{it-1}}\right);\quad [11]$$

where

$$\gamma_0=\frac{a_K b_K(1-\delta)}{b_K(1-\delta)+c_K};\ \gamma_1=\frac{(1-\delta)}{b_K(1-\delta)+c_K};\ \gamma_2=-\frac{b_L+c_L(1-\delta)}{b_K(1-\delta)+c_K};$$

$$\gamma_3=-\frac{c_K(1-\delta)}{b_K(1-\delta)+c_K};\ \gamma_4=\frac{a_L b_L}{b_K(1-\delta)+c_K};\ \gamma_5=-\frac{c_L}{b_K(1-\delta)+c_K};$$

The parameters of the investment rate equation are γ_0 to γ_5 and are related to the parameters of the adjustment cost function as shown in equation [11]. As in the basic Q model of investment, the Q variable is constructed as follows:

$$Q_{it}=\frac{P_{it}^K(1-\Gamma_{it})}{(1-\tau_t)P_{it}}\left[\frac{V_{it}}{P_{it}^K(1-\Gamma_{it})(1-\delta)K_{it-1}}-1\right]$$

As a result, due to the presence of more than one quasi-fixed factor, the tax-adjusted average q of each input ($\overline{q}_{L,it}$ for labour and Q_{it} for capital) is not a sufficient statistic for either the net hiring rate or the investment rate, in contrast with the basic Q model of investment with one homogeneous capital good (i.e. the case in which $a_L=b_L=c_L=c_K=0$). If $\overline{q}_{L,it}$ and Q_{it} were only taken into account in the empirical analysis, I would be omitting relevant variables to explain the net hiring rate and the investment rate.

3. Econometric implementation

3.1 Data sources and preliminary evidence

The empirical study is based on a sample of 107 Spanish firms that were quoted on the stock exchange over the period 1987-97. The data come from the Bank of Spain's Central Balance Sheet Office (*Central de Balances del Banco de España,* in Spanish). There were initially 291 firms in the data set. Public and service companies are excluded due to the fact that their investment and employment decisions may differ greatly from those of the remaining firms. Thus, I obtain a homogeneous sample formed by the manufacturing firms that have passed a series of filters, described in Appendix A1.

The investment and capital stock variables are the result of the aggregation of the firm's depreciable physical capital assets. These assets are: buildings; utility plants in service; machinery, equipment and tools; transport equipment; and computer equipment. A LIFO-type recursive valuation formula is used to obtain the market value from the book value of the capital stock. The firm's market value is constructed as the sum of the stock market value at the end of year and the value of the short and long-term debt with cost.

Table A1.3 shows the sample statistics of the relevant variables for the period 1987-97. Given that the sample size is very small, the descriptive statistics reported are robust in the presence of outliers in the data. Figures 1 to 5 show the path of the average values of some economic variables relevant to this empirical analysis. In Figure 1, labour's average q follows a procyclical pattern; the ratio of the firm's market value to the labour costs increases in business cycle expansions and falls in business cycle contractions.

FIGURE 1
Average q of the labour factor over the period 1987-97

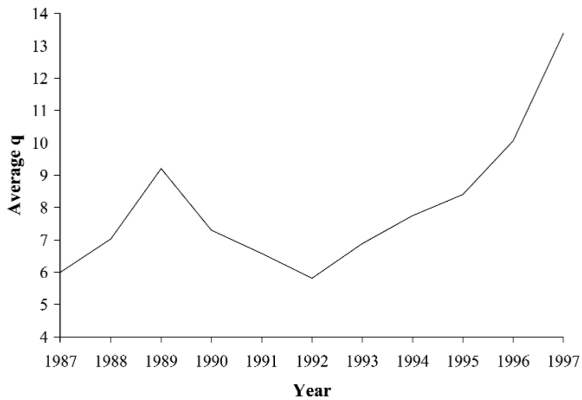


FIGURE 2
Average net rate of hiring workers over the period 1987-97

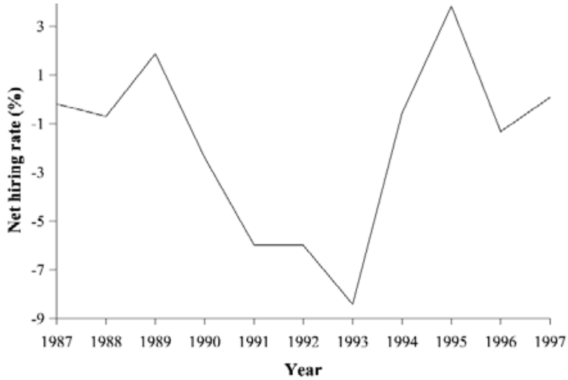


Figure 2 shows the procyclical behaviour of the net hiring rate. Over the sample period, most firms reduced their staff size in spite of enjoying business cycle expansions. The analysis of the net hiring rate in aggregate terms may hide the existence of a process of replacing permanent workers by temporary ones, irrespective of whether the size of the firm's staff increases.

In order to study this potential substitution, Figure 3 shows both the path of the size of the firms' staff size and the composition of temporary and permanent workers over time. Most firms have a high proportion of permanent workers on their staff, and the use of temporary contracts increases gradually and weakly over time. Furthermore, firms use fixed-term contracts for adjusting their staff depending on the business cycle; they create employment using fixed-term contracts in economic expansions, and these temporary jobs are destroyed in recessions. When service firms are included in the sample, I observe that the use of fixed-term contracts is more widespread and cyclical.

FIGURE 3
Average size and composition of the firm's staff broken down by the length of the employment contract over the period 1987-97

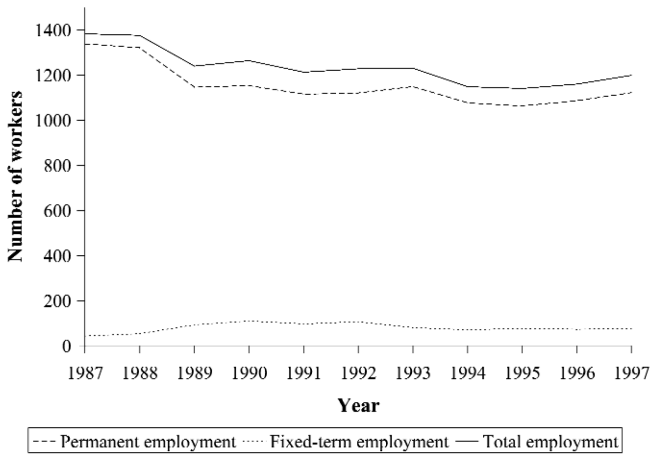
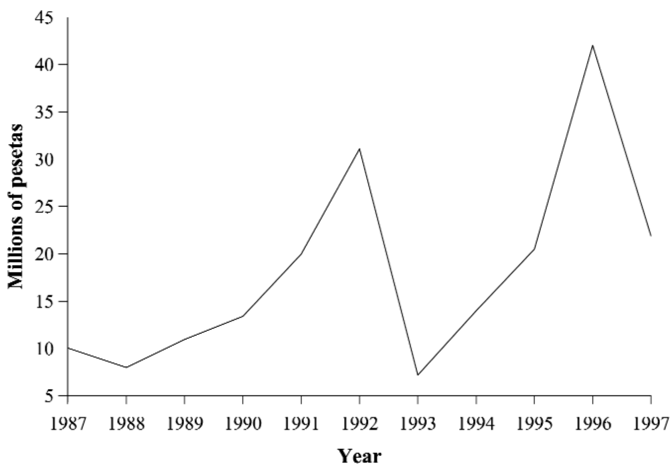


Figure 4 shows the path of the capital stock in real terms over time. Firms hold higher levels of capital stock in economic expansions, whereas these levels are lower in recessions. However, the capital stock has a narrow range of variation across business cycles and also exhibits a steady and upward trend over time, consistent with the idea that capital is a long-run variable. Finally, Figure 5 reveals that investment is a procyclical short-run variable, since it changes considerably from one year to other according to the business cycle, in contrast to the capital stock.

FIGURE 4
Average value of the firms' capital stock over the period 1987-97

FIGURE 5
Average value of the firms' investment in capital goods over the period 1987-97



3.2 Econometric issues

The goal of this empirical study is to estimate the costs of adjusting labour and capital using a Q model that relates the firms' market value to their hiring and investment rates. For this purpose, I estimate the parameters of the empirical equations implied by the theoretical model, and then I recover the estimates of the structural parameters of the adjustment cost function in equation [2] using minimum distance estimation (MD), as explained later. I estimate alternative model specifications depending on whether I assume $c_L = 0$ and $c_K = 0$ in the adjustment cost function and depending on whether I only focus on the hiring rate equation in the empirical analysis or I estimate the reduced-form system of the two equations implied by the theoretical model (i.e. also taking the investment rate equation into account). The empirical equations are obtained by including additive error terms into equations [10] and [11]:

$$h_{it} = \alpha_0 + \alpha_1 \overline{q}_{L,it} + \alpha_2 \left(f_{it} \frac{k_{it-1}}{w_{it}} \right) + \alpha_3 \frac{k_{it-1}}{w_{it}} + \alpha_4 \left(p_{it}^K k_{it-1} \right) + + \alpha_5 f_{it} + \alpha_6 \left(h_{it} \frac{k_{it-1}}{w_{it}} \right) + \eta_i + u_{it}; \quad [12]$$

$$f_{it} = \gamma_0 + \gamma_1 Q_{it} + \gamma_2 \left(h_{it} \frac{w_{it}}{k_{it-1}} \right) + \gamma_3 h_{it} + \gamma_4 \frac{w_{it}}{k_{it-1}} + + \gamma_5 \left(f_{it} \frac{w_{it}}{k_{it-1}} \right) + \xi_i + v_{it}; \quad [13]$$

The parameters of both equations, from α_0 to α_6 and from γ_0 to γ_5, are related to the structural parameters, a_L, a_K, b_L, b_K, c_L, c_K and δ, as shown in equations [10] and [11]. The firm-specific time-invariant effects, η_i and ξ_i, and the firm and time varying shocks, u_{it} and v_{it}, account for measurement errors (mainly in the firm's market value) and technological shocks unobserved by the econometrician.[10] These

[10] In the basic Q model, when only $a_K \neq 0$ and $b_K \neq 0$, the intercept and the additive shocks, $a_{K,it} = a_K + \xi_i + v_{it}$, are interpreted as the *normal* investment rate that does not cause any adjustment costs for firm i in period t, as if the parameter a_K in equation [2] really varies across firms and time [see Blundell *et al.* (1992) and Bond and Cummins (2000)]. Similarly, I could also interpret $a_{L,it} = a_L + \eta_i + u_{it}$ as the *normal* hiring rate at which firms do not suffer any adjustment costs. In the model described here, to maintain this interpretation, the empirical equations should also contain another permanent fixed effects and time-varying effects interacted with the ratios, $\frac{k_{it-1}}{w_{it}}$ and $\frac{w_{it}}{k_{it-1}}$. The structural parameters, a_L and a_K, appear in the intercepts (in α_0 and γ_0 respectively) as well as take part in the reduced-form coefficient of one explanatory variable in the other empirical equation (a_L in the coefficient, γ_4, of the ratio, $\frac{w_{it}}{k_{it-1}}$, and a_K in the coefficient, α_3, of the ratio, $\frac{k_{it-1}}{w_{it}}$).

Bond and Cummins (2000) solve this problem assuming that only one multiple quasi-fixed capital good, tangible capital, has the *normal* investment rate specified like this and that the second quasi-fixed factor, intangible capital stock, and its shocks are assumed to be independent across firms, although the firm-specific components, η_i and ξ_i, may be correlated within firms as well as the time-varying shocks, u_{it} and v_{it}. The latter type of error may also be serially correlated.

Due to the presence of measurement errors and unobserved technological shocks, the explanatory variables (mainly $\overline{q}_{L,it}$ and Q_{it}) are endogenous. Moreover, the decision of hiring and investing, h_{it} and f_{it}, are simultaneous in equations [12] and [13]; as a result, these variables are also endogenous and correlated with the error terms in both equations. Therefore, ordinary least-squares (OLS) estimates are inconsistent; I use the generalised method of moments (GMM) for estimating the model, but not all the orthogonality conditions are exploited. To remove the permanent firm-specific effects from these equations, I need to transform the empirical equations into first-differences or into forward orthogonal deviations.[11] I decide to estimate the model in orthogonal deviations due to the fact that the firms' market value, V_{it}, and the remaining ratios used as explanatory variables may suffer from a serious problem of measurement errors. First-differences tend to amplify the measurement error problem, since the variance of the first-difference errors is larger than the one in levels; on the contrary, the variance of the errors in orthogonal deviations remains unchanged.

I estimate the structural parameters in two stages. In the first stage, two different strategies can be carried out: first, I can only estimate the parameters of one of the two empirical equations (for example, those of the hiring rate equation) taking into account that the other simultaneous decision is an endogenous explanatory variable (for instance, the investment rate, f_{it}, in the hiring rate equation). This can be done since the structural parameters are overidentified and exactly identified in equations [12] and [13], respectively, once I calibrate the depreciation rate of the capital stock. The second strategy I can implement in the first stage is to estimate the reduced-form system from the struc-

price are an exogeneously fixed proportion of the tangible capital and its price. Therefore, they do not estimate an equation for the intangible investment rate and their specification of the tangible investment rate equation becomes considerably simplified. I think that these assumptions are not appropriate for the Q model implemented in this paper, and I assume that these *normal* rates are constant across firms and time (a_L and a_K).

[11] The variable, x_{it}, is transformed into orthogonal deviations, x^*_{it}, as follows: $x^*_{it} = c_t \left[x_{it} - \frac{1}{T-t} \cdot (x_{it+1} + x_{it+2} + ... + x_{iT}) \right]$, $c_t^2 = \frac{T-t}{T-t+1}$. The length of the sample period of firm i is denoted by T.

tural equations [12] and [13]. In this way, I use further information about the relationships between the variables and the parameters of interest. Both strategies give consistent estimates of the reduced-form and structural parameters, but the second strategy is more efficient. However, the latter strategy also needs a relatively larger sample size than the former does, since the number of estimated coefficients and the number of orthogonality conditions involved are much larger.

In the second stage, I recover the estimates of the structural parameters of the adjustment cost function from the first-stage estimates using minimum distance [see Arellano (2003)]. To do this I first calibrate the depreciation rate of the capital stock by regressing the firms' capital stock on investment and the previous period's capital stock. The calibrated depreciation rate is equal to one minus the coefficient estimate of the second regressor, and it is considered to be known in the MD estimates.

Due to the correlation of the explanatory variables with the time-varying shocks, I use the first two lags of all explanatory variables as instruments to estimate the parameters of the empirical equations in orthogonal deviations. Because of limitations of the sample size, not all the potential orthogonality conditions among instruments and error terms will be used, but only the moment conditions of a standard instrumental variable estimator. The full GMM approach cannot be implemented here due to the fact that the number of orthogonality conditions grows very fast with long time periods; in my case, this number is very large relative to the size of the sample of firms.

The empirical results show two-step GMM estimates with optimal weighting matrix; the validity of the instrument set and of the over-identifying restrictions is tested using Sargan test statistics. The absence of serial correlation of the errors in levels is tested using the m_2 statistic proposed by Arellano and Bond (1991); the m_2 statistic tests the absence of second-order serial correlation of the first-difference residuals, which are computed using the estimates of the model in orthogonal deviations. To estimate the model, I need firms with at least four consecutive observations; one observation is lost to transform the model into forward orthogonal deviations, and the other two observations are lost to use lagged variables as instruments.[12]

[12] The parameter estimates of the hiring rate equation are done using the DPD program written by Arellano and Bond (1998), and the estimation of both the structural parameters and the reduced-form equation system is programmed in GAUSS.

TABLE 1
Two-step GMM estimates of the hiring rate equation in orthogonal deviations and their corresponding MD estimates of the estructural parameters of the adjustment cost function

$$h_{it} = \alpha_0 + \alpha_1 \overline{q}_{L,it} + \alpha_2 \left(f_{it} \frac{k_{it-1}}{w_{it}} \right) + \alpha_3 \frac{k_{it-1}}{w_{it}} + \alpha_4 \left(p^K_{it} k_{it-1} \right) + \alpha_5 f_{it} + $$
$$+ \alpha_6 \left(h_{it} \frac{k_{it-1}}{w_{it}} \right) + \eta_i + u_{it};$$

$$G(I_{it}, H_{it}, K_{it-1}, L_{it-1}) = \frac{b_L}{2} \left[\frac{H_{it}}{L_{it-1}} - a_L \right]^2 \frac{W_{it}}{P_{it}} L_{it-1} + \frac{b_K}{2} \left[\frac{I_{it}}{K_{it-1}} - a_K \right]^2 K_{it-1} +$$
$$+ c_L \frac{H_{it}}{L_{it-1}} \frac{I_{it}}{K_{it-1}} \frac{W_{it}}{P_{it}} L_{it-1} + c_K \frac{H_{it}}{L_{it-1}} \frac{I_{it}}{K_{it-1}} K_{it-1};$$

	1) $c_L = 0, c_K = 0$		2) $c_L \neq 0, c_K \neq 0$	
	Hiring equation (h_{it})		Hiring equation (h_{it})	
Empirical equation:	Estimates	T-ratios	Estimates	T-ratios
α_0	0.0004	0.04	−0.0041	−0.80
α_1	0.0082	2.51	0.0052	4.73
α_2	0.0472	1.03	0.0463	3.20
α_3	0.0472	0.82	0.0384	0.73
α_4	−0.0840	−1.40	−0.0684	−1.35
α_5			−0.1171	−4.12
α_6			0.1983	5.39
Test p-values:				
m_2	0.58		0.41	
W(GS)	0.08		0.00	
Sargan	0.24(4)		0.16(6)	
Adjustment costs:	Estimates	T-ratios	Estimates	T-ratios
a_L	0.001	0.06	−0.001	−0.21
a_K	1.109	0.48	−0.190	−2.60
b_L	147.619	2.21	185.062	4.40
b_K	−3.437	−0.57	32.813	3.96
c_L	0.000	-	28.996	4.40
c_K	0.000	-	−40.738	−4.43
δ	0.117	-	0.117	-
Test p-values:				
W(GS)	0.00		0.00	
Sargan	0.19(1)		0.21(1)	

Notes to Tables 1 to 3: No. firms: 70. No. observations: 266. Sample period: 1989-96. The instrument sets in the estimates of the empirical equations are the first two lags of all explanatory variables in levels.

The p-values of the following tests are reported: m_2 is the test of absence of second-order serial correlation of the first-difference residuals, Sargan statistic is the test of overidentifying restrictions with the number of overidentifying restrictions in parentheses, and W(GS) is the test of the joint significance of all explanatory variables in the empirical equations estimates and of all structural parameters in the MD estimates.

The calibration of the capital stock depreciation rate, δ, arises from the following OLS estimates with standard errors in parentheses:

$$K_{it} = \underset{(0.014)}{1.003}\ I_{it} + \underset{(0.005)}{0.883}\ K_{it-1} + \widehat{e}_{it}, \text{ Adjusted } R^2 = 0.998.$$

3.3 Empirical results

The first panel of Table 1 shows the GMM coefficient estimates of the empirical equations for the hiring rate in orthogonal deviations, and the second panel contains the corresponding MD estimates of the adjustment cost function parameters. In column 1), the structural parameters, c_L and c_K, are restricted to zero; thus, the explanatory variables in the hiring rate equation [12] are the following: $\overline{q}_{L,it}$, $f_{it}\frac{k_{it-1}}{w_{it}}$, $\frac{k_{it-1}}{w_{it}}$, $p^K_{it}k_{it-1}$ and the intercept. In this specification, the m_2 statistic does not reject the absence of second-order serial correlation of the first-difference residuals of the hiring rate equation, and the Sargan test does not give evidence against the validity of the instrument set used.[13] However, a Wald test rejects the global significance of the explanatory variables used in this specification at the 5% level; $\overline{q}_{L,it}$ is the only significant variable at the 5% level and has a very small coefficient estimate of 0.0082.

Concerning the MD estimates of the structural parameters involved in specification 1), the Wald test does not give evidence against the global significance of the adjustment cost function without interaction effects between the demands for labour and capital. The Sargan test does not reject the overidentifying restriction that arises from calibrating the depreciation rate of capital stock, which has the value of 0.117. However, all structural parameter estimates are not significant individually except for the parameter b_L, which has an estimated value of 147.619. Although the estimate of b_K is not significant, its estimated value of -3.437 is not consistent with the presence of capital adjustment costs nor other empirical studies of investment models.

Specification 2) allows for interaction effects between both demands in the adjustment costs relaxing the restriction on the values of parameters c_L and c_K; thus, I include the investment rate, f_{it}, and the variable, $h_{it}\frac{k_{it-1}}{w_{it}}$, as two additional explanatory variables in the estimation of the hiring rate equation. Wald tests give evidence for the joint significance of all explanatory variables and for the joint significance of these two additional explanatory variables at the 1% level (this last Wald statistic is not reported in Table 1). Thus, specification 2) rejects the null hypothesis of the absence of interaction effects between

[13] Blundell *et al.* (1992) estimate a Q model of investment in first differences. In addition to the regressors, they also include first differences of all variables lagged once, due to the fact that the m_2 statistic rejects the absence of second-order serial correlation.

labour hiring and investment in the adjustment costs. Specification 1) seems to be subject to specification error due to the omission of the two interaction terms in the adjustment cost function.

In the MD estimates associated with specification 2), all structural parameter estimates are significantly different from zero except for the parameter a_L. The estimated value of parameter, a_K, is -0.190 and indicates that, in the absence of cross-adjustment effects, firms incur larger adjustment costs if they invest in capital stock ($f_{it} > 0$) than firms do if they disinvest selling part of their capital goods ($f_{it} < 0$). Apart from the interaction effects, I do not find any evidence for asymmetric net labour adjustment costs depending on whether the firms enlarge or reduce their staff, since the parameter, a_L, has an estimated value of -0.001, which is near zero and insignificant. This finding may be due to the fact that I can only capture net costs of adjusting labour with this data sample, but not gross costs. Because of the firing costs, the gross adjustment costs associated with dismissals may be larger than those incurred when hiring new workers; on the contrary, the net costs caused by disruptions to production and the rearrangement of the production process may not differ greatly. Alonso-Borrego (1998) also finds similar results, larger net hiring costs among permanent nonproduction workers.

The estimated values of the parameters, b_L and b_K, are 185.062 and 32.813 respectively; they indicate that firms incur large costs of adjusting labour and capital. The size of b_K is similar to that estimated by Alonso-Borrego and Bentolila (1994) using the basic Q model of investment and data from the CBSO. The fact that the estimated size of b_L is much larger than that of b_K does not mean that the marginal cost of adjusting labour is much larger than that of adjusting the capital stock as shown later in Figure 6. The larger estimate of b_L is due to the fact that hiring and labour are in terms of the number of workers, and investment and capital stock are measured in million pesetas. The relative size of the marginal adjustment costs also depends on real wages; in fact, the estimate of $b_L w_{it}$ is much lower than that of b_K in all sample observations (it ranges from 2.297 to 24.362). The estimated parameters, c_L and c_K, of equation [2] that account for the cross-adjustment terms between the demands for both inputs are also significant; these interaction effects depend on the size of both the staff and capital stock held in the previous period.

Finally, in order to take all available information into account to estimate the structural parameters of the adjustment cost function, Table 2 shows the joint estimates of the reduced-form equation system that arises from the structural equations [12] and [13]. I obtain the reduced-form equations by solving the structural equation system for the net hiring rate and the investment rate as functions of the remaining variables: an intercept, $\overline{q}_{L,it}$, $f_{it}\frac{k_{it-1}}{w_{it}}$, $\frac{k_{it-1}}{w_{it}}$, $p_{it}^{K}k_{it-1}$, $h_{it}\frac{k_{it-1}}{w_{it}}$, Q_{it}, $h_{it}\frac{w_{it}}{k_{it-1}}$, $\frac{w_{it}}{k_{it-1}}$, and $f_{it}\frac{w_{it}}{k_{it-1}}$. Following Wooldridge (2002), in this model I can identify the parameter estimates of the equations [12] and [13] from the estimates of the reduced-form system, and I can also recover the structural parameters of the adjustment costs using MD estimation.

TABLE 2

Parameter estimates of the reduced-form equation system and their corresponding parameter estimates of the structural equations and the adjustment cost function

$$h_{it} = \alpha_0 + \alpha_1\overline{q}_{L,it} + \alpha_2\left(f_{it}\frac{k_{it-1}}{w_{it}}\right) + \alpha_3\frac{k_{it-1}}{w_{it}} + \alpha_4\left(p_{it}^{K}k_{it-1}\right) + \alpha_5 f_{it} + \alpha_6\left(h_{it}\frac{k_{it-1}}{w_{it}}\right) + \eta_i + u_{it};$$

$$f_{it} = \gamma_0 + \gamma_1 Q_{it} + \gamma_2\left(h_{it}\frac{w_{it}}{k_{it-1}}\right) + \gamma_3 h_{it} + \gamma_4\frac{w_{it}}{k_{it-1}} + \gamma_5\left(f_{it}\frac{w_{it}}{k_{it-1}}\right) + \xi_i + v_{it};$$

$$G(I_{it}, H_{it}, K_{it-1}, L_{it-1}) = \frac{b_L}{2}\left[\frac{H_{it}}{L_{it-1}} - a_L\right]^2\frac{W_{it}}{P_{it}}L_{it-1} + \frac{b_K}{2}\left[\frac{I_{it}}{K_{it-1}} - a_K\right]^2 K_{it-1} + $$
$$+ c_L\frac{H_{it}}{L_{it-1}}\frac{I_{it}}{K_{it-1}}\frac{W_{it}}{P_{it}}L_{it-1} + c_K\frac{H_{it}}{L_{it-1}}\frac{I_{it}}{K_{it-1}}K_{it-1};$$

	Hiring equation (h_{it})		Investment equation (f_{it})	
Reduced-form system:	Estimates	T-ratios	Estimates	T-ratios
Constant	0.023	0.77	−0.023	−0.43
$\overline{q}_{L,it}$	0.004	4.12	0.008	6.42
$f_{it}\frac{k_{it-1}}{w_{it}}$	0.009	1.29	0.184	20.02
$\frac{k_{it-1}}{w_{it}}$	0.057	2.45	−0.010	−0.29
$p_{it}^{K}k_{it-1}$	−0.080	−3.07	−0.007	−0.21
$h_{it}\frac{k_{it-1}}{w_{it}}$	0.155	10.37	−0.009	−0.61
Q_{it}	−0.001	−1.67	0.000	−0.31
$h_{it}\frac{w_{it}}{k_{it-1}}$	0.618	6.04	0.161	1.14
$\frac{w_{it}}{k_{it-1}}$	0.004	0.14	0.066	1.39
$f_{it}\frac{w_{it}}{k_{it-1}}$	0.028	2.41	0.450	25.46
m_2	0.47		0.22	
W(GS)	0.00		0.00	
Sargan		0.21(18)		

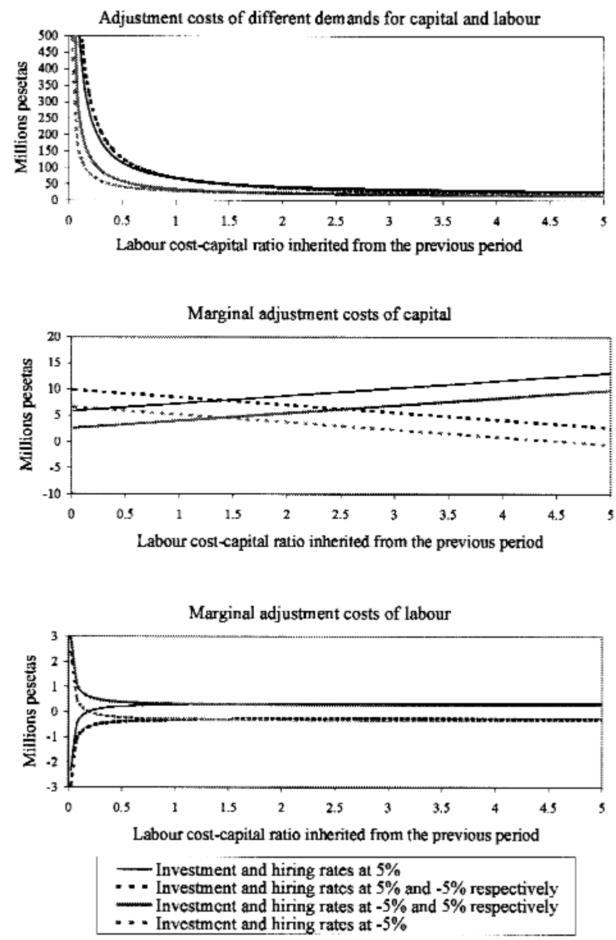
TABLE 2
Parameter estimates of the structural equations and the adjustment cost function *(continuation)*

Structural equations:	Estimates	T-ratios
α_0	0.018	2.34
α_1	0.001	4.59
α_2	−0.026	−15.77
α_3	0.018	2.54
α_4	−0.027	−3.69
α_5	−0.040	−10.41
α_6	0.101	17.29
γ_0	0.213	8.46
γ_1	0.000	0.04
γ_2	0.985	8.61
γ_3	−1.794	−35.66
γ_4	−0.179	−5.79
γ_5	0.608	41.54
W(GS)	0.00	
Sargan	0.00(7)	
Adjustment costs:	**Estimates**	**T-ratios**
a_L	−0.062	−23.83
a_K	−0.292	−28.15
b_L	217.993	41.83
b_K	20.863	25.38
c_L	7.110	22.71
c_K	18.383	26.25
δ	0.117	-
W(GS)	0.00	
Sargan	0.00(14)	

The first panel of Table 2 contains the coefficient estimates of the reduced-form system and the second panel shows the MD estimates of the structural equations, i.e. of the parameters α_0 to α_6 and γ_0 to γ_5. In the first panel, the reduced-form equation system is also transformed in orthogonal deviations to remove the permanent firm-specific effects and is estimated by two-step GMM using the first two lags of all explanatory variables as instruments. The reason why I prefer the estimates in specification 2) of Table 1 to those in Table 2 is that the number of orthogonality conditions involved in the latter specification is 38, which is very large relative to the number of firms over which the estimates are made, which is 70. Moreover, in the MD estimates the Sargan test rejects the large number of overidentifying restrictions.

- Estimates of the costs and marginal costs of adjusting capital and labour

FIGURE 6
Estimated costs and marginal costs of adjusting capital and labour according to the ratio of the labour costs to the capital stock inherited from the previous period



The estimated costs correspond with the estimates of specification 2) in Table 1, which includes interaction effects. All costs are calculated for the mean firm in the estimation sample and changing the value of the ratio of labour costs to capital stock inherited from the previous period, $\frac{w_{it}}{k_{it-1}}$. The mean firm's demands for inputs in period $t-1$ are $K_{it-1} = 118.5$ and $L_{it-1} = 1750$, and its current real wage is $w_{it} = 0.0327$.

Figure 6 shows the estimates of both the costs and marginal costs of adjusting capital and labour, corresponding with the estimates of specification 2) in Table 1. These costs are calculated over different values of the ratio of labour costs to capital stock existing at the beginning of period t, $\frac{w_{it}}{k_{it-1}} = \frac{w_{it}L_{it-1}}{K_{it-1}}$, for the mean firm ($w_{it} = 0.0327$ and $L_{it-1} = 1750$) and for different values of the investment and hiring rates (combining the rates of 5% and −5%). The labour cost-capital ratio is lower than 1.5 for the 90% of firms in the estimation sample.

The first graph plots the adjustment costs against the labour cost-capital ratio for different values of the investment and hiring rates. The more labour-intensive the firms are, the smaller the costs of adjusting capital and labour. The graph also shows that the adjustment costs seem to be much larger when firms acquire new capital stock than those incurred when they disinvest.

The second and third graphs show the marginal adjustment costs of capital and labour, respectively. The marginal costs, $\frac{\partial G(I_{it},H_{it},K_{it-1},L_{it-1})}{\partial I_{it}}$ and $\frac{\partial G(I_{it},H_{it},K_{it-1},L_{it-1})}{\partial H_{it}}$, are defined as the changes in adjustment costs per extra unit of investment (one million pesetas) and per extra unit of labour hired (one worker). Comparing the scale of both graphs, marginal costs are considerably larger when firms adjust their capital stock than those incurred when they adjust the number of workers on staff. Nevertheless, the sizes of the marginal adjustment costs of both factors are not strictly comparable with each other as the production factors are measured in different units. In the mean firm where the ratio of the labour costs to the capital stock is 0.48, the marginal costs of adjusting capital and labour at the rates of 5% are 6.55 and 0.22, respectively. Those numbers represent 5.53% of the previous period's capital stock and 0.38% of the wage bill paid for the previous staff, respectively.

The second graph shows two features of the marginal adjustment costs of capital. First, for the same hiring rate, the marginal costs are always larger when firms invest in more capital stock than when they disinvest (the black solid line lies over the grey solid line and the black dotted line over the grey dotted line). Second, the interaction effects between input demands on the marginal adjustment costs of capital are very significant, since the marginal costs depend greatly on the demand for labour factor. Without interaction effects, the black solid and dotted lines would coincide with each other, and the same would happen to the lines that represent the marginal costs of decreasing the same amount of capital stock with different labour demands (the grey solid and dotted lines). The marginal costs are only independent of the hiring rate when the labour costs per capital stock at the beginning of period are $-\frac{\widehat{c}_K}{\widehat{c}_L} = 1.41$.

The last graph shows that the interaction effects of the demands for inputs on the marginal labour adjustment costs are very important among the capital-intensive firms [the solid lines (the dotted lines) are very distinct from each other in firms with small labour cost-capital ratio]. On the contrary, in the labour-intensive firms in which the labour cost-capital ratio exceeds the threshold of $-\frac{\widehat{c}_K}{\widehat{c}_L}$, the marginal adjustment costs of labour are practically independent of the demand for capital.

- *Adjustment costs and heterogeneity of labour factor according to the length of the employment contract*

Finally, I am also interested in looking at the variation in labour adjustment costs across sectors and its relationship with the heterogeneity of the labour factor, depending on the length of the workers' employment contract. The appropriate way of studying the adjustment costs of heterogeneous labour inputs is to consider the existence of three quasi-fixed production factors (capital, permanent labour and temporary labour) and to repeat the analysis carried out in Section 2. However, this strategy cannot be implemented here due to the small sample size; the number of explanatory variables that the empirical model should allow for is very large in comparison with the number of sample observations.

Instead, I consider an *ad-hoc* specification of the hiring rate equation that allows for time and sector-specific adjustment costs in a parsimonious way. The economic sectors that incur smaller labour adjustment costs (i.e. smaller values of b_L) will tend to use temporary labour more intensively. To investigate this, I interact labour's tax-adjusted average q, $\overline{q}_{L,it}$, with a measure of the importance of the temporary labour input in the economic sector j to which the firm belongs, TL_t^j.[14] This measure is constructed as the annual average of the proportion that

[14] This specification of the hiring rate equation is *ad-hoc* and ignores the interaction term of this new variable, TL_t^j, with the rest of explanatory variables, since the parameter, b_L, appears in other reduced-form coefficients.

temporary workers account for the firm's staff, tl_{it}, across economic sectors, as follows:

$$TL_t^j = \frac{\sum\limits_{i \in \text{industry } j} tl_{it}}{N_t^j}$$

TABLE 3
Orthogonal-deviation two-step GMM estimates of the hiring rate equation taking into account the use of temporary employment contracts across economic sectors.

Dependent variable: Net hiring rate in orthogonal deviations

$$h_{it} = \alpha_0 + \left(\beta_o + \beta_1 TL_t^j\right) \overline{q}_{L,it} + \alpha_2 \left(f_{it}\frac{k_{it-1}}{w_{it}}\right) + \alpha_3 \frac{k_{it-1}}{w_{it}} + \alpha_4 \left(p_{it}^K k_{it-1}\right) + \alpha_5 f_{it} +$$
$$+ \alpha_6 \left(h_{it}\frac{k_{it-1}}{w_{it}}\right) + \eta_i + u_{it}$$

	Estimates	T-ratios
Constant	−0.0045	−0.93
$\overline{q}_{L,it}$	−0.0001	−0.07
$TL_t^j \cdot \overline{q}_{L,it}$	0.0427	2.61
$f_{it}\frac{k_{it-1}}{w_{it}}$	0.0337	2.49
$\frac{k_{it-1}}{w_{it}}$	0.0139	0.44
$p_{it}^K k_{it-1}$	−0.0464	−1.38
f_{it}	−0.1073	−4.77
$h_{it}\frac{k_{it-1}}{w_{it}}$	0.1735	5.18
m_2	0.14	
W(GS)	0.00	
W(Q_L)	0.00	
Sargan	0.25(7)	

W(Q_L) shows the p-value of the Wald test of the joint significance of $\overline{q}_{L,it}$ and its interaction with the average proportion of temporary workers across economic sectors, TL_t^j.

The variable, tl_{it}, is the ratio of the number of temporary workers to the total number of workers in firm i in period t. The index j indicates the industry to which firm i belongs; and N_t^j is the number of firms in industry j in period t. Thus, the empirical equation for the net hiring rate will have the following form:

$$h_{it}= \alpha_0+ \left(\beta_o + \beta_1 TL_t^j\right) \overline{q}_{L,it}+\alpha_2 \left(f_{it}\frac{k_{it-1}}{w_{it}}\right) +\alpha_3 \frac{k_{it-1}}{w_{it}}+\alpha_4 \left(p_{it}^K k_{it-1}\right) + +\alpha_5 f_{it}+\alpha_6 \left(h_{it}\frac{k_{it-1}}{w_{it}}\right) +\eta_i+u_{it}$$

In Table 3, the coefficient on the interaction of $\overline{q}_{L,it}$ with the sectoral average proportion of the number of temporary workers has a positive estimated value of 0.0427. This interaction is significant at the 1% level and the Wald test, W(Q_L), gives evidence for the joint significance of labour's tax-adjusted average q and its interaction at the 1% level. In this *ad-hoc* specification of the hiring rate equation, the joint estimate of the coefficients on $\overline{q}_{L,it}$ given by $(\hat{\beta}_o + \hat{\beta}_1 TL_t^j)$ is inversely related to the size of labour adjustment costs. Thus, the positive sign of the estimated coefficient on the interaction of $\overline{q}_{L,it}$ with TL_t^j is consistent with the idea that the industries that incur smaller labour adjustment costs due to their specific technology and economic activity characteristics tend to use temporary labour more intensively.[15]

4. Conclusions

The main contribution of this paper to the labour demand literature is to estimate a model of labour demand using a Q model in which both capital and labour are quasi-fixed factors. The estimates of the model are based on a sample of 70 Spanish firms that were quoted on the stock exchange over the period 1989-96. The data come from the Bank of Spain's Central Balance Sheet Office (*Central de Balances del Banco de España*, in Spanish). The model assumes that firms use two production factors, labour and capital, which entail adjustment costs. The adjustment cost function is convex and takes into account the existence of interaction effects between the demand for both inputs.

[15] Because of the low p-value of the m_2 statistic, I have also estimated the same model using other two different sets of instruments, so that the incremental Sargan test can accept the validity of the use of the first lag of the explanatory variables as instruments. The first instrument set contains the first three lags of the explanatory variables, and the second only has the explanatory variables lagged twice and three times. The incremental Sargan test does not give any evidence against the instrument set containing the first lags, and the estimation results are similar to those here.

The estimated results are summarised as follows. First, the corresponding tax-adjusted average q of labour factor, which is the ratio of the firm's market value to the beginning-of-period labour costs, is significant in explaining the net hiring rate. However, its estimated coefficient value is very low, as also encountered in the studies of the Q model of investment, and this implies that the labour adjustment costs are large.

Secondly, the estimates also find important interaction effects between the investment and the demand for labour on the costs that firms incur to adjust labour and capital factors. The cross-adjustment effects depend on both the size of the firms' staff and the capital stock existing previously. The marginal adjustment costs of capital depend greatly on both the hiring rate and the ratio of labour to capital. On the contrary, the marginal adjustment costs of labour only vary with the demand for capital and the labour-capital ratio when firms are capital-intensive.

Finally, I also take into account that the costs of adjusting labour may differ across economic sectors. When I include *ad hoc* the interaction of labour's tax-adjusted average q with the average proportion of temporary workers in the sector to which the firm belongs, I find that the use of temporary labour seems to be more widespread in the industries in which the disruptions to production and labour adjustment costs are smaller due to the specific characteristics of their technology and economic activity.

Appendix

A1. Construction of variables

A1.1 Sample selection

The sample is formed by non-financial firms that were quoted on the stock exchange over the period 1987-97; the data come from the CBSO. Some filters are applied to the data to obtain a homogeneous sample of firms. The observations that satisfy at least one of the following characteristics drop out of the sample:

1. The book value of the capital stock is negative or null.

2. At least one of the assets in which the capital stock is broken down has a negative book value.

3. The book value of leasing is negative.
4. The book value of the accumulated depreciation of the capital stock is negative or zero.
5. The accumulated depreciation of one of the assets in which the capital stock is broken down is negative.
6. The accumulated depreciation of the leasing is negative.
7. The annual depreciation of one of the capital assets or the one of the leasing is negative.
8. Employment is negative or null.
9. Salaries and wages paid by the firm are negative or null.
10. The debt with cost has a negative value.
11. The value of the financial expenses is negative.
12. Firms that carried out a merger, a split or a business cession.
13. Public firms or those firms in which the sum of the direct and indirect public participation is more than 50%.
14. Firms that changed their main economic activity. These activities are classified according to the 1993 Spanish National Classification of Economic Activities [hereafter, CNAE(93)].
15. Non-manufacturing firms whose one-digit CNAE(93) group is different from 1, 2 and 3.

TABLE A1.1
Unbalanced panel of industrial firms (1987-97)

No. of consecutive observations	No. of firms
2	18
3	19
4	11
5	16
6	11
7	4
8	10
9	8
10	4
11	6

After applying the filters, the sample size decreases from 291 to 107 firms. The sample structure is detailed in Table A1.1. Table A1.2 shows the industry classification, and the number of firms in each economic activity.[16]

Table A1.2
Industry classification

Industry	CNAE(93)	No. of firms
Metals and metal goods	27-28	15
Other minerals and mineral products	10-14, 23, 26	23
Chemicals and man made fibres	24-25	13
Mechanical engineering	29	9
Electrical and instrument engineering	30-33	4
Motor vehicles and parts	34-35	8
Textiles, clothing, leather and footwear	17-19	8
Food, drink and tobacco	15-16	19
Other	20-22, 36-37	8

A1.2 Definition of variables

I follow Alonso-Borrego and Bentolila (1994), Alonso-Borrego (1998) and Estrada, *et al* (1997) to construct the variables used in the estimates.

1. The average labour cost per employee, W_{it}, is the ratio of the salaries and wages paid by the firm to the total number of employees.

2. The total number of employees, L_{it}, is the sum of the number of permanent and temporary workers. The number of temporary workers is computed as an average weighted by the number of weeks that each employee worked in the firm.

3. The market value of a firm, V_{it}, is equal to the sum of the end-of-period stock market value and the value of the short and long-term debt with cost.

4. Investment and capital stock.

   The survey breaks down the capital stock into five categories: a) Buildings and other structures; b) Machinery, equipment and tools; c) Utility plants in service; d) Transport equipment; e) Computer equipment and other.

[16] Industry classification used by Blundell *et al* (1992).

The capital stock is constructed as the value in replacement terms of the capital stock book value using a LIFO-type recursive valuation formula.

A methodological change in the survey occurred in 1990. Leasing took part in the physical capital stock before 1990, afterwards leasing is considered as another type of intangible assets in the firm accounts. Therefore, the values of both the investment and capital stock are constructed by taking into account the firm's leasing, so that these variables are homogeneous over the sample period.

The physical capital stock is broken down into five different assets; KM_{it}^{j} indicates the market value of capital good j; $P_{K,it}^{j}$ is the price of capital asset j; and K_{it}^{j} is the value of capital asset j in real terms:

$$KM_{it}^{j} = P_{K,it}^{j} K_{it}^{j} \qquad j = 1, \cdots, 5$$

The capital stock is constructed from the book value by using a perpetual inventory method:

$$KM_{it}^{j} = \left(\frac{P_{K,it}^{j}}{P_{K,it-1}^{j}} KM_{it-1}^{j} (1 - \delta_j) + GI_{it}^{j} \right) \qquad j = 1, \cdots, 5$$

The economic depreciation rate of capital good j is denoted by δ_j and is taken from Hulten and Wykoff (1981); GI_{it}^{j} is the gross investment in capital good j in period t.

Given that I have no information about asset sales, gross investment is estimated by the following way:

$$GI_{it}^{j} = KNB_{it}^{j} - KNB_{it-1}^{j} + Dep_{it}^{j}$$

KNB_{it}^{j} and Dep_{it}^{j} are the net book value and the annual depreciation of capital asset j in period t, respectively.

5. The market value of the capital stock in the first period the firm is observed in the sample is computed as follows:

$$KM_{it}^{j} = \left(\frac{P_{K,it}^{j}}{P_{K,it-aa_i^j}^{j}} \right) KNB_{it}^{j} (1 - \delta_j)^{aa_i^j}$$

In this formula, t refers to the year in which the firm is observed for the first time, and aa_i^j is the average age of capital good j. The age is estimated as an average across firms at the two-digit industry level in CNAE(93), due to the fact that the firm's average age is a very erratic variable. The average age by firm is defined as:

$$\overline{aa}_i^j = \frac{1}{N_i}\sum_{t=1}^{N_i}\frac{AD_{it}^j}{Dep_{it}^j}$$

AD_{it}^j is the accumulated depreciation of capital good j of firm i in period t, and N_i is the number of sample observations of firm i.

This recursive valuation sometimes produces negative estimates of the market value of the capital stock. Given the small number of sample observations, when I obtain negative values, the value of the capital stock is computed again using the same method as that used in the first observation.

In that case, the gross investment is reestimated as follows:

$$GI_{it}^j = KM_{it}^j - \frac{P_{K,it}^j}{P_{K,it-1}^j}KM_{it-1}^j(1-\delta_j)$$

Both the capital stock and the investment in fixed asset j are obtained in real terms by deflating the value in replacement terms of the capital stock and the gross investment. The deflators are the following: the building price index is used in buildings; the industrial price indices (hereafter, IPRI) broken down by the economic destination of the goods are used in the remaining capital goods, they came from the *Boletín Estadístico*, edited by the Bank of Spain. The index "machinery and other equipment material" is used in machinery, equipment and tools; the item "Total" of the capital goods index is used in utility plants in service; and the item "Transport material" is used in transport equipment. Finally, the index "Manufacture of Office Machines and Computers" coming from the IPRI according to the two-digit CNAE(93) is used in computer equipment and other.

The investment and the capital stock in real terms are obtained by aggregating these five categories.

6. Tax variables.[17]

   a) The corporate tax rate, τ_t, is 35% of the tax base every period.
   b) The investment tax credit, h_t, of the tax base is 15% in 1986 and 1987, 10% in 1988 and over the period 1992-94, and 5% over the periods 1989-91 and 1995-97.
   c) The present value of the depreciation allowances, z_{it}, permitted by law on each unit of the new capital stock in the current and future periods is computed as the formulae provided by González-Páramo (1991). I assume that firms choose the depreciation system that provides the largest present value. The firm's discount rate is the firm's average of the annual cost of borrowing funds, measured as the ratio of the financial expenses to the value of debt with cost.

7. The price of the capital stock, $P_{it}^K(1-\Gamma_{it})$, is given by the weighted aggregation of the tax-adjusted price of each asset:

$$P_{it}^K(1-\Gamma_{it}) = \sum_{j=1}^{5} \omega_{it}^j (1 - h_t - \tau_t z_{it}^j) P_{K,it}^j$$

   The weighting, ω_{it}^j, varies across firms depending on the proportion of the value of asset j to the total value of the capital stock:

$$\omega_{it}^j = \frac{KNB_{it}^j}{\sum_{s=1}^{5} KNB_{it}^s}$$

   Thus, the price of the capital stock is different across firms according to the structure of their physical capital.

8. The net employment change in firm i, H_{it}, is defined as the difference in the total number of employees between the current and previous periods:

$$H_{it} = L_{it} - L_{it-1}$$

[17] The data come from the book entitled "*Sistema Fiscal Español*" written by Albi and García-Ariznavarrete. This book is reedited every year and contains the legislative changes in the taxation system.

9. The output price of firm i, P_{it}, is the industrial price index of its main economic activity at the two-digit CNAE(93) classification.

TABLE A1.3
Sample statistics for the period 1987-97

	Median	IQR	Minimum	Maximum
h_{it}	−0.022	0.078	−0.966	1.340
$\overline{q}_{L,it}$	7.272	14.189	0.038	102.421
$f_{it}\frac{k_{it-1}}{w_{it}}$	0.246	0.458	−2.466	12.903
$\frac{k_{it-1}}{w_{it}}$	1.867	2.324	0.180	40.221
$p_{it}^{K}k_{it-1}$	2.065	2.504	0.177	39.478
$h_{it}\frac{k_{it-1}}{w_{it}}$	−0.033	0.143	−1.392	3.828
f_{it}	0.139	0.255	−0.716	4.634
Q_{it}	3.434	6.647	−0.953	200.212
$h_{it}\frac{w_{it}}{k_{it-1}}$	−0.010	0.042	−1.820	0.889
$\frac{w_{it}}{k_{it-1}}$	0.536	0.676	0.025	5.548
$f_{it}\frac{w_{it}}{k_{it-1}}$	0.082	0.230	−1.274	10.381

All variables are in real terms. The unit is million pesetas except for the employment variables, which are measured in number of workers.

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Resumen

Este estudio analiza la demanda de trabajo mediante un modelo de la Q en el que trabajo y capital presentan costes de ajuste, utilizando un panel incompleto de empresas para el período 1989-96. La variable Q correspondiente al factor trabajo es significativa para explicar la tasa de contratación. Su coeficiente estimado varía entre sectores, lo que sugiere que el trabajo temporal se utiliza relativamente más en sectores que presentan menores costes de ajuste dadas sus características tecnológicas y su actividad económica. También se observan efectos de interacción entre las demandas de trabajo e inversión en los costes de ajuste.

Palabras clave: Modelo de la Q, costes de ajuste, demanda de trabajo, datos de panel.

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