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2004

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This version:
March 2002

Abstract

This paper is aimed at structurally assessing the employment effects of the innovative activities of firms. We estimate firm level displacement and compensation effects in a model in which the stock of knowledge capital raises firm relative efficiency through process innovations and firm demand through product innovations. Displacement is estimated from the elasticity of employment with respect to innovation in the (conditional or Hicksian) demand for labour. Compensation effects are estimated from a firm-specific demand relationship. We also assess the enlargement and weakening of these effects due to firm agents' behaviour aimed at appropriating innovation rents. We find that the potential employment compensation effect of process innovations surpasses the displacement effect, both in the short and long run (when competitors react), and that product innovation doubles the expanding impact by unit of expenditure, but also that agents' behaviour can seriously reduce these effects. The actual elasticity of employment to knowledge capital is estimated, however, not far from unity, while "passive" productivity growth is suggested to have null or negative employment effects.

JEL classification: J23; L6; O3
Keywords: Innovation; Knowledge capital; Employment.

We gratefully acknowledge useful comments by P. Beneito, R. Carrasco, M. Delgado, J. Dolado, A. de la Fuente, R. Griffith, N. Janz, M. Machado, J. Mairesse, P. Mohnen, C. Ornaghi, S. Reeding, and M. Waterson as well as numerous seminar audiences. This research is part of the project "Innovation and employment in European Firms," supported by the European Commission under contract IHPSE-CT-2001-00047, and has been partially funded by CICYT project SEC2000-0268.
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1. Introduction

The relationship between technology and employment is a lively issue in current debates on employment. Frequently, fears are expressed about the job losses associated with the introduction of innovations, but economists claim that technology always has two effects of the opposite sign. Innovation can destroy some jobs, but also creates others, and the balance is expected to be positive. For standard expositions of this line of reasoning see, for example, OECD (1994, 1996). Much less is known and said about the working in practice of these mechanisms and their impact on economic policy.

The basic mechanism is assumed to work, first of all, at the firm level. Formalisations of this idea at the firm level can be found, for example, in Stoneman (1983), Katsolaucos (1984) and Hamermesh (1993)). At this level, on the one hand, (process) innovations are expected to reduce the number of workers needed to produce any given output (displacement effect). But, on the other hand, the increased efficiency of labour (and the other factors) will cause a reduction in marginal cost which, if passed on to prices, will raise demand and employment (compensation effect). The result of these two offsetting effects is generally expected to be positive, and its magnitude related to the price elasticity of demand. Furthermore, the change in demand may be reinforced by the (product) innovations of firms.

The result of these two effects only gives, however, the upper bound of the impact that innovation can actually have on employment. Agents' behaviour at the level of the firm, trying to appropriate the rents of innovation, can worsen the displacement effect and weaken the compensation effect. If unions take advantage of innovation to bargain higher wages, part of the cost savings due to innovation may be offset in this way. If the firm uses the new competitive environment to enlarge the exercise of market power by increasing (or not lowering sufficiently) prices, the compensation effect will be dampened.

Hence, the employment impact of innovation depends on the combination of a series of technological and product demand characteristics, and their interaction with firm agents' behaviour. There is, however, a sore lack of empirical studies which attempt to assess the working of these forces at the firm level. The main reason is the difficulty of obtaining suitable data: firm or plant level panel data for broad samples, including technological indicators and enough firm activity measures, to model these relationships taking into account both heterogeneity and variables endogeneity.

Of course, there has been a growing body of literature documenting the creation of employment, as well as the behaviour of other performance indicators, in "technology-based" or "innovative" firms (see OECD (1998) for a recent survey on this type of studies). However, this evidence only provides a reduced-form approach to the employment effects of innovation coming from more or less selective samples of firms (starting-up firms, high-growth firms...) which limits the scope of the conclusions. In turn, a number of studies have obtained results relating employment or employment growth to technological innovation measures in broader samples of firms and establishments, often finding a positive correlation (see, for example, Doms, Dunne and Roberts (1995)). But the data limitations have often blurred the conclusions, at the same time preventing more structural approaches.

Displacement and compensation effects do not necessarily imply the reallocation of physical workers, but this type of turnover may be a sign of their operation. Two bodies of literature have recently indirectly stressed the likelihood and importance of technological displacement and compensation effects by pointing at employment reallocation at the firm level. The first type is the literature on job creation and destruction. Even though these studies present but a marginal view of intra-plant and intra-firm gross flows, they have already uncovered the importance of employment reallocation at this level (see, for example, the evidence collected in Davis, Haltiwanger and Schuh (1997)). One important part of this reallocation is likely to be technologically influenced or even driven. On a different strand, there is the important and growing literature concerning changes in the composition of the workforce and their relationship with technological change and, in particular, the generalisation of the new technologies (see, for example, Berman, Bound and Griliches (1994) and Machin and Van Reenen (1998)). This literature starts from the evidence of the recent demand shift towards more highly skilled workers relative to the less skilled, and has developed different tests for the sources of this "skill-biased technical change." Related studies have explored the relationships of these composition changes and the changes in wages and pay inequality (see, for example, Chennels and Van Reenen (1998)). As authors studying these facts at the plant or firm level have stressed (Bresnahan, Brynjolfsson and Hitt (2002), Aguirregabiria and Alonso-Borrego (2001)), changes in relative shares are likely to occur as the result of a firm level, technologically (and organisationally) driven combination of different degrees of episodes of destruction of more unskilled than skilled jobs and creation of more skilled than unskilled ones.

A few studies have adopted a more structural approach to the relationship between innovation and employment. Nickell and Kong (1989 a,b) studied the effect of technical change on employment with data on a number of UK manufacturing industries, using a structural production function and output demand approach very close to the one adopted here. And Smolny (1998) constructs a model for the impact of innovations on output, employment and prices, estimated from qualitative data on innovation and price changes for a sample of German firms.

And, in any case, there are many related studies which can serve to specify the relationships involved in a structural assessment of the firm level employment impact of innovation. On the one hand, there are the many studies on the effect of innovative activities on productivity in the rich tradition started by Griliches (1979) (see the survey by Griliches (1995)). Van Reenen (1997) in turn estimates, with panel data on a sample of UK companies, a demand for labour explicitly derived from a production function specifying the impact of innovations. These studies are relevant to estimating the displacement effects, and they probably have not been extended until now, simply because of the lack of suitable data to cope with the demand side. On the other hand, there are virtually no examples of firm demand relationships estimated across industries, but there is a rich experience cumulated at the industry level estimates (see Bresnahan (1989) for an early account) plus some suggestions as to how to treat the unobservability of rivals' prices (Baker and Bresnahan (1988)). Finally, the study of the effects of agents' behaviour through wage bargaining can be based on the firm level type of models set in Layard, Nickell and Jackman (1991) or Van Reenen (1996).

This study is aimed at assessing the effects of the innovative activities of firms on their employment from a structural point of view. To do that, we estimate firm level displacement and compensation effects in a model in which the stock of knowledge capital raises firm relative efficiency through the incorporation of innovations. Displacement is given by the elasticity of employment with respect to innovation in the (conditional or Hicksian) demand for labour, which is estimated alternatively from the production function and from the demand for labour. Compensation effects are estimated from a firm specific demand relationship, which the stock of knowledge capital shifts through the introduction of product innovations, possessing a finite elasticity with respect to the product price. The combination of the estimated elasticities gives the displacement, compensation and total effects of innovations on employment.[1] But displacement and compensation effects may be respectively enlarged and weakened by the behaviour of firm agents if the incorporation of innovations starts wage and price changes aimed at appropriating innovation rents. We assess the likelihood of these effects through the estimation of wage bargaining and margin determinants equations.

The model is applied with micropanel data on an (unbalanced) sample of 1,286 Spanish firms, observed during the period 1990-98.[2] The sample is representative of the manufacturing population of firms. In particular, firms performing and not performing R&D enter the sample according to the population proportions. The data include observations on the firms' output, inputs, R&D expenditures, innovations, demand-related variables and, a crucial and rather unusual feature, firms' individual input and output price changes and some firm-market idiosyncratic observations.

The rest of the paper is organized as follows: Section two explains the theoretical framework and defines the different effects to be estimated. Section three specifies the model.

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1 Notice that our work is complementary to the firm level exercises aimed at measuring the skills composition change and its sources. Once the total amount of labour to be shed and/or contracted is determined, the firm can optimally decide its composition among different types of workers according to a conditional cost minimisation problem that takes into account the post-innovation productivity, adjusting costs and so on for each type of worker. Here is where specifications in the tradition of Berman, Bound and Griliches (1994) begin.

2 The data come from the Encuesta Sobre Estrategias Empresariales (ESEE), a firm level panel survey of Spanish manufacturing starting in 1990, sponsored by the Ministry of Industry.

Section four details the econometric equations. Section five introduces the data, variables and highlights some facts. Section six presents the empirical results and Section seven concludes. Appendix A gives details on the data and employed variables. Appendix B reports the details on the construction of the knowledge capital.

2. Theoretical framework

This section is aimed at explaining the theoretical firm-level framework and relationships on which we base our empirical model. Firstly, we define the basic set-up and the displacement and compensation effects. Then we show how to account for the fact that the basic effects can be modified by the firm agents' behaviour. The next section further specifies the model in order to build the empirical counterpart.

Assume a cost minimising firm with a constant returns to scale technology in the conventional inputs, which competes in a product differentiated market. The firm currently invests in R&D activities in order to obtain process and product innovations. Innovations, when obtained, are incorporated into production at the beginning of the following period. When this period begins, the firm adjusts the product price, output and employment according to its new technology and expected demand.

Suppose for the moment that innovation effects on technology and demand can be represented by the impact of variations in the accumulated "knowledge" capital,[3] which we denote by K. Let $c(w,K)$ be marginal cost, where w stands for the vector of input prices, and let μ be the mark-up the firm charges on marginal cost,[4] p the product price, Y output, L employment, d^e an indicator of market expected dynamism, and K_R and p_R rivals' knowledge capital and prices. At a given moment, employment will be the result of the price

[3] Since Griliches (1979) this specification has been the standard framework for exploring the effects of R&D activities of firms, and hence innovation, on productivity. See below.

[4] Hence $1+\mu$ is the ratio price-marginal cost and $\mu = \frac{pcm}{1-pcm}$, where $pcm = \frac{p-c}{p}$ is the Lerner index of market power.

set by the firm, determining (expected) output, and deriving the labour needs according to the following equations (we drop firm and time subindices for simplicity):

$$p = (1+\mu)c(w,K) \tag{1}$$

$$Y = D(d^e, p, p_R, K, K_R) \tag{2}$$

$$L = c_L(w,K)Y \tag{3}$$

where c_L stands for the derivative of marginal cost with respect to the price of labour (Shephard's lemma). Hence, employment is given by the semi-reduced form

$$L = c_L(w,K)D(d^e,(1+\mu)c(w,K), p_R, K, K_R),$$

and the short-run[5] employment impact of innovation can be written as

$$\frac{dL}{dK} = \frac{\partial c_L}{\partial K}Y + c_L\left(\frac{\partial Y}{\partial K} + \frac{\partial Y}{\partial p}\frac{\partial p}{\partial K}\right)$$

Multiplying by K/L, and assuming a Hicks-neutral impact of the knowledge capital variations, we obtain the overall effect

$$-\varepsilon + (\lambda + \eta\varepsilon) \tag{4}$$

where ε is the absolute value of the (output conditional or Hicksian) elasticity of labour with respect to K, λ is the elasticity of demand with respect to K, η is the absolute value of the elasticity of demand with respect to price, and the second term in parenthesis follows from the equality of the elasticities of marginal cost and labour with respect to knowledge capital.[6] If the impact of knowledge capital were not Hicks-neutral, which is necessarily associated with an elasticity of substitution σ different from unity, the absolute value of the conditional elasticity

[5] Before the competitors react, in particular, by introducing similar innovations (see below).

[6] $\frac{K}{p}\frac{\partial p}{\partial K} = \frac{K}{c}\frac{\partial c}{\partial K}$, and Hicks neutrality implies $\frac{K}{c}\frac{\partial c}{\partial K} = \frac{K}{c_L}\frac{\partial c_L}{\partial K}$.

of labour with respect to K would differ from the absolute value of the elasticity of marginal cost with respect to knowledge capital .[7]

Expression (4) gives the overall effect of innovation on employment, in the form of sensitivity of employment to variations of the knowledge capital. The first term of (4) gives the displacement effect, the second the sum of two compensation effects: firstly, the demand effect of product innovations; secondly, the demand effect of passing on the cost reduction to the product price. An important consequence of (4) is that the overall effect of innovation on employment or, at least, its upper bound corresponding to the absence of offsetting effects, can be assessed from the estimation of three elasticities, one which characterises technology and two which correspond to the firm's demand relationship. In case of biased technological change, an additional technological elasticity must be estimated.

Innovation can trigger behaviour on the part of the firms' agents which may change this potential effect. Suppose that, at the beginning of the period at which an innovation is going to be implemented: a) the firm must bargain the wage w_L with a union that is concerned with the pay and employment consequences of the innovation; and b) the firm considers (optimal) changes in its pricing behaviour (changes in μ) according to the new competition environment induced by innovation. Let z stand for other possible determinants of wages and mark-ups, and add two (probably reduced form)[8] equations to the relationships which are relevant to employment determination

$$w_L = w_L(z, K) \tag{5}$$

$$\mu = \mu(z, K) \tag{6}$$

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[7] Think of factor L in terms of efficiency, $L^* = g(K)L$, with price $w_L^* = \frac{w_L}{g(K)}$. In this case $\frac{K}{c}\frac{\partial c}{\partial K} = \alpha\tau$, where α is the elasticity of output with respect to labour (see footnote 9) and τ the elasticity of function g with respect to knowledge capital. Demand for labour is $L = \frac{c_L(w^*)}{g(K)}Y$, and it is not difficult to show that the absolute value of the elasticity of L with respect to K can be approximated as $(1-\sigma)\tau + \alpha\tau$.

[8] A sensible structural specification of the wage equation will probably include the firm market power through expected pricing, while the structural margin equation is likely to take wages as given adopting a "right to manage" modelling perspective.

Now, employment is given by the semi-reduced form

$$L = c_L(w(z,K),K)D(d^e,(1+\mu(z,K))c(w(z,K),K),p_R,K,K_R)$$

The employment impact of innovation can be written as

$$\frac{dL}{dK} = \left(\frac{\partial c_L}{\partial K} + \frac{\partial c_L}{\partial w_L}\frac{\partial w_L}{\partial K}\right)Y + c_L\left(\frac{\partial Y}{\partial K} + \frac{\partial Y}{\partial p}\left[(1+\mu)\frac{\partial c}{\partial K} + c\frac{\partial \mu}{\partial K} + (1+\mu)\frac{\partial c}{\partial w_L}\frac{\partial w_L}{\partial K}\right]\right)$$

and multiplying by K/L we again obtain an overall short-run effect in terms of elasticities

$$-\varepsilon - (1-\alpha)\gamma + (\lambda + \eta\varepsilon) - \eta(\theta + \alpha\gamma) \qquad (7)$$

where α is the elasticity of output with respect to labour, γ is the elasticity of wage with respect to *K*, and θ is the elasticity of the price-cost ratio with respect to *K*.[9]

Expression (7) shows, through two additional terms to expression (4), that agents' behaviour is likely to worsen the expulsion effects and lessen the compensation effects. The displacement or expulsion effect can be reinforced by a labour substitution effect as the result of increased wages. Compensation effects may be weakened by higher prices as the result of higher wages and/or mark-ups. The assessment of (7) requires, in addition to the previous parameters, the use of an estimate of the technological elasticity α and the estimation of two behavioural elasticities: wages and margins with respect to innovation.

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[9] Notice that $\frac{w_L}{c}\frac{\partial c}{\partial w_L} = \frac{w_L}{c}\frac{L}{Y} = \frac{L}{Y}\frac{\partial Y}{\partial L} \equiv \alpha$, where last equality comes from minimisation condition $\frac{\partial Y}{\partial L} = \frac{w_L}{c}$. Moreover, $\frac{w_L}{c_L}\frac{\partial c_L}{\partial w_L} = -(1-\alpha) + \frac{w_L}{\alpha}\frac{\partial \alpha}{\partial w_L}$, where the second term on the right is likely to be small and can be neglected in approximations. If the underlying production function presents constant elasticity of substitution, the whole right hand collapses to $-\sigma(1-\alpha)$.

3. Model specification

Let us now further specify the relationships involved in order to build up the econometric model. In doing so, we adopt some more particular constraints. Some of them will be tested in the empirical exercise, but the relaxation of others would be a useful exercise which is left for later steps of the research.

Assume that the firm production function takes the form

$$Y = A(t)K_1^{\varepsilon} F(C,L,M), \quad 0 < \varepsilon < 1 \tag{8}$$

where $A(t)$ gives the degree of efficiency reachable for any firm, independently of its R&D activities, as a result of learning, knowledge spill-overs, embodied technological change and so on.[10] K_1 is the relevant stock of knowledge (see below) and F stands for the conventional inputs production function, where C represents capital stock, L the labour input and M raw materials.[11] This specification implies a cost function $C(w,Y,K) = c(w)\dfrac{Y}{A(t)K_1^{\varepsilon}}$ and a (Hicksian) labour demand

$$L = \frac{\partial C(\cdot)}{\partial w_L} = c_L(w)\frac{Y}{A(t)K_1^{\varepsilon}} \tag{9}$$

where $c(\cdot)$ and $c_L(\cdot)$ are homogeneous of degree one and zero respectively. Notice that ε and α can be estimated both from (8) and (9), parameter ε through the coefficients on technological capital, and parameter α through the coefficients on labour changes and wage changes respectively (see footnote 9).

Assume that firm demand can be written as

[10] If investment goods are not adjusted for quality change, part of the embodied productivity growth can appear as disembodied, see Hulten (1992).

[11] We start then from the beginning imposing Hicks-neutrality of all productivity increments. This assumption will be confronted with the data and tested in the empirical part.

$$Y = \left(K_2^{\lambda} / K_R^{\lambda_R}\right) \tilde{D}(d^e, p, p_R) \tag{10'}$$

where K_2 represents the relevant knowledge capital and K_R knowledge capital of market competitors.[12] One of the main problems at the time of estimating a relationship as (10') is the absence of direct information on the rivals' prices and knowledge capital.[13] However, assuming that every firm in the relevant market faces the same technology and input prices, we can write $p_R = (1+\mu_R)\dfrac{c(w)}{A(t)K_R^{\varepsilon}}$. Substituting for the prices of rivals (that is, using the "residual demand" approach of Baker and Bresnahan (1988))[14] we have the relationship

$$Y = \left(K_2^{\lambda} / K_R^{\lambda_R}\right) D(d^e, p, w, A(t), K_R, \mu_R) \tag{10}$$

The advantage of (10) is that it somewhat mitigates the estimating problems of (10'): w is observable under the assumption of common input prices, and changes in K_R and μ_R are likely to be less frequent and easier to proxy. Elasticities λ and η can be estimated in relationship (10), from which λ_R and even a cross-price elasticity η_R could be estimated with enough data.

The specification of a knowledge capital measure as a weighted sum of past gross investments in R&D has become since Griliches (1979) the standard framework for exploring the effects of R&D activities, and hence innovation, on productivity.[15] Two critical aspects of this specification are, however, the implicit assumptions of a continuous and smooth transformation of research effort into innovations, and of these innovations into productivity increments (see, for example, Griliches (2000)). We will improve on the traditional

[12] Notice that we don't try to distinguish between rivals' operative capitals.

[13] The replacement of the right variables by sector averages computed at some breakdown detail of standard industry classifications is an oft-employed device which is likely to introduce serious mismeasurement errors.

[14] See also Scheffman and Spiller (1987).

[15] See, for example, Hall and Mairesse (1995) for a recent application. Klette (1996) uses a similar framework, but innovating in the specification of the stock of knowledge, and Crepon, Duguet and Mairesse (1998) experiment with the direct modelling of the impact of innovations.

specification by employing the information available on innovation to model the transformation of research into productivity improvements. Let knowledge capital K_t depend as usual on past investments R and depreciation rate δ, $K_t = (1-\delta)K_{t-1} + R_{t-1}$, but define the "operative" knowledge capitals K_1 and K_2 (for process and product innovations, respectively) as

$$K_{jt} = d_{jt}K_t + (1-d_{jt})K_{jt-1}, \qquad for \quad j = 1,2 \tag{11}$$

where d_{jt} (j=1,2) are dummy variables which take value one at time t if the firm introduces an innovation (process and product innovation, respectively). This amounts to the construction of two "step" functions with the following rate of change behaviour:

$$\frac{K_{jt} - K_{jt-1}}{K_{jt-1}} = \begin{cases} \dfrac{K_t - K_{t-s}}{K_{t-s}} & if \quad d_{jt} = 1 \quad and \quad d_{jt-r} = 0 \quad \forall r < s \\ 0 & otherwise \end{cases}$$

Hence productivity and demand changes are expected to be associated with the introduction of innovations of each kind as well as to be proportional to the change that the stock of knowledge capital has experienced since the last innovation of each type. We also construct and use a third operative version of capital K_3, shifting at any innovation, to model price changes.

If wages are to be set, it seems natural to assume that they will be bargained over when an innovation is going to be applied. To determine the variables which must enter the wage equation, we will use the model of bargaining over wages between a union and a firm in which the firm sets subsequent employment unilaterally (the "right to manage" model of Layard, Nickell and Jackman (1991); see also Van Reenen (1996)). The general Nash solution to this bargain is $\frac{w_L - w_A}{w_L} = \left(\varepsilon_{Sw}(\cdot) + \frac{w_L L}{b\pi}\right)^{-1}$, where w_A stands for alternative income, $\varepsilon_{Sw} = \varepsilon_{SL}|\varepsilon_{Lw}|$ is the (absolute value of the) elasticity of the probability of being employed in the firm the following period ("survival" probability) with respect to wage, b represents union bargaining power and $\frac{w_L L}{\pi}$ is the ratio of labour costs to profits. Assuming that the union is concerned about current employment at the moment of bargaining (L_{-1}), our model particular specification gives the equilibrium condition

$$\frac{w_L - w_A}{w_L} = \frac{1}{\varepsilon_{SL}\left(\frac{L^e(\cdot)}{L_{-1}}\right)(1+(\eta-1)\alpha) + \frac{\alpha(1-pcm^e)}{b\ pcm^e}} \tag{12}$$

where ε_{SL} is the (positive) elasticity of survival with respect to expected employment, with derivative $\varepsilon_{SL}^{'} < 0$ (see Layard et al. (1991), pp.537), and where L^e is a function, among other things, of d^e, w, K and pcm^e.

Equation (12) shows that firm bargained wages are likely to differ from alternative income through the operation of different mechanisms. Firstly, wages will be higher the higher surviving probability is, linked to expected employment at the firm in the next period. Secondly, wages will be higher the higher union bargaining power b is. The first reason gives the rationale for including in the wage equation the changes embodied in d^e and, of course, knowledge capital K (and also perhaps expected input price changes). The second suggests including union bargaining power changes. Thirdly, there is the likely important role of market power. The sign of the effect of market power, however, is not defined *a priori* (see, for example, Nickell, Vainiomaki and Wadhwani (1994)). Notice that market power enters the equation for two reasons with opposite effects: stimulating rent sharing but also depressing employment perspectives L^e given the value of the other indicators.

The elasticity of demand with respect to price is assumed to be independent of K (see equation 10'). Hence, changes in μ must come from changes in the firm itself and in rivals' behaviour (e.g., in the degree of collusion, and hence in the sustainable price, or in the relative leader-follower pricing roles). Then, in regressing margins on innovation (through knowledge capital K_3, taking into account K_R), it seems natural to try to control directly for changes of behaviour through μ_R and also for exogenous variables which are likely to trigger these changes. The main variable of the latter type is market expected dynamism d^e (see, for example, the cyclical pricing models summarised in Tirole (1989)). This is what we will do in specifying the margin equation.

4. Econometric model

Let us specify the econometric model to estimate the relevant elasticities. The model consists of four equations, based on the differentiation of the theoretical relationships (8), (10), and the theoretical suggestions on wage and price determinants, plus the dual alternative for the first equation based on the differentiation of (9). Equations model the firm production function (demand for labour), product demand, and wage and margins formation. Dropping firm and time subscripts for simplicity, and using lowercase letters to represent log differences, the equations may be expressed as follows:

$$y_p = \beta_0 + \varepsilon k_1 + \beta_c c + \alpha l + \beta_m m + \beta_{cu} cu + D\beta + v_1 \qquad (13)$$

$$l = \beta_0^{'} + \beta_c w_c - (1-\alpha) w_l + \beta_m w_m + y_p - \varepsilon k_1 + D\beta^{'} + v_1^{'} \qquad (13')$$

$$y_d = \delta_0 + \lambda k_2 + \delta_d d + \delta_a a - \eta p + \eta_R (\beta_c w_c + \alpha w_l + \beta_m w_m) + (\lambda_R - \eta_R \varepsilon) k_R + \delta_\mu \Delta\mu_R + D\delta + v_2 \qquad (14)$$

$$w_l = \varphi_0 + \varphi_w w_l^e + \varphi_u u + \varphi_d d + \varphi_a a + \varphi_c w_c + \varphi_m w_m + \varphi_n n_{-1} + \gamma_0 k + \varphi_\mu \Delta pcm + \varphi_b \Delta b + D\varphi + v_3 \qquad (15)$$

$$\Delta\tilde{\mu} = \rho_0 + \rho_d d + \rho_\mu \Delta\mu_R + \theta k_3 + \rho_k k_R + D\rho + v_4 \qquad (16)$$

where y_p, y_d, c, l, n, m, k_1, k_2, k_3, k and k_R are, respectively, the rates of growth of output, sales, capital, labour (total hours, say), workers, materials, and the relevant knowledge capitals (process, product, process and product, total, rivals); p, w_c, w_l and w_m are the rates of growth of the relevant prices; w_l^e and u are the "outsider" factors, the economy- wide wage rate of growth and unemployment rate, respectively; Δpcm stands for the differences of the Lerner index, Δb for the differences of the union bargaining power indicator, and $\Delta\tilde{\mu} = \Delta \ln(1+\mu)$ are the log differences of the price cost ratio. The theoretical specifications of the previous section are slightly modified by substituting a market dynamism index (*d*) and the firm advertising growth rate (*a*) for the expected demand index d^e. To account for the union bargaining power we will employ the (inverse) index given by the proportion of temporary workers. D represents the set of dummy variables to be included at each equation (see details on the variables in Section 4 and Appendix A).

We are not able to observe variables K_R and $\Delta\mu_R$ directly, but we are going to use two sensible proxies for them. Variations in competitors' knowledge capital could be roughly approximated by the differences of a dichotomised variable of contents $1(k_R - k > 0)$, if available. This variable would substitute 1 for high relative growth states and zero for the opposite. According to our model, $k_R - k$ governs the evolution of the firm market share relative to its competitors once prices are controlled for. Hence, we will use as an indicator the available dummy variable "rivals share increase" (rsi). Similarly, we will substitute an available dummy variable that indicates when the firm has decreased price as a result of a change of competitors' prices for the rivals' margin changes. Competitor margins are likely to be falling when the observed firm is forced to reduce prices as the result of a decrease of rivals' prices. We will call this variable "rivals' price decrease" (rpd).

Estimation of production function (13) makes it important to control for input utilisation, and hence our inclusion of the variable capacity utilization (*cu*). Labour demand (13'), wages (15) and margins (16) are likely in turn to present some delay in their adjustment. We will test for the suitability of dynamic versions of these three equations by including the dependent variable lagged one period and accordingly using the long-term elasticity when relevant.

Equations are specified in log differences or rates of growth. This has two important implications. Firstly, equations can be read as approximations to the time differentiation of the relevant relationships, and hence they imply no assumptions on functional forms. In fact, differenced equations are even compatible with the lack of the Hicks-neutrality property which we have imposed through knowledge capitals entering the equations multiplicatively. Secondly, any level time invariant individual or heterogeneous effects (like differences in firms' efficiency, employed labour, demand size, wage or margin levels) are differenced out. Moreover, the sets of dummies included at each equation enlarge the flexibility of the specification by allowing for unspecified forms of heterogeneity in rates of growth.

Coefficients are elasticities (or approximate elasticities). Notation stresses the elasticities of main interest $(\varepsilon, \alpha, \lambda, \lambda_R, \eta, \eta_R, \gamma, \theta)$ and equality constraints across equations are underlined keeping the same symbols. Parameters α and ε can be alternatively estimated either from the production function (13) or labour demand (13'), parameters λ and η are estimated from the demand relationship (14), parameter γ from the wage equation (15) and parameter θ from the margin equation (16).

Theory points out some constraints which can either be tested and imposed on estimation in order to gain efficiency, or used to assess the likelihood of the estimates. Constant returns to scale imply $\beta_c + \alpha + \beta_m = 1$ in equation (13) and the unit coefficient on y in equation (13'). Homogeneity of degree zero of $c_L(w)$ implies $\beta_c^{'} - (1-\alpha) + \beta_m^{'} = 0$ in equation (13'). Homogeneity of degree one of $c(w)$ implies that $\delta_c + \delta_l + \delta_m$ provides an estimate of the cross-price elasticity of demand in equation (14).

5. Data, variables, and some facts.

Model estimation is carried out with an unbalanced panel data sample of 1,286 manufacturing firms, observed during the period 1990-1998, which comes from the broader sample of the official survey ESEE (see footnote 2). The sample employed here results from retaining the firms with more than three consecutive time observations after dropping all the time observations for which the data needed to perform the exercise are incomplete. It can be considered approximately representative of manufacturing, and hence inferences can be taken to be globally valid for this ambit. In particular the sample includes, approximately in population proportions, surviving, entrant and exiting firms, although also experiences some decay over time due to attrition. More details are provided in Appendix A.

The data required for each firm include its output and sales, capital, labour and intermediate inputs (materials and purchase of services), its innovative and advertising expenditures and introduction of process and product innovations, its costs, the changes in the product price and the price changes experienced in the input markets, some market evolution details and an extensive list of identity variables (activity, age, participation in mergers and acquisitions, and so on). A unique feature of the data set is the availability of information on the changes in the prices set by the firm, and on the changes in the prices that the firm pays for its non-labour inputs. A decisive advantage of the employed data set is the availability of information on a number of key market idiosyncratic variables provided by the firm. This ensures that the variables are referred to the right market boundaries, as defined by the firm. Details on all the employed variables are provided in Appendix A. Let us briefly comment here on some characteristics of a few key variables.

To construct knowledge capital we use the yearly sum of all R&D expenditures (intramural, contracted outside and the acquisition of licenses abroad). Standard knowledge capital is obtained, as usual, recursively on a yearly basis by depreciating the existing stock by 0.15% and adding adequately deflated current investments (see Hall and Mairesse (1995)) . Knowledge capital when the firm enters the sample is estimated with data on the firms' age, but only the firms with some observed R&D expenditure while they are in the sample are assumed to have a non-zero capital. Operative capitals for process and product innovation are obtained as described above, using the innovation data. More details are given in Appendix B.

A process innovation is assumed to occur when the firm answers positively to the question of whether it has introduced some significant modification of the productive process (affecting machines, organisation or both) along the year. The question appears in the questionnaire along with all the other R&D and innovation related-questions, and is clearly separated from other sections on technology adoption and usage. A product innovation is assumed to occur when the firm answers positively to the question of whether it has obtained completely new products or products with such important modifications (affecting materials, components, design, functionality) which made them different from the old ones. Hence it is likely that answers indicate precisely what firms consider major innovative changes in their productive process and products, as well as the frequency of these changes.

Table 1 reports the sample arranged according to firm size (the sample must be understood to consist of two subsamples, firms with up to 200 workers and firms with more than 200 workers; see Appendix A). Ninety-two percent of the biggest firms have R&D expenditures, but only 41% of the smaller ones do. Data for these firms are accordingly reported distinguishing between R&D performers and non-performers (non-zero and zero knowledge capital). The table also reflects the frequency with which firms introduce innovations. The figures of frequency of innovations are constructed by averaging across firms the relative frequencies or proportions of their time observations in which they report innovations. Innovation is highly correlated with knowledge capital and higher for the biggest firms. R&D performing firms show a probability of introducing innovations a given year which fluctuates from one third to a half.

Interestingly, the data cover a complete industrial cycle. At the beginning of the nineties, manufacturing experienced an important downturn that reached bottom in 1993. Next, manufacturing recovered steadily with only a minor halt in 1996. Labour, labour productivity and even knowledge capital accumulation reflect this evolution in the figures reported in Table 1.

Average figures of knowledge capital accumulation, labour evolution and labour productivity growth show a heterogeneous picture with some puzzling aspects, at least at first sight. For example, labour slightly decreases over the nineties at the small non-performing firms and slightly increases at the small performing ones. This could be taken naively as evidence of the positive employment impact of innovation. But knowledge capital accumulation turns out to be similar for the R&D performing firms of any size, and employment falls sharply in the biggest firms. Obviously, a more complex look at the data is needed to say something.

A simple accounting identity tells us that the variation in employment is minus labour productivity growth plus output growth. If we then split labour productivity growth into its sources and output growth into its components, we can transform the identity into a decomposition. In particular, we can isolate the labour productivity and output rates of growth attributable to innovation and assess their partial and global role. This is what our model does. A crucial test of its usefulness will be its contribution to a satisfactory explanation of the average figures of Table 1 and their relationships.

6. Empirical results

In this section we proceed to report and comment on the results of the estimation of equations 13(13')-16. Tables 2 to 5 present the results, and the main estimated elasticities are summarised in table 6. Estimations share a number of characteristics that we detail in what follows.

Equations include industry dummies (18) and yearly time dummies (1991-98), [16] as well as two dummies to pick up the likely heterogeneity of the firms born during the period and the firms which are going to die before its end. Moreover, to control for large discrete changes, we include dummies when a merger/acquisition or a scission affects a firm. Industry and time variables are always included with their coefficients constrained to add up to zero (Suits method), and hence a constant can be included in each regression to give account of a general mean. Coefficients for the control variables are not reported in order to save space, but the value of the constant plays an important role in interpreting some results.

All equations constitute linear models with predetermined and endogenous variables and we apply GMM techniques for their estimation (for a recent review of the methods available for estimating such equations, see Arellano and Honoré (2002)). Instrumental

[16] These sets may be suppressed in a particular equation when they become irrelevant or can be meaningfully replaced by a variable: e.g. the macroeconomic wage replaces time dummies in equation (16).

variables used in each equation are detailed at the bottom of each table. In general they exploit a mix of moments involving lagged levels of the variables, some lagged values of the differenced variables, and certain variables of other equations which can be taken as exogenous for the particular equation considered. Sargan tests of the overidentifying restrictions are reported for each estimate.

Implicit equations in levels are always supposed to present an uncorrelated zero mean disturbance, and hence disturbances of the differenced equations are expected to show a significant negative first order autocorrelation and an absence of correlation of higher orders. Each estimate includes the m_1 and m_2 Arellano and Bond (1991) tests to confirm that this is the pattern of the obtained residuals.

6.1 Production function and labour demand equations.

Production function estimation is carried out taking knowledge capital and labour as endogenous variables, and capital as predetermined. Results are summarised in Table 2, the preferred outcome is estimate *e*, and estimates *a* to *d* are presented to check its robustness.

On the one hand, constant returns to scale in the conventional inputs capital, labour and materials are easily accepted (see estimate *a* and the Wald test for this restriction). On the other, output presents identical elasticities with respect to workers (*n*) and working hours per worker (*h*), although more imprecisely estimated in the case of *h* (see estimate *b*). Therefore, we specify the labour input as total hours of work (*l*). This greatly simplifies the specification of the rest of the equations (in general we will not distinguish between the two input dimensions) without any loss of generality: our employment conclusions will be referred to the total hours of work demanded by firms. Utilisation of capacity turns out to be an important variable to explain production shifts, but its inclusion virtually doesn't change the coefficients of the other variables (see estimate *c*).

Input coefficients show likely values and, in particular, the capital elasticity estimate avoids the endemic problems found with estimators in differences[17]. The implicit capital weight in value added takes the sensible value of 0.36. Importantly, the elasticity of output with respect to knowledge capital shows a plausible value, inside the range of the values obtained by the best estimates of this type of augmented production functions, and the operative capital specification clearly outperforms the use of the standard knowledge capital (see estimate *d*). In addition, a remarkable feature of the estimate is that only a scarce 1% of total factor productivity growth remains to be explained. Recall that we interpret this growth as the result of all the non-accounted determinants of productivity growth: spill-overs, learning, embodied technical change and so on.

The estimation of the demand for labour function must allow us to reassess the estimates of the parameters of interest from a dual perspective. Our results, summarised in Table 3, and the preferred estimate *d*, turn out to confirm the previous estimates, but also contribute new insights on the sources of productivity growth. Estimations are carried out assuming that wages and knowledge capital are endogenous, treating the capital user cost as predetermined, and taking into account the correlation of lagged labour with the disturbances.

According to the result of our previous testing, we impose constant returns to scale from the start, constraining the output coefficient to unity. Our equation can then be seen as basically regressing labour requirements growth (minus the growth of productivity) on input prices and knowledge capital. Theory indicates the expected value for the input price coefficients and their sum. Estimate *a* and a Wald test allows us to accept this constraint, and the value of the coefficients in the preferred estimation are remarkably close to their theoretically expected values.

With labour specified in total effective hours of work (normal hours plus overtime minus loss hours), and given the weight reached at that time by temporary workers in the labour force of Spanish manufacturing, it is highly unlikely to obtain an equation with strong dynamics derived from adjustment costs or even any dynamics at all. In fact, only a very small

[17] For discussions of this problem see Blundell and Bond (1998) and Griliches and Mairesse (1997).

and non-significant dynamic effect shows up, which we do not drop from the equation only to avoid the impact on other coefficients (see estimate *b*).

The coefficient on knowledge capital is sensible, clearly superior to the one given by specifiying the standard knowledge capital (see equation *c*), but also presents a value somewhat higher than the value obtained in the production function. In what follows we advance reasons to think that this can be a slightly biased estimate, and hence why we will stick to the value previously obtained.

A puzzling characteristic of the estimates of the labour demand function is the high and significant average rate of autonomous labour productivity growth measured by the constant (3.8%), which sharply contrasts with the production function total factor estimate (1%). This is especially surprising when prices are in principle satisfactorily accounting for labour substitution (showing the right elasticities) and knowledge capital accounts for even more productivity growth than expected. Detailed justification of the sources of this divergence lies outside of the scope of this paper, but careful theoretical and empirical checking has allowed us to trace back its main origin to the firm processes of "outsourcing" of several activities during the period.[18]

This source offers the unique combination of input changes that are not likely to show up in the production function estimate of productivity growth while, at the same time, they will imply a strong "autonomous" increase of labour productivity.[19] Shadow price fluctuations not accounting for the observed prices, and biased (labour or capital saving) technical change linked to a non-unity elasticity of substitution, very unlikely given the price coefficient estimates,

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[18] The "outsourcing" or contracting out of manufacturing activities and business services has been a growing characteristic of manufacturing firms during the eighties and nineties, particularly the biggest ones. See Abraham and Taylor (1996) for evidence on this fact in relation to business services in US industry; Aguirregabiria and Alonso-Borrego (2001) document it in Spanish industry at the end of the eighties; Delgado, Jaumandreu and Martin (1999) show its relationship with the industrial cycle during the nineties.

[19] Recall that the rationale for the "outsourcing" of a task is that the cost of performing it inside the firm turns out to be at least as high as contracting it out. This will imply substitution of intermediate consumption for labour for approximately the same value, virtually without impact on total factor productivity growth, i.e., $|w_L \Delta L| \cong w_M \Delta M$ and hence for changes with this origin will hold the equality $-\alpha l \cong \beta_m m$.

have been in turn tested and rejected as explanations for the divergence.[20] The implication is however that the absence of a variable to account explicitly for the outsourcing-rooted productivity increases may bias the estimated knowledge capital elasticity.

Production function and labour demand give us estimates of parameters ε and α. Given the slight misspecification of the labour demand equation, we assume the estimates provided by the production function, which we report in the summary of elasticities of Table 6, to be confirmed and more reliable.

6.2 The product demand equation.

Our specification relies on the information provided by the firms on their price changes and on some firm and market idiosyncratic facts. It turns out to provide very sensible results on the demand impacts of the own and rivals' prices and knowledge capitals, even if estimates are more imprecise in the case of the competitors' effects as a result of the nature of the employed variables.

Our estimation takes knowledge capital, price, and the dummy indicating rivals' share increases as endogenous variables; and the index of market dynamism, the rate of growth of advertising, the user cost of capital and the dummy indicating rivals' price decreases as predetermined. Results are summarised in Table 4, where *d* is the preferred estimate.

The constant of the estimations shows a small, negative and scarcely significant autonomous trend in the growth of real sales, while the index of market expansion and the rate of growth of advertising expenditures account jointly for significant movements in the firm's demand. The elasticity of demand with respect to the own price seems sensibly estimated (-

[20] Shadow prices impact was checked by adding to the equation a utilisation indicator. The result was significant but without impact on the coefficients and the constant. The likelihood of an elasticity of substitution different from unity was tested by estimating the σ value corresponding to composite price changes of the form $-0.65(w_l - w_c) + 0.45(w_m - w_c)$, with the result of $\hat{\sigma} = 0.95$ with a standard error of 0.28.

2.4).[21] Interestingly enough, this value is only reached when the variables aimed at giving account of the rivals' price (and knowledge capital) movements are included (compare regressions *a* and *b* with the preferred specification). On the other hand, the elasticity of demand with respect to the own knowledge capital also detects an important effect (1.89). Again, the operative capital specification turns out to be superior (compare estimate *c*).

Rivals' price changes, specified through the inclusion of the input price changes and the rivals' price decrease dummy variable (to represent changes in behaviour), seem reasonably picked up. The value estimated for this elasticity is 0.87, a sensible outcome which exhibits in particular a reasonable magnitude with respect to the own-price elasticity (see Table 6).

Recall that rivals' knowledge capital must enter the equation for two reasons: as a direct indicator and as an argument for the rivals' price specification. Given the value of its coefficient, the dummy indicating rivals' share increases seems to pick up convincingly the impact of this knowledge capital (this must be the case once the price reasons for share movements are already controlled for). The value for the elasticity of sales with respect to rivals' knowledge capital, -0.47, turns out to be again sensibly estimated (see Table 6).

The key estimates of the demand function are the own-price and own-knowledge capital elasticity estimates, on which the compensation effects of innovation hinge. But the identification of the corresponding rivals' effects on the demand of the firm will allow us to measure (although more imprecisely) the suggested long-run effects of innovation (i.e., when the process and product innovations are also adopted by the competitors).

6.3 Wage and margin equations.

The estimation of these equations is aimed at assessing the degree by which the firm agents' behaviour dampens the working of the compensation effects of innovation. Together

[21] This elasticity implies, however, an average margin higher than observed with our Lerner index or mark-up measurements. But notice that, in replacing marginal cost by average cost, these estimates are likely to wrongly include many fixed outlays at the cost estimation. Our specification does not rely in any case on the level of these estimates.

they form a subsystem in which we assume wages to be set in bargaining in accordance, among other things, to the expected firm pricing behaviour, and the firm setting its prices given the bargained wage. Rents from innovation turn out to result on average in somewhat higher wages and, particularly, price increases.

The wage equation is estimated considering employment, knowledge capital, the firm margin and the proportion of temporary workers as endogeneous variables, as well as taking into account the correlation of lagged wage with the disturbances. Estimation also instruments the rate of growth of advertising and the user cost of capital with lagged differences, and the price of intermediate consumption with the price of raw materials. This may be necessary because of the substitution of realised values for the theoretically needed expectations formed at time t-1 on these variables. The margin equation is estimated taking knowledge capital and rivals' share increases as endogenous variables and rivals' price decreases as predetermined. Estimates of both equations are presented in Table 5, and preferred estimates are *b* and *a*.

Results from the estimation of the wage equation give a sensible "insider-outsider" wage relationship, fully comparable to similar estimates. Dynamics is low, showing quick wage adaptation. As far as the "outsider" factors are concerned, bargained wage closely follows the economy-wide wage trend and tends to react negatively to widespread unemployment. "Insider" factors may be divided in turn into two sets. Firm expected demand-related variables, and input prices other than labour, enter the equation with the expected signs and more or less significance. None of these variables are crucial nor determine the other coefficients (see estimate *a*).

Lagged employment and knowledge capital are the most interesting "insider" factors. Lagged employment represents the number of employers concerned about their future when wage is bargained for. Its coefficient, although imprecisely estimated, shows the sign expected in these types of models and can be interpreted accordingly: wages tend to be lower the higher the number of insiders for a given employment perspective. The coefficient on k also shows the expected sign: an increase in knowledge capital indicates the firm's potential for larger employment, favouring the pressure for higher wages.

Union power, represented by the temporary workers proportion (inverse) index, increases the likelihood of higher wages. And firm market power, represented by the price-cost margin, moderates the evolution of wages for given employment perspectives. Recall that market power renders rent-sharing possible, but it also reduces the output and employment expansion expected to be derived from positive shocks, including innovations. Hence the negative and very significant sign points to the prevalence of the second effect.

The margin equation shows a clearly pro-cyclical margin that, in addition, falls sharply with the indicators of changes in competitive conduct (the effects of the rivals' price decreases and share increases variables are more efficiently picked up when added in a unique variable). Margin turns out to depend positively on the knowledge capital increases associated with the introduction of process or product innovations (recall that this is the content of k_3). That is, prices tend to be revised to appropriate the advantages created by innovation. In fact, notice that the price reaction is enough, for instance, to almost outweigh the price decrease that the cost reduction associated to a process innovation could induce (0.32 vs. –0.35).

As a joint result of this fact and the impact of market power on wage growth, and despite the significant direct effect of knowledge capital on wages, the global average wage impact of knowledge capital is lower and does not differ significantly from zero (see Table 6). The interpretation is the following: unions try in principle to take advantage of the rents derived from innovations in the form of higher wages, but the price increases planned by innovating firms with high market power tend to discourage the wage increases for fear of the employment effects. The estimated coefficients then tell us a sensible story for the period and sample concerned, especially with respect to the rents derived from innovation (this may not have been the case with productivity increases with other origins).

6.4 The employment effects of innovation

Table 7 combines the different estimated elasticities in a global assessment of the effects of innovation on the labour requirements of firms. We distinguish between short-run effects, obtained by assuming that competitors do not react to the introduction by the firm of process and product innovations, and long-run effects, in whose computation we use the estimated cross-elasticities, assuming that competitors completely match the incumbent firm innovation and behaviour. Both types of effects can be divided into potential and corrected or actual. The latter embody the firm agents' estimated behaviour. Of course these estimates are associated with very different levels of precision, as Table 6 renders clear. Nowadays, they give clear and sensible suggestions as to how and even how much innovation influences labour.

The most remarkable facts are the following. The displacement effect of process innovations is clearly surpassed (more than doubled) by the potential employment effect of a price decrease based on the reduction of marginal cost. In addition, product innovations show a direct effect on employment per unit of innovative expenditure that doubles the compensation effect of process innovations. The displacement effect is in turn hardly increased by substitution, and firms' pricing behaviour appears as the main reason why compensation effects are weakened, although in competition with wages. Long-run compensation effects are, of course, lower. They suggest the persistence of weak potential positive effects of process innovations and relatively high potential effects of product innovations. Overall, actual elasticity of employment with respect to knowledge capital seems not to be far from unity, but it must also be taken into account that pricing behaviour can reverse the positive effects coming exclusively from process innovation.

The model does a good job of explaining the data of Table 1. Moreover, the comparison of the data with the model predictions produces interesting new insights. Assume that average labour productivity growth of the small and non-performing R&D firms (2.6%) was the baseline labour productivity growth during the period, reachable without accumulating knowledge capital (and different from the 1% total factor productivity growth shown by the production function because it consists of this 1%, plus the labour substitution associated to the wages increase, plus the effect of the tendency of "outsourcing" to grow over time). Given their knowledge capital evolution, a 0.5 displacement effect can explain around an additional percentage point of productivity growth for the small and big R&D performer firms. This does not leave much more labour productivity growth to be explained in the small performers (less than 1 point) although much more in the biggest (3 percentage points). Assume now that 1.7% was the "normal" output growth during the period (again the output growth of the non-performers, computable as the sum of productivity and employment growth). The higher (implicit) average output rates of growth of the performers of all sizes can be easily explained assuming mild compensation effects coming from the rate of increase of the respective knowledge capitals.

This comparison highlights two main things. Firstly, the model successfully explains important positive differences in the employment growth path of the innovative firms. But secondly, it also stresses that productivity increases induced by innovation constitute only a fraction of productivity growth, especially in what concerns labour productivity growth. Non-innovation-related labour productivity growth emerges significantly in all types of firms and increases with size. Our model and data also suggest that this type of productivity increase, rooted in effects resembling process innovations together with the "outsourcing" of activities, can have serious negative effects on employment.

7. Conclusion.

This paper has been aimed at structurally assessing the labour effects, and hence employment effects, of the innovative activities of firms. We have successfully estimated a structural econometric model to account for the firm-level displacement and compensation effects of innovation. Innovation has been measured jointly by means of the traditional stock of knowledge capital and the available information on the firm introduction of process and product innovations. Implementation of the model has been rendered possible by the rich information available from an (unbalanced) panel sample representative of Spanish manufacturing firms, observed during the nineties. The main conclusions are as follows.

Innovation displaces labour but also creates the firm level conditions to over-compensate this displacement. Process innovations significantly reduce marginal costs and this reduction can be passed on to prices to expand demand with an employment effect that doubles the first effect. In addition, product innovations, which most of the innovative firms carry out at the same time (at a slightly smaller frequency) than process innovations, double the expanding effect obtained by unity of innovative expenditure. Positive potential net effects of process innovation are, however, estimated to be seriously reduced in the long run, when competitors match the innovations, but positive potential net effects of product innovation of a significant magnitude tend to persist in the long run.

However, the working of the compensation mechanisms can be dampened, and in some cases even completely outweighted, by the behaviour of the agents of the firm. In our sample, the pricing by the firms endowed with market power, taking advantage of innovations, considerably weakens the expansive effects of innovation. And wages seems to refrain the same behaviour only because of the restraining effect of the exercise of market power by firms. In any case, average global actual net employment effects are estimated to be positive, even in the long-run, and with an elasticity value with respect to knowledge capital not far from unity.

Innovation is only one of the sources of firm-level productivity growth. Other sources are the non-innovative production improvements (embodied technical change, learning, spill-overs) and, for labour productivity growth, substitution and the "outsourcing" of firm activities. Our analysis also makes it apparent that these sources of productivity growth are forces governing the process of employment as well, at a level at least as important as innovation. The non-innovative production improvements can be compared with process innovations in which they can only have compensation effects through price reductions. If wage or pricing behaviour dampens the working of these mechanisms (which has not been specifically tested in this paper but is likely behaviour in many contexts), this productivity growth is likely to have negative net effects on employment. This plus "outsourcing" completes the picture to explain global employment evolution in our sample.

Appendix A: Data.

All employed variables come from the information furnished by firms to the survey ESEE (see footnote 2). The unit surveyed is the firm, not the plant or establishment, and some firms closely related answer as a group. At the beginning of this survey, firms with fewer than 200 workers were sampled randomly by industry and size strata, retaining 5%, while firms with more than 200 workers were all requested to participate, and the positive answers represented more or less a self-selected 60%. To preserve representation, samples of newly created firms were added to the initial sample every subsequent year. At the same time there are exits from the sample, coming from both death and attrition. The two motives can be distinguished and attrition was maintained to sensible limits. Composition in terms of time observations of the unbalanced panel sample employed here is shown in Table A.1.

Definition of variables

Advertising expenditure: Firm's advertising expenditure deflated by the consumer price index.
Aggregate wage: Hourly economy-wide wage, taken from the Earnings Survey, INE. Divided by the consumer price index.
Capacity utilization: Yearly average rate of capacity utilization reported by the firm.
Capital stock: Capital at current replacement values is computed recursively from an initial estimate and the data on firms' investments in equipment goods (but not buildings or financial assets), actualised by means of a price index of capital goods, and using sectoral estimates of the rates of depreciation. Real capital is then obtained by deflating the current replacement values. Details on this variable can be found in Martín and Suárez (1997).
Entrant firm: Dummy variable that takes the value 1 when the firm has been created during the period.
Exiting firm: Dummy variable that takes the value 1 when the firm is going to exit during the period (stop activity or leave manufacturing).
Hours of work (total) : Total normal hours of work plus overtime minus lost hours, computed multiplying hours per worker by the number of workers.
Hours per worker: Normal hours of work plus overtime minus lost hours per worker.
Industry dummies: Eighteen industry dummies.
Intermediate consumption: Sum of purchases of materials and external services minus the variation of intermediate inventories. Nominal intermediate consumption is deflated by the firm's specific price index.
Knowledge capital stock: Weighted sum of the firm's real R&D expenditures, which include: the cost of R&D intramural activities, payments for outside contracts and expenditures on imported technology (patent licenses and technical assistance). We construct a standard knowledge capital and three operative stocks: for process innovation, for product innovation and for both. Computation is fully explained in Appendix B.
Market dynamism index: Weighted index of the market dynamism reported by the firm for the markets in which it operates. The index can take the values $0<d<0.5$ (slump), $0.5<d<1$ (expansion) and $d=0.5$ (stable markets). Included in regressions in differences from 0.5.

Market share evolution index: Weighted index of the share evolution reported by the firm for the markets in which it operates. The index can take the values $0<s<0.5$ (decreases), $0.5<s<1$ (increases) and $s=0.5$ (stable share). Included in regressions in differences from 0.5.
Mark-up: Approximated by the value of output minus variable costs of production, divided by cost. Variable costs of production include total labour costs and intermediate consumption.
Merger and acquisition: Dummy variable that takes the value 1 in the years subsequent to a merger or acquisition. In a few cases the succession of mergers imply an accumulated dummy value higher than 1.
Output: Goods and services production. Sales plus the variation of inventories deflated by the firm's output price index.
Price: Paasche-type price index computed starting from the percentage price changes that the firm reports to have made in the markets in which it operates. Divided by the consumer price index except when used as a deflator.
Price cost margin: Approximated by the value of output minus variable costs of production, divided by value of output. Variable costs of production include total labour costs and intermediate consumption.
Price of intermediate consumption: Paasche-type price index computed starting from the percentage variations in the prices of purchased materials, energy and services reported by the firms. Divided by the consumer price index except when used as a deflator.
Price of materials: Percentage variation in the prices of purchased materials reported by the firm. Divided by the consumer price index.
Product innovation: Dummy variable that takes the value 1 when the firm reports the accomplishment of product innovations.
Process innovation: Dummy variable that takes the value 1 when the firm reports the introduction of a process innovation in its productive process.
Proportion of temporary workers: Proportion of workers under fixed term contracts which carry very small or no firing costs.
Rivals' share increase: Dummy variable that takes the value 1 when the firm reports a rivals' share increase (a fall in its share; see the variable *Market share evolution index*)
Rivals' price decrease: Dummy variable that takes the value 1 when the firm reports an own-price decrease which has been motivated by a reduction of prices of competitors in its main market.
Sales: Firm sales deflated by the firm's output price.
Scission: Dummy variable with value 1 in the years subsequent to a scission. In a few cases the succession of scissions implies an accumulated dummy value higher than 1.
Size: Dummy variable that takes the value 1 when the firm has more than 200 workers.
Unemployment rate: Taken from the Population Activity Survey, INE
User cost of capital: Weighted sum of the cost of the firm values for two types of long-term debt (long-term debt with banks and other long-term debt), plus a common depreciation rate of 0.15 and minus the rate of growth of the consumer price index.
Wage: Firm's hourly wage rate (total labour cost divided by effective total hours of work). Divided by the consumer price index.
Workers: Approximation to the average number of workers during the year.

Appendix B: Knowledge capital construction

Knowledge capital is assumed to be zero for firms which are not observed to do any R&D spending during their time in the sample. Firms with positive expenditure can be classified into two types: firms born during the period (entrant firms) and firms with likely pre-sample formal innovative activity. Knowledge capital of entrants is assumed to grow starting from their first R&D investments and, when it is the case, we drop the pre-investment observations to avoid attributing a value to the rate of growth corresponding to the zero-positive capital change. Firms with likely pre-sample activity are estimated an initial or pre-sample knowledge capital stock.

A firm's knowledge capital *K* for sample year *t* is computed recursively with the usual formula

$$K_t = (1-\delta)K_{t-1} + R_{t-1}$$

where *R* stands for R&D expenditure (current expenditure is assumed to be transformed into useful knowledge with a lag). Expenditures are deflated with the consumer price index and δ is assumed to have a value of 0.15. Results are, as usual, not sensible to modifications of this rate.

To compute the pre-sample capital of a firm in moment τ (first firm observation), we attribute the average sample (deflated) expenditure to the *s* previous years of the firm life using the formula

$$K_\tau = \overline{R}\left[\frac{1-(1-\delta)^s}{\delta}\right]$$

where $\overline{R}$ is average observed expenditure and $s = \min\left[10 + t - 1990,\ \textit{firm age}\right]$. That is, we use the real age of the firm while it does not imply the accumulation of expenditures previous to the year 1980. We experimented replacing this limit with the inclusion of different weighting schemes for the R&D expenditures previous to 1990, but results did not differ very much and performed worse in regressions.

Operative capitals for process and product innovation K_1, K_2 and K_3 are computed from *K* and the innovation dummies as explained in the text.

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Table 1
Knowledge capital, innovation and labour 1991-98

	No. of firms	1991	1992	1993	1994	1995	1996	1997	1998	1991-98
More than 200 workers	433									
R&D performers	397 (91.7%)									
Knowledge capital (% of growth[1])		7.7	0.4	1.2	-0.1	3.5	0.5	2.1	3.0	2.1
Labour productivity (% of growth[1])		6.5	3.9	2.5	11.1	9.9	5.6	6.6	6.2	6.6
Labour input (% of growth[1])		-4.9	-7.1	-9.3	-0.9	1.9	-1.9	1.4	1.8	-2.5
Freq. of process innov. (% of years[2])										53.9
Freq. of product innov. (% of years[2])										40.9
Up to 200 workers	853									
R&D performers	349 (40.9%)									
Knowledge capital (% of growth[1])		3.6	6.5	-0.0	2.1	1.3	0.9	3.8	5.4	2.7
Labour productivity (% of growth[1])		7.7	0.1	-1.7	7.8	9.0	2.7	5.5	4.3	4.4
Labour input (% of growth[1])		0.9	-2.0	-4.8	1.6	2.3	1.0	2.6	3.3	0.6
Freq. of process innov. (% of years[2])										38.2
Freq. of product innov. (% of years[2])										33.5
R&D non-performers	504 (59.1%)									
Labour productivity (% of growth[1])		3.3	3.7	-0.7	3.7	5.6	0.2	1.5	4.7	2.6
Labour input (% of growth[1])		-1.9	-2.9	-6.9	-1.1	1.3	0.2	2.3	2.0	-0.9
Freq. of process innov. (% of years[2])										16.9
Freq. of product innov. (%of years[2])										13.0
Total	1286									

[1] Average of individual log-rates. [2] Average of individual percentages.

Table 2
Firms' production function estimates

Sample period: 1992-98
No. of firms: 1,286; No of observations: 5,199
Estimation method: variables in log-differences, GMM estimates[1]

Dependent variable: y_p

Independent variables[2]	a	b	c	d	e
Constant	0.012 (1.4)	0.009 (1.1)	0.011 (1.4)	0.006 (0.7)	0.009 (1.2)
k_1	0.39 (2.4)	0.28 (1.7)	0.36 (2.1)		0.35 (2.1)
k				0.21 (1.4)	
c	0.15 (1.4)	0.25	0.21	0.21	0.20
l	0.30 (3.2)		0.34 (4.2)	0.34 (4.4)	0.35 (4.4)
n		0.30 (3.5)			
h		0.30 (1.3)			
m	0.46 (13.5)	0.45 (13.6)	0.45 (14.5)	0.45 (14.3)	0.45 (14.1)
cu	0.09 (4.2)	0.09 (3.9)		0.08 (4.1)	0.09 (4.1)
Industry dummies[3]	Inc.	Inc.	Inc.	Inc.	Inc.
Time dummies[3]	Inc.	Inc.	Inc.	Inc.	Inc.
m_1	-6.7	-6.5	-6.5	-6.4	-6.7
m_2	-0.3	-0.1	-0.5	-0.4	-0.2
Sargan test (df)	25.9 (25)	28.7 (32)	26.2 (26)	32.4 (26)	26.2 (26)
Wald test (df)	0.8 (1)				

Heteroskedasticity robust t-ratios shown in parentheses
[1] IVs: k_1 and l lagged levels t-2 and t-3 at each cross-section, lagged log-differences of c, and one size dummy (>200 workers).
[2] Wald test allows us to accept constant returns to scale. Estimates from b to e impose the constraint.
[3] 18 industry dummies and 7 year dummies, with the coefficients of both sets constrained to add up to zero; dummies for entrant and exiting firms, as well as mergers and scissions, also included.

Table 3
Firms' labour demand estimates

Sample period: 1992-98
No. of firms: 1,286; No of observations: 5,199
Estimation method: variables in log-differences, GMM estimates[1]

Dependent variable: *l-y*

Independent variables[2]	a	b	c	d
Constant	-0.038 (7.9)	-0.039 (7.9)	-0.04(8.8)	-0.038 (-8.4)
l_{t-1}	0.09 (1.0)		0.10 (1.1)	0.09 (1.0)
w_c	0.21 (1.2)	0.20	0.24	0.24
w_l	-0.67 (-2.6)	-0.60 (-2.4)	-0.66 (-3.3)	-0.66 (-3.3)
w_m	0.22 (1.3)	0.40 (2.8)	0.42 (3.3)	0.42 (3.2)
k_I	-0.50 (-2.4)	-0.52 (-2.3)		-0.46 (-2.2)
k			0.21 (1.4)	
Industry dummies[3]	Inc.	Inc.	Inc.	Inc.
Time dummies[3]	Inc.	Inc.	Inc.	Inc.
m_1	-4.0	-4.2	-4.1	-4.1
m_2	-0.2	-0.5	-0.1	-0.2
Sargan test (df)	37.8 (40)	28.3 (29)	39.2 (41)	36.9 (41)
Wald test (df)	0.1 (1)			

Heteroskedasticity robust t-ratios shown in parentheses
[1] IVs: *l* lagged levels t-2 and t-3 at each cross section (except in estimate b), w_l lagged levels t-3 and t-4 at each cross section, lagged log-differences of w_c, k_I lagged levels from t-2 to t-4 at each cross-section and one size dummy (>200 workers).
[2] Wald test allows us to accept homogeneity of degree 0 in prices. Estimates from b to d impose the constraint.
[3] 18 industry dummies and 7 year dummies, with the coefficients of both sets constrained to add up to zero; dummies for entrant and exiting firms, as well as mergers and scissions, also included.

Table 4
Firms' product demand estimates

Sample period: 1992-98
No. of firms: 1,286; No of observations: 5,199
Estimation method: variables in log-differences, GMM estimates[1]

Dependent variable: y_d

Independent variables	a	b	c	d
Constant	-0.008 (-0.8)	-0.029 (-1.9)	-0.019 (-1.3)	-0.024 (-1.53)
k_2	1.16 (1.9)	2.07 (2.5)		1.89 (2.2)
k			0.72 (1.4)	
d	0.78 (6.5)	0.96 (5.8)	0.98 (6.2)	1.01 (5.9)
Δd	0.47 (5.6)	0.24 (1.7)	0.40 (3.2)	0.26 (1.8)
a	0.07 (3.0)	0.06 (1.8)	0.06 (2.0)	0.05 (1.7)
p	-1.38 (-4.3)	-1.79 (-4.8)	-2.47 (-4.8)	-2.41 (-4.3)
w_c		0.13 (0.3)	0.20 (0.6)	0.16 (0.3)
w_l		0.21 (2.2)	0.20 (2.1)	0.21 (2.1)
w_m		0.40 (1.9)	0.59 (2.5)	0.50 (2.1)
rsi		-0.74 (-3.3)	-0.49 (-2.9)	-0.77 (-3.3)
rpd	-0.12 (-1.30)		-0.40 (-3.0)	-0.34 (-2.3)
Industry dummies[2]	Inc.	Inc.	Inc.	Inc.
Time dummies[2]	Inc.	Inc.	Inc.	Inc.
m_1	-2.4	-3.7	-3.0	-3.6
m_2	-1.3	-0.9	-1.0	-0.9
Sargan test (df)	44.6 (17)	29.7 (17)	37.2 (17)	27.4 (17)

Heteroskedasticity robust t-ratios shown in parentheses
[1] IVs: k_2 (or k) lagged levels t-3 and t-4 at each cross section, p lagged level t-2 at each cross section, lagged levels of d, a and *rpd*, and *rsi* levels lagged twice, lagged log-differences of w_c, and the process innovation dummy, the number of workers, and the growth rate of the price of raw materials.
[2] 18 industry dummies and 7 year dummies, with the coefficients of both sets constrained to add up to zero; dummies for entrant and exiting firms, as well as mergers and scissions, also included.

Table 5
Wage and margin equations

Sample period: 1992-98
No. of firms: 1,286; No of observations: 5,199
Estimation method: variables in log-differences, GMM estimates[1,2]

Dependent variable: w_l | Dependent variable: $\Delta \ln(1+\mu)$

Independent variables	a	b	Independent variables	a
Constant	-0.012 (-2.1)	-0.012 (-2.2)	*Constant*	-0.005 (-1.6)
w_{lt-1}	0.16 (3.6)	0.17 (4.2)	d	0.033 (3.1)
w^e	0.99 (2.1)	0.99 (2.1)	k_3	0.32 (2.4)
u	-0.08 (2.3)	-0.05 (-1.5)	$rsi+rpd$	-0.06 (-2.5)
d		0.026 (2.3)		
a		0.009 (0.8)		
w_c		-0.13 (-0.8)		
w_m		-0.13 (-2.3)		
n_{t-1}	-0.15 (-1.6)	-0.10 (-1.2)		
k	0.39 (2.4)	0.31 (2.2)		
pcm	-0.51 (-5.1)	-0.52 (-5.2)		
b	-0.186 (-1.7)	-0.15 (-1.5)		
Industry dummies[3]	Inc.	Inc.	*Industry dummies*[3]	Inc.
Time dummies[3]			*Time dummies*[3]	Inc.
m_1	-9.3	-9.4	m_1	-6.3
m_2	-1.5	-1.3	m_2	-1.0
Sargan test (df)	49.6 (38)	48.5 (38)	Sargan test (df)	13.3 (10)

Heteroskedasticity robust t-ratios shown in parentheses
[1] Wage equation IVs: lagged levels t-2 and t-3 of variable n and lagged levels t-2 of variables w_l, k, pcm and b at each cross section, dummies of process and product innovation. Lagged log-differences of a and w_c, and the growth rate of the price of raw materials.
[2] Margin equation IV's: k_3 lagged values t-2 at each cross section, *rdi* level lagged twice and *rpi* level lagged once, dummies of process and product innovation, and price and market share evolution index levels lagged twice.
[3] 18 industry dummies and 7 year dummies, with the coefficients of both sets constrained to add up to zero; dummies for entrant and exiting firms, as well as mergers and scissions, also included.

Table 6
Main estimated elasticities

Elasticity	Symbol	Estimated value	(Standard error)
Labour and marginal cost wrt knowledge capital[1]	ε	-0.35	(0.17)
Output wrt labour[1]	α	0.35	(0.08)
Sales wrt knowledge capital[1]	λ	1.89	(0.84)
Sales wrt rivals' knowledge capital[2]	λ_R	-0.47	(0.33)
Sales wrt price[1]	η	-2.41	(0.55)
Sales wrt rivals' price[2]	η_R	0.87	(0.51)
Wage wrt knowledge capital[3]	γ	0.19	(0.19)
Margin wrt knowledge capital[1]	θ	0.32	(0.13)

Robust standard errors of non-directly estimated elasticities are computed from linear approximations to their formulas neglecting (setting to zero) the cross-equation parameter covariances.

[1] Coefficients of estimates e, d and a in tables 2, 4 and 5 respectively.

[2] η_R computed from the sum of input price coefficients in estimate d of Table 4; λ_R computed from the coefficient on *rsi* plus $\eta_R \varepsilon$.

[3] γ computed from the long-run value of the sum of the direct and indirect capital effects in estimate b of Table 5: $\gamma = (\gamma_0 + \varphi_\mu (1+\mu)^{-1}\theta)/(1-\varphi_l)$, where φ_l is the coefficient on lagged wage and μ is evaluated at the sample mean.

Table 7
Firms' employment effects of innovation
(percentage variations corresponding to a 1% variation of knowledge capital[1])

		Short-run estimates		Long-run estimates[2]	
		Potential	Corrected	Potential	Corrected
Displacement effect	$-\varepsilon$	**-0.35**		**-0.35**	
plus labour substitution effect (wage premia effect)	$-(1-\alpha)\gamma$		-0.12		-0.12
Corrected displacement effect			**-0.47**		**-0.47**
Process innovation (price decrease effect)	$\eta\varepsilon$	0.84		0.54	
Product innovation	λ	1.89		1.42	
Compensation (demand) effects		**2.73**		**1.96**	
minus cost increase effect (wage premia effect)	$-\eta\alpha\gamma$		-0.16		-0.10
minus price increase effect (margin premia effect)	$-\eta\theta$		-0.77		-0.49
Corrected compensation effects			**1.80**		**1.37**
Total effect (displacement + compensation)		**2.38**	**1.33**	**1.61**	**0.90**

[1] Computed from the elasticity estimates of Table 6.
[2] Long-run estimates use product and price effects net of rivals' similar product introduction and price movements, i.e., they are computed using the net elasticities $\lambda-\lambda_R$ and $\eta-\eta_R$.

Table A1
Firms by no. of observations

No. of observations	No. of firms
3	172
4	220
5	186
6	146
7	158
8	173
9	231
Total	1286

Table A2
Variable descriptive statistics

Variables	Symbol	Mean[1]	S. dev.	Min	Max
Advertising expenditure (growth rate[2])	a	0.026	0.904	-2.000	2.000
Aggregate wage (growth rate[3])	w_l^e	0.010	0.009	-0.008	0.025
Capacity utilization	cu	0.796	0.155	0.050	1.000
Capital stock (growth rate[3])	c	0.081	0.316	-2.052	7.280
Entrant firm (dummy)		0.022	0.147	0	1
Exiting firm (dummy)		0.039	0.193	0	1
Hours of work (total) (growth rate[3])	l	-0.010	0.189	-2.159	1.749
Hours per worker (growth rate[3])	h	-0.001	0.072	-1.698	1.650
Intermediate consumption (growth rate[3])	m	0.024	0.371	-3.606	5.375
Knowledge capital stock (growth rate[3])	k	0.014	0.223	-0.165	3.207
Market dynamism index[4]	d	0.497	0.322	0	1
Market share evolution index[4]	s	0.538	0.293	0	1
Mark-up	μ	0.114	0.169	-0.933	2.139
Merger and acquisition (dummy)		0.013	0.114	0	1
Output (growth rate[3])	y_p	0.034	0.265	-3.221	2.569
Price (growth rate[3])	p	-0.025	0.059	-0.751	1.053
Price cost margin	pcm	0.079	0.241	-13.920	0.681
Price int. consumption (growth rate[3])	w_m	-0.004	0.062	-0.546	0.894
Price of materials (growth rate[3])		-0.002	0.080	-0.866	1.053
Product innovation (dummy)		0.344	0.475	0	1
Process innovation (dummy)		0.272	0.445	0	1
Proportion temporary workers	e	0.198	0.215	0	1
Rivals' share increase (dummy)	rsi	0.227	0.419	0	1
Rivals' price decrease (dummy)	rpi	0.060	0.238	0	1
Sales (growth rate[3])	y_s	0.035	0.288	-5.471	5.913
Scission (dummy)		0.007	0.081	0	1
Unemployment rate[4]	u	0.214	0.023	0.169	0.239
User cost of capital	w_c	0.134	0.047	0.091	0.354
Wage (growth rate)	w_l	0.014	0.196	-3.001	2.387
Workers (growth rate[3])	n	-0.009	0.172	-2.061	1.749

[1] Simple averages of individual values 1991-1998. [2] Growth rates computed as $(x_t - x_{t-1})/\frac{1}{2}(x_t + x_{t-1})$.

[3] Average log-rate. [4] Included in the regressions in differences from the mean. [5] Index divided by the consumer price index.