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Firm size and productivity in Spain: a stochastic frontier analysis

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Abstract This paper analyses the performance of the small and medium-sized manufacturing firms during the period 1995–2001, focusing on the degree of technical inefficiency and its determinants. We use a micro panel data set to simultaneously estimate a stochastic frontier production function and the inefficiency determinants using an unbalanced panel of manufacturing firms. Our empirical results suggest that small and medium-sized firms tend to be less inefficient than the large firms are. Also, we centre our analysis in the effect on efficiency of some organisational factors related to the managerial ability to use and adjust capital and labour properly.

Keywords Stochastic frontier · Panel data · Technical efficiency · Size · Organisational factors

JEL Classifications C23 · J21 · J29 · L60 · L26

1 Introduction

Searching for explanations for the slowdown in productivity growth in Spain that occurred between the middle of 1995 and the end of 2000, economists have analysed real factors, as well as possible measurement problems. But most of these debates have been focused on technological innovation, leaving aside human and organisational factors. One of the characteristics of the Spanish economy is the high percentage of small and medium-sized firms. Size is one of the factors that condition the managerial organisation of the firm, so it is important to understand its effect on productivity.

Changes in productivity are regarded as consequences of two different factors. On the one hand, the adoption of technical innovations in processes and in products, pushing the frontier of potential production upwards, is measured by technological progress. On the other hand, efficiency change reflects the capacity of firms to improve production with given inputs and available technology. While productivity and technical efficiency are not easily separable, the distinction allows us to test different factors that are supposed to be at the root of these two indicators of performance.

We are interested in analysing determinants of technical efficiency in Spanish manufacturing firms. Efficiency determinants can be due to environmental or firm specific factors. We focus on these firms' specific factors to provide an explanation of the differences in technical efficiency among manufacturing firms.

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We follow the frontier approach, first developed by Farrell (1957) and widely used in empirical works for specific activity sectors[1]. This approach measures the technical inefficiency of a production unit as the ratio of a firm's production over its optimal level. The optimal behaviour, the technically efficient result of the production process, is represented by a production function, a frontier, which shows the maximum level of output a firm can achieve, given the technology and a given level of inputs. The first step of this approach is to estimate the practice frontier obtained from the sample information, using their best observations. If a firm produces this optimal level of output, it is technically efficient and it will be on the frontier. If a firm produces less than is technically feasible, given both, the technology and a level of inputs, it is inefficient and we can measure the degree of technical inefficiency as the distance from each individual observation and a corresponding point on the frontier. We use the Battese and Coelli 1995 model to simultaneously estimate the frontier production function and the inefficiency model, to avoid the econometric problem of the two-step procedure.

Using frontier techniques, several studies have analysed both external and internal factors to explain the sources of technical inefficiency. Caves and Barton (1990) examine technical inefficiency of the manufacturing industry in United States, while Green and Mayes (1991) analyse technical inefficiency for United Kingdom firms. Caves et al. (1992) compare inefficiency and its determinants between developed countries. Other studies focus on particular determinants of inefficiency, such as the Hay and Liu study (1997), which focuses on the relevance of a competitive environment on efficiency; Patibandla (1998), who shows the relevance of capital market imperfections on the structure of an industry; and Dilling-Hansen et al. (2003), who analysed whether relative efficiency is due to R&D investment.

For the Spanish economy, studies by Gumbau (1998), Gumbau and Maudos (2002) and Martín-Marcos and Suárez-Gálvez (2000) provide evidence on the existence of technical inefficiency of production in the Spanish manufacturing sector. Others focus on particular determinants of efficiency; for instance, Delgado et al (2002) centre on the relation between efficiency and export, while Díaz and Sánchez (2004) examine the link between technical efficiency and the make-up of the labour force. With other econometrics techniques, Fariñas and Ruano (2004) measure the contribution of continuing firms and turnover to total factor productivity; Huergo and Jaumandreu (2004) analyse the probability of introducing innovations by manufacturing firms at different stages of their lives. All of them use the EESE data set (*Encuesta sobre Estrategias Empresariales*, *or* Survey on Business Strategies) of Spanish manufacturing firms.

The purpose of this paper is to analyse the effect on efficiency of some organisational factors related to the managerial ability to use properly and adjust capital and labour according to environmental conditions. Size is included in the analysis as one of the most important factors that condition the organisation of firms and then the degree of their efficiency.

Our paper contributes to the empirical evidence of productivity in Spain, adding to the previous papers the relevance of changes affecting the factors of production and the way these factors are used and combined. Secondly, our paper differs from previous literature in Spain in that we use an improved frontier model that not only allows us to estimate the firm's technical inefficiency but, simultaneously, identify the variables that are statistically related to inefficiency, i.e. the determinants of the reached inefficiency.

We examine the evolution of individual firm technical efficiency during the period 1995–2001 and analyse their determinants through an unbalanced panel of 1898 firms. We use an improved version of the Stochastic Frontier Approach (SFA), developed by Battese and Coelli (1995), which allows us to estimate simultaneously individual technical efficiency scores and the significance of a series of variables that can affect the level of efficiency reached by firms.

The paper is organised as follows: Sect. 2 introduces the econometric method of estimation. In Sect. 3, we describe the sample, the data, and define the variables used for estimation. In Sect. 4, we present the estimated frontier and explain the effects of the inefficiency determinants. Finally, in Sect. 5 we summarise the main conclusion.

[1] Specially, sectors such as banking, agriculture, transport and electricity industries, hospitals and other non-profit sectors, see Lovell (1993) for a good survey of the frontier approach.

1.1 Stochastic frontier and the inefficiency model

We use the SFA to estimate a production frontier with inefficiency effects. Specifically, we use a panel data version of the Aigner et al. (1977) approach, following the Battese and Coelli (1995) specification, in which technical inefficiency is estimated from the stochastic frontier and simultaneously explained by a set of variables representative of the firms' characteristics. This approach avoids the inconsistency problems of the two-stage approach used in previous empirical works when analysing the inefficiency determinants[2]

The Battese and Coelli (1995) model can be expressed as:

$$Y_{it} = f(X_{it};\beta)\exp(v_{it} - u_{it}) \tag{1}$$

Where i indicates firms and t represents the period, X is the set of inputs; β is the set of parameters, v_{it} is a two-sided term representing the random error, assumed to be iid N(0, σ_v^2); u_{it} is a non-negative random variable representing the inefficiency, which is assumed to be distributed independently and obtained by truncation at zero of N(μ_{it},σ_u^2). The mean of this distribution is assumed to be a function of a set of explanatory variables: $\mu_{it} = \delta_i Z_{it}$ so therefore the inefficiency term is:

$$u_{it} = \sum_{j=1}^{M} \delta_j Z_{ijt} + W_{it} \tag{2}$$

Where Z_{ijt} is a (Mx1) vector of variables that may have effects over firm efficiency, δ_j is a $(1 \times M)$ vector of parameters to be estimated, and W_{it} is a random variable defined by the truncation of the normal distribution with zero mean and variance σ^2.

The production function coefficients (β) and the inefficiency model parameters (δ) are estimated by maximum likelihood together with the variance parameters: $\sigma_S^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2/\sigma_S^2$.

Given that technical efficiency is the ratio of observed production over the maximum technical output obtainable for a firm (when there is no inefficiency), the efficiency index (TE) of firm i in year t could be written as[3]:

$$TE = \frac{f(Xit;\beta)\exp(v_{it} - u_{it})}{f(Xit;\beta)\exp(v_{it})} = \exp(-u_{it}) \tag{3}$$

The efficiency scores obtained from expression (3) take value one when the firm is efficient, and less than one otherwise.

2 Data and variables

The data source is published in the Spanish Industrial Survey on Business Strategies *(Encuesta sobre Estrategias Empresariales, ESEE)*. The data is collected by the *Fundacion Empresa Pública* (FEP) and sponsored by the Spanish Ministry of Industry. This is supplied as a panel of firms' representative of twenty manufacturing sectors. A characteristic of the data set is that firms participating in the survey were chosen according to a selective sampling scheme. The sample of firms includes almost all Spanish manufacturing firms with more than two hundred employees. Firms employing between ten and two hundred employees were chosen according to a stratified random sample representative of the population of small firms. Given the procedure used to select firms participating in the survey, both samples of small and large firms can be considered as samples that allow us to estimate the distribution of any of the characteristics of the population of Spanish manufacturing firms with information available from our data set. Each year a number of additional firms were selected according to a random sampling procedure among the whole population of firms. This selection is conducted using the same proportion as in the original sample (see Fariñas and Jaumandreu (1999) for technical details of the sample)

From the original sample, a number of firms have been eliminated, most of them due to a lack of

[2] In a two-stage procedure, first of all a stochastic frontier production function is estimated and the inefficiency scores are obtained under the assumption of independently and identically distributed inefficiency effects. But in the second step, inefficiency effects are assumed to be a function of some firm-specific variables, which contradicts the assumption of identically distributed inefficiency effects.

[3] Individual efficiency scores ui, which are unobservable, can be predicted by the mean or the mode of the conditional distribution of ui given the value of (vi−ui) using the technique suggested by Jondrow et al (1982).

Table 1 Summary statistics

	Minimum	Maximum	Mean	SD
Value added	25.53	6261936.25	20262.92	116717.94
Capital stock	.45	4547098.98	33140.83	168237.88
Total employment	9.97	15063.05	206.31	636.07
Proportion of temporary	.00	45.00	.69	2.29
Foreign shareholders	.00	1.00	.21	.40
Market share	.00	1.25	.013	.041
Capital by worker	.03	2342.88	85.07	124.12
Public limited company	.00	1.00	.64	.48
Gross investment over capital	−174.49	8.91	.055	2.37

relevant data. Others were eliminated because they reported a value-added annual growth rate per worker in excess of 500% (in absolute value), and some were rejected because they have fewer than ten workers and, in both cases, they would distort the analysis. Also, we do not include firms after a merger or division process in our sample data of. Our sample includes 1,898 firms from the ESEE Survey and refers to an unbalanced panel where we have eliminated those firms, which we do not have two consecutive years of data for. Firms employing between ten and two hundred workers represent 72.1% of our sample. Our period of analysis runs from 1995 to 2001. Summary statistics of the data are presented in Table 1.

We estimate a stochastic translog production function adding a term of inefficiency, whose mean is the function of a set of inefficiency determinants[4]:

$$\ln Y_{it} = \beta_0 + \sum_j \beta_j \ln x_{ijt} + \frac{1}{2}\sum_j \sum_k \beta_{jk} \ln x_{ijt} \ln x_{ikt} + \sum_j \varphi_j S_{ij} + v_{it} - u_{it} \qquad (4)$$

$$u_{it} = \sum_j \delta_{ij} Z_{it} + W_{it} \qquad (5)$$

[4] We imposed the usual symmetry conditions to the translog function: βkj = βjk; j $\neq$ k.

The variables used for estimation of the production frontier are the value-added, as the output variable, and the number of employees in the firm, capital stock and trend, as input variables (x_{it}), and the industrial sector dummies (S_i). Here we present a more precise definition of the variables used for estimation and the definition of the inefficiency determinants considered:

2.1 Variables of Stochastic Frontier estimations

VA: The value added in real terms. This is the dependent variable.
CAPITAL STOCK (K): Inventory value of fixed assets excluding grounds and buildings.
L: Total employment by firm.
T: This is the time trend.

Sector classification: There are seven dummy variables that take value one when the firm belongs to the corresponding sector of activity; otherwise this value is zero.

SEC1: Meat and manufacturing of meat; food industry and tobacco drinks; textiles, clothing and shoes; leather, shoes and derivatives.
SEC2: Wood and derivatives, paper and derivatives.
SEC3: Chemical products; cork and plastic; non-metallic mineral products.
SEC4: Basic metal products; manufactured metal products; industrial equipment.

SEC5: Office machinery and others; electrical materials.
SEC6: Cars and engines; other material transport.
SEC7: Other manufactured products.

2.2 Determinants of efficiency estimation:

Proportion of Temporary: This is the proportion of temporary over permanent workers.
Foreign Shareholders: This is a dummy that takes value one when the firm has foreign shareholders, and zero otherwise.
Market Share: The ratio of the sales of an individual firm over sector sales by year.
Capital by Worker: It is the capital-total labour ratio.
Gross Investment Over Capital: This is the ratio between gross investments over capital by firm.
Public Limited Company: This is a dummy variable that takes value one when the firm is a public limited company and zero otherwise.
Size: There are six dummy variables that take value one when the firm belongs to the corresponding interval of workers, zero otherwise:
- Size 1: Firms with no more than twenty workers.
- Size 2: from 21 up to 50.
- Size 3: from 51 up to 100.
- Size 4: from 101 up to 200.
- Size 5: from 201 up to 500.
- Size 6: Firms with a number of workers higher than 500.

3 Results

From the frontier approach, we obtain the measure of a firm's inefficiency compared with the best observations of the sample. The value of the estimates allows us to explain the differences in the inefficiency effects among the firms. As technological and market conditions can vary over sectors, we have included sector dummy variables in the production function in order to be able to control it.

The maximum-likelihood estimates of the production frontier parameters, defined in Eq. 4, given the specification for the inefficiency effects, defined in Eq. 5, are presented in Table 2. These estimates were obtained using the computer program FRONTIER 4.1 (Coelli (1996)). Table 3 presents the tests of the null hypotheses, based on the generalised likelihood ratio (LR) test[5], concerning the selection of the functional form and the relevance of the inefficiency effects.

The functional specification of the stochastic production frontier was determined by testing the adequacy of the translog specification to the data relative to the more restrictive Cobb-Douglas. The first line of Table 3 reports this test, where the first null hypothesis is rejected showing that the translog specification fits the data better than the Cobb-Douglas.

The variance parameter, γ, which lies between 0 and 1, indicates that technical inefficiency is stochastic and that it is relevant to obtaining an adequate representation of the data. The value of γ picks up the part of the distance to the frontier explained for the inefficiency. In our estimation, the value of the variance parameter γ is around 0.86. That means that the variance of the inefficiency effects is a significant component of the total error term variance and then, firms' deviations from the optimal behaviour are not only due to random factors. The stochastic frontier with inefficiency effects is a more appropriate representation than the standard OLS estimation of the production function.

The second test reported in Table 3 reinforces the relevance of the inefficiency effects in the model. The null hypothesis, which considers that the inefficiency effects are not present in the model, is strongly rejected. Thus, the frontier model could not be reduced to a mean-response production function (OLS estimation) to accurately represent the data.

The third test picks the joint effect of the determinants included in the inefficiency model. We strongly reject the null hypothesis, which means that these determinants are not relevant to explain inefficiency.

[5] LR = $-2(\ln[L(H0)]-\ln[L(H1)]($, where L(H0) and L(H1) are the values of the likelihood function under the null and alternative hypotheses. LR has an approximately χ^2 distribution with degrees of freedom equal to the number of restrictions.

Table 2 Stochastic Frontier Analysis translog production function estimates

Variables		Coefficient	Standard-error	*T*-student
Constant	β_0	3.240	0.073	44.660
K	β_1	0.015	0.019	0.802
L	β_2	1.001	0.031	31.970
T	β_3	0.024	0.014	1.673
K^2	β_{11}	0.042	0.003	16.668
L^2	β_{22}	0.058	0.008	7.720
T^2	β_{33}	0.000	0.001	−0.280
K × L	β_{12}	−0.092	0.008	−11.250
K × T	β_{13}	−0.003	0.002	−1.286
L × T	β_{23}	0.001	0.004	0.171
Wood and derivatives, paper and derivatives	ϕ_1	0.194	0.017	11.561
Chemical products; non-metallic mineral products	ϕ_2	0.203	0.014	14.353
Basic metal products; industrial equipment	ϕ_3	0.285	0.014	20.910
Office machinery and others; electric materials	ϕ_4	0.277	0.018	15.097
Cars and engines; other material transport	ϕ_5	0.157	0.020	7.786
Others manufactured products	ϕ_6	0.115	0.020	5.784
Inefficiency model				
Constant	δ_0	−1.367	0.258	−5.299
Temporary workers' proportion	δ_1	0.090	0.009	10.572
Foreign shareholders	δ_2	−3.568	0.393	−9.089
Market share	δ_3	−1.541	0.291	−5.299
Capital by worker	δ_4	0.002	0.000	10.146
Gross investment over capital	δ_5	−0.002	0.003	−0.616
Public limited company	δ_6	−1.177	0.111	−10.619
Size1: Up to 20 workers	δ_7	−0.764	0.089	−8.564
Size2: From 21 to 50	δ_8	−1.237	0.122	−10.134
Size3: From 51 to 100	δ_9	−1.354	0.151	−8.971
Size4: From 101 to 200	δ_{10}	−0.436	0.077	−5.656
Size5: From 201 to 500	δ_{11}	−0.956	0.099	−9.669
Variance parameter				
	σ^2	0.987	0.082	11.975
	γ	0.859	0.013	65.666

Table 3 Generalised likelihood-ratio (LR) tests of null hypotheses[a]

Null hypothesis, H_0	Test statistic	Critical value
H_0:β_{ij} = 0, i = 4,....,10	413.12	12.59
H_0: $\gamma = \delta_0 = ... = \delta_{11} = 0$	680.63	20.4[b]
H_0: $\delta_1 = ... = \delta_{11} = 0$	285.66	19.68

[a] The test statistics have a χ^2 distribution with degrees of freedom equal to the difference between the parameters involved in the null and the alternative hypothesis

[b] As γ takes values between 0 and 1, in H_0: $\gamma = \delta_0 = ... = \delta_{11} = 0$ the statistic is distributed according to a mixed χ^2 whose critical value is obtained from Kodde and Palm (1986)

3.1 Efficiency analysis of the Spanish manufacturing firms

The analysis of efficiency is important because it is a component of productivity and from the structural approach point of view productivity is a long run determinant of competitiveness, so there is a link between efficiency and competitiveness. Since Spain belongs to the European Union, the structural aspect of competitiveness has received more attention, i.e. productivity and its determinants: management organisation, innovation, the endowment of labour and capital and the degree of use, market competition etc. These determinants have been included in the analysis to know their relevance to the degree of inefficiency in Spain.

Inefficiency tends to be larger for firms with a high ratio of temporary over fixed workers (*Temporary workers' proportion*). The positive sign of the estimated parameter means that the higher the ratio, the lower technical efficiency is (higher inefficiency). Temporary contracts became attractive to employers because of their short duration and low firing costs. The great difference in firing costs payments between temporary and permanent contracts is a key to understanding their success (see Dolado et al 2002). However, in Spain, even if job creation increased temporary contracts, no permanent employment was created because renewal rates within permanent contracts were very low (see Amuedo-Dorantes 2001; and Güell and Petrongolo 2000). Temporary contracts can have a positive effect on effort if workers perceive that the rehiring probability depends on past performance. If the rate of renewal is low, firms and workers may be less inclined to invest in specific human capital, which implies that workers with temporary contracts will tend to receive less training and that this will affect their productivity. This result is in favour of the hypothesis of the absence of incentives and training. Thus, following the efficiency wage framework, this type of contracts would diminish productivity because workers perceive that their effort will not be recognised.

The variable *foreign shareholders* identify firms with foreign capital. We expect that firms oriented towards international markets would be more efficient than those mainly focused on domestic markets. The coefficient of this variable is negative and significant affecting efficiency positively. This variable could be a proxy of the degree of competitiveness of firms. The market selection hypothesis is an explanation of our result. The exporting firms have a greater productivity and this fact explains why they could attract foreign capital. This correlation has been recently analysed by Delgado et al. 2002. This hypothesis implies that only the most productive firms survive in the highly competitive export market.

The *market share* variable, defined as firm sales over total sector sales, is significant and shows a negative sign, which means that the higher the market share is, the lower the inefficiency of the firm is. This variable captures the relevance of the market power of the firm inside its sector. The evidence related to the effect of this determinant on efficiency is not conclusive. Hay and Liu 1997 find a positive relationship between a firm's efficiency and its market share. Nickell 1997, argues that increased competition will increase firm productivity.

Unexpectedly, the effect of the intensity of capital (*capital by worker*) is positive and significantly different from zero, which means the higher the intensity of capital, the lower the level of firm's efficiency is. This variable picks the effect on efficiency of the combination of inputs. One possible explanation is that changes in efficiency generated by a technical innovation depend on their nature and diffusion. If it is easy for firms to adopt it, then this change affects efficiency positively, while if it requires an important investment as well as organisational modification, then it could cause a shift in the frontier, thus the relative distance augment. This means that even if an increase in the stock of capital improves efficiency to do it in a different timing than the rest of the firms, this could cause losses of productivity derived from the capital adjustment in the short-run. Green and Mayes (1991) explain that capital-intensive industries have higher sunk costs and then find it more difficult to alter behaviour as demands and technology change.

The effect of the *gross investment over capital* is negative but it is not significantly different from zero, which means that this variable does not contribute to explaining firms' inefficiency.

The effect of the *Public Limited Company* variable is negative and significant, which means that this kind of firm organisation is the most efficient. The effects of the dispersion of ownership on efficiency have been analysed by several studies (see Short 1994;

Gugler 2001). The discussion focuses on the separation of firms' ownership and control, under the assumption that owners and managers have different objectives. Generally, Public Limited Companies are expected to be more efficient because for such firms, the commercial risk is limited to the share capital, so they can take higher risks with expected higher returns on their investment projects (see Dilling-Hansen et al. 2003). Dilling-Hansen et al. 2003 obtain that the most important influence from ownership comes from the legal form, specifically limited liability companies versus personal ownership, with the former type of firms being more efficient than other firms are.

Now we will analyse the *size* of the firm in terms of workers. In our results, we find a negative and significant relationship between size and efficiency. If large firm size allows for the realisation of costs advantages, the relationship between size and technical efficiency should be positive. However, there are at least two reasons for expecting a negative relationship. First, large firms may suffer more from bureaucratic frictions, lack of motivation of workers, and difficulty in monitoring than smaller firms. Second, large firms are more able to remain in the market even if they have economic problems due to a low technical efficiency than small firms because of the existence of market imperfections. Due to this effect of market selection, the surviving small firms that we observe may on average show a higher level of technical efficiency than the larger firms do.

In our econometric analysis we have found that size is an important determinant of technical efficiency. To illustrate the evolution of efficiency along the analyzed period, we report in Fig. 1 the average efficiency index of small-sized firms (51–100 workers) with respect to the rest of the groups.

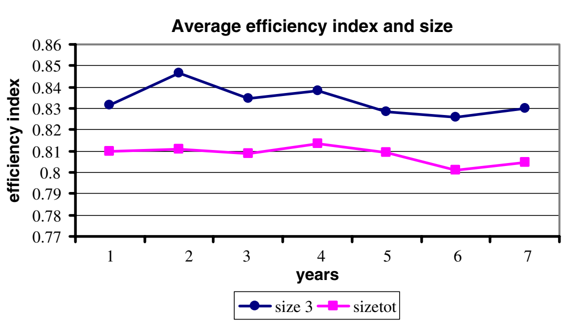

Fig. 1 Efficiency by year and size

4 Concluding remarks

In this paper, we were interested in analysing the determinants of the technical efficiency in the Spanish manufacturing firms. Efficiency determinants can be due to environmental or firm specific factors. We focus on these firms' specific factors to provide an explanation to the differences in technical efficiency among manufacturing firms. Small and medium-sized firms seem to be more efficient than large firms are. This result could be explained by the complexity of larger firms in organisation and managerial control. Also the less efficient small firms will exit the market under economic difficulties more easily than large firms will. This self-selection hypothesis explains that small and medium sized firms could appear as more efficient in our analysis.

In addition, inefficiency tends to be smaller for firms with a small proportion of temporal workers when the firm has a higher market share and when it obtains foreign capital. The latter result could be explained through the market selection hypothesis as the explanation for greater productivity.

Summing up, after controlling for market share, foreign shareholders, the proportion of temporary over fixed workers, the intensity of capital and firm legal status, we have obtained that small and medium-sized firms tend to be more efficient than large firms are.

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