TECHNICAL EFFICIENCY IN THE RETAIL FOOD INDUSTRY: THE INFLUENCE OF INVENTORY INVESTMENT, WAGE LEVELS, AND AGE OF THE FIRM*

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ABSTRACT

The objective of this paper is to estimate technical efficiency in retailing; and the influence of inventory investment, wage levels, and firm age on this efficiency. We use the output supermarket chains' sales volume, calculated isolating the retailer price effect on its sales revenue. This output allows us to estimate a strictly technical concept of efficiency. The methodology is based on the estimation of a stochastic parametric function. The empirical analyses applied to panel data on a sample of 42 supermarket chains between 2000 and 2002 show that inventory investment and wage level have an impact on technical efficiency. In comparison, the effect of these factors on efficiency calculated through a monetary output (sales revenue) shows some differences that could be due to aspects related to product prices.

KEY WORDS: efficiency, retailing, supermarkets.

JEL CLASSIFICATION: L25, L81, M11.

RESUMEN

El objetivo de este trabajo se centra en la estimación de la eficiencia técnica en distribución comercial minorista, así como en analizar la influencia que la inversión en existencias, el nivel de salarios y la edad de la empresa tienen sobre dicha eficiencia. A tal efecto, se utiliza un output que pretende aislar el efecto de los precios de cada cadena de supermercados analizada, lo que permite estimar un concepto de eficiencia estrictamente técnico. La metodología se basa en la estimación de una frontera paramétrica de naturaleza estocástica. Los resultados de la aplicación empírica sobre una muestra de 42 cadenas de supermercados que operan en España entre 2000 y 2002 muestran que la inversión en existencias y el nivel de salarios ejercen una influencia positiva sobre la eficiencia. Por comparación, el efecto de estos factores sobre la eficiencia económica muestra algunas diferencias que podrían ser atribuidas al efecto de los precios aplicados por los distribuidores.

PALABRAS CLAVE*:* Eficiencia, distribución comercial minorista, supermercados.

1. Introduction

In recent years, growing competitiveness among retailing companies and the globalisation of markets have given rise to an economic environment in which it is becoming increasingly difficult for companies to survive. In this context, technical efficiency has become an important issue in retailing (Lusch, Serpkenci and Orvis, 1995), as it favours intermediary management (Sinigaglia, Zidda, Panier, and Bultez, 1995). Several approaches have been proposed to evaluate productivity and efficiency in retailing: Econometric approach (e.g. Ratchford, 2003), DEA approach (e.g. Thomas, Barr, Cron, and Slocum, 1998) or Switching regression models (Berné, Múgica, and Yagüe, 1999). Among these, switching models deserve special attention, as they allow distinguishing between supply and demand restrictions.

Particularly, the technical efficiency of a firm reflects its success in producing as large an output as possible from a given set of inputs (Farrell, 1957); and it is important to know how far a given retailer can be expected to increase its output by simply increasing its efficiency, without absorbing further resources. Regarding the estimation of technical efficiency in retailing, important studies are those of Thomas et al. (1998), Donthu and Yoo (1998), and Barros and Alves (2003, 2004). However, these papers examine technical efficiency using outputs in monetary units (sales revenue and profits) when technical efficiency focuses mainly on production processes and on the organisation of firm activities, i.e. on amounts (outputs in non-monetary units such as services offered (Kamakura, Lenartowicz and Ratchford, 1996), the number of customers, the number of transactions or sales volume). This way of operating with monetary outputs to measure technical efficiency appears to be due to the fact that the extent and depth of the range of products in the retail sector makes the use of non-monetary outputs very difficult. In any case, the non-zero capacity of retailers when setting their prices means that the estimated efficiency is not strictly technical when an output in monetary units is used (for example, sales revenue gives output price and output quantities sold). Even more importantly, there could be some confusion between technical efficiency and market power (Bain, 1951), service quality (Berger and Mester, 1997) or elasticity of demand, among others. Thus, a high level of monetary output (which, in principle, could be interpreted as a high level of technical efficiency) could also be a consequence of less favourable prices for customers (as retailers with high market power usually have higher prices) derived from the traditional hypothesis of market power; a consequence of a higher service quality (as retailers with high service quality usually charge higher prices); or a consequence of a higher elasticity of demand (as high sales revenues can be made by retailers with low prices). Consequently, it is important to isolate the price effect when estimating technical efficiency with a monetary output.

Our study analyses the influence of various managerially controlled factors (inventory investment per square meter, wage levels per employee, and firm age) on technical efficiency, distinguishing its impact on the efficiency estimated using a non-isolated price effect output and on the efficiency estimated using a price effect isolated output. The selection of these variables is based on previous literature that estimates the determinant factors of retail productivity. Given that we find no studies that examine the determinant factors of technical efficiency in the food retailing industry, our study fills this gap in the literature of efficiency, based on its technical component and on some managerially controlled variables used to explain retail productivity. Regarding the isolation of the price effect in retailing, Ratchford and Brown (1985) and Ratchford and Stoops (1988) used producer price indexes to estimate productivity (but not efficiency). However, the use of producer price index assumes that retailer prices move with the producer prices. To solve this problem, in this paper we use retailer price indexes.

Thus, the contribution of this paper to the literature is based on the estimation of a strictly technical concept of efficiency (using an output isolated from the price effect) and, simultaneously, on the estimation of some determinant factors of such efficiency. The methodology is based on a stochastic parametric frontier model which makes it possible to estimate efficiency and the corresponding determinant factors at the same time. The empirical analysis is applied to a sample of 42 supermarket chains operating in the Spanish market between 2000 and 2002.

Having defined the objective of our work, the rest of the paper is organised as follows. In the following section we develop and argue the hypotheses of the paper. In the third section the sample and methodology are described. The results obtained and the discussion are shown in Section 4, and our conclusions and the main implications for management are presented in the final section.

2. Factors determining technical efficiency. Research hypotheses

A considerable amount of theorizing and empirical research has been done on the correlates of retail labour productivity (Lusch and Moon, 1984). These correlates can be classified as: (i) Marketing variables (store location, price levels, inventory investment, advertising expenditures); (ii) Characteristics of a retail firm (type of store, legal form of ownership); and (iii) Traditional economic correlates (wages, capital to labour ratio, scale or size of firm) (Hall, Knapp and Winsten, 1961; George and Ward, 1973; Ingene, 1982; Nooteboom, 1983; Good, 1984; Lusch and Moon, 1984; Van Dalen, Koerts and Thurik, 1990).

However, empirical papers analyzing the correlates of retailing efficiency are scarce; moreover, the only studies found are based on retail banking (e.g. Berger and Mester, 1997). This paper is the first step towards identifying the factors (inventory investment per square meter, wage level per employee and age of the firm) to be further studied, and which may be some of the causes of technical efficiency in the food retailing industry.

2.1. Inventory investment per square meter

In retailing, a traditional correlate of productivity is inventory investment. A proper way to measure product assortment is the width (narrow or wide) and depth (shallow or deep) of all product lines at a retail store (Lusch and Moon, 1984). However, when analysing retail firms it is very difficult to obtain information regarding this variable. Alternatively, the ratio of inventory investment to the square meter of selling area is considered a surrogate measure of product assortment in retailing. The rationale for this surrogate measure is that a store which has more inventory investment per square meter will be able to provide more selection to its customers than others with lower investment (Lusch and Moon, 1984).

Traditionally, literature on productivity in retailing assumes a positive relationship between inventory investment and labour productivity (Lusch and Moon, 1984). When a store has a large assortment of merchandise (derived from a larger inventory investment) then a customer entering the store will be more likely to find the item or the bundle of merchandise that he or she is seeking. This probability will increase the productivity of labour since employees will not need to help the customer find substitute products, and also since it will help prevent customers from walking out of the store empty-handed.

In virtue of the above and as technical efficiency includes the capacity of firms to generate outputs based on certain production resources it could be expected that an increase in productivity as a consequence of a greater inventory investment per square meter would also have a positive effect on technical efficiency which leads to the following research hypothesis:

H_1: *The average inventory investment per square meter of selling area of a supermarket chain has a positive effect on its technical efficiency.*

However, there may be "pecuniary effects". Implicit in the assortment decision is a trade-off between investment in inventory (and the related inventory carrying costs) and stockouts. The two cannot be minimized simultaneously. Thus, although maximizing assortment and inventory investment may make the salespersons' job easier, this course of action may not be the most profitable. Consequently, the main role of retailing is identifying consumers' needs and attempting to satisfy them with the right assortment of merchandise at the right price. The right assortment has the proper depth and width of products and the appropriate quantity in inventory of each product to maintain stockouts at an economic level (Lusch and Moon, 1984). In brief, this pecuniary effect is more observable with a non isolated price effect output to estimate efficiency.

2.2. Wage level per employee

Another economic correlate of technical efficiency is wage level. One of the main areas of agreement in the literature which examines the labour factor as a productivity correlate is the need to consider the different levels of professional qualifications of employees. In fact, traditional economic theory upholds a positive relationship between wage level (average wage level per employee) and productivity, where wage level acts as a proxy of the level of professional qualification. This comes from the fact that a greater wage level makes it possible for the company to attract a more highly skilled labour force (Lusch and Moon, 1984), thus reducing the corresponding rotation ratio and improving productivity (Carey and Otto, 1977). In particular, a low employee turnover fosters team work and provides a foundation for establishing practices designed to enhance customer intimacy (Thomas et al., 1998). Furthermore, greater salaries allow firms to have more full time employees, who are more expensive to support than part time employees; however they benefit their employer by establishing long term customer relationships (Thomas et al., 1998), thus improving productivity.

At an empirical level, there is evidence of the positive influence of average wage level on the productivity of the labour factor (George and Ward, 1973; Ingene, 1982; Lusch and Moon, 1984; Van Dalen et al., 1990). In virtue of the above, and as technical efficiency includes the capacity of companies to generate outputs based on certain production resources, it could be expected that an increase in productivity as a consequence of a greater average wage level per employee would also have a positive effect on technical efficiency, which leads to the following research hypothesis:

H_2: *The average wage level per employee of a supermarket chain has a positive effect on its technical efficiency.*

However, there may be "pecuniary" effects arising from the indicator of labour expense. For example, there are a number of other potential reasons for high wages, such as, "de novo" firms as opposed to established firms: corporate officers might be paid higher salaries to compensate for the fact that the "de novo" firms typically do not pay dividends. The "de novo" firms may have to pay a premium to coerce experienced workers away from safe jobs at established firms (De Young and Hasan, 1998). This pecuniary effect is more observable with a non isolated price effect output to estimate efficiency.

2.3. Age of the firm

The effect of experience on a firm's productivity is a question seldom addressed in the literature. In principle, a positive relationship between the seniority of a company and its sales and profits might be expected (Thomas et al., 1998). Experience has three components that are expected to have positive relationships with sales and profits: (i) Employees with longer tenure are felt to be more satisfied employees, better at providing positive and more extensive information to customers, and more concerned with store and company success than employees with short-tenure; (ii) Experienced managers are able to better understand the customer, the market and human resources skills needed to improve store performance than less experienced managers; and (iii) As a store becomes established within the business community, awareness and reputation are expected to become more widespread along with positive word-of-mouth (Thomas et al., 1998).

In the particular case of efficiency, and generally speaking, greater seniority affords the company greater know-how, which can lead to a greater capacity for developing its activities in a more efficient way (Thomas et al., 1998). In the case of firm experience, (typically measured by firm age) Mester (1996) and Berger and Mester (1997) consider that a firm's age might be related to technical efficiency since firm production might involve "learning by doing". Consequently, the following hypothesis is put forward:

H_3: *The age of a supermarket chain has a positive effect on technical efficiency*.

However, there may be "pecuniary" effects arising from the indicator of age's expense and the investment in customer service. These pecuniary effects may merely reflect younger firms' higher start-up costs, for example the costs of establishing customer relationships (Mester, 1996). This pecuniary effect is more observable with a non isolated price effect output to estimate efficiency.

3. Sample and methodology

3.1. Sample, data and variables

The research objectives were analysed in the particular case of the Spanish retail food industry, which, as in most occidental countries, has undergone a series of transformations in recent years that have affected its structure; such as the following: (i) growth of self-service establishments, (ii) increase in market concentration (Cruz-Roche, Rebollo, and Yagüe, 2003), and (iii) intensification of competition between different retail formats (Carasco, Muñoz, and González, 1999; Giménez, Pérez and Sánchez, 2002; Santos and González, 2002). In particular, our work focuses on supermarket chains, given that this retail format has become one of the leading players in the distribution of grocery products in almost all Spanish cities (Casares and Martín, 2003).

In order to test the different hypotheses put forward, we used panel data for 42 supermarket chains for the period 2000 to 2002. This final sample was obtained through the following process, beginning with supermarkets in the ALIMARKET database: Firstly, the estimation of efficiency requires homogeneous units, so in order to guarantee the consistency of the companies analysed, discount stores and hypermarkets were excluded, because the assortment and services provided to consumers are quite different from supermarkets. This led to an initial sample of 166 companies. Secondly, from this original sample, some firms were eliminated because there was no information available for the three years on some of the variables necessary for estimating the frontier function and testing the inefficiency effects. This led to a final sample of 42 supermarket chains between 2000 and 2002 (resulting in 126 observations used in the analysis). Despite the apparently reduced number, these companies represent more than 50% of total supermarket sales and more than 60% of the number of outlets for the period 2000-2002 in Spain. Furthermore, the size of this sample is similar to other studies estimating efficiency in retailing. For example, Donthu and Yoo (1998) analysed 24 units for 3 years, Barros and Alves (2003; 2004) examined 47 outlets for 1 and 2 years, respectively, and Keh and Chu (2003) studied 13 outlets for 10 years.

With regard to the variables used, the definition of inputs and outputs is the main problem faced when analysing efficiency in distribution (Alderson, 1948). In the specific case of technical efficiency, the main problem lies in the conceptualisation and measurement of the output used. Although the variety of services which facilitate the task of exchange (Bucklin, 1978) or the number of clients are considered the fundamental physical output of a retail store, our paper uses an output isolated from the price effect, obtained by dividing sales revenue by retailers' price level. Previous approaches that have isolated retail price levels in sales revenue have been used to estimate productivity (Ratchford and Brown, 1985; Ratchford and Stoops, 1988), but their main shortfall is that they use producer prices. This assumes that retailer prices move with producer prices, which may not be the case in reality as there could be differences due to the market power of the retailer. In other words, it could be that the better prices obtained by the retailer are not passed on to the customer by retailers with high market power. In fact, Cruz-Roche et al. (2003) show, in the case of Spain, that concentration processes among retailers result in an increase in the market power of retailers in local markets; with the consequent price rises. In our case, we also detect a positive correlation between market power (measured by the Herfindahl Index) and retailer price index (coef= 0.43; prob=0.003). Apart from this, as we use panel data, sales revenue is deflated by the consumer price index (CPI) provided by the National Statistical Institute and is expressed in constant 2000 Euros. Thus, the variable used as output is a result of dividing the sales revenue (in constant euros) of each supermarket chain (price time quantity) by a price index for each supermarket chain. The resulting variable estimates, to some extent, the quantity sold measured in euros (Ratchford and

Stoops, 1988), and will allow us to estimate technical efficiency, as it isolates the effect that price has on sales revenue.

The price indicator for each supermarket chain is based on the studies carried out by the Spanish Consumer Association OCU in 2000, 2001 and 2002 to evaluate the price level of various supermarket chains. The price index for each supermarket chain is made by averaging the prices of a basket of products in its outlets. This acts as a proxy for the price level of the products that make up the supermarket's assortment. This index varies between 100 (supermarket chain with the lowest prices) and 143 (supermarket chain with the highest prices) in 2000, between 100 and 139 in 2001, and between 100 and 138 in 2002. This index has previously been used in Spain by Yagüe (1995) and Cruz-Roche et al. (2003) as an indicator of the price level of the supermarket chains.

In relation to the definition of the inputs, we use four controllable productive factors that affect the shape of the production technology defining the production function: (i) the number of employees in the supermarket chain (full-time equivalent), an input representing the labour factor (for example, Bucklin, 1978; Ingene, 1982; Pilling, Henson, and Yoo, 1995; Yoo, Donthu, and Pilling, 1997; Thomas et al., 1998); (ii) the average selling area of the chain's outlets, measured in m^2, (square meters of total chain floor space/number of outlets), which represents supermarket chain size (Lusch and Moon, 1984; Good, 1984; Donthu and Yoo, 1998) and reflects capital investments; (iii) the average inventory investment per square meter of the chain's selling area, which is a surrogate measure of product assortment (Lusch and Moon, 1984) and also reflects the related expenses; and (iv) the average annual wage level per employee (in euros) of the supermarket chain (obtained by dividing total wages paid (expressed in constant 2000 Euros) by the number of full-time equivalent employees). This variable reflects the qualification level of the staff and the labour expense.

Furthermore, this paper considers some factors that are assumed to directly affect technical efficiency and define the degree to which firms fail to reach the efficient frontier because of technical inefficiencies of production. Regarding the selection of these determinant factors, some authors use the same variables used as inputs (Lundvall and Batesse, 2000), while Huang and Liu (1994) consider the interactions between the inefficiency effects and the input variables in the stochastic frontier. In fact, De Young and Hasan (1998) argue that the use of shared variables will not cause bias or inefficiency in the estimation. Recall that efficiency is estimated from both the output (which is observed) and the error term (which is estimated). Thus, shared variables will only affect efficiency through their impact on the output, because by definition the shared variables are orthogonal to the error term. Thus, assuming the underlying hypothesis that all firms share the same technology; represented by the production frontier (which defines the relation of outputs to inputs) and that some variables affect technical efficiency (factors that have an influence only on the distance that separates each firm from the best practice function), our paper considers the following determining factors, which could affect efficiency estimates obtained using an output isolated vs. non-isolated from the price level of each retailer: (i) the average inventory investment per square meter of the chain's selling area (Lusch and Moon, 1984); (ii) the average annual wage level per employee (in euros) of the supermarket chain (obtained by dividing total wages paid (expressed in constant 2000 Euros) by the number of full-time equivalent employees); and (iii) the age of the chain, measured by the years since it was established, which shows the seniority or experience of the firm and the related expenses.

The descriptive statistics of the variables used are shown in Table 1.

3.2. Methodology

To estimate efficiency, we employ a stochastic frontier production function (Battese and Coelli, 1995). In this parametric model, a production function is specified which defines output as a function of a given set of inputs that affect the shape of the production technology, together with technical inefficiency effects which define the degree to which firms fail to reach the frontier because of technical inefficiencies of production. Further, this model specifies that these inefficiency effects are modelled in terms of other observable variables (average selling area of the outlets, inventory investment per square meter of selling area, wage level per employee and age of the firm) and all parameters are estimated simultaneously. The stochastic element of this model allows some observations to lie above the production function, and accounts for measurement error and other random factors (Coelli, Prasada and Battese, 1998). The random disturbance is the result of favourable and unfavourable external events such as luck. Moreover, errors of observation and on measurement of production constitute another basis for the presence of this random error in the frontier model, which makes the model less vulnerable to the influence of outliers in the data than with deterministic frontier models, as some observations can lie above the estimated production function.

TABLE 1. Descriptive statistics of the variables used (2000-2001-2002)

	Sales volume = Sales revenue prices	Employees	Average selling area (m²)	Inventory investment per square meter (euros/year)	Average wage level per employee (euros/year)	Age of the firms (years)
2000						
Mean	2066.9	2126.4	702.8	860.4	12241.7	18.4
SD	4586.4	3770.8	261.8	130.3	4995.6	13.8
Max	28647.6	19419	1492	1156.0	20230	69
Min	58.6	46	376	631.1	2130	2
2001						
Mean	2443.8	2462.7	797.1	860.1	11928.8	19.4
SD	5828.5	4802.5	644.6	139.3	4512.5	13.8
Max	36695.8	27400	4482.8	1174.6	19310	70
Min	63.3	46	370.2	611.5	3040	3
2002						
Mean	3270.6	2668.1	710.8	878.5	13491.1	20.4
SD	7618.1	5473.6	287.8	141.7	4497.4	13.8
Max	46204.8	31694	1638.3	1189.9	24350	71
Min	57.2	47	376.1	642.8	2810	4
2000-2002						
Mean	2593.8	2419.1	736.9	866.4	12553.8	19.4
SD	6110.1	4701.7	433.3	136.4	4686	13.7
Max	46204.8	31694	4482.8	1189.9	24350	71
Min	57.2	46	370.2	611.5	2130	2

To make the proposed model operative, the most popular functional form in both the marketing and economics literature is the Cobb-Douglas production function (e.g. Arndt and Olsen, 1975; Doutt, 1984; Ingene, 1984; Thurik and Kooiman, 1986; Ratchford 2003). We assume that the frontier technology of firms in the retail sector in Spain is represented by a Cobb-Douglas production function. In any case, the results obtained should be interpreted with caution, since there is no theoretical justification for the inclusion of such a restrictive supposition. In particular, the stochastic frontier production function is then defined as:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln E_{it} + \beta_2 \ln S_{it} + \beta_3 \ln I_{it} + \beta_4 \ln W_{it} + \beta_5 t + v_{it} - u_{it} \qquad (1)$$

where the subscript *i* and *t* indicate the observation for the i-th firm (i=1,...,N, where N is the number of firms in the sample) in year *t* (where *t*=1,2, and 3 correspond to 2000, 2001 and 2002, respectively). Y_{it} represents the output (sales volume = sales revenue / retailer's price index) of the *i*-th chain in year *t,* and E_{it}, S_{it}, I_{it}, and W_{it} represent the inputs: number of employees (E_{it}), average selling area (S_{it}), inventory investment (I_{it}), and wages paid (W_{it}) in the *i*-th chain in year *t*, respectively. β represents the parameters to be estimated. *t* is the time trend and allows for shifts of the frontier over time, which are interpreted as technical change. Deviations from the production function are captured in the two error terms: i) v_{it} are i.i.d.~N(0, σ^2_v) and represent random errors. The v-error accounts for measurement error in outputs and the effects of misspecification in the production technology; and ii) u_{it} are non-negative random variables. The u-error is associated with technical inefficiency of production, and is not the same for all the supermarket chains, but is rather a function of a set of observable variables and a vector of parameters. u_{it} is assumed to be independently distributed, such that u_{it} is the truncation (at zero) of the normal distribution with mean η_{it}, and variance σ^2_u, where η_{it} is defined by:

$$\eta_{it} = \delta_0 + \delta_1 z_{1it} + \delta_2 z_{2it} + \delta_3 z_{3it} + \delta_4 z_{4it} \tag{2}$$

where z_{1it} is the average inventory investment per square meter of selling area, $z2_{it}$ wage level per employee of the i-th chain in year *t*, z_{3it} is the age of the i-th chain in year *t*, and z_{4it} is the time trend, which may capture factors such as the macro-economic environment or general tendencies of efficiency change over time. δ_m is a vector of unknown parameters to be estimated, which makes it possible to analyse the effect of each of the previous variables on technical efficiency. It should be noted that since the explained variable in the inefficiency function (2) is the mode of inefficiency, a positive sign on a δ-parameter indicates that the associated variable has a negative effect on efficiency, while a negative sign indicates a positive efficiency effect.

The test of the relative importance of the effects of technical inefficiency regarding the frontier specification error is carried out by the following parameter:

$$\gamma = \frac{\sigma^2_u}{\sigma^2_u + \sigma^2_v} \tag{3}$$

where $0 \leq \gamma \leq 1$. A value of γ equal to zero means that the deviations of the frontier are the exclusive result of the effects of specification error, where there is no sense to the inclusion in the estimation of the determinants of technical inefficiency. If this null hypothesis is true, the production function is equivalent to the traditional average response function which can be efficiently estimated using ordinary least-square regression. However, if $\gamma > 0$, it implies that a proportion of the total variability is associated with inefficiency of production.

Technical efficiency of the *i*-th firm in the *t*-th year is defined by the ratio between the maximum output that the i-th chain could obtain given the production function, $f(X_{it};\beta)e^{(v_{it})}$, and the real output obtained Y_{it} (Battese and Coelli, 1988). Thus:

$$TE_{it} = \frac{f(X_{it};\beta)e^{(v_{it})}}{Y_{it}} = e^{-u_{it}} \tag{4}$$

where, $0 \leq TE_{it} \leq 1$. Technical efficiency equals one only if a firm has an inefficiency effect equal to zero; otherwise it is less than one. The lower this index is, the more inefficient the corresponding chain. The estimation of $TE_{it}=\exp(-u_{it})$ involves the technical inefficiency effect, u_{it}, which is unobservable. Even if the true value of the parameter vector, β, in the stochastic frontier model was known, only the difference, $e_{it} = v_{it}-u_{it}$, could be observed. Therefore, the best predictor for u_{it} is the conditional expectation of u_{it}, given the value of $v_{it}-u_{it}$. Battese and Coelli (1988) point out that the best predictor of $\exp(-u_{it})$ is obtained by using:

$$\mathrm{E}(\exp(-u_{it})|e_{it}) = \frac{1-\Phi\left(\sigma_A + \gamma e_{it}/\sigma_A\right)}{1-\Phi\left(\gamma e_{it}/\sigma_A\right)}\exp(\gamma e_{it} + \sigma_A^2/2) \tag{5}$$

where $\sigma_A = \sqrt{(1-\gamma)\sigma_u^2}$; $e_{it} = \ln(y_{it}) - X_{it}\beta$ and $\Phi(.)$ is the density function of a standard normal random variable.

Various tests of null hypotheses of the parameters in the frontier function and in the inefficiency model can be performed using the generalised likelihood-ratio test statistic, defined by:

$$\lambda = -2[L(H_0) - L(H_1)] \tag{6}$$

where $L(H_0)$ is the log-likelihood value of a restricted frontier model, as specified by a null hypothesis, H_0; and $L(H_1)$ is the log-likelihood value of the general frontier model under the alternative hypothesis, H_1. This test statistic has approximately a (mix)chi-square distribution with degrees of freedom equal to the difference between the parameters involved in the null and alternative hypothesis.

4. Results and discussion

The results obtained from estimating the stochastic frontier production model defined in (1) using the method of maximum likelihood (ML) and the proxy of the non-monetary output "sales volume" are presented in the first column (model A) in Table 2.

TABLE 2. Estimation of alternative stochastic frontiers

		Model A	Model A*	Model B
		OUTPUT: Sales volume = Sales revenue / prices	OUTPUT: Sales volume = Sales revenue / prices	OUTPUT: Sales revenue
Variable	**Parameter**	**Coefficient (SD)**	**Coefficient (SD)**	**Coefficient (SD)**
Intercept	β_0	-1.331*** (0.383)	-1.323*** (0.383)	3.810*** (0.361)
Employees (E)	β_1	0.574*** (0.051)	0.569*** (0.050)	0.592*** (0.040)
Average selling area (S)	β_2	-0.038 (0.058)	-0.041 (0.059)	-0.058 (0.053)
Inventory investment per square meter (I)	β_3	1.145*** (0.135)	1.163*** (0.142)	1.050*** (0.103)
Wage level per employee (W)	β_4	0.246*** (0.053)	0.243*** (0.048)	0.303*** (0.043)
Time trend (t)	β_5	0.007 (0.030)	-	-
Intercept	δ_0	5.388*** (1.219)	5.855** (3.253)	6.814*** (2.592)
Inventory investment per square meter (z_1)	δ_1	-0.473** (0.251)	-0.615** (0.341)	-3.773*** (1.150)
Wage level per employee (z_2)	δ_2	-1.653*** (0.189)	-1.740** (0.968)	-2.547*** (0.970)
Age of the firm (z_3)	δ_3	-0.952*** (0.113)	-1.139* (0.834)	1.097** (0.637)
Time trend (z_4)	δ_4	-0.449*** (0.225)	-	-
	γ	0.934*** (0.020)	0.925*** (0.041)	0.997*** (0.001)
	σ^2	0.629*** (0.059)	0.574** (0.315)	4.087*** (0.904)
	logL	-5.213	-5.567	-44.201
	Mean TE	0.863	0.870	0.751

where $\gamma = \sigma^2_u/(\sigma_u^2+\sigma_v^2)$, $\sigma^2 = (\sigma_u^2+\sigma_v^2)$. ***=Prob<0.01; **=Prob<0.05; *=Prob<0.10

Several generalised likelihood-ratio tests of null hypotheses involving restrictions on the parameters in both the frontier and the inefficiency model are presented in Table 3. The first test considers the global significance of model A (defined in equation (1) in the previous section). The likelihood-ratio test (λ=435.03; critical value = 16.92), allows us to reject the proposal that all parameters (except the intercepts) are zero ($H_0^{'}: \beta_1=\beta_2=\beta_3=\beta_4=\beta_5=\delta_1=\delta_2=\delta_3=\delta_4=0$). Furthermore, the second null hypothesis considers that the inefficiency effects in the production function are not presented in the model, and so the supermarket chains are fully technically efficient ($H_0^{''}: \gamma=\delta_1=\delta_2=\delta_3=\delta_4=0$). This hypothesis is also rejected by the data. However, given the specification of model A, the third null hypothesis of no technical change (β_5) nor time effect (δ_4) in the inefficiency model ($H_0^{'''}: \beta_5=\delta_4=0$) is not rejected. Therefore, the preferred model, without β_5 and δ_4, is denoted by model A* in Table 2. In fact, Table 3 also presents several generalised likelihood-ratio tests of null hypotheses involving restrictions on the parameters in the inefficiency model for the preferred model A*. The first test allows us to reject the proposal that all parameters (except the intercepts) are zero ($H_0^{'}: \beta_1=\beta_2=\beta_3=\beta_4=\delta_1=\delta_2=\delta_3=0$). Furthermore, the null hypothesis of no inefficiency effects ($H_0^{''}: \gamma=\delta_1=\delta_2=\delta_3=0$) is also rejected by the data. As Model A* (no time effect) is the preferred model, the rest of the results will be discussed in terms of this model.

The estimated parameters of the production function for the preferred model (Model A*) are significant and show the expected positive sign for all the variables except for the average selling area, which is negative but not significant. Furthermore, the average technical efficiency for the sample of supermarkets analysed was 0.87 (SD=0.095) during the period 2000 to 2002, which indicates that these firms could have obtained the same output level by using 13% fewer resources. The mean technical efficiency is 0.854 (SD= 0.12) for 2000, 0.868 (SD= 0.09) for 2001 and 0.889 (SD= 0.067) for 2002.

While the proxy of the non-monetary output “proxied sales volume” is our preferred measure to estimate technical efficiency and its determinant factors, it is helpful to compare it with the results obtained with the monetary output sales revenue (which could incorporate other factors related to product prices), following Akhavein et al. (1997). The results of this estimation (Model B) are shown in the third column of Table 2. Particularly, when the output is specified as the sales revenues of the firm (Model B) the results show some differences. Firstly, the sales revenue efficiency ratios are lower on average than with the proxied sales volume efficiency ratios, which could be indicating that the sales revenue output also captures the price effect. Secondly, and regarding the possible explanatory factors of this technical inefficiency, although all the variables show the same sign, the levels of significance obtained in Model B are generally bigger than those obtained under Model A*.

TABLE 3. Generalised likelihood-ratio test of hypothesis for parameters of the stochastic frontier production function

Null Hypothesis	λ	Critical value (95%)	Decision
Model A			
$H_0^{'}: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$ $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$	435.03	16.92	Reject H_0
$H_0^{''}: \gamma = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$ (1)	83.53	10.371	Reject $H_0^{''}$
$H_0^{'''}: \beta_5 = \delta_4 = 0$	0.708	5.99	Accept $H_0^{'}$
Model A*			
$H_0^{'}: \beta_1 = \beta_2 = \beta_3 = \beta_3 = 0$ $\delta_1 = \delta_2 = \delta_3 = 0$	434.32	14.07	Reject H_0
$H_0^{''}: \gamma = \delta_1 = \delta_2 = \delta_3 = 0$ (1)	81.74	8.761	Reject $H_0^{'}$

(1) The asymptotic distribution of hypothesis tests involving a zero restriction on the parameter γ has a mixed chi-squared distribution, therefore, the critical value for this test is taken from Kodde and Palm (1986), Table 1, p. 1246.

Regarding the coefficient of the variable that includes the effect of the inventory investment per square meter on technical inefficiency (Model A*, sales volume output), we can see that it is negative, which indicates that this variable has a positive effect on technical efficiency. This result supports hypothesis 1. A store with a bigger assortment per square meter (derived from a larger inventory investment) will be able to provide more selection to its customers than others with lower investment; thus improving productivity, which has a positive effect on technical efficiency. In Model B (sales revenue output), the sign of this variable is maintained while the level of significance is increased. This result can be explained by the fact that a high level of sales revenue output captures other aspects derived from product prices, such as inventory carrying costs. Thus, implicit in the assortment decision is the trade-off between inventory investment (and the related inventory carrying costs) and stockouts. Both cannot be minimized at the same time. A store with a high level of stockouts will lose customer loyalty, since customers will patronize stores with more adequate inventory levels (Lusch and Moon, 1984). The loss of loyal customers will decrease sales revenue.

Regarding the coefficient of the variable that includes the effect of wage level per employee on technical inefficiency (Model A*, sales volume output), we can see that it is also negative, which indicates that this variable has a positive effect on technical efficiency. This result supports the traditional hypothesis that the wage level variable acts as a proxy of the level of professional qualification, and makes it possible for the company to attract a more highly skilled labour force (Lusch and Moon, 1984), thus reducing the corresponding rotation ratio and improving productivity (Carey and Otto, 1977) (a low employee rotation fosters team work and customer intimacy), which has a positive effect on technical efficiency. Consequently, hypothesis 2 is supported. In Model B (sales revenue output), the sign of wage level is maintained and the significance level is increased. This result can be explained thus: a high level of sales revenue output captures other aspects derived from product prices, such as labour expenses. For example, a high salary level reduces employee rotation; and a low employee turnover diminishes hiring and training costs (Thomas et al. 1998), which can be reflected in product prices and sales revenue.

Finally, the coefficient of the age of the firm variable is negative but only significant at the 10% level in Model A (sale volume output). Several researches could consider this 10% level as not significant. For this reason, although this result could allow us to support hypothesis 3, we can't accept it. The fact that this variable is not significant could indicate that the expected positive effect of experienced supermarkets on technical efficiency (it involves "learning by doing" in firm production and greater know-how (Mester, 1996), which may lead to greater capacity for carrying out activities in a more efficient way (Thomas et al., (1998)) can be masked by other aspects, such as the new entrants using leapfrogging technology to become more efficient than current firms that have much more experience, or older chains have more obsolete and therefore less productive assets. Consequently the effect of this variable is not clear. However, model B (sales revenue output) shows a negative and significant effect at the 1% level. This result supports the positive effect of experience on supermarkets efficiency and could be explained by a high level of sales revenue output capturing other aspects derived from product prices. Thus, the result probably does merely reflect younger firms' higher start-up costs; for example, the costs of establishing customer relationships (Meter, 1996), which can be reflected in product prices and sales revenue.

In summary, given that the value of the monetary output sales revenue is the dependent variable in the frontier function in Model B, rather than physical output, the inefficiency effects in the model may be influenced not only by technical efficiency but also by other aspects (e.g. occupation costs per square foot of selling area, inventory carrying costs, wage levels as training costs, or start-up costs) reflected in output prices. Sales revenue efficiency has an economic foundation for analysing the efficiency of distribution institutions based on an economic optimization in reaction to market prices and competition. However, sales volume efficiency measures how close a firm is to producing the maximum possible sales volume given a particular level of inputs. In other words, technical efficiency is based around production processes and the organization of firm activities, whereas the estimation of efficiency through the monetary output of sales revenue leads us to estimate an economic concept of efficiency, which could be influenced by prices.

5. Conclusions

The purpose of this paper has been to estimate a strictly technical concept of efficiency in the Spanish food retailing industry, as well as the impact of inventory investments, wage level per employee and firm age. To this end, we use an output that stochastic parametric function, which makes it possible to estimate efficiency and the corresponding determinant factors at the same time. The empirical analysis to panel data for a sample of 42 supermarket chains between 2000 and 2002 shows the existence of high levels of technical inefficiency in the supermarket chains examined. Furthermore, inventory investment and wage level per employee have a positive impact on technical efficiency. In comparison, the impact of these factors on efficiency calculated through a monetary output (sales revenue) shows some differences that could be due to aspects related to product prices.

The results obtained have significant implications for management in retailing. Firstly, the estimation of the efficiency of the different supermarket chains helps the management of the producers of goods and services (Sinigaglia et al., 1995), since they can identify the technically efficient supermarket chains, which is important for vertical relationships in the distribution channel.

Secondly, the analysis of the determinant factors of efficiency for 42 different chains may be used as external benchmarking. The process of benchmarking requires measuring the difference between the current performance level of an organization and the best possible practice, in order to later identify the underlying causes of this difference (Camp, 1989). In terms of efficiency, this process implies that an inefficient firm should examine the reasons why other companies are more efficient. In other words, the consideration of the efficiency with which different entities operate allows the identification of the determinant causes of their different efficiency levels, which finally allows a measurement of the value of the different strategies adopted. In particular, the results show a positive impact of inventory investment per square meter on technical efficiency, highlighting the importance of having more merchandise for the customers to select from (Lusch and Moon, 1984). Furthermore, wage level per employee has also a positive effect on technical efficiency, and shows the importance of correct employee motivation through an appropriate wage level. In other words, human resource management policies and practices are of vital importance for management, combining wage levels for employees, adequate staffing of stores with full-time employees, fostering team work and establishing practices designed to enhance customer intimacy.

The limitations of the study include the generalisation of the conclusions to the entire sector, which must done with due care, since only one of the players in the distribution channel has been analysed, i.e. the supermarket chains. Furthermore, although this paper analyses supermarket chains as DMUs, it could be also very useful to consider the outlets of each supermarket chain as individual DMUs when analysing technical efficiency in retailing. The consideration of these outlets could offer different results. Another limitation of this paper is that we don't consider possible supply and demand restrictions derived from the scope of retail activity as a service activity. This problem could be solved using switching models. Additionally, it would be possible to include other relevant variables in the production process of the supermarket chains, such as the degree of technological development of the companies themselves. Future research lines should try to overcome these limitations.

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