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RESEARCH ARTICLE

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Feed prices and production costs on Spanish dairy farms

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Abstract

This paper analyses the impact of livestock feed prices and pasture quality on the long and short-term costs of milk production in a region of Spain (Navarre). The empirical results are obtained from the estimation of a flexible short-run cost function, followed by the approximation of long-run equilibrium based on the quasi-fixed factors adjusted to their optimal levels. The results reveal a high sensitivity of milk production costs to changes in livestock feed prices due to two reasons. One is that, as milk production expands, it tends to become technologically more intensive. The other is that, in the current structure of dairy farming, land input is suboptimal, particularly in the case of large farms and areas of poor pasture. The results reveal that short-run substitution between feed and livestock is a potential strategy for farms to respond to feed price increases. They also suggest that structural policies designed to strengthen the dairy sector's competitiveness should vary according to agro-climatic conditions. In areas of poor pasture, herd growth might be used as a long-term measure to increase competitiveness through economies of scale; while the alternatives for farms in better-endowed regions also include extensification of dairy production.

Additional key words: restricted cost function; milk production costs; short and long run elasticities; agro-climatic areas.

Introduction

Since 1984, milk production in the European Union (EU) has been regulated by a quota system that has affected milk prices and competitiveness within the sector. While the possibility of within-region quota transfers has helped to concentrate production into more competitively-sized units, transaction costs in the quota market and the ban on cross-border quota transfers have stood in the way of an efficiency-oriented restructuring of milk production.

The EU milk sector is currently facing a period of uncertainty due to the prospect of the abolition of the milk quota regime by 2015 (announced in the Mid-Term Reform of 2003 and later confirmed in "Health Check" 2008), which will increase competition between farms and between regions within the EU. This institutional change is being planned against a current background of rising prices and high volatility in the international livestock feed market (OECD-FAO, 2010; FAO, 2012). Given these circumstances, and the fact that feed is the milk producer's main cost component, determination of the impact of feed prices on milk production costs could prove useful in the assessment of farm-level competitiveness and in the design of structural policies to strengthen it.

Dairy farms use two different livestock feed sources: they can either purchase it on the market (externalization) or produce it on their own land (internalization). Various factors, such as farm-level land endowment and availability of pasture, farm-growth strategies and regional livestock feed patterns, determine the degree of externalization, which also varies with different milk quota transfer regulations across EU member countries and the attachment of milk quotas to land.

In Spain, separate transfer of milk quotas and land has always been permitted. This may have contributed

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Abbreviations used: AWU (annual work unit); EU (European Union); INE (Instituto Nacional de Estadística); INITIA (Instituto Navarro de Infraestructuras y Tecnologías Agroalimentarias); LRMC (long run marginal costs); SRMC (short run marginal costs); SUR (seemingly unrelated regressions).

to the fact that the major restructuring of the Spanish milk sector in recent decades has been accompanied by an intensification of production systems[1] and what appears to be an increase in the externalization of the livestock feed supply. In the last decade alone, there has been a 67% reduction in the number of dairy farms, while the number of cows per farm has doubled and cows per hectare have risen by 30%. This process has left Spain with one of the most highly intensified milk production systems in the EU. In 2007, dairy stocking density in Spain was 1.48 cows ha^{-1}, versus 0.73 cows ha^{-1} for France and 1.58 cows ha^{-1} for Holland, which has the most intensified system in the EU[2].

Some studies show that these changes in the Spanish milk sector have led to productivity and competitiveness gains of such a calibre that, according to EU reports, Spain's milk sector stands to be among those most highly benefited by the removal of milk quotas (EC, 2009). Nevertheless, the intensification of the production system may have placed the sector in a more vulnerable position by increasing the sensitivity of costs to the variability of feed prices. This possibility increases the timeliness of an analysis to assess the impact of the livestock feed component on Spanish milk production costs.

The precise aim of this paper is to analyse the impact of livestock feed prices on Spanish milk costs and supply, taking into account farm size and agro-climatic conditions. We base this analysis on estimates of a milk production cost function using micro data from dairy farms in different agro-climatic zones of Navarra.

With respect to the choice of methodology for estimating production cost functions, various papers (Hoque & Adelaja, 1984; Mosheim & Lovell, 2009) dealing with the economic performance of dairy farms recommend a short run approximation to capture the strong impact of quasi-fixed factors in milk production. Moreover, Hoque & Adelaja (1984) and De Frahan *et al.* (2011) show that firm structure also has a high impact on milk production costs and that firm-size adjustment enables substitution between fixed and variable inputs (). To analyse the impact of the livestock feed component on milk production costs, therefore, it is important to approximate long-run costs using the short-run estimates. This paper adopts the approach used by Morrison (1988) and Kim & Lee (2001) to approximate long-run costs based on the estimates of a short-run cost function. This enables us to identify the optimal amount of quasi-fixed factors for each production unit and use these values to construct a long-run cost function.

Methodology

Functional form for the short-run cost, product supply, and factor demand function

To analyse the role of livestock feed as a component of milk production costs, we estimate a short-run variable multi-output cost function with variable returns to scale[3], $C(w,z,y,t)$. This function gives the lowest variable cost of producing outputs y at variable factor prices w holding constant the amount of quasi-fixed factors z at time t. The rationale for this procedure is as follows. Firstly, the production units in question use a series of fixed or quasi-fixed factors that are difficult to adjust or increase in response to factor price changes[4]. Furthermore, although the sample farms specialise in milk production, they also produce meat as a subsidiary product in not-necessarily fixed proportions. Finally, as previous research (Mosheim & Lovell, 2009) shows, it is important to consider economies of scale in milk production.

The functional form selected for the specification of the short-run cost function is the multiproduct symmetric generalised McFadden cost function (MSGM)[5], which is flexible and provides a symmetric system of input demand functions containing all the unknown parameters of the cost function. It has the added advantage of allowing the inclusion of null input

[1] Intensification is not a univocal concept: we base our interpretation on milk production per unit of land.

[2] Eurostat: Farm structure of agricultural holdings (http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/en/ef_esms.htm)

[3] This approximation assumes technological homogeneity across the sector as a whole (Chambers, 1988), the requisite conditions being either imposed or evaluated a posteriori in this paper.

[4] In addition to the potential problem of asset fixity, as pointed out by Mosheim & Lovell (2009), the transaction costs in markets for factors such as land are also considerable (Mosnier & Wieck, 2010).

[5] The multiproduct symmetric generalized McFadden cost function (MSGM) was proposed by Diewert & Wales (1987) as an extension of the quadratic functional form. It was later extended by Kumbhakar *et al.* (1989) to include quasi-fixed factors and further extended to suit multi-product contexts by Kumbhakar (1994). The combined version can be found in Rask (1995) or Peters & Surry (2000).

demand values. Thus, the specified functional form is expressed as follows:

$$C(w,z,y,t) = \left(\sum_m \varphi_m y_m\right)\left[\frac{\sum_i\sum_j a_{ij}w_iw_j}{2\left(\sum_i \theta_i w_i\right)}\right] + \sum_i a_i w_i + \left(\sum_m \varphi_m y_m\right)\sum_i b_i w_i t + \sum_i\sum_m f_{im} w_i y_m + \sum_i\sum_k c_{ik} w_i z_k + \left(\sum_i \theta_i w_i\right)\left[\sum_m\sum_n e_{mn} y_m y_n + \sum_k\sum_l b_{kl} z_k z_l + \sum_m\sum_k g_{mk} y_m z_k\right] \quad [1]$$

where w is the variable input price vector (*subscripts* $i, j=1,\ldots,I$))[6]. The quasi-fixed factors are given by z (*subscripts* $k, l = 1,\ldots,K$). The products are given by y (*subscripts* $m, n = 1,\ldots,M$). Technical change is denoted by the time variable t. The unknown parameters of the function are a_i, b_i, f_{im}, c_{ik}, e_{mn}, b_{kl} and g_{mk}. A priori determination of the parameters θ_i and φ_m[7] permits the parsimonious specification of the MSGM functional form while maintaining functional flexibility (Diewert & Wales, 1987).

This specification of the cost function satisfies the condition of linear homogeneity in input prices. The symmetry condition is imposed by restrictions on the parameters by $a_{ij} = a_{ji}$, $b_{kl} = b_{lk}$, and $e_{mn} = e_{nm}$; and the adding-up condition is imposed by $\sum_j a_{ij} = 0$. The price concavity condition is met if the matrix of parameters, A, is semi-definite positive, where the parameter a_{ij} is the element of the i^{th} row and j^{th} column. If it is not met, it can be enforced by reparameterizing the matrix using the Cholesky method (Diewert & Ostensoe, 1988). However, the lack of constraints on the quadratic relationships between output levels and fixed factor endowments enables the estimated function to capture positions that are far removed from short-run optimal positions (such as those of farms located on the downward-sloping portion of the marginal cost curve).

In line with the results of recent studies of the EU milk sector (*e.g.* Cathagne *et al.*, 2006; Wieck & Heckelei, 2007), constant returns to scale and linear homogeneity of fixed factors are not imposed a priori. The suitability of this more relaxed specification will be evaluated later in the paper. Finally, the variable cost function includes a dummy to capture differences in agro-climatic conditions (or pasture quality) between the various production zones. We assume the agro-climatic zone to have a linear effect on variable factor demand and on the marginal costs of milk production[8].

The demand of every input x_i can be derived using Shephard's lemma:

$$\frac{\partial C(w,z,y,t)}{\partial w_i} = x_i(w,z,y,t) = \left(\sum_m \varphi_m y_m\right)\left[\frac{\sum_j a_{ij}w_j}{\left(\sum_i \theta_i w_i\right)} - \frac{\theta_i \sum_i\sum_j a_{ij}w_iw_j}{2\left(\sum_i \theta_i w_i\right)^2}\right] + a_i + \left(\sum_m \varphi_m y_m\right)b_i t + \sum_m f_{im} y_m + \sum_k c_{ik} z_k + \theta_i\left[\sum_m\sum_n e_{mn} y_m y_n + \sum_k\sum_l b_{kl} z_k z_l + \sum_m\sum_k g_{mk} y_m z_k\right] \quad [2]$$

Meanwhile, the derivative of the variable cost function with respect to quasi-fixed factor endowment, z_k, represents minus the shadow price or marginal revenue of the factors in short-run equilibrium and is given by r_k from equation:

$$\frac{\partial C(w,z,y,t)}{\partial z_k} = -r_k(w,z,y,t) = \sum_i c_{ik} w_i + \left(\sum_i \theta_i w_i\right)\left[2\sum_l b_{kl} z_l + \sum_m g_{mk} y_m\right] \quad [3]$$

Finally, the marginal cost function of the m^{th} output is approximated by the derivative of the cost function with respect to the output:

$$\frac{\partial C(w,z,y,t)}{\partial y_m} = MC_m(w,z,y,t) = \varphi_m\left[\frac{\sum_i\sum_j a_{ij}w_iw_j}{2\left(\sum_i \theta_i w_i\right)}\right] + \varphi_m \sum_i \beta_i w_i t + \sum_i f_{im} w_i + \left(\sum_i \theta_i w_i\right)\left[2\sum_n e_{mn} y_n + \sum_k g_{mk} z_k\right] \quad [4]$$

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6 The farm and year subscripts has been omitted for the sake of simplicity of presentation.

7 The summatory $\sum_i \theta_i w_i$ can be interpreted as a variable input price index, while the summatory $\sum_m \varphi_m y_m$ can be considered an output quantity index. Parameters θ_i gives the average percentage cost of every i^{th} input for the sample as a whole, and parameters φ_m and gives the average percentage of revenue from every m^{th} product for the sample as a whole.

8 The dummy is included as $(\sum \theta_i w_i) \sum_{p=1,3} f_p d_p y_1$, where p represents the agro-climatic zones (highland, p = 1, and lowland p = 3, the valley zone, p = 2, is excluded in order to avoid collinearity between variables. We prefer this specification to one that links the dummy to land endowment, which is impossible in the case of so-called "landless" holdings.

The impact of the livestock feed component on long- and short-run costs: marginal cost and feed demand elasticities

To analyse the impact of feed prices on production costs, we use the elasticities of marginal costs and feed demand with respect to the cost function variables: factor prices, output quantities and, in the short run, quantities of fixed factors.

To calculate long-run elasticities, it is necessary to approximate the long-run cost function from the short-run estimates. This can be done by using either the shadow prices or the optimal amounts of the quasi-fixed factors. The latter of these alternatives has the advantage of capturing long-run firm equilibrium at market prices and enabling inter-firm comparison, whereas, in the former, the shadow prices are firm-specific. The approximation of long-run costs is based on the following equivalence (Kim & Lee, 2001):

$$C\left(w,w_K,y,t\right)=C\left(w,z^*\left(w,w_K,y,t\right),y,t\right)+w_K z^* \quad [5]$$

where z^* is the optimal amount of quasi-fixed input needed to minimise the long-run costs of producing a quantity, y, of output at market prices of the variable factors, w, and the quasi-fixed factors, w_K.

Having estimated the short-run cost function, it is straightforward to estimate the long-run one by finding the optimal quantity of quasi-fixed factors, which can be done by using the specification of the shadow prices [3]. The optimal quantity of a fixed factor is that at which the market price of this factor is equal to its shadow price:

$$w_k=-\partial C(w,z^*,y,t)/\partial z_k^*=-\sum_i c_{ik}w_i+\left(\sum_i \theta_i w_i\right)\left[2\sum_l b_{kl}z_l^*+\sum_m g_{mk}y_m\right] \quad [6]$$

By solving this system of equations for all the quasi-fixed factors, we obtain the optimal quantities of each, z_k^*. For a specific case, such as the one in hand, in which there are only two quasi-fixed factors, which we denote by k and l, the specification of the optimal quantity of the quasi-fixed factor k is given by the following equation:

$$z_k^*=\frac{\left[-b_{ll}(w_k+\sum_i c_{ik}w_i+\sum_i\theta_i w_i\sum_m g_{mk}y_m)+b_{lk}(w_l+\sum_i c_{il}w_i+\sum_i\theta_i w_i\sum_m g_{ml}y_m)\right]}{2\sum_i\theta_i w_i(b_{kk}b_{ll}-b_{kl}^2)} \quad [7]$$

where w_k and w_l are the market prices of the two quasi-fixed factors, w_i is the price of the i^{th} variable factor and y_m is the quantity of the m^{th} ouput. In this relationship, the optimal quantity of factor z^* depends on the market prices of all the variable and quasi-fixed factors, and on the quantity of output, and shows the zero-price homogeneity that is typical of factor demand, and if b_{ll} is positive, the elasticity of the quasi-fixed factor with respect to its own market price is negative.

It has been shown (Kim & Lee, 2001) that long-run variable factor demand and marginal costs are equal to short-run demand and marginal costs evaluated at $z^*: x_i\ (w,w_K,y,t)=x_i\ (w,z^*,y,t)$ and $MC_m\ (w,w_K,y,t)=MC_m\ (w,z^*,y,t)$. Thus, having approximated the short-run variable cost function, we can use [2] and [4] to obtain the long-run variable factor demand and marginal cost function.

Meanwhile, the short-run marginal cost elasticities with respect to factor prices are defined by [8], where ζ_h denotes indistinctly the price of the i^{th} input, the quantity of the m^{th} output, or the quantity of the k^{th} quasi-fixed factor.

$$\varepsilon^{SR}_{y_m,\zeta_h}=\partial\ln MC_m \big/ \partial\ln\zeta_h \quad [8]$$

The short-run feed demand elasticities, x_1, are defined analogously:

$$\varepsilon^{SR}_{x_1,\zeta_h}=\partial\ln x_1 \big/ \partial\ln\zeta_h \quad [9]$$

The long-run elasticities can be easily deduced from the correspondence between the short- and long-run marginal cost and factor demand evaluated at optimal z^* (Morrison, 1988). In other words, the long-run elasticity of the marginal cost (factor demand) would break down into two parts. One would be the same as the short-run marginal cost (factor demand) evaluated at optimal z^*. The other would be the summatory of the elasticities of the short-run marginal cost (factor demand) with respect to each quasi-fixed factor multiplied by the elasticity of the demand for the quasi-fixed factor with respect to variable ζ_k, where ζ_k generically denotes the inputs and output prices. For example, the long-run marginal cost elasticities are given by [10]; the long-run feed demand elasticities by [11] and the long-run land demand elasticities, by [12].

$$\varepsilon^{LR}_{y_1,\zeta_h}=\partial\ln MC_1 \big/ \partial\ln\zeta_h\Big|_{z_k=z_k^*} z_k+\sum_k \partial\ln MC_1 \big/ \partial\ln z_k \; \partial\ln z_k \big/ \partial\ln\zeta_h \quad [10]$$

$$\varepsilon^{LR}_{x_1,\zeta_h} = \left.\frac{\partial \ln x_1}{\partial \ln \zeta_h}\right|_{z_k = z_k^*} + \sum_k \frac{\partial \ln x_1}{\partial \ln z_k} \frac{\partial \ln z_k}{\partial \ln \zeta_h} \quad [11]$$

$$\varepsilon^{LR}_{z_2,\zeta_h} = \frac{\partial \ln z_2}{\partial \ln \zeta_h} \quad [12]$$

The model variables

This paper uses unbalanced panel data for a sample of 139 dairy farms over a period running from 1994-2005 with a total of 850 observations. The farm data, which were provided by the Navarre Institute of Agro-food Technology and Infrastructures (Spanish acronym INTIA), refer to farms specializing in cows' milk production in the Spanish region of Navarre. The extent of complementary agricultural/livestock farming in the region is null or insignificant[9]. The INTIA database, originally compiled for accounting purposes, was adapted for the purposes of our economic analysis. The price data were obtained from Eurostat, the National Statistics Institute of Spain (INE) and the Navarre Institute of Statistics (IEN), and adapted to the study variables.

We specify the activity of our sample units using two outputs, four input variables and two quasi-fixed factors. With respect to outputs, while the majority of Navarre's dairy farms specialise in milk production, some also produce meat and other by-products[10]. Pearson's coefficient of correlation between the milk production and other outputs in the sample is 0.7. Thus, since milk production only partially explains the associated meat production, we decided to include the latter as an independent product in the cost function. Thus, the two products considered in this paper are cows' milk ($m = 1$) and by-products of milk production ($m = 2$). Milk production per farm, y_1, is expressed in metric tons, and the farmer-received price, p_1, in euros per ton. The quantity of other products is calculated in constant euros, y_2. It is obtained by dividing the aggregate value by the Laspeyres price index, weighted based on the sample mean of the items included, p_2. The reason for the choice of the Laspeyres price index is its correspondence with the Eurostat aggregate price series indices, which provide the basis for the choice of study variables. Aggregate sectoral price index statistics were used due to the unavailability of specific input and output prices, other than milk prices.

The four input variables are: externally purchased livestock feed, ($i = 1$), livestock costs ($i = 2$), other variable costs, ($i = 3$), and non-family labour, ($i = 4$). The prices of the variables, p_i, are the aggregate Laspeyres price indices from the Eurostat database for Spain. Input consumption, x_i, was then calculated by dividing each cost by its respective price index.

Family labour ($k = 1$) and land ($k = 2$) are considered quasi-fixed factors because of the difficulty involved in their short-run reallocation[11]. Family labour endowment is quantified in terms of annual work units (AWU), and the regional average farm foreman wage is taken as its market price. Land is quantified in hectares, and its market price is approximated in terms of the land-investment opportunity cost. For this purpose, we use the Navarre pasture land price data from the INE land price survey, multiplied by the 10-year public bond interest rate. Table 1 summarises the database variables and statistical sources.

Agro-climatic zones

One of the model's main variables is the agro-climatic dummy. The three agro-climatic zones considered in the paper are depicted in Fig. 1. The classification, which was made in collaboration with INTIA, is related to the Papadakis agro-climatic classification[12] (which is a combination of rainfall regimes, evapotranspiration and annual temperatures), and the orographic features of the various zones. The aim of this environmental dummy is to capture differences in the availability and yield of grazing land in each of the three milk production zones.

Zone 1, which is mountainous, takes in the townships of northern Navarre and comprises both warm maritime and warm temperate maritime agro-climatic areas. It is characterised by high annual rainfall and pasture management problems due to the

[9] The sample was first screened to exclude farms of less than one annual work unit (AWU) and fewer than 10 cows.
[10] This phenomenon can be captured by considering milk and meat as an aggregate product (Pierani & Rizzi, 2003), as independent products (Stefanou *et al.*, 1992; Cathagne *et al.*, 2006) or excluded altogether (Colman *et al.*, 2005; Álvarez *et al.*, 2006; Álvarez & Del Corral, 2010).
[11] Some studies also consider long-run family labour input (*e.g.* Kempen *et al.*, 2011)
[12] A more detailed description can be found in MAGRAMA (2013).

Table 1. Definition of model variables

	Variable	Description	Source
Inputs	Outsourced livestock feed	Concentrate feed, forage and mix purchased off-farm	
	w_1	Laspeyres price index (2005 = 1)	Eurostat
	x_1	Quantities (expenditure/ price index)	INTIA
	Livestock costs	Veterinary costs and imputed dairy cow stock costs	
	w_2	Laspeyres price index (2005 = 1)	Eurostat
	x_2	Quantities (expenditure/ price index)	INTIA
	Other costs	General and capital depreciation costs	
	w_3	Laspeyres price index (2005 = 1)	Eurostat
	x_3	Quantities (expenditure/ price index)	INTIA
	Non-family labour	Wage costs	
	w_4	Laspeyres price index (2005 = 1)	INE
	x_4	Quantities (expenditure /price index)	INTIA
Outputs	Milk	Cows' milk	
	p_1	Milk price (€ t^{-1})	Eurostat
	y_1	Milk production (t)	INTIA
	Other products	Sale of calves, cull cows and other associated revenue	
	p_2	Laspeyres price index (2005 = 1)	Eurostat
	y_2	Quantities (income/price index)	INTIA
Fixed factors	Family labour	Family labour	
	r_1	Prices: farm foreman wage (€ AWU^{-1})	INE
	z_1	AWU	INTIA
	Land	Land used for milk production	
	r_2	Land opportunity cost (€ ha^{-1})	INE
	z_2	Pasture land (ha)	INTIA

AWU: Annual work units. INITIA: Instituto Navarro de Infraestructuras y Tecnologías Agroalimentarias (http://www.intiasa.es). INE: Instituto Nacional de Estadística (http://www.ine.es).

smallness and steepness (average gradient over 12%) of the holdings. Zone 2, which lies in the mid-northern region of Navarre, comprises cool maritime and cool Mediterranean agro-climatic areas. It is characterized by high annual rainfall and wide valleys with ample, easily manageable grasslands (average gradient 3-12%). Finally, zone 3, which lies in the mid-southern region of Navarre and comprises temperate Mediterranean and temperate steppe (Mets) agro-climatic areas, it is a plain characterised by low annual rainfall and large expanses both of dry and irrigated farmland (average gradient less than 3%).

Results

In this section, we present a statistical description of the variables, the specification and estimation of the panel data model, the long- and short-run marginal cost estimates, and the feed cost and demand elasticities.

Description of the variables

Table 2 summarises the statistics of the variables in the sample. The average size of the sample farms over the study period is 61.5 cows, which is much larger than the Spanish national average, which stood at 33 cows per farm in 2009. The average area of pasture land per farm is 23.9 ha, which represents a stock density of 2.67 cows ha^{-1}. This is higher than the 2009 Spanish average of 1.23, and also higher than the Navarre average for that year, which was 1.88 cows ha^{-1}, due to the sample being taken exclusively from dairy specialist farms with more than 10 cows.

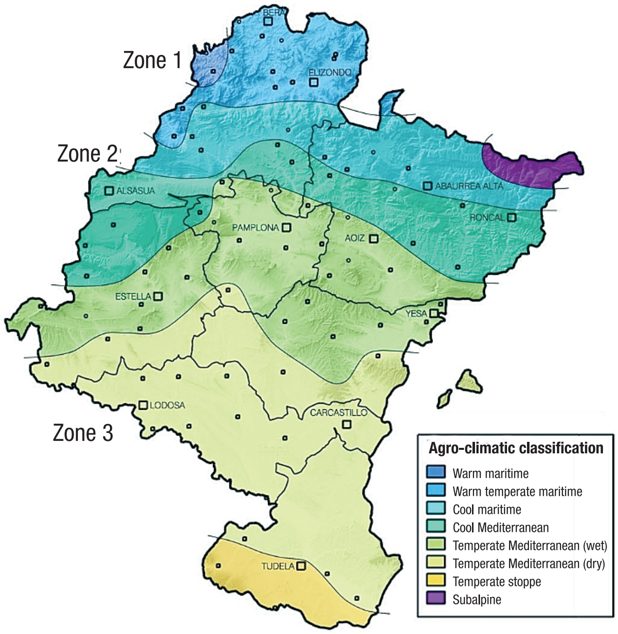

Figure 1. Papadakis agro-climatic classification of Navarre. Source: Meteo Navarra (http://meteo.navarra.es/definiciones/papadakis.cfm).

All these descriptive statistics are the more revealing when taken in conjunction with the farm structure, level of intensification and agro-climatic zone relationships. Farms have grown in size by intensifying their production systems, albeit not to the same extent in all three agro-climatic zones. In zone 1, a mountainous area, farms remain small and run less intensive production systems. Although the farms in zones 2 and 3 are similar in size, low-intensity production systems persist in the pasture valleys of zone 2, while highly intensive systems prevail on the plains of zone 3. This may be due to the low forage capacity of the dry farmland in this last zone and to the high opportunity cost of using irrigated land to graze livestock.

Specification and estimation of the panel data model

This paper has estimated the input demand equations specified in Eq. [2] using a fixed-effects panel data model[13] at differences around the mean. Given the unbalanced nature of our panel data[14], a sample selection bias test (Hausman & Wise, 1979) was undertaken prior to the model estimation.

After the testing and validation of the econometric specification of the panel model, the system of demand Eq. [2] was estimated. The observed correlation in the residuals of the equations in [2] led to the use of Seemingly Unrelated Regressions (SUR) (specifically the SUR routine in the TSP 4.5 package) for this purpose. The parameters were calculated following White's proce-

Table 2. Descriptive statistics of the panel data

Variable	Mean	SD	Min.	Max.
w_1 Feed price	0.949	0.065	0.829	1.004
w_2 Livestock price	0.856	0.089	0.707	1.000
w_3 Other costs price	0.778	0.160	0.388	1.000
w_4 Non-family labour price	0.805	0.097	0.674	1.000
y_1 Milk production	465	325	43	1,769
y_2 Other products	12,697	10,939	431	73,085
z_1 Family labour	1.53	0.65	0.50	4.00
z_2 Land	23.9	18.0	0.0	100.0
x_1 Feed quantity	66.181	52.365	2.871	303.951
x_2 Livestock quantity	36.648	25.028	3.678	139.621
x_3 Other costs quantity	44.450	32.613	4.071	218.821
x_4 Non-family labour quantity	1.781	5.572	0	46.975
p_1 Milk price	297	26	231	370
p_2 Other products price	0.998	0.057	0.894	1.060

[13] We assume this specification based on the results of a Hausman (1978) test, which are not included here but are available from the authors upon request.

[14] We have applied to each demand equation the test suggested by Verbeek & Nijman (1992, 1996) and Wooldridge (1995, 2003) and the quasi Hausman test (Verbeek & Nijman, 1992). The results of both tests allow us to rule out the presence of sample selection bias in our study. Tables showing the results of these tests are available from the authors upon request.

Table 3. Parameter estimates of the model

Param.	Variable[a]	Estimate	St. Error	*p*-value[b]	Param.	Variable	Estimate	St. Error	*p*-value
a_1^c	w_1	4226.99	403.42	** [0.000]	c_{21}	w_2z_1	–4266.65	1179.98	** [0.000]
a_2^c	w_2	1102.36	199.60	** [0.000]	c_{22}	w_2z_2	250.83	306.32	[0.413]
a_3^c	w_3	–733.79	364.05	* [0.044]	c_{31}	w_3z_1	–7143.69	1392.01	** [0.000]
a_4^c	w_4	494.39	150.68	** [0.001]	c_{32}	w_3z_2	269.52	373.66	** [0.000]
b_1	w_1t	–0.058	0.102	[0.570]	c_{41}	w_4z_1	–3020.61	317.56	** [0.000]
b_2	w_2t	0.195	0.068	** [0.004]	c_{42}	w_4z_2	283.08	951.06	** [0.003]
b_3	w_3t	0.494	0.066	** [0.000]	e_{11}	y_1^2	0.014	0.013	[0.293]
b_4	w_4t	0.114	0.043	** [0.009]	e_{12}	$2y_1y_2$	–0.001	0.25E-03	[0.699]
a_{11}	$w_1^2/_2$	–969.23	464.300	* [0.037]	e_{22}	y_2^2	–0.53E-05	0.65E-05	[0.415]
a_{12}	w_1w_2	975.43	321.345	** [0.002]	f_{11}	w_1y_1	303.80	187.20	[0.105]
a_{22}	$w_2^2/_2$	–981.68	441.299	* [0.026]	f_{12}	w_1y_2	945.55	170.94	[0.580]
a_{13}	w_1w_3	–127.53	110.068	[0.247]	f_{21}	w_2y_1	–271.77	124.36	** [0.029]
a_{23}	w_2w_3	128.35	133.231	[0.335]	f_{22}	w_2y_2	–329.45	113.71	** [0.000]
a_{33}	$w_3^2/_2$	–0.168	0.329	[0.610]	f_{31}	w_3y_1	–803.34	121.53	** [0.000]
a_{14}	w_1w_4	121.33	291.554	[0.677]	f_{32}	w_3y_2	–829.48	110.760	** [0.000]
a_{24}	w_2w_4	–122.10	256.301	[0.634]	f_{41}	w_4y_1	–200.16	798.69	* [0.012]
a_{34}	w_3w_4	0.160	0.370	[0.666]	f_{42}	w_4y_2	–190.88	730.60	** [0.009]
a_{44}	$w_4^2/_2$	–0.152	0.686	[0.825]	g_{11}	y_1z_1	–387.46	774.30	** [0.000]
b_{11}	z_1^2	6746.34	1670.79	** [0.000]	g_{12}	y_1z_2	–167.00	0.197	** [0.000]
b_{22}	z_2^2	103.15	152.86	** [0.000]	g_{21}	y_2z_1	0.796	0.197	** [0.000]
b_{12}	$2z_1z_2$	129.71	465.60	** [0.005]	g_{22}	y_2z_2	0.004	0.005	[0.484]
c_{11}	w_1z_1	–9578.75	2153.10	** [0.000]	f_1^d	d_1y_1	174.05	300.62	** [0.000]
c_{12}	w_1z_2	–621.63	559.37	** [0.000]	f_3^d	d_3y_1	148.60	327.26	** [0.000]
Corrected R^2 for autonomous equations					Eq [1]	Eq [2]	Eq [3]	Eq [4]	
					0.968	0.960	0.917	0.376	

[a] To simplify the presentation of the results, this column includes all the parameter variables, but omits the price normalisation terms, and quantities of the original quadratic function. For these, see main Eq. [2]. [b] * denotes a 95% level of confidence and ** a 99% level of confidence. [c] Parameter estimates obtained in the second stage estimation. [d] Dummy parameter estimates, where d_1 is 1 for zone 1 and 0 otherwise, and d_3 is 1 for zone 3 and 0 for the rest.

dure, which gives heteroskedasticity-robust estimates. The removed constants of the demand functions contain the sector parameters and the farm-specific fixed effects. The sector parameters were obtained by subsequent estimation using the interactive TSP method of SUR on the deviation between the actual demand levels and the portion explained by the previous estimation.

The goodness-of-fit of the variable estimates and parameter estimates of the system of variable input demand equations are satisfactory, as can be seen from Table 3, which gives the results of the estimation of the model. The parameter estimates show a high level of significance, with 67% of the parameters significantly different from zero at the 95% level of confidence.

In relation to variable input prices, the linear homogeneity of the cost function is imposed by the specification of the functional form, and to overcome difficulties in meeting curvature constraints, concavity is imposed by means of a Cholesky decomposition. Convexity in the fixed factors takes the form of a positive definite matrix *B* and the convexity condition is satisfied for the parameter estimation. The cost function also satisfies the monotonicity condition: variable factor demand and output elasticities are positive and shadow prices are a decreasing function of factor endowment for all observations. Finally, the estimates show a slightly increasing short-run milk supply curve and an increasing return to scale estimate of 1.34[15].

[15] Wald's test for the presence of economies of scale yields a value of 438.0 (p<0.001) which enables us to reject the hypothesis of constant returns to scale. This hypothesis is consistent with the overall non-significance of the parameter matrices *E, B* and *G* (Wieck & Heckelei, 2007), where the parameters e_{mn}, b_{kl} and g_{mk} are the elements of the i^{th} row and j^{th} column of the respective matrices. By ruling out the presence of constant economies of scale, we are also able to reject the hypothesis of homotheticity (Stewart, 2009).

Table 4. Marginal costs for the average farm for the period 2003/2005 [a]

	SRMC	LRMC	SRMC	LRMC	Price (€ t^{-1})	Excess of fam-labour[b]	Excess of land[b]
	(average sample farm)		(whole sample)				
Total			290.3	295.2	324.6	0.772	–9.7645
By area:							
zone 1	277.0	287.2	304.5	317.1	324.6	0.599	–1.199
zone 2	262.3	272.3	252.4	277.0	329.8	0.779	–0.722
zone 3	274.9	285.0	318.4	293.6	318.9	0.936	–28.379
Signif. variation			**	**	**		**
By herd size:							
herd < 50			309.6	326.5	320.3	0.630	–1.678
50 < herd < 90			292.0	302.3	325.7	0.737	–4.040
herd > 120			270.7	253.1	325.8	0.968	–29.456
Signif. variation			*	*	**		*
Signif. variation by area and herd size			**	**			**

LRMC (long run marginal costs); SRMC (short run marginal costs). [a] Variation by zone, by herd size and by Zone × Herd size, where * denotes a 95% level of confidence and ** a 99% level of confidence. [b] Excess = $(z_k - z_k^*)/z_k$, where z_k is the actual quantity of the k^{th} quasi-fixed factor and z_k^* is the optimal quantity.

Long- and short-run marginal costs and their elasticities

Table 4 gives the estimated marginal costs, excess of family labour and land fixed factor inputs, and milk price per zone and herd size over the period 2003/05. It also includes the level of significant variation in farm costs by zone and herd size and the combined effect, Zone × Size. In order to isolate the effect of agro-climatic zone on milk production costs, we estimated the short and long-run marginal costs in the three agro-climatic zones on the average sample farm.

The short-run marginal costs (SRMC) were calculated using Eq. [4]. Estimates of the long-run costs and excess input of the quasi-fixed factor were based on the long-run optimal quantity of the quasi-fixed factor, z_k^*, land and capital, for each farm, using the specification shown in Eq. [7]. The long-run marginal costs (LRMC) were obtained by estimating the same Eq. [4], while replacing the current quantity of the quasi-fixed factor of each farm, z_k, with the optimal long-run quantity, z_k^*. Excess demand for the quasi-fixed factor is determined as a percentage of the current endowment, as shown at the foot of Table 4.

The results suggest, firstly, that agro-climatic differences have a major impact on marginal costs. The short-run marginal costs of milk production for the average sample farm would be € 262.3 t^{-1} if it were located in zone € 2, 277.0 t^{-1} if located in zone 1, and € 274.9 t^{-1} if located in zone 3. Zone 2 enjoys the same relative advantage in terms of long-run marginal costs. The natural advantages deriving from zone 2's better-quality pasture land therefore translate into approximately 10% lower marginal costs.

The estimated average LRMC and SRMC for the period 2003/2005 are € 290.3 t^{-1} and € 295.2 t^{-1}, respectively. The fact that the LRMC are slightly higher than the SRMC is indicative of overcapacity, such that the quantity of quasi-fixed factors allocated by the farm is higher than the total cost-minimizing quantity for a given quantity of output. The data displayed in Table 4 reveal an over-optimal quantity of farm family labour, with no significant variation across agro-climatic zones. Excess input of family labour increases with herd size at the 10% level of significance due to the fact that larger farms hire more non-family labour. Indeed, total farm labour exhibits the monotonicity property: that is, demand increasing with production. Our estimates for the land factor indicate under-provision of land, which increases with herd size. Under- allocation of Land is higher in agro-climatic zone 1 due to its steep gradients and highest of all in agro-climatic zone 3, where pasture quality is very poor.

Marginal cost variations by herd size are significant both in the long and the short run. Larger farms are at

Table 5. Short-run (SR) and long-run (LR) marginal cost and demand elasticities. Standard deviations in parentheses

		Production		Price				Quantity (Price)	
		Milk	Other outputs	Feed	Cows	Other inputs	Non-family labour	Family labour	Land
Milk marginal cost	SR	0.059 (0.042)	–0.012 (0.010)	0.513 (0.010)	0.205 (0.009)	0.254 (0.006)	0.028 (0.004)	–0.208 (0.123)	–0.154 (0.153)
	LR	–0.285 (0.203)	0.872 (0.071)	0.382 (0.014)	0.208 (0.006)	0.286 (0.006)	0.017 (0.002)	0.084 (0.011)	0.024 (0.004)
Feed demand	SR	1.118 (0.244)	0.035 (0.044)	–0.234 (0.084)	0.233 (0.084)	–0.028 (0.011)	0.029 (0.010)	0.007 (0.106)	–0.179 (0.108)
	LR	0.995 (0.279)	–0.107 (0.326)	–0.512 (0.237)	0.317 (0.182)	0.113 (0.070)	0.052 (0.026)	–0.027 (0.013)	0.057 (0.029)
Land demand	LR	0.697 (0.072)	0.264 (0.074)	0.661 (0.310)	–0.171 (0.080)	–0.616 (0.288)	–0.129 (0.060)	0.451 (0.211)	–0.197 (0.095)

a greater advantage in the long-run. These results suggest that farms are in a position to achieve considerable economies of scale by increasing in size.

Table 5 shows the estimates of the elasticity of marginal milk costs with respect to output, variable factor prices, and short- [8] and long-run [10] fixed factor quantities. These results provide new evidence about both the technology and the strategies used by dairy farmers.

The first main observation is that the average short-run elasticity of marginal milk costs is 0.059 for the last three years of the sample period and it maintains positive values across the entire sample. A 1% increase in milk production would increase marginal costs by 0.059%, which makes for a very elastic short-run supply curve. The average long-run elasticity of supply, however, is –0.285 and it maintains negative values across the entire sample. So, as farm size increases, marginal costs decrease. This is consistent with the presence of economies of scale, our estimation of which has shown that, if farms could adjust their fixed factors, their marginal costs would decline with increases in output.

A second point worth noting is the high impact of the price of livestock feed on both short- and long-run supply. The elasticity of the SRMC with respect to the price of feed is 0.513. This high value may be due to the fact that short-run cost estimation limits the possibility of substitution between variable and fixed factors. However, the long-run elasticity of marginal costs with respect to the price of feed also takes a high average value of 0.382. Thus, even while taking into account the possibility of farms replacing purchased feed with land, the marginal costs are highly sensitive to feed price variations. In short, these results suggest that the sample farms are immersed in a production system that relies heavily on purchased livestock feed and in which land input is currently below its long-run equilibrium level.

The estimates of the elasticity of marginal costs with respect to the (short-run) quantity and (long-run) price of land are also eloquent in this respect. Firstly, the quantity of land has a noticeable impact on SRMC. A 1% increase in the quantity of land would result in a –0.154% decline in short-run marginal costs. Furthermore, land prices have little impact on long-run supply, as shown by its quasi-null elasticity value (0.024). The remaining input prices also have a positive effect on marginal costs which is consistent with the monotonicity condition.

In summary, the results suggest that, due to insufficient land input, farms have fallen into overuse of purchased livestock feed as a means to increase output. However, even if they were to succeed in achieving long-run equilibrium by adjusting fixed factors to output level, milk supply would remain heavily dependent on livestock feed prices.

Feed demand and substitution relationships

To continue with our analysis of the impact of livestock feed prices on milk supply, we now turn to the short- and long-run effects of feed demand and the long-run effects of land demand. The long- and short-run elasticities are estimated by means of the methodology specified for the short-run in Eq. [9], and the long-run in Eqs. [11] and [12][16]. Table 5 gives the long- and short-run elasticities of feed demand and the long-run elasticity of land demand.

A 1% increase in the price of feed would, in the short run, reduce feed demand by 0.234%, and a 1% increase in milk production requires a proportionately larger increase (1.118%) in the quantity of purchased livestock feed. The rate of substitution between land and purchased feed is estimated at –0.179. These values reveal that short-run livestock feed demand is very rigid and that any increase in milk production is associated with a higher increase in the use of purchased feed. This dependence highlights the importance of taking feed price trends into consideration when assessing dairy farm profitability and competitiveness in a liberalised milk market.

Cross price elasticities of purchased feed and dairy cow show that these factors are substitutes in the short run. In order to validate this result, we calculated the Morishima elasticity of substitution[17] following Peeters & Surry (1993). A positive value indicates substitution between the input factors, while a negative value indicates their complementarity. Having found that the elasticity of the ratio of feed to cows with respect to the price of dairy cows is 0.649 (the inverse elasticity is 0.724) we are able to confirm that these two inputs are substitutes. This means that, farms adjust the feed/cow ratio in accordance with input price trends. The milk yield per cow is thus, to some extent, adjusted to the price of feed, with yields increasing (decreasing) with falling (rising) feed prices. We view the validation of this variable relationship as considerable support for our model specification and a noteworthy contribution to the existing literature on the sector.

Long run elasticities of feed demand and land demand with respect to milk output are 0.995 and 0.697, respectively. Thus, an increase in milk production implies an almost proportionate increase in the purchase of livestock feed and a less than proportionate increase in the demand for land by dairy farms. This suggests that the production system becomes more land-input intensive as output expands. Thus, the intensification of production currently observed in the sector may just as easily be due to the characteristics of the technology as to the short-run sub-optimal allocation of land by farms.

Farms could be much less vulnerable to feed price increases if they were able to adjust their fixed factors. A long-run increase of 1% in the price of feed would reduce demand by 0.512%. This adjustment is mainly due to an increase in the demand for dairy cows, other variable costs, non-family labour, and land; while family labour is complementary to the demand for purchased livestock feed.

Likewise, a long-run increase in feed prices would have a major positive impact on the demand for land (0.661), which is, in turn, complementary to dairy cow demand (–0.171). An increase in the price of dairy cows would cause a decline in the demand for land. This effect contrasts both with the long- and short-run substitutability of feed and dairy cows. Thus, the results suggest that dairy farms show a current latent demand for land, which is a complement to the number of cows and a substitute for purchased livestock feed.

Overall, milk production costs appear highly sensitive to changes in livestock feed prices. This could be largely due to the fact that the farms are currently operating under sub-optimal land input. Short-run feed demand is increasing at a higher rate than milk production and production systems are more intensive than is optimal at current market prices. Insufficient land input is particularly evident in large farms, and in farms located in poor quality pasture areas (the mountainous zone 1 with its steep gradients or the dry land of zone 3). Milk production is less intensive in areas with better quality pastures (such as zone 2 in the sample).

If farms were able to adjust their fixed factors, the pressure of livestock feed prices on milk production costs would diminish. It should be noted, however, that livestock feed is the cost component that has the greatest influence on production costs in the long term, due to the heavy reliance of farms on purchased livestock feed. This dependence increases with farm size: at constant prices, feed demand increases at almost the same rate as milk production, while land demand increases at a slightly lower rate in comparison. Thus, as production increases, farms tend to reduce their reliance on land as the main factor of production, thereby leaving themselves more vulnerable to the volatility of livestock feed markets.

[16] For reasons of lack of space, we have omitted the detailed specification of each of the 12 estimated elasticity equations.

[17] Blackorby & Russell (1989) show that crossed price elasticity or the Allen-Uzawa elasticity of substitution are not suitable measures of substitution in multiple factor production functions, and recommend the use, instead, of dual Morishima elasticities.

Reducing milk yields by restricting dairy cattle diets would appear to be a means to mitigate the impact of livestock feed price increases in the short term, given that herd size is a substitute for livestock feed in the demand function. Feed rationing is also an important long-term option for farmers to adapt to increases in feed prices. The results of this study also suggest other structural strategies for strengthening farm competitiveness in the face of changes in livestock feed prices. They involve pursuing economies of scale through firm growth and an increase in land endowment.

Discussion

Various studies attribute Spain with the potential to increase milk production in a liberalised market due to relatively low marginal costs. Using a sample period coinciding with the middle part of ours (1998/2001) and an average herd size similar to that of our small-size group (fewer than 50 dairy cows per farm), Moro *et al.* (2005) estimated marginal costs at € 210 t^{-1} for Spain excluding the northwestern region of the country. Cathagne *et al.* (2006) estimated marginal costs at € 216 t^{-1} for Spain as a whole. In comparasion, we found in our study an estimated marginal cost of € 284 t^{-1}. For a sample period roughly coinciding with the first three years and for small-size group of ours, INRA-Wageningen (2002) estimated the marginal cost at € 178 t^{-1} compared to € 242 t^{-1} in our case. Finally, De Miguel *et al.* (2003) estimated the average quota rent for Spain's Galicia region at € 108 t^{-1}, versus the € 266 t^{-1} estimated for our sample over approximately the same period. Less favourable estimates of milk marginal costs, however, such as the € 177 t^{-1} presented by Álvarez *et al.* (2006) from a farm sample of north of Spain, have also been found. For the last part of our sample period, we found a SRMC = € 290 t^{-1} and LRMC = € 295 t^{-1}. These figures strike us as being consistent with the difficulties that have beset the Spanish milk sector and the major adjustment and restructuring process it has undergone in recent years.

One finding of this paper is that the marginal costs of milk production decrease with herd size. According to recent research (Mosheim & Lovell, 2009), the LRMC of milk production in the USA decrease with herd size for herds of fewer than 2,000 cows. This is consistent with the concentration of milk production into large holdings, which has taken place in countries such as the USA, where there is no institutional regulation to prevent it. Cathagne *et al.* (2006), Sckokai (2007) and Wieck & Heckelei (2007) and also reported decreasing SRMC for various regions of Europe and Spain, while Tauer & Mishra (2006) reported average variable costs to be constant and average fixed costs to be decreasing with farm size. This paper finds a similar long- and short-run pattern of marginal costs in relation to herd size.

With respect to the impact of quasi-fixed factors on SRMC, Aldanondo *et al.* (2001) and Álvarez *et al.* (2006) presented an estimation of the use of physical plant capacity in relation to land endowment. The results of the cited studies are not comparable to ours, however, because they compared the quantity of fixed factors with a benchmark unit. Ours is the first study to examine the optimality of fixed factor endowment in Spanish dairy farms. The results, which point towards a process of intensification through the overexploitation of land, are consistent with the Spanish milk sector dynamics reported by other studies (Álvarez & Del Corral, 2010).

With respect to the main aim of this paper, however, which is to analyse the sensitivity of milk production costs to livestock feed prices, our results suggest considerable dependence of both, short- and long- run milk supply on feed prices. Marginal costs are highly sensitive to feed prices, feed demand is very elastic with respect to milk output and very rigid with respect to own prices. This echoes the findings of Pierani & Rizzi (2003) for a sample of Italian dairy farms for the period 1980-1992. They estimated short-run feed demand elasticities of –0.312 with respect to feed prices and 1.483 with respect to milk output. Meanwhile, in a study of Belgian dairy farms for a period running from 1996-2006, de Frahan *et al.* (2011) found slightly higher long-run feed demand elasticity with respect to feed prices (–0.664).

In relation to substitution between factors of production, a study of the UK dairy sector by Colman *et al.* (2004), found concentrate feed to have been replaced by greater use of grassland for pasture, due to the low profitability of dairy farms in that country. Meanwhile, de Frahan *et al.* (2011) reported long-run complementarity between cows, purchased feed and pasture. The findings of the present paper show land and purchased feed to be substitute factors of production, land and cows to be complementary, and cows and purchased feed to be substitutes. There are two possible reasons for the divergence between the findings of de Frahan *et al.* (2011) and our own: 1) that Belgian farms largely supplement their cows' diets with purchased feed, while farmers in Navarre also use purchased forage and, 2) that de Frahan *et al.*'s long-run approximation differs from ours in that their specification estimates a long-run cost function, while ours estimates a short-run cost function, which it uses to approximate the long-run cost function.

By way of conclusion, therefore, analysis of the impact of dairy cows' diet on milk production is important in order to assess the potential influence of feed prices on farm economic performance. This paper shows that production costs and milk supply are highly sensitive to changes in the feed price trend, for two important reasons. The first is the presence of suboptimal land input by farms, which increases with herd size, particularly in the case of farms located in areas where the grazing is scant or of poor quality. The second is that milk production technology tends, of itself, to intensify with increasing herd size.

These findings suggest that the upward price trend and high volatility of the livestock feed market may be having a strong impact on Spanish dairy farm competitiveness, especially in the case of large farms located in areas of poor pasture. This study also shows, however, that milk production costs can be reduced by increasing herd size, and reallocating fixed factor inputs. The results therefore suggest the possibility of using structural measures to strengthen the competitiveness of the sector and reduce its vulnerability to livestock feed prices. Particularly in areas of poor pasture, farm growth aimed at capturing economies of scale emerges as one of the potential measures that might improve competitiveness and compensate for feed price increases. In areas of better quality pasture land, there are two available options for strengthening farm competitiveness: one is to promote extensification by increasing land endowment; the other is to pursue growth in herd size.

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