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Contribution of the calving interval to dairy farm profitability: results of a cluster analysis of FADN data for a major milk production area in southern Italy

G. Dono[1], L. Giraldo[1]* and E. Nazzaro[2]

[1] *Department of Agriculture, Forest, Nature and Energy (DAFNE). University of Tuscia. Viterbo, Italy*
[2] *Agroscenari research project. Latina. Italy*

Abstract

In this study we investigated the potential economic impact of good management of the calving interval on dairy farms. This involved the assessment of economics and production of a sample of farms, selected from the Farm Accountancy Data Network (FADN), and located in Sardinia, Italy. Two farm models were derived from clustering the sample by k-means, which were validated by verifying their consistency in relation to nutritional needs, feed supply and milk production of the herds. Differences in indices of performance and dynamics were found (*e.g.* ROE is –0.8% *vs* 4.7%), with evident linkages between economic performance, greater efficiency, reproductive capacity, and potential turnover. The model better performing reflected greater economic feeding efficiency and a shorter calving interval. Hence, management, more than structural aspects, determined the economic results of the sampled farms.

Additional key words: milk profitability; herd management; cluster analysis; economic performance.

Introduction

Management of the calving interval and its optimal length are important aspects of the economic performance of dairy farms. Several studies have focused on the economics of managing this aspect in relation to milk production, while others have considered the involvement of general farm management in addition to milk production (Bertilsson *et al.*, 1997; Arbel *et al.*, 2001; Hansson & Öhlmér, 2008). The findings have been controversial, but there is general agreement that 12 months represents a short calving interval, based on a pregnancy period of 280 days and a non-pregnancy period of 85 days. Sørensen & Østergaard (2003) noted that different management criteria and skills can affect the economic performance of dairy farms and many are the factors affecting the calving interval, *i.e.* the post-partum interval – PPI (Sanz *et al.*, 2004) and having cost implications. For most factors, *e.g.* the body condition score (BCS), it is very hard to collect secondary data and the almost only way is the direct on-farm observation. The present study aimed to explore this topic through an investigation of the economics and production of a sample of farms in Arborea (central-western Sardinia, Italy), which were selected from the Farm Accountancy Data Network (FADN). Such kind of data is already accessible to researchers on economic analysis, but show some limits for the identification of factor defined in the literature as relevant (BCS, sub-year nutrition schedule and facts, etc.). However, FADN contains proxy variables that can be used to carry economic analysis considering farm management practices.

Dairy farms in this area are the source of most of the dairy milk produced in Sardinia, and all use a milk production process that is common to most Italian dairy farms. Consequently, the conclusions of this study may be of wider interest. The analyses were

* Corresponding author: giraldo@unitus.it
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Abbreviations used: ACI (average calving interval); BCS (body condition score); EFE (economic feeding efficiency); FADN (farm accountancy data network); FUM (feed unit milk); GMM (gross margin over milk); GSP (gross saleable product); IS (reproductive capacity); LE (livestock equivalent); OLS (ordinary least squares); PPI (post-partum interval); ROE (return on equity).

conducted by using *hierarchical* and *non-hierarchical* clustering methods to cluster the FADN sample farms into groups of differing economic performance. The farms in each cluster were assessed for their technical and economic consistency. The linkages between economic performance and management indicators were examined, including the calving interval. The results provide guidance for targeted technical assistance to improve the efficiency and profitability of the farms.

Material and methods

Study area and data

The study focused on a very intensive milk production area situated in the municipality of Arborea, in the central-west of the island of Sardinia, Italy. The area was drained and reclaimed in the first half of the 20th century, and transformed into a productive flood plain that was settled by farmers, predominantly from northern Italy; after the 1950's they began to specialize in the breeding of milking cows. Specialization in high levels of milk production now concerns cooperatives and other associations involved in the purchase of inputs, as well as milk processing and commercialization. The FADN data concerned 50 Arborea dairy farms during three years, from 2005 to 2007. The data include economic accounts, structural conditions, use of land and labour, and other technical elements. The average values for these parameters, as well as economic indicators from the dataset, were the basis for establishing the clusters. For privacy reasons it was not possible to match the FADN information to databases of farmer organizations, which are very detailed with respect to the parameters related to management of the calving interval. However, the FADN provided various technical and structural data concerning the breeding farms, enabling comparison with the many economic data that it contains. These data were integrated with the results of a survey conducted to selected dairy farms in the area. This survey collected information on the animals' diet, represented by the feeding ration used in the area.

Statistical analyses

Cluster analysis

Cluster analysis comprises a set of statistical techniques that are widely used for exploring and evaluating data on populations involving large numbers of units. Algorithms group the units that are considered homogeneous with respect to specific characteristics. The average values (centroids) of the characteristics in the clusters are used to represent the entire group, and for studying its performance. Cluster analysis, unlike other multivariate statistical approaches, does not make a priori assumptions about the types that characterize the groups being studied. Clearly, such analyses are affected by the focus of the research, which influences the choice of *cluster variables* used for grouping the study units. This choice in turn depends on the type of information that is contained in the available data.

The *clustering variables* used in this study were defined following preliminary correlation analysis in order to assess whether the sample farms had homogeneous structural and dimensional characteristics. Dimensional variables were first examined, revealing that, except from remarkable ranges of variation for some dimensional variables, the absence of evidence for a correlation between farm dimensions and profitability suggested that superior economic performance are related to management practices.

To assess the role of those practices, two economic and two technical indicators were chosen as clustering variables for the FADN sample farms. The economic indicators were *return on equity* (ROE) and *gross margin per ton of milk* (GMM). ROE is the ratio of the income that remains to remunerate the equity (after all other factors are compensated) to the value of the equity. It is thus a measure of the productivity of the invested property capital, and a synthetic expression of the economic performance (Woolridge & Gray, 2006). ROE disregards a crucial objective of family farms, which is to maximize labour use, and is not sufficient for assessing the economic performance of these types of units. However, it provides a good indication of the productivity of the capital invested. GMM expresses the farm economic performance prior to subtracting fixed costs. Unlike ROE, GMM is less dependent on the structural characteristics of the enterprise, but is more related to the efficient use of variable inputs. GMM can therefore be considered to be a measure of management and organization. The two technical indicators, adopted in this study to reflect the effects of management choices and farmer skills, were respectively termed the *illness score* (*IS*) and the *reproductive capacity*. The *IS* is derived from the insights of Hansson & Öhlmér (2008) concerning managerial practices related to animal health, and Halasa *et al.* (2010) concerning the links between the length of breeding cycle and cow intra-mammary infection. These analyses suggested that managerial performance could be assessed by considering indicators of animal health. Relevant health indicators were not available in the FADN database, so expenditure on veterinary interventions was used as a proxy. To standardize with respect to farm dimensions, the cost of veterinary interventions for each farm was divided by the quantity of milk it produced. The *reproductive capacity* indicator is directly related to the length of breeding period (calving, milking and dry) (Arbel *et al.*, 2001; Sørensen & Østergaard, 2003). Therefore, the ratio of female calves to dairy cows was calculated from the FADN data, and used as a measure of the *reproductive capacity* of the herd because it linked the length of the calving period to fertility.

Clustering methods

In addition to the choice of variables, the method for measuring the distance between clusters must also be chosen. Several indices of distance can be used for quantitative variables (Hartigan, 1975). One of the most common is the square of the Euclidean distance, which gives a gradually increasing weight to objects that are beyond a certain distance. The clustering methods are classified as either hierarchical, which produce a series of groups ordered with increasing levels of homogeneity (Johnson, 1967; Everitt, 1979), or non-hierarchical, which aggregate the units in a number of groups that is specified a priori (Andemberg, 1973). This study integrated a *hierarchical* and a *non-hierarchical* method. The *hierarchical* cluster analysis was performed based on the method of *average linkage between groups*, which involves measurement of intervals with Euclidean squared distance for selected characteristics of the population. This resulted in a *preferable* number of groups, as indicated by a dendrogram output. The number of groups was indicated using a *non-hierarchical* definitive k-means method that clustered the FADN farms by maximizing the internal similarity of the groups. To avoid misleading results, the dataset variables, measured on different scales, were standardized before performing the cluster analysis (Stoddard, 1979).

Validation of clustering results

Clustering results are generally evaluated by measuring the similarity level within or between the groups obtained. The so-called *internal evaluations* assign the best score to the algorithm that produces groups with a high degree of similarity within a cluster, and low similarity among clusters. In contrast, *external evaluations* assess how close the clustering is to external benchmarks, which are typically created in unrelated studies or by experts and not used in the particular clustering. In this study we adopted a different approach, and evaluated the results by assessing the *centroids* for technical consistency and evidence of the sustainability of livestock feeding patterns. To achieve this, the FADN sample was first purged of farms with inconsistencies in declared milk production, the feed unit milk (FUM) required for such production, and the intake of FUM (based on the availability of fodder and its theoretical ingestibility by the cattle breeds involved). Therefore, the *centroids* of the clusters were assessed for consistency with the nutritional needs of the breeds, the feed used in the area, the computed on-farm fodder production, and the purchase of feed. Likewise, the consistency of the *centroids* was checked with respect to the amount of milk produced. The conversion rates adopted for crops production it terms of dry matter (DM), crude protein (CP), neutral detergent fibre (NDF), and FUM within all the study were as reported by Jarrige (1988).

Analysis of performance

The different technical and economic performance of the *centroids* was explained using an analysis of the structural and economic characteristics of the productive models, and by indicators of resources productivity. The economic assessment was mainly focussed on results related to family labour, and on consequent compensation accrued to this resource. As the ROE does not reflect the major objectives of family farms, the use of indicators of employment and the ability to compensate the family labour helped to verify the achievement of these objectives. The key technical indicators were *economic feeding efficiency* (*EFE*), represented by the ratio between the value of milk and the cost of feed, and the *average calving interval* (*ACI*). The latter index was derived from the number of *dairy cows* and the number of *calves younger than one year old*, distinguished as males and females. The number of *female calves younger than one year old* was doubled[1] and increased by 5%[2] to obtain a value for the number of *calves born per year* for each herd[3]. The ratio of *dairy cows* to *calves born per year* was proportioned to 85 days of non-pregnancy of a *short calving period*[4], and added to the 280 days of the pregnancy period to determine the number of days for the calving interval, as described by the following formula:

$$\frac{Dairy\ cows\ (heads)}{Calves\ born\ per\ year\ (heads)} * 85(days) + $$
$$+ 280\ (days) = Calving\ interval\ (days)$$

Finally, we performed a regression with OLS in order to explain GMM by mean of EFE, reproductive capacity expressed by ACI, and IS. The variables are logged thus the parameters' estimate gives directly the elasticity.

Results

Preliminary treatment of the FADN sample data

The preliminary analysis assessed each sample farm for consistency with respect to declared milk production, the FUM required for such production, and the intake of FUM (given its availability and the theoretical ingestibility). The estimation of the FUM available at the farm level was based on three components: forage farm production, fodder purchase, and feed purchase. The estimation of farm production of FUM was based on data on the land cultivated with each species, and their average yields and conversion rates (Table 1).

The FUM for purchased fodder was estimated by dividing the related expenses by the ryegrass price (€0.10 kg^{-1}; typically the least expensive forage), and converting the result using a rate of 0.55 FUM kg^{-1}. The FUM from purchased feed was obtained by dividing the related expenses by the average price (0.26 € kg^{-1}), and converting the result at the rate of 1 FUM kg^{-1}. The sum of these three elements was the total available FUM. Consistency was checked between this availability and composition of FUM, and the most common daily fodder ration used in the area. This ration is composed of silage corn (27 kg), alfalfa, and ryegrass hay (7 kg), consistently with the results of Wolter (1994) regarding the optimal composition of rations. This ration of fodder provided 13.7 ingestible FUM day^{-1} head^{-1}, and thus any farm FUM availability exceeding 13.7 FUM was not assigned to animal feeding. An amount of 5 FUM was subtracted from the 13.7 FUM to account for animal maintenance, and 0.5 FUM was allocated to the production of each litre of milk (Jarrige, 1988). The resulting values were indexed for the number of cows, and were compared with the declared milk production using a tolerance of ± 5%. Based on this analysis, 16 farms showed inconsistencies with respect to their declaration of milk production, and were excluded from further analysis. The remaining 34 farms were considered to be representative of the almost 200 dairy farms operating in the area.

Outcome and validation of the hierarchical and non-hierarchical clustering

The dendrogram from the hierarchical clustering indicated the presence of two clusters (Fig. 1). Based on this result, two groups of homogeneous farms were produced using the non-hierarchical k-means

Table 1. Conversion rates of cultivated species in feed unit milk (FUM) production

	Production (t ha^{-1})	Losses		FUM t^{-1}	Price (€ t^{-1})	Notes
		(%)	(t)			
Ryegrass	9.0		9.0	5.5	100	Rated as hay
Alfalfa	10.5		10.5	5.5	180	Rated as hay
Forage grass	35.0	10	32.0	2.1	40	Triticale silage
Forage maize	60.0	10	54.0	2.8	55	Silage

Source: Technicians and field surveys in the area (Agroscenari research project).

[1] An equal gender distribution of 50% was assumed.
[2] This is assumed as the average birth mortality rate.
[3] This computation referred only to females because, based on interviews, male calves are sold as soon as possible, while female calves are kept for more than one year to enable selection of the best ones for herd turnover.
[4] The *short calving period* is intended to provide an *optimal* nativity rate of one calf per dairy cow per year.

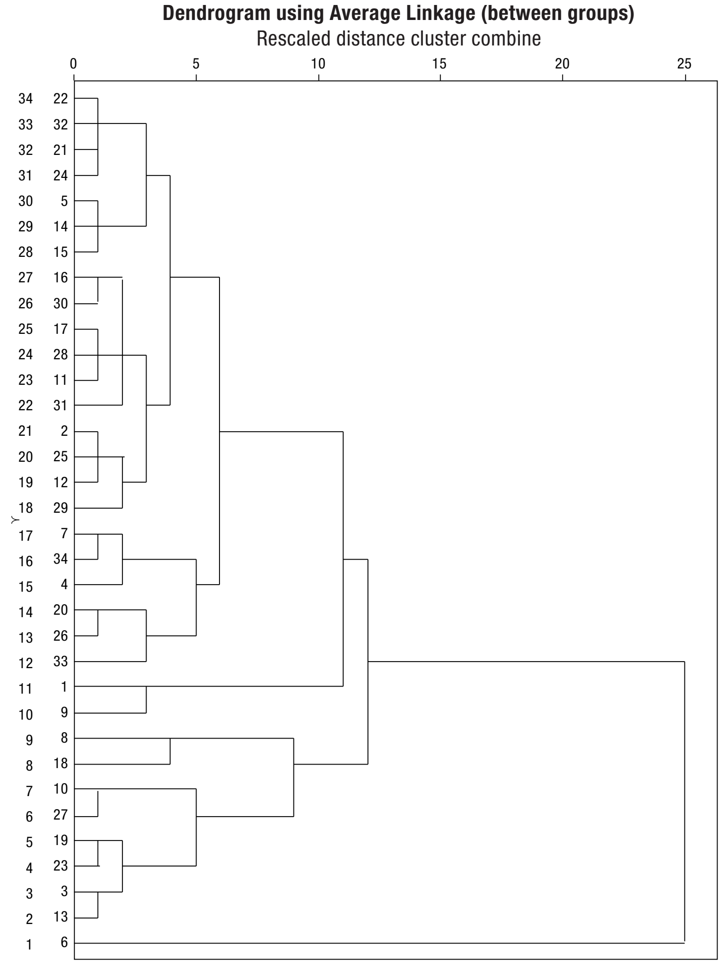

Figure 1. Dendrogram resulting from the hierarchical cluster analysis, showing the re-scaled distances between the identified grouping solutions (average linkage between groups).

clustering method. Table 2 shows the ANOVA for defining the contribution of the clustering variables.

Table 3 shows the means of the two clusters and the t-test results confirming the statistical significance of their difference. Of the 34 farms, 8 comprised the first group and 26 comprised the second. In further analyses the centroid of each cluster was taken as representative of the group of farms in that cluster. The two clusters represented different farming models producing different economic results, and the t-tests confirmed the presence of marked economic similarities amongst the units within each cluster. Cluster 2 appeared to

Table 2. ANOVA results for two clusters on the variables ROE (return on equity), GMM (gross margin over milk), IS (illness score) and reproductive capacity

	Cluster square mean	df	Error square mean	df	F	Sig
ROE	13.381	1	0.613	32	21.826	0.000
GMM	15.804	1	0.537	32	29.409	0.000
IS	5.833	1	0.849	32	6.870	0.013
Reproductive capacity	13.210	1	0.618	32	21.360	0.000

The variables actually differentiate the clusters in term of means (all the F-tests were statistically significant at 0.05).

Table 3. *t*-test on clustering variables. In parenthesis the number of farms per cluster

t-test	CL 1 (8)	CL 2 (26)	*t*-test *p*-value
ROE	–0.8%	4.7%	0.00*
GMM	19.65	26.24	0.00*
Illness score	1.7	1.1	0.05*
Reproductive capacity	26.73%	35.91%	0.01*

* Statistically significant at 0.05.

reflect better performing farms, with a remarkable ROE of 4.7 compared with the ROE for cluster 1 (–0.8%), and an appreciably higher GMM.

Technical coherence of the productive cluster models

Consistency was evaluated for the technical and economic relationship in the two farming models by comparing the centroids of the clusters with respect to production of forage from the farm land, the feed costs, the number of animals to be fed, and the quantity of milk produced. The farm production of feed was first computed at the centroids in terms of DM, CP, NDF and FUM (Table 4). The area under the various crops was multiplied to the respective average yields determined in the field survey. The data for individual crops were used to determine the total production of each farm. In addition, the demographic structure of the herds in each cluster was specified, and the feed requirements of each livestock category were defined (Jarrige, 1988) (Table 5). The feed rations applied on the various farms were surveyed and found to be very similar, which was attributable to the role of the cooperatives in providing technical information. The feed ration amounts were applied to the two centroids (Table 6), the nutritional contribution was calculated for the herds associated with each centroid, and their elements intended to come from farm production were evidenced and compared with the nutritional contributions that originated from the estimated farm production (Table 7). In addition, the cost of the purchased components of the rations was calculated using local prices, and was compared with the equivalent value in the centroids. The last two rows

Table 4. Feed farm production in the centroids of cluster 1 (CL 1) and 2 (CL 2)

Production of forage	Yields (kg ha^{-1})	CL 1					CL 2				
		ha	DM (kg)	CP (kg)	NDF (kg)	FUM (units)	ha	DM (kg)	CP (kg)	NDF (kg)	FUM (units)
Pure forage	33,000	0.42	2,792	503	1,173	2,066	0.00	0	0	0	0
Mixed forage	32,000	0.00	0	0	0	0	0.00	0	0	0	0
Ryegrass	11,000	23.85	228,240	25,106	125,532	168,897	25.37	242,831	26,711	133,557	179,695
Silage corn	54,000	24.67	439,571	36,484	197,807	373,636	26.19	466,736	38,739	210,031	396,725
Alfalfa	12,000	2.28	23,752	3,563	11,876	14,251	3.87	40,368	6,055	20,184	24,221
Total farm production		51.22	694,356	65,656	336,388	558,851	55.43	749,934	71,506	363,772	600,641

DM: dry matter. CP: crude protein. NDF: neutral detergent fibre. FUM: feed unit milk.

Table 5. Daily feed requirements of livestock categories

	CL 1					CL 2				
	First calf	Fresh cows	Close-up cows	Dry cows	Calves	First calf	Fresh cows	Close-up cows	Dry cows	Calves
Live weight (kg)	580	650	650	650	**220**	580	650	650	650	**220**
Std. milk[1] (kg)	*21.3*	*37.2*	*20.8*	3.5	5	*19.3*	*36.6*	*17.9*	3.5	5
FUM (units)	14.3	21.7	14.4	6.8	4.9	13.4	21.4	13.2	6.8	4.9
CP (kg)	2.4	3.8	2.4	0.9	0.6	2.2	3.8	2.1	0.9	0.6
NDF (kg)	7.3	8.1	8.1	8.1	2.8	7.3	8.1	8.1	8.1	2.8
DM (kg)	18.6	25.3	19.9	14.2	6.1	18	25.1	18.9	14.2	6.1
Heads	28.2	28.6	51.1	19.4	129.5	26.3	27.7	56.4	18.2	105.5

[1] Std. milk: production of milk standardized on 3.75% of fat content. *Source:* Own elaboration based on Piccioni (1989).

Table 6. Feed rations for the single livestock categories

Feed ration	CL 1 and CL 2						
	First calver	Cow		Dry cow	Calves		
		Fresh	Close-up		< 1 yr	> 1 yr, < 2 yr	> 2 yr
From farm production (kg)							
Silage corn	21.3	21.3	28.8	7.0		6.0	7.0
Alfalfa hay	1.7	1.7	2.3	1.5		2.3	1.5
Ryegrass hay	2.6	2.6	3.5	1.5	2.5	2.3	1.5
From market (kg)							
Straw				3.0			3.0
Meal and corn flakes	3.4	3.4	4.6				
Feed	3.8	3.8	5.2	1.5	2.0	1.0	1.5
Soy flour	2.1	2.1	2.9	0.5		0.8	0.5
Supplement		0.0		0.1		0.1	0.1
Milking supplement	0.5	2.0	0.7				

Table 7. Nutritional components and expenses for the herds: feed rations *vs.* actual farm production and expenses

	CL 1					CL 2				
	DM (kg)	CP (kg)	NDF (kg)	FUM	€	DM (kg)	CP (kg)	NDF (kg)	FUM	€
Total nutritional components of feed ration	1,278,538	189,922	469,459	1,111,767		1,248,639	185,532	453,197	1,091,978	
Ration components from farm production	721,090	73,516	350,657	560,085		697,460	70,613	338,183	543,644	
Ration cost for feed					169,229					167,841
Farm production of nutritional components	694,356	65,656	336,388	558,851		749,934	71,506	363,772	600,641	
Farm cost for feed					163,321					174,628
Balance of farm nutritional components (%)	–3.7%	–10.7%	–4.1%	–0.2%		+7.5%	+1.3%	+7.6%	+10.5%	
Balance of costs (%)					–3.5%					+4.0%

of Table 7 show acceptable unbalances, and most importantly there were consistency with the production of milk reflected by the centroids. This indicates the technical plausibility of the models, and was the main method used for validation of the clustering results.

General features of the productive model in the two clusters

The main structural, economic and technical features of the *centroid* of each of the two clusters (henceforth *models*) were assessed to explain their differing economic performances.

Structural and technical aspects

Table 8 presents data on the structural features of the models: land, capital and labour. To assess the occurrence of statistically significant differences a *t*-test was performed using the means for each variable. The absolute dimensions of land endowment and use of soil (hectares of forage and irrigated cultivation) was not a differentiating factor between the two models. Model 2 was more likely to involve tenant farmers, although the farmers in each model owned most of their land. There was also similarity between the two models with respect to the economic dimension defined by capital endowment, with no statistically significant differences found for total capital, equity or debt quota. Similarly, for farms in each model the family contributed the total labour supply, with marginal recourse to external sources of labour. The use of family labour was greater in Model 1, although it was not significantly different.

Data on the size and demography of the herds, changes in the herds during the analysis period, and herd reproductive performance are shown in Table 9.

Table 8. Land, capital and labour endowment in the two models

	Land (ha)	Model 1	Model 2	*t*-test
Land (ha)	Total	34.91	33.04	0.778
	Own	28.17	24.86	0.489
	Forage	57.14	55.41	0.871
	Irrigated	30.48	29.02	0.815
	Own/Total	83.0%	77.3%	0.019
Capital (€)	Total	2,313,557	2,174,265	0.713
	Equity	2,251,904	2,110,184	0.700
	Debt	61,653	63,321	0.955
Use of labour (hours)	Family	13,811	9,644	0.176
	Total	13,811	10,049	0.216

The *t*-test has been considered significant at *p*-values < 0.10.

The model results were very similar for the total number of heads of stock, and numbers per hectare of forage, which is commonly used as an indicator of breeding intensity. However, significant differences occurred during the study period. Farms associated with the better performing Model 2 increased in size in general terms (+ 3.1%), while those associated with the other model shrunk. This was coupled to analogous changes in the number of dairy cows and the total value of the herd. Farms associated with the less well performing Model 1 spent more on the purchase of animals, but this was not sufficient to counteract the loss of value of the herds. Conversely, farms comprising Model 2 spent less on the purchase of animals, but the herd size increase was statistically very significant because of a greater reproductive capacity, and the potential turnover (yearly availability of females of 1-2 years of age, which can potentially replace the cows in the herd).

Table 10 shows the milk production of the farms in absolute terms, and in terms of percentage variation during the study period. The increase in herd size and value reflects the variation in milk production during the three years, with Model 2 farms having grown in size and milk production, and probably having bought milk quotas from Model 1 farms. However, the growth in production among the farms in Model 2 did not coincide with an increase in milk produced per cow; this parameter decreased, although not significantly. However, in terms of milk production and value (total and per cow) the differences between the two models were not statistically significant. In addition, the milk prices received by farms in each model were almost identical. Given that the milk cooperative pays a

Table 9. Breeds and demographics in the two models

	Model 1	Model 2	*t*-test
Breeds (head)			
Livestock equivalent, LE	189	201	0.749
Male calves < 1 yr	9	9	0.964
Male calves 1-2 yr	1	1	0.931
Male calves > 2 yr	0	1	0.802
Female calves < 1 yr	36	45	0.305
Female calves 1 to 2 yr	29	41	0.142
Heifers	31	33	0.710
Cows	129	127	0.951
Cows ha^{-1} of forage land	2.40	2.38	0.959
Herd value	298,777	318,206	0.835
Animals purchase (€)	2,977	797	0.303
Animal sales (€)	22,164	24,673	0.619
LE variation 2005 to 2007	–2.7%	3.1%	0.000*
Cows variation 2005 to 2007	–0.9%	6.1%	0.000*
Herd-value variation 2005 to 2007	–1.9%	5.6%	0.000*
Demographic indicators			
Reproductive capacity	26.7%	35.9%	0.009*
Potential herd turn-over	22.8%	25.9%	0.157

* Statistically significant at 0.01.

Table 10. Milk production

Production	Model 1	Model 2	*t*-test
Milk (100 kg)	9,603	10,344	0.703
Milk production variation 2005 to 2007	–0.6%	2.0%	0.005*
Milk per cow (×100 kg)	75.46	79.28	0.498
Milk per cow variation 2005 to 2007	1.5%	–4.1%	0.293
Milk price (€/100 kg)	39.24	39.33	0.855
Milk value (€)	377,813	407,283	0.705

* Statistically significant at 0.05.

premium price according to the fat and protein content of milk, it can be concluded that the farms comprising each of the two models produced milk of comparable quality, and that the difference in economic performance was not a consequence of this parameter.

The economic account

The data in Table 11 highlight differences in revenue and costs in the farm economic accounts. With the exception of crops gross saleable production there were no statistically significant factors explaining the differences in income and profit between the two models. However, the differences in gross saleable production were not sufficient to explain the large difference in gross income, and no major differences were evident among the various components of fixed costs between the two farming models.

Resources productivity and performance indicators

In contrast to other analyses, substantial differences were found for indicators of productivity, the efficiency of use of various resources, and the economic performance of farms. Table 12 shows the various indicators computed as a function of 100 kg of milk produced, and per hour of family labour input. The indicators related to each 100 kg of milk produced were almost all significantly different. The farms comprising Model 2 received a larger non-milk animal GSP (gross saleable product), which suggests higher sale prices for calves, heifers and reformed cows. They also had less expenditure for feed and veterinary services, which had the effects of lowering the variable costs per 100 kg of milk and increasing gross income. The indicator of fixed costs was not significantly different, although the value for Model 2 was lower. Model 2 also had a lower value for family labour remuneration; as the same hourly salary was applied to the two models, this suggests that less family labour was used to produce 100 kg of milk. The greater productivity of family labour among the farms in Model 2 is confirmed by figures in the second section of Table 12, which shows greater values for milk, non-milk animals, and crops for sale, as a function of the use of family labour.

Table 11. Economic account

Income statement (€)	Model 1	Model 2	*t*-test
Gross saleable product (GSP)	452,531	507,160	0.569
Animal GSP	407,539	452,338	0.606
Crop GSP	4,518	11,708	0.038*
Other	41,040	43,725	0.716
Variable costs	261,903	237,522	0.632
Feed	159,181	143,928	0.659
Bedding and forage	15,447	19,693	0.394
Health	16,694	11,549	0.301
Other animal expenditures	9,708	7,296	0.217
Electricity	5,791	6,091	0.821
Machinery	26,224	22,913	0.476
Seasonal workers	0	407	0.273
Other (mainly forage crops)	28,859	25,872	0.558
Gross income	190,628	269,638	0.095*
Fixed costs	77,892	70,415	0.636
Depreciation	35,406	30,291	0.345
Farm maintenance	5,239	5,096	0.922
General expenses	12,497	12,304	0.968
Employees	0	1,892	0.089*
Legal duties for family	18,483	12,547	0.196
Rents	3,420	4,801	0.521
Passive interests	2,847	2,294	0.688
Net income	112,737	199,224	0.013
Land assets remuneration	33,804	29,837	0.489
Current assets remuneration	34,291	32,020	0.681
Family labour remuneration	124,063	92,370	0.237
Profit	–79,421	44,996	0.000

* Statistically significant at 0.05.

Table 13 shows a conclusive set of technical and economic indicators that reassume the different models. The EFE was significantly higher for Model 2, with each €1 spent on feed transformed to €2.60 of milk (*versus* €2.22 for Model 1). The ACI was also less for the farms comprising Model 2. The family labour remuneration % net income indicates the income accruing to family labour at current market salary rates, and was markedly different between the

Table 12. Indicators per 100 kg of milk and per hour of family labour. GSP is gross sellable product

	Model 1	Model 2	*t*-test
€/100 kg of milk			
Non-milk animal GSP	2.91	4.35	0.093*
Feed	17.93	15.50	0.022*
Health	1.65	1.07	0.052*
Variable costs	38.75	32.69	0.007*
Gross income	19.65	26.24	0.000*
Fixed costs	8.35	7.00	0.120
Net income	19.24	11.29	0.000*
Family labour remuneration	13.38	9.77	0.027*
€/hour of labour			
Profit	–9.52	3.09	0.000*
Net income	8.35	23.30	0.000*
Profit	–6.06	6.14	0.000*
Milk value	28.57	48.35	0.014*
Crops GSP	0.28	1.19	0.000*
Non-milk animal GSP	1.95	4.83	0.001*

* Statistically significant at 0.05.

Table 13. Indicators of performance: economic feeding efficiency (EFE), average calving interval (ACI), family labour remuneration on net income and return on equity (ROE)

Performance indicators	Model 1	Model 2	*t*-test
EFE	2.22	2.60	0.019*
ACI (days)	446.0	394.2	0.061*
Family labour remuneration % net income	135.6%	52.9%	0.022*
ROE	–0.8%	4.7%	0.000*

* Statistically significant at 0.05.

two models. The value for Model 1 (> 100%) indicates that net income was not sufficient to pay for the family labour at market salary levels, and no compensation was paid to capital, and no profit was achieved. These latter results are also highlighted by the negative value of ROE. In contrast, for Model 2 half of the net income was sufficient to fairly compensate the family labour, at market salary rates. Furthermore, the ROE for this model was 4.7%, indicating that profits were achieved after adequately compensating the equity resource.

Table 14 reports the results on the regression explaining GMM by mean of EFE, ACI and IS (all variables are logged), showing that all the variables are highly significant and can explain more than half of the variability (Adjusted $R^2 = 0.517$). First, signs of the estimates are consisted with the expected, since EFE and ACI changes accordingly to GMM, whilst profitability decreases with increased IS. The magnitude of the estimates indicate that EFE is the more effective, follows by the ACI and finally by IS.

Discussion

The Arborea area is of general interest because its dairy farms produce most of the milk consumed in Sardinia, and the milk production model that is commonly in use is very similar to that which operates in the Po Valley, where most of the dairy milk in Italy is produced. Hence, the conclusions reached for the Arborea area may have implications for Italian dairy milk production generally. Cluster analysis techniques were applied to a representative sample of Arborea dairy farms, using records from the FADN. Technical and economic indicators were obtained (*e.g.* ACI) or calculated from the records, using assumptions derived from the scientific literature and verified by interviews with farmers and technicians from the area. A preliminary hierarchical and the following non-hierarchical cluster analysis (k-means) indicated the occurrence of two homogeneous clusters of farms, which was confirmed by ANOVA and t-test results. The analysis was

Table 14. Regression to explain gross margin over milk (GMM) by the variation of economic feeding efficiency (EFE), calving interval (CI) and illness score (IS)

Variable	Coefficient	SE	*t*-statistic	Prob.
LOG(EFE)	0.770346	0.120095	6.414483	0.0000
LOG(ACI)	0.417879	0.018430	22.67364	0.0000
LOG(IS)	–0.186810	0.043743	–4.270643	0.0002
Dependent variable	LOG(*GMM*)	Mean dependent variable		3.192702
Adjusted R^2	0.517774	SD dependent variable		0.169455
SE of regression	0.117674	Sum squared residuals		0.429259

SE: standard error. SD: standard deviation.

based on the centroid of each of the two clusters, which represented two farming models having differing economic performance, according to the values of ROE and gross margin over milk. The technical coherence of the two models was verified by comparing the production of forage from farmland and the costs of feed with the feed requirements of the herds and the quantity of milk produced. Relatively small inconsistency was found, which suggested their technical plausibility and sustainability; this constituted the main validation of the clustering process. The differences among the main structural, economic and technical features of the two models were investigated to explain the differing economic performance between the farms in each of the clusters. The land endowment, production of forage, and irrigation activity were not significantly different between the two models. Although the farms in the more profitable cluster tended to involve a greater proportion of tenant farming, the farmers in each cluster owned most of their farmed land, managed a similar number of cattle, and had similar levels of capital invested and equity. Significant differences were evident in the dynamics of the two models, with the better performing model showing increasing herd size through internal turnover, and having greater efficiency in terms of reproductive capacity and potential turnover. These dynamics influenced the differences in milk production, with the increasing herd size on farms in Model 2 probably coupled to the purchase of milk quotas from the farms in Model 1. Conversely, the farms in Model 1 were not able to counteract the decline in herds despite resorting to new purchases of animals. However, these changes did not result in statistically significant differences in milk production and value (total and per cow). In addition, the milk price was almost identical between the two clusters. As the milk cooperative pays farmers a premium price for milk quality based on fat and protein content, it was therefore concluded that the farms in each of the clusters produced comparable quality milk, and that the difference in economic performance was not a result of this factor. Similarly, no statistically significant differences in the components (variable and fixed costs) in the economic accounts of the two farming clusters were sufficient to explain the different income and profit results. However, major differences were evident in the productivity of farms in each of the two models. Based on indicators computed per unit of milk sold, the better performing farms of Model 2 had higher sale prices for calves, heifers and reformed cows, and less expenditure on feed and veterinary services, with no significant differences evident with respect to unitary fixed costs. Similarly, significant differences were evident between the models in terms of the values of milk, non-milk animals and crop sales produced using family labour. The more productive use of resources by farms in Model 2 was confirmed by indicators related to crucial aspects of herd management; the farms comprising Model 2 had a significantly higher level of EFE and a shorter ACI. In conclusion, management rather than structural aspects appeared to determine the net income and profit among the farms in the study. The farms represented by Model 2 had healthier herds, leading to fewer veterinary expenses. This was coupled with a shorter ACI, reflecting that healthier cows become pregnant sooner after the last *partum*. This more efficient breeding activity generated other benefits in addition to milk production, and was achieved with lower animal feed costs. These general management conditions enabled the farms comprising Model 2 to remain profitable despite using approximately half of the net income to compensate the family labour, while those in Model 1 undercompensated family labour and generated negative profits. However, the possibility of further efficiency gains was plausible for the farms in Model 2, where there was a 7% difference between the number of days forming the ACI and that optimality resumed by the short calving interval of 12 months. The analysis undertaken in this study suggests that farmers should be supported to improve management skills by providing technical assistance and training to improve efficiency.

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