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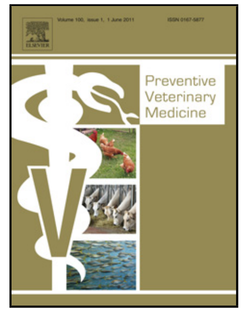

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Impact of *Mycobacterium avium* subspecies *paratuberculosis* on profit efficiency in semi-extensive dairy sheep and goat farms of Apulia, southern Italy

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Highlights

- In Apulia, semi-extensive dairy sheep and goat farms are affected by Paratubercolosis;
- Providing detailed economic information for decision makers is crucial;
- The impact of MAP on profit efficiency in semi-extensive flocks is assessed;
- Several farmer-related, productive and managerial factors contribute to farm inefficiency;
- The highlighted hot spots could assure effectiveness and efficiency to future intervention plans.

Abstract

A recent study on paratubercolosis in semi-extensive dairy sheep and goat farms in Apulia revealed a positivity in the flocks of 60.5% and a seroprevalence of 3.0% for sheep and 14.5% for goat, with peaks of 50%. In such a context, providing detailed economic information is crucial for the implementation of a suitable control plan.

In this paper we investigated the impact of *Mycobacterium avium* subspecies *paratuberculosis* (MAP) on profit efficiency of the Apulian dairy sheep and goat farms. Empirical results through a stochastic frontier model showed that the uninfected farms had a mean level of profit efficiency of 84%, which dropped to 64% in the presence of paratubercolosis as it negatively affected the productivity of feeding, veterinary and labour factors. Structural, managerial and production aspects were involved in the greater inefficiency of the infected farms compared to the uninfected ones: lower experience and schooling of farmer, no access to credit, fewer family members (women in particular) participated in the farming activities, high density of animals per hectare, small flocks, high number of goats in mixed flocks, no confinement practices for young and purchased animals and no pasture rotation. Hence, targeted interventions on these factors by decision makers can ensure effectiveness and efficiency to veterinary and economic action plans.

Keywords: Paratubercolosis; Dairy sheep and goat farms; Stochastic frontier; Profit efficiency; Apulia.

1. Introduction

Paratubercolosis (PTB), also known as Johne’s disease, is a contagious, chronic and sometimes fatal infection that primarily affects the small intestine of ruminants (Stabel, 1998; Sweeney, 1996; Whittington and Sergeant, 2001; Pistone et al., 2012). The disease leads to economic losses (Winterhoff et al., 2002; Wiszniewska and Szteyn, 2002) due to decrease in milk production, costs involved in diagnosis and disease control, culling of affected animals and low carcass value at slaughter (Mendes et al., 2004). Besides, PTB is potentially connected with Crohn’s disease in humans (El-Zaatari et al., 2001; Hermon-Taylor et al., 2000; Kennedy and Benedictus, 2001; Lund et al., 2002; Naser et al., 2002; Richter et al., 2002; Raja et al., 2014). The infection is distributed throughout the world (Daniels et al., 2003; Olsen et al., 2002; Nielsen and Toft, 2009; Attili et al., 2011) and its prevalence tends to increase (Winterhoff et al., 2002). The etiologic agent, MAP, is believed to be capable of infecting and causing disease in all ruminants (e.g. cattle, sheep, goats, llamas and deer) both in captive and free-ranging living conditions.

Recent studies have highlighted a strong spread of paratuberculosis (PTB) on dairy sheep and goat farms in Apulia (Scaltrito et al., 2015). The epidemiological results showed that 60.5% of flocks, 3.0% of sheep and 14.5% of goat are positive to MAP. The number of positive animals per farm ranges from 0 to 49, with a mean of 3.48. Among the risk factors, biological (age of the animal), structural (number of goats in mixed flocks, number of species on small farms, flock size and stagnant water in the fold) and managerial aspects (faecal contamination of water and food, farmer experience, management of births in individual boxes, confinement of the purchased animals in separate pens, partition and rotation of pastures) proved to affect seroprevalence in the sampled farms (Sardaro et al., 2015).

In order to ensure suitable monitoring and surveillance of infection so to reduce the impact of PTB, epidemiologic, risk factor and economic studies are crucial to provide appropriate information for the development of suitable control strategies, prophylactic programs and economic aid plans (Kahrs, 2008; Birkhaeuser et al., 1991). In particular, economic studies can supply useful information regarding the impact of infection on profit efficiency. Profitability and efficiency in dairy farming depend on a combination of structural, productive and managerial factors, coordinated through decision-making in the long, medium and short run (Rougoor et al., 1998). Empirical literature has shown that dairy farms often prove to be inefficient for several reasons and reducing their inefficiency requires a better (i.e. optimal) combination of inputs (feeding, labour, etc.) and outputs (dairy products, meat, etc.) (Lawson et al., 2004; Heshmati and Kumbhakar, 1994; Bravo-Ureta and Rieger, 1991).

In this framework, MAP infection could negatively affect a non-optimal combination of structural, managerial and productive factors, thus generating inefficiency, in terms of lower outputs and/or increased production costs. Should this be the case, the inefficiency factors need to be identified and a strategy developed for farms to improve their efficiency levels whilst controlling the infection. Several studies on economic efficiency in the livestock sector have been carried out worldwide (for example, van Rensburg and Mulugeta, 2016; Huang et al., 2016; Shomo et al., 2010; Gaspar et al., 2009; Lawson et al., 2004). However, to our knowledge, this is the first attempt to quantify the economic effects of MAP infection on sheep and goat farms in general, and specifically in Italy.

The paper aims to study if and how the presence of MAP in semi-extensive dairy sheep and goat farms in Apulia influences their profit inefficiency. Through a stochastic profit frontier model (Battese and Coelli, 1993; Battese and Coelli, 1995), the analysis illustrates the inefficiency differences between uninfected and infected farms. This approach investigates factors which can be adjusted in the short, medium and long run so as to improve the effectiveness and efficiency of proper sanitary measures, avoiding economic losses. The rest of the paper is organized as follows: i) discussion on small ruminant production in Apulia, the target population and management system, data collection and the empirical model used; ii) brief description of the survey samples iii) presentation of the empirical results; iv) discussion and policy implications and v) conclusions.

2. Materials and Methods

2.1 Small ruminant production in Apulia

Apulia, in southern Italy, is the country's fifth greatest region in the dairy sheep and goat sector, with about 3,000 farms and 300,000 animals (ISTAT, 2010). In addition to productive (mainly meat and dairy products) and economic elements, the sector also affects social and environmental aspects in the internal and disadvantaged territories of the region (Gargano, Murgia, north Salento). Due to their particular socioeconomic dynamics (aging population, marginal productive activities, lack of infrastructure, etc.), these areas are at risk of abandonment, and the sheep and goat sector is held back by structural, managerial and market weaknesses. Indeed, despite several high-quality typical products, processing occurs almost entirely in a great number of small family-run farms, often managed by elderly farmers. Such structural production characteristics generate short and local market channels that are not underpinned by suitable strategies capable of countering the problems of market globalisation, with consequent high productions costs and low profits.

2.2 Target population and management system

The Apulian target population of this study included 26,272 animals (16,903 sheep and 9,369 goats) in 526 farms (334 ovine and 192 caprine farms). The mixed farms were classified as sheep or goat according to the prevailing species. The sheep belonged to the Meticcia, Comisana, Sarda, Altamurana and Gentile di Puglia breeds, while the goats to the Meticcia, Ionica, Garganica and Camosciata delle Alpi. All the animals in the flocks had not been vaccinated against MAP.

Concerning the management system, animals are mainly bred in semi-extensive flocks for milk production. They graze on pastures throughout most of the year, spending most of the day outside, and are moved into the shed during the night. Does mate in June–August and deliver from November to January of the following year. Kids are weaned 15–30 days after birth and dams are mechanically or manually milked, once daily. Milking lasts 6 months and the annual replacement rate is approximately 20%.

2.3 Data collection

The study was based on primary data collected through face-to-face questionnaire-based interviews with semi-extensive dairy sheep and goat farmers in Apulia. The survey was carried out from February to October 2015. Detailed data on profit and production costs were collected and two samples were created, one for uninfected (224) and another for MAP-infected (220) farms, located over the whole region.

The questionnaire was divided into four sections: structural (farm area, flock size, sheepfold structure, etc.), management (nutrition, vaccinations, breed type, disease prevention, milking and manure management, etc.), production (production parameters) and socioeconomic aspects (age and level of schooling of the farmer, etc.). Interviews lasted about 50 minutes. Questions were closed (yes/no, always/frequently/seldom/never) and semi-closed (information on number of days) and the accuracy of the information provided by each farmer was checked with a direct inspection of the structures and facilities.

Sample size was defined based on the evidence reported in the stochastic frontier literature (for example: Janssens and Van Den Broeck, 1993; Kumbhakar et al., 2015), for which a good fitting of the efficiency model, in terms of a smaller estimation error of efficiency scores through the maximum likelihood estimates, was obtained through large sample sizes (roughly greater than 200 observations).

The farms in each sample were selected following a stratified random sampling based on the regional census data (ISTAT, 2010) relating to the number of animals and the area of the farms. The aim was to obtain representative samples of the regional dairy sheep and goat sector and to compare the economic efficiency results of the two samples.

2.4 The empirical model

The analysis was carried out through a stochastic profit frontier (Aigner et al., 1977; Meeusen and van den Broeck, 1977; Coelli, 1996; Coelli et al., 1998; Kumbhakar et al., 1989), which calculated the profit efficiency of uninfected and MAP-infected sheep and goat farms in Apulia. Profit efficiency is defined as the ability of a farm to achieve the highest possible profit given the prices and levels of fixed factors (Ali and Flinn, 1989) and converts any error of the production choice into lower profits (Ali and Flinn, 1989; Wang et al., 1996).

A translog stochastic frontier was used as the functional form since it is more flexible than a Cobb–Douglas function for its minor restrictions on farm technologies concerning constant production elasticity and unitary elasticity of substitution (Wilson et al., 1998). In formal terms, a stochastic profit frontier is a combination of two models. The first is a profit function (Kumbhakar et al., 2015) which models the relationship between profit and several productive costs. For the *i*th farm (uninfected or infected), it has the following form:

$$\ln \ \pi_i = \beta_0 + \sum_{j=1}^{n} \beta_j \ln x_{ij} + \frac{1}{2} \sum_{j=1}^{n} \sum_{k=1}^{n} \beta_{jk} \ln x_{ij} \ln x_{ik} + v_i - u_i \qquad [1]$$

where the dependent variable π_i is the annual profit of the *i*th farm, x_i's are the costs of production inputs, β_0, β_j, β_{jk} are the unknown coefficients to be estimated, j and k stand for the input costs considered. The error component v_i is assumed to be identically and independently distributed (i.i.d.) as $N(0, \sigma^2_v)$, while u_i is a nonnegative, unobservable random variable that captures the technical inefficiency of the observations and is assumed to be distributed independently of the normally distributed error term v_i.

The annual profit (euros/litre of milk) was calculated as gross return[1] minus total farm costs. The costs of production inputs (euros/litre of milk) considered as explanatory variables were: a) capital costs, i.e. depreciation, maintenance and other costs not recorded as variable costs and concerning cultivation and breeding practices, such as tractor, machinery, etc.; b) total labour cost, i.e. hired and family labour; c) cultivation costs, concerning seeds and fertilizers; d) feeding costs, namely fodder and concentrates; e) veterinary cost, i.e. medicines and sanitization products; f) other costs, i.e. fuel, electricity and other miscellaneous expenses (Table 1).

The second model concerns profit inefficiency and investigates the farm-specific characteristics which cause inefficiency. It is expressed as:

$$u_i = \delta_0 + \sum_{m=1}^{M} \delta_m z_{mi} + \omega_i \qquad [2]$$

where z_i's are the explanatory variables that are thought to be the cause of inefficiency, δ_0 and δ_m are the unknown coefficients to be estimated and ω_i is the unobservable random error assumed to be independently distributed with a positive, half-normal distribution. In similar studies, the most frequently used independent variables are farmer's education and experience, access to credit, farm size, land tenure and environmental and non-physical factors, like information and supervision, which may influence the capability of producers to use the available technologies. However, in general terms, the indicators to be used in the model depend on the relevant conditions in the

[1] Gross return did not include CAP aids. Other dairy revenues (i.e. from wool and cheese) were not included in profit valuation because they represented less than 2% of gross return in all the sampled farms.

research area and the availability of data. In our case, the following factors were used: farmer's age and education; household size; share of labour force members in the household, with particular attention to the female labour; access to credit; livestock unit per hectare[2]; seroprevalence; number of heads. Moreover, we added other structural and managerial variables which affect seroprevalence in flocks (Sardaro et al., 2015), which may influence the farming costs and, consequently, profit. Such variables are: share of goats in mixed flock; management of births in individual boxes; confinement of purchased animals in separate pens; partition and rotation of pastures (Table 1).

Table 1 - Definition of independent variables considered in the analyses and expected signs.

Considerations were made regarding the expected signs of the factors used although, due to the lack of efficiency studies in the sheep and goat sector, we mainly derived that information from the efficiency analyses carried out in the agricultural and livestock sector in general (for example: Lawson et al. 2004; Bozoğlu and Ceyhan, 2007; Hansson and Öhlmér, 2008; Rahman, 2003; Tzouvelekas et al., 2001; Tan et al., 2010). In particular, age is a proxy for breeding experience so its impact on inefficiency in Apulian farms is expected to be negative. However, this variable could also be positively related to inefficiency if it is synonymous with obsolete breeding practices. A higher level of education can lead to a better assessment of the importance and complexities of production decisions, in particular in infected farms, resulting in a better arrangement of breeding practices. The impact of education on inefficiency is therefore negative. A larger household size may imply more time for housework (taking care of children, for example), thus the impact of this variable on inefficiency is positive. A larger share of household members in the labour force usually implies more labourers and thus more time given to farming activities, leading to lower inefficiency. Availability of credit encourages technical innovation and reduces monetary constraints on production, facilitating a timely monetary liquidity as needed for production. Hence, it is supposed to reduce inefficiency. For the other variables added to the analysis no information on their sign was detected in the literature. In this connection, the contribution of women to the farm's labour force was included in the model following the results of several studies focusing on the agricultural sector in general (Ani et al., 2004; Iheke, 2008; Udoh, 2005; Oladeebo and Fajuyigbe, 2007), although they mainly concerned developing countries. According to these findings, female support in business activities is positive in terms of profit, innovation, management, etc., so the impact on inefficiency should be negative. The livestock unit/hectare ratio may be considered a

[2] In accordance with Ministerial Decree of April 7, 2006, as well as with Commission Regulation (EC) 1974/2006, a dairy sheep or goat head of more ten months corresponds to 0.15 livestock unit (LU), referred to a dairy cow of more 24 months.

dummy measurement of feeding sustainability on a semi-extensive farm, i.e. its capacity in meeting the daily food demand of the flock, so it may be positively related to inefficiency. Besides, in environmental terms, high density may generate sanitary issues, hence an increase in costs and greater inefficiency. However, from a profit standpoint, a high density could trigger economies of scale with higher profit and low inefficiency. The impact of this variable is thus uncertain. Seroprevalence and the number of goats in mixed flocks are also expected to be positively related to inefficiency, while the number of animals could reduce inefficiency as larger flocks may benefit, for example, of economies of scale and more attentive sanitary interventions. Finally, amongst the management variables, management of births in individual boxes, confinement of purchased animals in separate pens and partition and rotation of pastures are expected to be negatively related to inefficiency as aspects capable to reduce seroprevalence (Sardaro et al. 2015).

The parameters of the profit function and the inefficiency model were estimated simultaneously by the maximum likelihood (ML) procedure following Battese and Coelli (1993). The analysis was carried out using the NLOGIT 5 software.

The check of the models' fitting was carried out through the statistics γ, σ^2 and γ^*. In particular, the first indicates a high level of inefficiency on farms and ranges from zero (no inefficiency) to one (maximum inefficiency) (Battese and Coelli, 1995). σ^2 indicates inefficiency affecting profit in farms, while γ^* (Coelli et al., 1998) measures the differences in the efficiency levels between the considered farms and the maximum frontier. The following hypotheses were also verified:

1. H_0: $\beta_{ij} = 0$ (The translog stochastic frontier production function can be reduced to a Cobb Douglas model);
2. H_0: $\gamma = \delta_0 = \delta_m = 0$ (Inefficiency effects are absent in farms);
3. H_0: $\delta_0 = \delta_m = 0$ (Firm-specific factors which enable to explain inefficiency are absent in farms).

Technical efficiency (TE_i) of the *i*th farm was obtained from the stochastic frontier model using the predictor proposed by Battese and Coelli (1992):

$$TE_i = E\left[\exp(-u_i) \mid \varepsilon_i\right] = E\left[\exp\left(-\delta_0 - \sum_{m=1}^{M} \delta_m z_{mi}\right) \mid \varepsilon_i\right] \quad \text{where} \quad \varepsilon_i = v_i - u_i \qquad [3]$$

where E is the expectation operator. A farm's technical efficiency is between zero and one and it is inversely related to the inefficiency effect.

However, the first-order coefficients of the translog function are not very informative so determination of profit elasticity (i.e. the measurement of how responsive profit is to a change in the costs of production inputs) is necessary. Hence profit elasticity for each input cost was calculated at the variable means (Awudu and Eberlin, 2001).

3 Results

3.1 Sample characteristics

Looking at the profit function data (Table 2), compared to uninfected farms, infected farms profit (€/litre of milk) was on average 23% lower and costs were 20% higher. In particular, all the considered costs increased from uninfected to infected farms, excepting the cultivation costs.

The Wilcoxon test showed that the *profit*, *labour*, *feeding* and *veterinary* variables were statistically mean-different in the two samples. For the inefficiency model, a different mean was detected for the *age*, *education*, *woman*, *goats*, *births*, *pens* and *rotation* variables, indicating that such factors may influence seroprevalence, hence costs and profits. Finally the average number of animals (*Heads*) and the density of flocks (*Density*) were not mean-different between the samples, as deliberately obtained through a stratified random sampling based on the regional census data, in order to get representative samples of the regional sector.

Table 2 – Descriptive statistics of the variables inserted in the analyses (profit and costs per litre of milk).

3.2 Stochastic frontier results

In the upper part of Table 3 regarding the profit function, the estimated parameters highlighted an inverse relation between profits and the costs considered in the analysis, except for the capital and feeding costs in the uninfected farms, just for the capital costs in the infected farms. Parameters for the infected farms were considerably higher, pointing to a more negative impact of costs on profitability when MAP infection was present.

The factors accounting for profit inefficiency were given by the estimated coefficients in the lower part of Table 3. For the uninfected farms, factors favouring the rise of inefficiency levels were: the farmer's little experience and education (*Age* and *Education*), the fact that few family members were employed on the farm (*Members*), the farm's scant access to credit (*Credit*), a high number of heads per hectare (*Density*), a small number of heads in the flock (*Heads*) and no pasture rotation (*Rotation*). Other family (*Household* and *Women*) and management (*Goats*, *Births* and *Pens*) factors were not statistically significant or important. Obviously, the variable *Seroprevalence* was not included in the analysis as a constant (0%) for all the sampled farms.

Similar trends were observed for the infected farms, but with a higher absolute value of the parameters (except for the *Heads* variable). In particular, seroprevalence was the main factor responsible for profit inefficiency. This was confirmed by other management variables related to the infection, thus a higher number of goats in mixed flocks (*Goats*), as well as the absence of suitable confinement practices for young animals (*Births*) and purchased animals (*Pens*) contributed to the increase of profit inefficiency together with the other aforesaid factors (less experience in breeding practices, fewer years of schooling by farmer, absence of family members involved in breeding activities, small number of heads in flock, high density of animals and the use of pasture rotations). The *Woman* variable was significant at 10%, indicating that the involvement of women in decision-making reduced profit inefficiency in the presence of MAP; besides, also an easy access to credit influenced the reduction of the inefficiency level. Finally a z-test (Paternoster et al., 1998; Clogg et al., 1995) highlighted a statistical difference of the aforesaid estimated coefficients between the infected and uninfected farms.

On the fitting statistics and tests (bottom of table 3), the parameters γ and σ^2 indicated that i) a high level of inefficiency existed in the uninfected farms and it tended to increase in the presence of MAP (parameters close to 1 and significantly different from zero) and ii) inefficiency affected the level and variation of profit in both uninfected and infected farms. The γ^* implied that 42% (uninfected farms) and 75% (infected farms) of the differences between the observed and the maximum frontier profits were due to existing differences in efficiency levels among farmers.

The null hypotheses on the reduction of the translog stochastic profit frontier to a Cobb-Douglas, the absence of the inefficiency effects and the zero values of the explanatory variables in the inefficiency model were rejected, confirming the validity of the functional form as well as of the variables included in the analysis (Table 4).

Table 3 - Maximum-likelihood estimates for parameters of translog stochastic profit function and inefficiency effect model.

Table 4 - Hypothesis tests for model specification and statistical assumptions.

Profit efficiency was 84% for uninfected farms and 64% for the infected farms and the efficiency values between the two samples were statistically different at the 1% level by the Spearman rank-order correlation coefficient, implying that the uninfected farms could increase profits by about 16% and the infected ones by 36% (Table 5). In other words, on average the profit of the uninfected (infected) farms was 84% (64%) of the best practice profit. Farmers exhibited a wide range of profit efficiency, from 54% (41%) to 92% (90%), however, while 35% of the uninfected farms had a profit efficiency between 91% and 100%, just 1% of the infected farms was included in this range. In fact, profit efficiency of the infected farms was on average 23% lower and its estimate per classes of seroprevalence showed a linear inverse relation (Figure 1).

Table 5 – Profit efficiency for uninfected and infected farms.

Figure 1 – Average profit efficiency per seroprevalence classes in the infected farms.

Table 6 presents the basic features of the production structure (profit elasticity). Inter alia, in the uninfected farms, estimates indicated that the increase in the milk price generated the higher profit growth, followed by the feeding and capital costs. By contrast, the increase in veterinary costs contributed the most to profit reduction, followed by labour, other and cultivation costs. In the presence of MAP infection, the negative impact of such costs on profitability increased, as well as that of feeding costs. In absolute terms, the largest percent variation of profit elasticity in the infected farms compared to the uninfected ones appeared for feeding, veterinary and labour costs, i.e. 75%, 66% and 60%, respectively. In the presence of MAP infection, the total elasticity for these factors was -1.053 (-0.165 in the uninfected farms) implying that, *ceteris paribus*, a 1% rise in feeding, veterinary and labour costs resulted in a 1.053% reduction in profit, while in the uninfected farms the negative impact of costs was dampened (profit reduced by only 0.165%). Profitability in the infected and uninfected farms was considerably elastic with respect to these factors, while the other quasi-fixed costs (capital, cultivation and other costs) had a lesser impact on profitability.

Table 6 - Price elasticity and returns to scale of the uninfected and infected farms.

4. Discussion and policy implications

The analysis highlighted that dairy sheep and goat farms in Apulia were affected by profit inefficiency and such a phenomena was worsened by MAP. In particular, in uninfected farms, capital and feeding investments facilitated profit increases, while labour, cultivation, veterinary and other costs caused profit contraction which could derive from an increase in costs and a contemporaneous reduction or a constant trend of milk prices. Such a market situation has been confirmed by recent studies on the Italian dairy sheep and goat sector (REF, 2014), a trend that substantially undermines the competitiveness of Apulian sheep and goat farms.

In the infected farms, instead, only capital costs generated greater profits. The size of the negative coefficients was higher in absolute terms, indicating that the infection exacerbated the negative impact of a non-optimal combination of production factors. Feeding, veterinary and labour costs had the greatest effect on profitability, so decision-makers should seriously consider implementing proper actions regarding such investments, for example through a reduction of feed prices, veterinary fees and taxation for employers.

Several farm characteristics were involved in this dynamics in the infected flocks, namely the farmer's experience and schooling, access to credit, participation of family members (and women in particular) in the farm's activities, density of animals per hectare, number of goats in mixed flocks, confinement practices for young and purchased heads and pasture rotation. In particular, a farmer's long years of experience can help roll out useful measures to improve flock management and high school education is a further added value. These two elements tend to increase their positive impact in the presence of PTB, streamlining structural and management innovation and bolstering efficiency levels. Easier access to credit could favour the adoption of new structural solutions, such as confinement structures for young and purchased animals and pasture rotation, countering the increase in the related cultivation costs. For that matter, such an approach could benefit from the measures contained in the 2014–2020 Rural Development Programme of Apulia (Apulia Region, 2015), which is based on a large set of regional objectives, such as modernizing and improving productive processes, implementing product diversification, enhancing production quality, ironing out difficulties in credit access etc. Hence, easier credit access for farms, suitable training programmes for farmers and a greater popularization of the available EU aids could contribute to the implementation of structural and management interventions in farms to reduce the infection and increase profit.

The study also highlights the positive impact that family members have on profit efficiency. Their activities on their farms can reduce labour costs and foster the implementation of innovative short food supply chain strategies, developing autonomous marketing strategies based on the differentiation of dairy products. Such strategies can increase the added value of production within the farm, hence profit. However, difficult working conditions and low revenues drive the new generations away from farming to look for more remunerative and comfortable jobs, often in urban areas. This is why decision-makers are called upon to enact proper policies for the generational turnover in the Apulian livestock sector in order to exploit the positive impact of this important efficiency factor.

The positive impact of women's activities in the presence of MAP was an interesting highlight of the analysis. The involvement of women led to a reduction of profit inefficiency probably because of their greater attention to sanitary aspects, especially in the birth and milking phases. Indeed, the role of women in a prevailing agricultural model in crisis fosters a reformulation of socioeconomic development priorities. In this context, recent studies highlighted that in the short food supply chain female entrepreneurship is often a reaction to the crisis of intensive agricultural models, promoting cultural and economic development of a specific area by leading the agricultural system towards well-being and sustainability. In the agricultural sector, farms managed by women tend to be multi-functional and to increase their production in quantitative and qualitative terms (Zirham and Palomba, 2016). Besides, women are more likely to undertake, innovate and diversify business activities strengthening the business structure and supporting the local economy through alternative strategies. Nevertheless, to date, female agriculture entrepreneurship is a phenomenon to better explore also in developed countries and the results of our study point to such a trend. Hence regional policy makers are called upon to consider that a greater involvement of women in the breeding businesses could favour higher efficiency levels in the Apulian sheep and goat farms.

The high density of animals per hectare reduces efficiency levels probably for feeding inefficiencies and sanitary issues, however, efficiency levels are similarly impacted by a small number of animals in the flock, maybe due to the inability in exploiting economies of scale. In other terms, large flocks increase efficiency on condition that the area of the farms is proportionate to the number of animals. Finally the presence of a high number of goats in mixed flocks affects inefficiency probably for sanitary issues.

Overall, the results point to the impact of MAP infection on the profitability of sheep and goat farms in Apulia, providing useful information for economic intervention programmes. The sector is important not only for private farmers' profit, but because it encompasses a wide set of positive externalities including the environment, agro-biodiversity, food safety and cultural heritage. Therefore, a broad policy agenda is needed in order to face the epidemiological and economic problems of infection.

5. Conclusions

This study derived the profit inefficiency factors for semi-extensive dairy sheep and goat farms in Apulia in the absence/presence of MAP infection by using the stochastic production frontier approach. The mean profit efficiency in the uninfected farms was 84% and exhibited a 20% drop to 64% in the presence of MAP infection.

Structural, managerial and production aspects are involved in the increase in the inefficiency level of infected farms compared to the uninfected ones, including the farmer's scarce experience and schooling, no access to credit, little or no involvement of family members (women in particular) on the farm, high density of animals per hectare, small flocks, high number of goats, no confinement practices for young and purchased heads, no partition or rotation of pastures and high seroprevalence.

Suitable strategies can be implemented in order to reduce profit losses: aids for capital, feeding, veterinary and labour investments; better services and training programmes for farmers; better access to credit to make the necessary structural (i.e. pens), technological and veterinary changes; promotion of larger flocks but with a proper density of heads per hectare; greater involvement of women and young breeders in production activities; better communication to farmers of the EU aids provided for the regional Rural Development Programme.

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Table 1 - Definition of independent variables considered in the analyses and expected signs.

Variable	Name	Unit	Expected sign
Profit function			
Capital costs	Capital	€	+/-
Labour costs	Labour	€	+/-
Cultivation costs	Cultivation	€	+/-
Feeding costs	Feeding	€	+/-
Veterinary costs	Veterinary	€	+/-
Other cost expenses	Other	€	+/-
Inefficiency effect model			
Age of farmer	Age	Year	+/-
Education of farmer	Education	Year	-
Household size	Household	Number	+
Share of labour force between household members	Members	%	-
Share of woman labour force	Woman	%	-
Dummy =1 if farmer received credit in the past	Credit	-	-
Livestock unit/hectare	Density	Ratio	+/-
Seroprevalence	Seroprevalence	%	+
Number of heads	Heads	Number	-
Share of goats in mixed flock	Goats	%	+
Dummy =1 if births are confined in individual boxes	Births	-	-
Dummy =1 if purchased animals are confined in separate pens	Pens	-	-
Dummy =1 if partition and rotation of pastures are carried out	Rotation	-	-

Table 2 – Descriptive statistics of the variables inserted in the analyses (profit and costs per litre of milk).

Variable	Uninfected farms (n=224)				Infected farms (n=220)			
	Min	**Max**	**Mean**	**S. d.**	**Min**	**Max**	**Mean**	**S. d.**
Profit function								
Profit*	0.24	0.43	0.30	0.16	0.18	0.33	0.23	0.17
Capital costs	0.05	0.10	0.07	0.02	0.05	0.12	0.08	0.03
Labour costs*	0.18	0.32	0.27	0.05	0.26	0.40	0.31	0.04
Cultivation costs	0.04	0.08	0.06	0.02	0.03	0.09	0.06	0.03
Feeding costs*	0.06	0.13	0.07	0.04	0.08	0.14	0.09	0.04
Veterinary costs*	0.01	0.03	0.02	0.01	0.02	0.07	0.05	0.02
Other costs	0.05	0.12	0.06	0.02	0.04	0.12	0.07	0.04
Inefficiency model								
Age*	24	77	52.13	8.32	23	75	56.86	9.70
Education*	5	14	8.93	4.47	5	16	7.82	5.71
Household	2	6	3.25	2.21	1	6	3.41	2.92

Members	10	100	49.8	15.39	8	100	31.42	17.84
Woman*	5	18	8.64	2.57	4	21	6.12	3.70
Credit	0	1	0.22	0.15	0	1	0.18	0.17
Density [a]	0.33	0.87	0.55	0.21	0.26	1.20	0.78	0.29
Seroprevalence	0	0	0	0	3.68	46.41	19.86	5.67
Heads [a]	17	582	139	30,23	23	626	144	29,55
Goats*	0	100	19,32	6.79	0	100	35.50	11.62
Births*	0	1	0.52	0.22	0	1	0.20	0.28
Pens*	0	1	0.62	0.14	0	1	0.31	0.27
Rotation*	0	1	0.69	0.20	0	1	0.36	0.16

* Difference in means between the two samples were statistically significant at Wilcoxon test.

[a] Through the Pearson correlation coefficient, the *Density* and *Heads* variables in the two samples were weakly correlated each other (uninfected farms: 0.1644 and p-value: 0.0001; infected farms: 0.1832 and p-value: 0.0001), excluding the effects of multicollinearity.

Table 3 - Maximum-likelihood estimates for parameters of translog stochastic profit function and inefficiency effect model.

Variable		Parameter	Uninfected farms			Infected farms		
			Coeff.	**T-ratio**	**Sig.**	**Coeff.**	**T-ratio**	**Sig.**
Profit function								
Constant	°°	β_0	12.105	10.937	***	11.421	9.277	***
ln(Capital)	°°°	β_1	0.740	4.265	***	1.009	4.923	***
ln(Labour)	°°°	β_2	-1.033	-2.703	**	-1.844	-4.881	***
ln(Cultivation)	°°	β_3	-0.641	-1.820	*	-0.813	-2.170	**
ln(Feeding)	°°	β_4	1.204	5.328	***	-1.639	-7.333	***
ln(Veterinary)	°°°	β_5	-1.139	-2.544	**	-1.488	-5.721	***
ln(Other)	°°	β_6	-0.724	-1.479	*	-0.382	-1.649	*
$[\ln(\text{Capital})]^2$	°°	β_{11}	0.077	3.920	***	0.249	0.800	
$[\ln(\text{Labour})]^2$	°°	β_{22}	-0.091	-1.441	*	-1.723	-1.255	*
$[\ln(\text{Cultivation})]^2$		β_{33}	-0.035	-0.722	*	-0.046	-0.063	
$[\ln(\text{Feeding})]^2$	°	β_{44}	0.084	2.786	**	-0.114	-2.294	**
$[\ln(\text{Veterinary})]^2$	°	β_{55}	0.642	2.003	*	0.423	1.990	*
$[\ln(\text{Other})]^2$		β_{66}	-0.037	-1.482		-0.070	-0.077	
ln(Capital) x ln(Labour)	°	β_{12}	-0.075	-1.391		-0.327	-1.070	
ln(Capital) x ln(Cultivation)	°	β_{13}	-0.012	-0.595		0.105	1.270	
ln(Capital) x ln(Feeding)	°°	β_{14}	0.253	2.592	**	-0.532	-0.081	
ln(Capital) x ln(Veterinary)	°	β_{15}	0.045	2.370	**	0.625	2.519	**
ln(Capital) x ln(Other)	°	β_{16}	0.012	0.033		0.011	0.093	
ln(Labour) x ln(Cultivation)	°	β_{23}	-0.865	-1.705	*	0.218	0.041	
ln(Labour) x ln(Feeding)	°°	β_{24}	0.449	2.369	**	0.557	2.660	**
ln(Labour) x ln(Veterinary)	°	β_{25}	0.032	0.947		0.243	2.044	*
ln(Labour) x ln(Other)	°	β_{26}	-0.093	-1.228		-0.434	-0.031	
ln(Cultivation) x ln(Feeding)	°	β_{34}	0.004	1.320		0.348	0.927	
ln(Cultivation) x ln(Veterinary)	°	β_{35}	0.003	0.040		0.246	0.409	
ln(Cultivation) x ln(Other)		β_{36}	-0.066	-0.582		0.109	0.022	
ln(Feeding) x ln(Veterinary)	°°°	β_{45}	0.191	2.436	**	-1.240	-1.891	*
ln(Feeding) x ln(Other)		β_{46}	0.027	0.200		-0.382	-0.209	
ln(Veterinary) x ln(Other)		β_{56}	-0.090	-0.738		0.003	0.046	
Inefficiency effect model								
Constant	°°°	δ_0	4.005	5.847	***	6.884	2.385	**
Age	°°	δ_1	-1.883	-5.773	***	-2.042	-2.609	**
Education	°°°	δ_2	-0.569	-1.811	*	-0.933	-2.328	**
Household	°	δ_3	-0.135	-0.054		0.037	0.750	
Members	°°	δ_4	-1.693	-6.380	***	-1.829	-4.236	***

Woman	°°	δ_5	-0.136	-1.214		-0.160	-1.807	*
Credit	°	δ_6	-0.637	-2.701	**	-0.859	-1.935	*
Density	°°	δ_7	0.409	3.858	***	0.602	2.394	**
Seroprevalence	-	δ_8	-	-	-	2.928	6.205	***
Heads	°°	δ_9	-1.762	-4.020	***	-0.937	-2.361	**
Goats	°°	δ_{10}	-0.347	-0.726		1.652	2.304	**
Births	°°°	δ_{11}	0.083	0.513		-1.640	-3.612	***
Pens	°°	δ_{12}	-0.067	-1.594		-0.228	-1.450	*
Rotation	°°	δ_{13}	-0.889	-2.386	**	-1.183	-2.600	**
Variance parameters								
$\sigma^2 = \sigma_v^2 + \sigma_u^2$			0.138	3.305	***	0.091	4.963	***
$\gamma = \sigma_u^2 / \sigma^2$			0.67	5.836	***	0.85	7.448	***
$\gamma^* = \gamma / \left[\gamma + (1-\gamma)\pi/(\pi-2)\right]$			42.43			74.60		
Log likelihood			-185.13			-157.10		
Obs.			224			220		

***: sign. 1%; **: sign. 5%; *: sign. 10%.

°°°: sign. 1%; °°: sign. 5%; °: sign. 10% at the z-test $\left(Z = b_1 - b_2 \Big/ \sqrt{SE_{b_1}{}^2 + SE_{b_2}{}^2}\right)$.

Table 4 - Hypothesis tests for model specification and statistical assumptions.

Null Hypothesis	λ		Critical values of λ (α=0.05)
	Uninfected farms	Infected farms	
1. The translog stochastic frontier production function can be reduced to a Cobb Douglas model	210.81	192.19	24.996
2. Inefficiency effects are absent in farms *	80.69	91.10	10.371
3. Firm-specific factors which enable to explain inefficiency are absent in farms	72.48	63.77	16.919

* Critical values from table 1 in Kodde and Palm (1986).

Table 5 – Profit efficiency for uninfected and infected farms.

	Profit efficiency classes										
	<50	51-60	61-70	71-80	81-90	91-100	Farms	Mean	Min	Max	S. d.
Uninfected farms	0	2	20	28	95	79	224	84.03	53.80	92.10	9.04
Infected farms	24	54	81	45	13	3	220	64.42	41.25	90.13	13.70

The Spearman rank-order correlation coefficient (ρ) between the profit efficiency values of the two samples was 0.133 and significant at the 1% level.

Figure 1 – Average profit efficiency per seroprevalence classes in the infected farms.

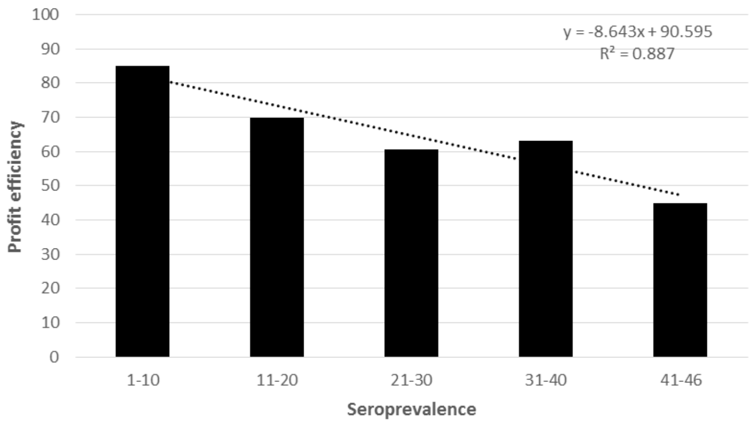

Table 6 - Profit elasticity of the uninfected and infected farms.

	Profit elasticity				
	Uninfected farms		**Infected farms**		**% variation [a]**
Milk price	1.837	***	2.203	**	+19.9%
Capital costs	0.088	**	0.114	*	+29.5%
Labour costs	-0.182	*	-0.291	*	+59.9%
Cultivation costs	-0.095	*	-0.147	**	+54.7%
Feeding costs	0.232	***	-0.406	**	+75.0%
Veterinary costs	-0.215	**	-0.356	**	+65.6%
Other costs	-0.128	**	-0.157	*	+22.7%

***: sign. 1%; **: sign. 5%; *: sign. 10%.

[a] Calculated as: [(Infected - Uninfected) / Uninfected] x 100