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Review

## Bio-economic models for deriving economic values for sheep: a review

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**Abstract.** Selection is an important part of animal breeding and is usually performed on the basis of a set of traits, each of them characterized by its BV (breeding value) and EV (economic value). Different approaches have been used in recent years for the calculation of the economic values of traits - simple profit functions and more complex bio-economic models. The most common approach nowadays is the bio-economic modeling of the production system due to its precision, flexibility, the inclusion of many biological details reflecting the changes in genetic values on overall profitability. The objective of this review is to present and summarize research on calculation of economic values for dairy, meat and indigenous (multipurpose) sheep breeds using bio-economic models. According to the type of sheep production, various productive and functional characteristics have been studied. Of particular importance for the predominance of a particular trait over others in terms of its contribution to profit on farms are the breed, production system, climatic conditions, market determinants, demand and supply of sheep products, etc., which may undergo changes over time. For this reason, a recalculation of the economic importance of profit-related traits in sheep is needed for the adaptation of the breeding objectives of the enterprises according to their economic importance.

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**Keywords:** sheep, bio-economic models, economic values, production traits, functional traits

### Introduction

Sustainability of productive systems in livestock is of particular importance, considering the declining profitability, demographic problems and the ecological footprint of animal production. A way to increase the income of sheep farmers and keep enterprises competitive is through genetic improvement by participation in a breeding program (Wolfová et al., 2009a). Setting a well-defined breeding objective is crucial to creating an opportunity for simultaneous genetic improvement of a set of traits (Dekkers and Gibson, 1998). Animal selection is an important part of animal breeding and is usually performed on the basis of a set of traits (Afshar and Aboozari, 2018), each of them characterized by its BV (breeding value) and EV (economic value). EV of a trait can be defined as the

change in the profit of the farm, as a consequence of one unit of change in the genetic merit of the trait considered (Charfeddine, 2000). As terms “economic value” and “economic weight” are often used interchangeably, they can be defined as the absolute and relative benefits of improving a trait (Amer et al., 2001). In order to establish a common index, it is necessary to define the relative share of the economic values of the traits involved (Fuerst-Waltl and Baumung, 2009). Therefore, the “economic weight” of a trait in the selection index is calculated on the basis of a comprehensive assessment of the economic importance of each of the studied traits (Krupová et al., 2009).

The methods for calculating of economic weights (EWs) in livestock can be divided into 2 groups - objective and subjective methods, presented in Table 1 (Krupová et al., 2008).

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**Table 1.** Methods for calculating economic values

Subjective methods	Objective methods				
	Positive approach		Normative approach		
	Data evaluation		Data simulation		
	Profit function		Bio-economic models		
		<i>Linear optimization</i>	<i>Dynamic optimization</i>	<i>Deterministic</i>	<i>Linear optimization</i>

Various approaches have been used for the calculation of the effect of changes in traits on the economic efficiency of sheep production systems (Wolfova et al., 2009a; Bohan et al., 2019), including simple profit functions (Ponzoni, 1988; Morais and Madalena, 2006; Nielsen et al., 2014), and more complex bio-economic models (Kosgey et al. 2003; Conington et al., 2004). Earlier studies on the economic effect of genetic changes in sheep traits were mostly focused on meat and wool breeds (Ponzoni, 1988; Cottle, 1990). The trait-by-trait approach has been used previously to calculate economic values for sheep in the UK (Conington et al., 2004), Ireland (Byrne et al., 2010) and Canada (Quinton et al., 2014), but it has been described as simplistic as it fails to account for the complex biological relationships that can occur between traits (Nielsen et al., 2014). In recent years, bio-economic modeling has been applied, allowing the incorporation of different types of farms and production systems (Conington et al., 2004; Jones et al., 2004).

Bio-economic models consist of a set of equations characterizing biological relationships, simulating management and economic situations and determining profitability or some other economic measures of efficiency of the production system (Krupova et al., 2008). They are commonly used to calculate economic values as they tend to expand the level of representation of biological interrelationships relative to simple profit equations (Groen et al., 1997; Michalickova et al., 2016). Economically

important characteristics are defined by building a model of the herd (flock) and its structure and profit is perceived as a criterion for economic efficiency. Bio-economic models have the advantages of precision, flexibility, the inclusion of many biological details, and they more accurately reflect the changes in genetic values on overall profitability. They provide a very powerful tool for estimating the economic value of genetic changes in different traits, as well as for studying their resilience to changes in nutrition, governance, and market prices (Jones et al., 2004).

### Applying bio-economic models to derive economic values for sheep

The object of this review is to present and summarize studies on calculation of economic values (weights) for small ruminants (particularly sheep) using bio-economic models. In sheep, the economic values of the traits related to milk production and its quality composition, growth abilities, reproductive indicators and productive life of ewes have been studied. Economic values of the most important productive and functional traits have been calculated for dairy, meat and local (multipurpose) sheep.

In terms of the main type of sheep production, authors investigated particular traits included in the breeding objective. Table 2 presents a list of studies on calculating economic values for dairy sheep applying the bio-economic model approach.

**Table 2.** List of studies focused on calculation of economic values for dairy breeds (or dual purpose breeds with emphasis on milk production) using bio-economic models

Author(s), year	Economic values (weights) of traits:
Wolfova et al. (2009a)	A model was developed for estimating of up to 35 milk production, growth, carcass, wool, and functional traits.
Wolfova et al. (2009b)	A bio-economic model was used to derive economic values of 15 performance and functional traits for the Slovakian Improved Valachian breed.
Krupova et al. (2009)	Marginal (MEV) and relative (REV) economic values of 14 production and functional traits for two Slovak dairy sheep breeds (Improved Valachian and Tsigai) were calculated.
Krupova et al. (2012)	MEV and REV of 14 performance and functional traits were calculated; influence of various production strategies on the REV of most important traits was investigated.
Krupova et al. (2013)	MEV and REV of 14 performance and functional traits were calculated; impact of changes in the economic parameters on the MEV and REV of the four most important traits was investigated.
Slavova (2020)	MEV and REV of 14 performance and functional traits in ewes of Bulgarian dairy synthetic population were estimated; impact of changes in the economic parameters on the MEV of the two most important traits was investigated.
Slavova and Laleva (2021)	MEV and REV of 14 performance and functional traits in ewes of Bulgarian dairy synthetic population were estimated.

A bio-economic model was developed by Wolfová et al. (2009a) aiming to estimate the effects of change in production and functional traits on profit of dairy (or dual-purpose with emphasis on milk production) sheep. The model included both deterministic and stochastic components, and Markov chain approach was used to calculate the stationary state of the ewe flock. The present value of profit was calculated as the difference between total revenues and total costs per ewe and year, both discounted to the birth date of the animals. Economic values of up to 35 milk, growth, carcass, wool, and functional traits may be estimated using the model, integrating the corresponding computer program established by Wolf et al., 2008. Wolfová et al. (2009b) estimated economic values of 15 important performance and functional traits for the Slovakian Improved Valachian breed.

Modern breeding programs in dairy farming focus primarily on milk production (Carta and Ugarte, 2003; Oravcová et al., 2005; Smulders et al., 2007) and litter size (Margetin et al., 2006), as milk and lambs being the main source of income on farms. All breeding sheep used to be selected on the basis of a simple selection index taking into account milk production and litter size (Krupová et al., 2009). At a later stage, functional traits have become important for efficient breeding schemes in the dairy sheep industries as well, due to increased costs of production relative to milk prices, and greater awareness of animal welfare (Barillet, 2007). Next in importance to milk production, lamb production accounts for a substantial part of the income for dairy sheep farms, so that reproductive performance of ewes, lamb survival, and lamb growth is important for the breeding programs in dairy sheep nowadays (Legarra et al., 2007; Fuerst-Waltl and Baumung, 2009).

Using a bio-economic deterministic computer model Krupová et al. (2009) calculated economic values of 14 production and functional traits for two Slovak dairy sheep breeds (Improved Valachian and Tsigai) with production system of one lambing per year. The marginal economic value of a trait was defined as the partial derivative of the profit function with respect to the trait. The relative economic value was expressed as the percentage proportion of standardized economic value (marginal economic value  $\times$  genetic standard deviation) of a trait in the sum of the absolute values of the standardized economic values of all traits. The traits for milk yield, conception rate, productive lifetime of ewes and litter size showed the highest economic importance, and the authors recommended female fertility traits and productive lifetime of ewes to be further investigated for their inclusion in an economic selection index. It is important to note that the proportion of milk processed to cheese on farms had a strong impact on the economic values of milk production traits and

productive lifetime of ewes. If the farm sells milk produced to dairies while keeping all other input parameters in the calculation constant, the marginal economic value of milk yield and productive lifetime will drop. Legarra et al. (2007) confirmed that the economic values for fertility (conception rate), prolificacy (number of lambs born) and milk yield was higher for cheese-seller farms than for milk-seller farms. In the calculation, which was based on a closed population model, productive lifetime of ewes was an important trait with a high economic value as well. On the other hand, when considering an open flock (Fuerst-Waltl et al., 2006) having the possibility of selling breeding animals, even a negative economic value of the productive lifetime of ewes may be achieved. This value turns to a positive one if the sale of breeding rams is not allowed.

In addition to derivation of economic values of traits, Krupová et al. (2012) carried out sensitivity analysis on the impact of various production strategies and performance levels on the relative economic values (REVs) of traits in dairy sheep using the bio-economic model implemented in the program package ECOWEIGHT (Wolf et al., 2011). REV of 14 production and functional traits were calculated. Simulated changes in the production circumstances (such as differing proportions of milk processed to cheese, customary and early weaning of lambs with immediate sale or sale after artificial rearing, seasonal lambing in winter and non-seasonal lambing in autumn) had a higher impact on the REV for milk yield than on REVs of the other traits investigated. The proportion of milk processed to cheese, weaning management strategy for lambs and level of milk yield were the main factors influencing the REV of milk yield

Krupová et al. (2013) investigated the impact of changes in the following economic parameters - market prices of lambs, milk, and cheese (variation  $\pm 40\%$ ), costs for roughage, concentrates, and total feeding rations, costs for labour and veterinary care, fixed costs (variation  $\pm 20\%$  for all costs), and discount rate of revenues and costs (0 and 3%), on the economic values of fourteen production and functional traits for the Improved Valachian breed. Results from the sensitivity analyses were presented for the marginal and relative economic values of the four most important traits: milk yield in the 150-day milking period, conception rate of ewes, litter size per ewe, and productive lifetime of ewes. Prices of sheep products were found to be the most important factor for both the marginal and the relative economic values of the evaluated traits. The relative economic values of milk yield and litter size were the most sensitive to the variation in economic circumstances. According to the authors, sensitivity analyses should be based on the relative economic values of traits rather than on their absolute

marginal economic values.

In Bulgaria, marginal and relative economic values of performance and functional traits in dairy sheep were estimated by Slavova (2020), and Slavova and Laleva (2021) for the Bulgarian Dairy Synthetic Population, using the EWSH2 program for sheep, as a part of ECOWEIGHT package program. Traits litter size and milk yield were found of greater economic importance. Slavova (2020) established that market prices of sheep products were of greater economic importance for the absolute value of the traits, compared to the prices of the raw materials for their production, especially when it comes to the traits milk yield and number of lambs born per ewe.

In meat producing sheep systems, traits related to the reproductive abilities of animals have high economic value. Table 3 describes studies on calculation of economic weights (EWs) for meat sheep using the bio-economic model approach. According to Conington et al. (2000), economic values (EVs) are required for each trait in the breeding goal so that selection emphasis is

proportional to the economic importance of each trait. In their manuscript, authors described how EVs for breeding goal traits suitable for UK hill sheep were derived for a combination of carcass, maternal and 'sustainability' traits using a bio-economic model. At a later stage, Conington et al. (2004) modeled three sheep farm types to reflect the three main hill types (intensive, semi-intensive, and extensive) in the United Kingdom. Results showed that the main influences on overall productivity were lamb output (number of lambs reared), lamb survival, and the weight of these lambs at the point of marketing. The authors stated that to improve prolificacy (which is of great importance to profit in meat sheep), the emphasis for selection could potentially be moved away from improving litter size toward the ability of the ewe to rear the lambs, which is very crucial for harsh environments. Selection for these traits will ensure that ewes of higher prolificacy will also have the ability to rear and nurture their lambs, which will lead to more sustainable breeding practices for hill sheep farms, which frequently suffer high neonatal losses.

**Table 3.** List of studies focused on calculation of economic values for meat producing sheep using bio-economic models

Author(s), year	Economic values (weights) of studied traits:
Conington et al. (2000)	It was described how EVs for breeding goal traits suitable for UK hill sheep were derived for a combination of carcass, maternal and 'sustainability' traits using a bio-economic model
Conington et al. (2004)	MEV and REV of 10 different maternal and carcass sheep performance traits were derived for hill sheep in the United Kingdom.
Afshari and Aboozari (2018)	EVs of seven important traits including pregnancy rate, litter size, lamb weight at birth, at three months (at weaning), at six months and at nine months, and survival rate until the age of 6 months were calculated for the Zel sheep under an intensive production system in Iran; sensitivity analysis of the EVs was investigated by changing prices of feed and live weight of 9-month-old lambs by $\pm 20\%$ .
Bohan et al. (2019)	MEV and REV of 14 traits of economic importance representing maternal, lambing, production and health characteristics in Irish meat sheep were calculated.

Afshari and Aboozari (2018) found that the most important trait in the intensive production system of raising Zel sheep for meat in Iran was litter size followed by the survival rate until the age of 6 months, conception rate, nine months' age weight, lamb weight at weaning, etc. The sensitivity of EVs of traits was investigated by changing prices of feed and live weight of 9-month-old lambs by  $\pm 20\%$ . Results showed that EV of live weight at 9 months of age was the most constant and EV of live weight at birth was the most variable. The study showed that the profitability of the production system could be increased by improving litter size, survival rate and pregnancy.

For a typical Irish flock, Bohan et al. (2019) calculated economic values and weights for the maternal, lambing, production and health traits in meat sheep within the

two Irish breeding objectives - terminal and replacement breeding objectives. The greatest emphasis was placed on production traits across both the terminal (62.56%) and replacement (41.65%) breeding objectives, and the maternal and lambing traits accounted for the 34.19% and 23.45% of the emphasis within the replacement breeding objective, respectively. Authors consider that the results from their study will enable the implementation of new economic values within the national terminal and replacement Irish sheep breeding objectives, which highlights the traits of importance for increasing overall farm profitability.

Studies on the value of some traits in local multipurpose sheep breeds were conducted by Rahimi et al. (2015) for the Makuii breed in Iran, by Bytyqi et al. (2015) - for several breeds in Kosovo, and by Gebre (2012) - for two breeds

in Ethiopia (Table 4). Using the software ECOWEIGHT, Rahimi et al. (2015) found that economic importance of the traits of birth weight, daily gain from birth until weaning, daily gain from weaning until end of period, conception rate of ewes, little size, lamb survival, lifetime for ewes, milk yield and wool yield were 0.66, 0.51, 0.03, 0.66, 0.25,

0.85, 0.93, 0.53 and 1, respectively. Therefore, wool yield, length of productive lifetime of ewes and ewe survival were the most important traits to increase the profit of the flocks. Authors recommended these traits to be recorded under flock conditions and hence to be considered in genetic improvement programs.

**Table 4.** List of studies focused on calculation of economic weights (EWs) for indigenous (dual or multipurpose) sheep breeds using bio-economic models

Author(s), year	Economic values (weights) of studied traits:
Rahimi et al. (2015)	MEV and REV of 9 traits were investigated - prolificacy, pregnancy rate, lamb weights from birth to the end of period, survival rate of lambs, wool production weight, average daily gain and milk production, productive lifetime of ewes in Makui sheep in Iran.
Bytyqi et al. (2015)	MEV and REV of dairy and meat traits in dual purpose Bardhoka, Balusha, Sharri and Kosova sheep breeds in Kosovo were estimated.
Gebre (2012)	EVs of the following traits were derived: daily gain, live weight of ewes, length of productive life, lambing interval, litter size, stillbirths and lamb survival.

All traits of economic importance should be included in the breeding goal of livestock breeding programs, Bytyqi et al. (2015) suggested. In Kosovo, the vast majority of sheep are indigenous managed under a traditional production system. Due to decreasing economic value of wool and increasing importance of ewe milk and lamb meat production, it is advisable breeding programs to be more focused on traits contributing to the overall profit of sheep farms. The relative economic values for milk yield and daily gain for Bardhoka, Balusha, Sharri and Kosova sheep breeds were 84.96:15.04, 84.42:15.58, 83.45:16.55, and 82.36:17.64, respectively, which gives economic advantage to the traits related to milk production.

A bio-economic model was adapted to estimate economic values for important traits of two Ethiopian indigenous sheep breeds - Menz and Horro, raised mainly for fattening lambs and rearing young replacements (Gebre, 2012). Negative economic values for the traits of productive lifetime and mature ewe live weight were estimated for both breeds. As it was mentioned above, in an open population model when selling young breeding animals the value of productive life is normally negative, while in the closed model – it is positive. Marginal economic value of mature weight of animals is usually negative, which is confirmed in the studies of a number of authors for different sheep breeds (Conington et al., 2004; Morais and Madalena, 2006; Wolfová et al., 2009a; Tolone et al., 2011; Slavova and Laleva, 2021). Often, the costs of feeding and maintaining life cannot be offset by the income from the sale of these animals.

Bio-economic models for calculating the economic significance of traits in livestock are increasingly being used nowadays, as they provide an opportunity to identify

the economic importance of productive and functional traits included in the selection index. Improvement of the computer programs integrated in the models contributes to the inclusion of more and more biological and economic components of the production system and a more comprehensive analysis of the interrelationships between individual traits. Thus, the enterprises may withstand changes in the dynamic market environment and stay viable for a long period of time.

## Conclusion

This review provided a brief overview of the research on calculation of economic values (weights) in sheep of different breeds. It is obvious that according to the different types of sheep production, different productive and functional characteristics and their economic values have been investigated. Of particular importance for the predominance of a particular trait over others in terms of its contribution to profit on farms are the breed, production system, climatic conditions, market determinants, demand and supply of sheep products etc., which may undergo changes over time. This necessitates a recalculation of the economic importance of profit-related traits in sheep and the adaptation of the breeding objectives of the enterprises according to the economic importance of the studied traits.

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