



RESEARCH ARTICLE

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A bio-economic model to improve profitability in a large national beef cattle population

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Abstract

A bio-economic model was developed for estimating economic values for use in improving profitability in a large national beef cattle population from birth to slaughter. Results were divided into fattening costs, production costs and income. Economic values were derived for 17 traits for two regions, mature weight (-0.43 € and -0.38 €/+1 kg of live weight), age at first calving (-0.13 € and -0.11 €/+1d), calving interval (-1.06 € and -1.02 €/+1d), age at last calving (0.03 € and 0.03 €/+1d), mortality 0-48 h (-5.86 € and -5.63 €/1% calves per cow and year), pre-weaning mortality (-5.96 € and -5.73 €/+1% calves per cow and year), fattening mortality (-8.23 € and -7.88 €/+1% calves per cow and year), adult mortality (-8.92 € and -7.34 €/+1% adult cows per cow and year), pre-weaning average daily gain (2.56 € and 2.84 €/+10g/d), fattening young animals average daily gain (2.65 € and 3.00 €/+10g/d), culled cow in fattening average daily gain (0.25 € and 0.16 €/+10g/d), culled cow dressing carcass percentage (3.09 € and 2.42 €/+1%), culled cow price (4.59 € and 3.59 €/+0.06 €/kg), carcass conformation score (16.39 € and 15.3 €/+1 SEUROP class), dressing carcass rate of calf (18.22 € and 18.23 €/+1%), carcass growth (9.00 € and 10.09 €/+10g of carcass weight/d) and age at slaughter (0.27 € and 0.44 €/+1d). Two sample herds were used to show the economic impact of calving interval and age at first calving shortening in the profit per slaughtered young animal, which was 178 € and 111 € for Herds A and B, respectively. The economic values of functional traits were reduced and production traits were enhanced when fertility traits were improved. The model could be applied in a Spanish national program.

Additional keywords: profit function; economic values, bioeconomic model.

Abbreviations used: AFC (age at first calving); CI (calving interval); UFC (unit of energy for animal in growth equivalent to 1820 kcal of net energy); UFL (unit of energy for animal in maintenance, gestation, lactation or low growth equivalent to 1700 kcal of net energy). SYA (slaughtered young animal).

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Introduction

The most important problems found from traditional and genomic evaluation in beef cattle are: phenotype deficiency, multiple breeds and crossbreeds, lack of artificial insemination, genetic un-connectedness and low profit (Berry *et al.*, 2016). A traditional or genomic breeding program needs to solve all these problems. One solution is to increase phenotyping in a large population to improve genetic responses (Berry *et al.*, 2016).

Animals are usually selected by their slaughter value and maternal or functional traits are therefore

not genetically improved. Functional traits should be the focus of data recording in breeding programs due to their low heritability and their economic importance (Short *et al.*, 1990). Functional and production traits should be included in selection and/or management choices in accordance with their influence on animal profitability. Improved production programs could be based on a bio-economic model seeking to maximize profit per slaughtered animal (SYA) per year. Nielsen *et al.* (2014) discussed the bio economic model and profit function applications as tools for use in defining breeding objectives with increased focus on functional

traits. Seeking to maximize the difference between the saleable meat yield and the feed purchased, Harris (1970) proposed a bio-economic model for comparing different types of animals, nutrition, management, health models and marketing. Dickerson (1970) introduced the concept of efficiency relative to per unit production cost. Several studies have proposed bio-economic models for arriving at economic values and establishing selection indexes for national beef populations, such as Fernández-Perea & Alenda (2004), Roughsedge *et al.* (2005), Wolfová *et al.* (2005a,b) and Pravia *et al.* (2014).

Currently in Spain, one cause of low profit is large periods of non-productivity on commercial farms. Age at first calving (AFC) is close to 3 years (Gutiérrez *et al.*, 2002; MAPAMA, 2014) and, in 2014, the number of calvings per cow per year was 0.67 (MAPAMA, 2014). Breeding programs should consider functional traits as one of the keys to improving farm profitability and hence animal profitability. This should be based on a large amount of phenotypic data to allow for economic comparison as proposed in this work. All information from all parties involved in the beef production sector, *i.e.* production, fattening and slaughterhouses, must be merged to maximize its value. All animals in the beef population should be considered, including crossbred animals. Officially, 53% of sucklers in Spain are crossbred animals (MAPAMA, 2014) and around 20% of inseminations in the dairy population are done with beef bulls.

The goal of this study was to develop a bio-economic model with costs and income information from birth to slaughter. Data from two herds from northwest and southeast Spain were used to test the model. The first application of the model was to estimate the economic values that can be applied to a large beef cattle population to optimize profit per slaughtered young animal (SYA) per year. The model also provides economic results suitable for application to different production improvement programs, allowing for comparison between herds, sucklers and production systems. The effects of improved fertility traits on economic results are shown.

Material and methods

Description of the production process

Production, breeding and marketing systems were described, in accordance with Ponzoni & Newman (1989). The beef production process was split into three phases: production, fattening, and slaughter of young animals. Costs incurred in each phase were called production cost and fattening costs. Production and fattening costs and incomes were determined in euros per SYA throughout the different phases in order to calculate profit per young animal. The production process is shown in Fig. 1, showing costs and incomes incurred in each of the three phases. This figure was developed as proposed by Charfeddine (1998) for

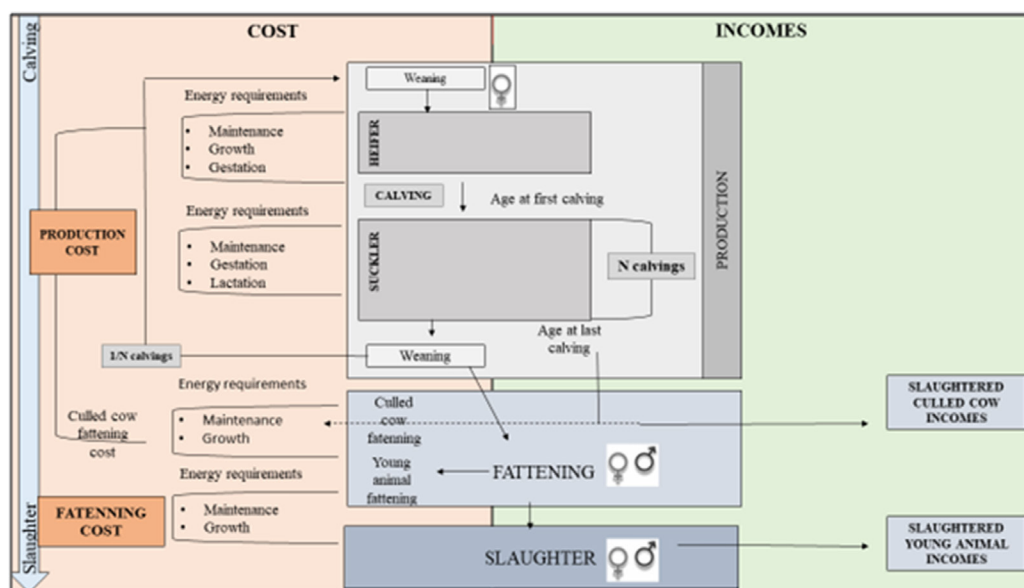


Figure 1. Description of production process and income and costs in the production, fattening and slaughter phases of the production process.

Spanish dairy cattle. The three phases are described as following:

— *Production phase*. The production phase includes suckler cows and their replacement and culling activities to produce one weaned calf. Heifer activity was from weaning to first calving in that period, and heifers required supplementation to meet maintenance, growth and gestation energy requirements. After first calving, heifers become suckler cows, with lactation, maintenance and gestation energy requirements. The feeding cost of suckler cows was determined by mature weight, calving interval (CI), milk yield, age at weaning and number of calvings per cow. After last calving, suckler cows become culled cows and give rise to fattening costs and income. The sum of the heifer, suckler cow, and culled cow feeding cost minus the income received for the culled cow carcass constituted production costs.

— *Fattening phase*. The fattening phase is the fattening process of calf (males and females) from weaning to slaughter. After weaning, some female calves are designated as replacements and become the batch of heifers. The remaining females and the entire group of males were sent through the fattening phase. These animals (males and females) are called “young animals” in this study. The inherent costs in the fattening process, involving meeting energy requirements for maintenance and growth, depended on the daily growth of the calf, the sex of the animal and the length of the fattening period.

— *Slaughter of young animals*. The slaughter phase describes the performance of males and females at slaughterhouse. After fattening, fattened males and females designated for slaughter give rise to income per SYA, which depends mainly on the carcass conformation score, slaughter weight, age at slaughter and sex.

Description of the bio-economic model: the profit function

A bio-economic model was developed to describe the beef cattle production system set forth above following the recommendations of Harris (1970) and Harris & Newman (1994) and in accordance with Ponzoni & Newman (1989). The proposed model shown in Fig. 1 shows profit per SYA and includes costs and income for all the animals of the herd (calves, heifers, suckler cows and culled cows) from birth to slaughter. The costs and income considered were only those that can be improved through animal production decisions, as per Dickerson suggestions (Tess & Davis, 2002). Therefore, in this study only feeding costs to satisfy energy requirements and incomes per animal at sale were included. Other costs, such as labor costs, were considered fixed costs not directly dependent on animal type. Profit per SYA

Table 1. Functional traits, production traits, and management conditions for Herd A and Herd B.

Traits and conditions	Herd	
	A	B
Functional traits		
Mature weight (kg)	600	585
Mortality 0-48 h (%)	2	3
Pre-weaning mortality (%)	2	2
Fattening mortality (%)	1	1
Adult mortality (%)	1	2
Calving interval (d)	514	458
Age at first calving (d)	1080	997
Age at last calving (d)	10	10
Milk yield (L/d)	5	6
Production traits		
Birth weight (kg)	39	38
Pre-weaning average daily gain (kg/d)	0.90	0.75
Fattening average daily gain (kg/d)	1.25	1.40
Carcass conformation score (SEUROP classification)	U	U
Dressing carcass rate of young animal (%)	58	56.5
Carcass growth (kg/d)	0.68	0.67
Carcass price of young animal (€/kg)	4.06	4.00
Culled cow price (€/kg)	2.10	2.10
Culled cow fattening ADG ¹ (kg/d)	1.50	1.20
Dressing carcass rate of culled cow (%)	52	52
Management conditions		
Age at weaning (d)	180	180
Age of slaughter (d)	365	365
Fattening period of young animal length (d)	180	180
Fattening period of culled cow length (d)	120	90
Price per unit of supplementation UFL ¹ (€/UFL)	0.12	0.12
Price per unit of supplementation in fattening UFC ² (€/UFC)	0.21	0.20

¹UFL: unit of energy requirements for animals in low growth, gestation, maintenance and lactation. ²UFC: unit of energy requirements for animals in fattening.

per year (PROFa) was calculated using the remaining income and costs as follows:

$$PROFa = n \times (I_s - FAT - PROD)$$

where n is the ratio of 365 days over age at slaughter. I_s is income per young animal at fixed age at slaughter. FAT is fattening costs of calves in feedlot to meet energy requirements. $PROD$ is production costs per young animal, including feeding cost of heifer, suckler cow and culled cow to meet their energy requirements minus income per culled cow carcass at sale. Further

information and detailed calculations are found in Table S1 [suppl]. The profit function was used as a tool for comparing herds, production systems, and different types of animals.

Economic values

The economic value of a given trait was defined as the partial derivative of the profit function with respect to the trait considered (Moav, 1973). This was measured in this study in terms of euros per SYA per year, and economic values were determined for a unit variation of the trait. The economic value, e_{xi} , of trait xi was obtained as follows.

$$e_{xi} = \frac{d(PROFa)}{dx_i}$$

In this study, economic values were determined for CI, AFC, age at last calving, 0-48 h mortality, pre-weaning mortality, fattening mortality, adult mortality, mature weight, pre-weaning average daily gain, fattening average daily gain of young animal, carcass dressing rate of young animal and culled cow, young animal carcass conformation score, culled cow carcass price and culled cow fattening average daily gain, carcass growth and age at slaughter of young animal.

Cases of study: Two sample Spanish herds

This study shows the profit function as applied to two herds (Herd A and Herd B). Also, economic values were determined and expressed in euros per SYA per year. The results were shown as income, production, fattening costs and profit, showing an adaptation of an average animal from each herd in each phase of the production system.

Inputs for Herd A and Herd B are shown in Table 1. The traits involved in the model were divided into three groups: functional traits, production traits, and management conditions. Functional traits were mature weight, mortality within the first 48h after birth (0-48 h mortality), pre-weaning mortality, fattening mortality, adult mortality, CI, AFC, age at last calving and milk yield. Production traits were birth weight, pre-weaning average daily gain, fattening average daily gain, young animal dressing carcass rate, young animal carcass price and carcass conformation score, young animal carcass weight and young animal carcass growth and carcass price of a culled cow, average daily gain during the fattening period of a culled cow and culled cow dressing carcass rate. Birth weight was assumed to be 2 kg heavier in males than in females. Average daily gain was assumed to be 10% and 20% higher for males in pre-weaning and fattening growth, respectively. Management

Table 2. Individual average daily energy requirements expressed in UFL¹ and UFC² per day for young animals in fattening, replacement heifers from weaning to first calving, suckler cows in lactation, maintenance and last third of gestation period and culled cow in fattening period, in Herd A and Herd B.

	Herd	
	A	B
Young animal fattening period (UFC/d)	12.8	12.1
Heifer from weaning to first calving (UFL/d)	3.8	3.9
Sucker cow lactation period (UFL/d)	8.6	9.8
Sucker cow maintenance period (UFL/d)	5.8	5.7
Sucker cow in last third of gestation (UFL/d)	7.1	6.7
Culled cow in fattening period (UFC/d)	11.6	11.5

¹UFC: unit of energy requirements for animals in fattening. ²UFL: unit of energy requirements for animals in low growth, gestation, maintenance and lactation.

conditions were defined by age at weaning, age at slaughter, fattening length of young animal and culled cow and unit price of supplementation expressed in UFL and UFC. UFC and UFL are the units used to express energy requirements. 1 UFC is equivalent to 1,855 kcal of net energy and 1 UFL is equivalent to 1,730 kcal of net energy (Vermorel *et al.*, 1978). Traits and conditions used in the bioeconomic model are modifiable by animal production decisions and type of animal and they allow the two cases of study to be compared in accordance with their performance in functionality (related with fertility, non-productive periods and mortalities) and production (traits related with growth and conformation).

Description of herd management

Herd A was a crossbreed herd in Extremadura (southwest Spain) in which dams were purebred or F1 from Avileña or Retinta breed dams and Charolais or Limousin breed sires. Herd B was in the southern Pyrenees (northern Spain) and based on the Brown Swiss and Pirenaica breeds. In both herds, calves were weaned at 6 months of age. Calving in Herd A was non-seasonal, avoiding summer calvings. Herd B had two calving seasons, spring and fall. Young bulls and non-intended for replacement females (young animals) were fed using an intensive concentrate-based system and slaughtered at one year of age. Culled cows were fattened for a period of four months in Herd A and three months in Herd B as per culling decision. Further Herd B management conditions are described in Sanz *et al.* (2004).

Description of feeding regime

Animals were divided in four groups according to age and sex (fattened young animals, heifers, suckler

cows and culled cows). Bulls and their replacements were ignored in this study (due to different strategies for sire management). Average daily energy requirements for each group and physiological status is shown in Table 2 and determined from the data shown in Table 1. The four groups are described as:

- Fattened young animals: males and females from 6 months to 12 months. Calves consumed the equivalent of 136 UFL of forage until weaning (Daza, 2014). After weaning, males and females consumed the equivalent of their energy requirements for maintenance and growth. Energy requirements were estimated by NRC (2000) and expressed in UFC per animal per day for the average animal of each herd and are a function of average daily gain (1.25 and 1.40 kg/day for Herd A and Herd B) and metabolic weight.

- Heifers: females from six months to first calving at 41 months (Herd A) and 33 months (Herd B). Maintenance, growth and last third of gestation energy requirements were included in this period. Growth rate was considered as achieving 65% of mature weight at first service (390 kg and 380 kg for Herd A and B respectively).

- Suckler cows: These are females from first calving to culling decision at 120 months and 108 months in Herds A and B, respectively. Energy requirements for suckler cows and replacement heifers were developed by INRA (1988) and Agabriel & D'Hour (2007). Energy requirements were expressed in UFL and UFC per day for animals with a body condition score of 3 on a scale of 1 to 5 in extensive conditions (Lowman *et al.*, 1976), determined by metabolic weight, management conditions (grazing under either intensive or extensive conditions) and physiological status. Energy requirements were estimated for growth, maintenance, gestation and lactation periods. Energy requirements for gestation were only calculated for the last 4 months of pregnancy.

- Culled cows: These are cows fattened for 3 and 4 months after culling decision in Herd A and B, respectively. Culled cows had energy requirements for maintenance and fattening.

Results are shown for Herd A and Herd B inputs. An optimal situation for both herds is also presented. In the scenarios shown, non-productive periods were reduced, whereby CI was reduced to 365 days to achieve one calving per cow per year, and AFC was set at 2 years. These optimal scenarios are called Herd A+ and Herd B+.

Results

Productive parameters

Results showed low fertility, long non-productive periods and large batches of replacement heifers given

the CI and AFC in the two herds studied (Table 1). These factors led to poor fertility values, expressed as number of calvings per cow per year for both herds which directly affected productivity, measured as number of young animals slaughtered per cow and per year (Table 3).

Reducing non-productive periods is the goal of every animal production system. The target CI was considered to be 365 days when calving was during a few months of a year. In our study, this amounted to a reduction of 149 and 93 days in the intervals observed respectively in Herd A and Herd B. CI reduction increased the fertility rate by 0.29 and 0.21, expressed in number of calvings per cow per year for Herd A and Herd B. The target AFC was set at 730 days, amounting to a reduction of 350 and 267 days for Herd A and Herd B. Lowering the AFC affected the number of heifers intended for replacement batches by 0.96 and 0.77 for Herds A and B, respectively. The target for young animals slaughtered per cow per year should be 0.85 for both herds due to achievement of optimal longevity, fertility and AFC. If cow longevity (*i.e.*, culling age) is constant, improvements in fertility and lifespan (number of calvings per cow) reduce replacement requirements and therefore more calves can be marketed.

Economic parameters

Estimated costs, income and profit per SYA per year using current inputs and target scenarios for the two herds are shown in Table 4. The value of the average slaughtered animal in this study was around 1,055 €. The small differences in income for both herds and optimal fertility scenarios (Herd A+ and Herd B+) were influenced by the number of females slaughtered per year. When optimal fertility is achieved, more females can be marketed. The rate of slaughtered females increased by in 2.8% and

Table 3. Productive results in Herd A and Herd B, and optimal situations (Herd A+ and Herd B+) with shorter non-productive periods (calving interval of 365 days and age at first calving of 730 days).

Productive results	Herd			
	A	B	A+	B+
Fertility (no. of calvings/(suckler cow · year))	0.71	0.79	1.00	1.00
Heifer replacement rate (no. of heifer/(suckler cow · year))	0.12	0.12	0.11	0.11
Batches of heifers (no. of batches/(suckler cow · year))	2.46	2.22	1.50	1.50
Productivity (slaughtered young animals/(suckler cow · year))	0.56	0.63	0.85	0.85
Culled cow rate (culled cow/(suckler cow · year))	0.11	0.10	0.09	0.09

Table 4. Economic results for Herd A and Herd B, with observed inputs and the optimal scenarios (Herd A+ and Herd B+) with shorter non-productive periods (calving interval of 365 days and age at first calving set as 730 days).

Economic results (€/SYA·year)	Herd			
	A	B	A+	B+
Income	1.060	1.068	1.057	1.065
Fattening cost	465	438	461	435
Production cost	576	549	400	437
Profit	19	81	197	192

SYA: slaughtered young animal

1.7% females per SYA for Herd A+ and Herd B+ as compared with Herd A and Herd B. Higher growth during the fattening period for Herd B was offset by the higher carcass prices for Herd A (Table 1) and incomes are similar for both herds.

Fattening costs were slightly higher in Herd A due to the higher weaning weight at commencement of feedlot (+28 kg) and subsequent higher maintenance energy requirements. However, Herd A had lesser fattening growth rate and differences were low. Improved fertility slightly affected fattening yield as a cost per SYA, given that the higher fertility increased the number of females slaughtered. The higher proportion of females lowered average income but females had low fattening yield (slaughter weight). The fattening cost per SYA was similar in the optimal Herd A+ and Herd B+ by 0.9 and 0.7% (3 € in both cases), respectively.

Production costs were shown by SYA per year. Production costs for Herd B were lower than for Herd A due to lower non-productive periods, with a lower CI and AFC. The decrease in non-productive periods in Herd A+ and Herd B+ led to lower herd feeding requirements for rearing heifer and suckler populations. Increases in the number of SYA per year were +0.29 and +0.22 SYA/suckler cow/year respectively for Herd A and Herd B and led to a significant decrease in production costs since feeding costs were spread over a larger number of SYA per year. The reduction in production costs was 176 € and 112 € per SYA per year for Herds A+ and B+, respectively. That amounted to a 31% and 20% respective decrease in production cost in Herds A and B that gave rise to 178 € and 111 € in increased profit per SYA per year for Herd A+ and Herd B+, respectively.

Economic values

Economic values are shown in Table 5. Results are expressed in euros per phenotype unit of increase for each trait (in parenthesis) per SYA per year.

Functional traits

Negative economic values for mature weight resulted from the increase in requirements for heifers and sucklers. A 1-kg increase in mature weight increased energy requirements by 2.82 and 2.84 UFL per cow for Herds A and B, respectively. However, income from the sale of heavier culled cows was 0.21 € and 0.18 € higher per SYA per year for Herds A and B, respectively. A one-day longer CI reduced the productivity rate, the number of young animals slaughtered per cow per year. The feeding cost of sucklers was distributed over a smaller number of slaughtered animals, such that the feeding cost of sucklers was 1.24 € and 1.19 € per SYA per year higher for Herds A and B, respectively. However, an increase of 1 day in CI also increased income per sale of culled cows by 0.31 € and 0.27 € per SYA per year. Economic values for AFC were negative because the additional day produced an increase of 0.16 € and 0.14 € per slaughtered animal per year in feeding cost for heifers. Also, similar to the case with CI, culled cow income rose by 0.06 € and 0.05 € per SYA per year for each additional day of AFC. The cause of this increase in culled cow income was the increase in the culling and replacement rates. Increased mortality rates produced a decrease in the productivity rate and hence an increase in the production cost per slaughter young animal and year.

The shorter non-productive periods in Herd A+ and Herd B+ caused a drop in economic values (CI, AFC and age at last calving) because profit was higher. Economic values for CI in Herd A+ decreased by 0.17 € per SYA and by 0.12 € per SYA in Herd B+ in comparison to Herd A and Herd B, amounting to a 16% and a 12% decrease in their economic values, respectively. Reducing the AFC led to a saving of 0.06 € and 0.04 € per SYA per day for Herd A and B, respectively. A 49% and 36% decrease was achieved respectively for Herd A and Herd B. The main changes resulted from the increase in the number of calvings per cow per year. This produced an important loss of culled cow traits and longevity. The change in functional traits was in age at last calving, with a decrease of its economic value of 79% and 61% for Herd A and Herd B. Economic value of adult mortality decreased by 43% and 33% and calving mortality and pre-weaning mortality decreased by over 31% in Herd A and over 21% in Herd B.

Production traits

Regarding growth, improvement in average daily gain in all phases (production, fattening of young animals and fattening of culled cows) increased slaughtered weight

Table 5. Economic values expressed in euros per slaughtered young animal (SYA) per year and unit of variation of each trait (in parenthesis) for actual Herds A and B, and optimal Herds A+ and B+ with shorter non-productive periods (calving interval of 365 days and age at first calving set as 730 days).

Trait (unit of variation) (€/SYA·year)	Herd			
	A	B	A+	B+
<i>Functional traits</i>				
Mature weight (+1kg)	-0.43	-0.38	-0.30	-0.30
Age at first calving (+1d)	-0.13	-0.11	-0.07	-0.07
Calving interval (+1d)	-1.06	-1.02	-0.89	-0.90
Age at last calving (+1d)	0.03	0.03	0.01	0.01
Mortality 0-48 h (+1%)	-5.86	-5.63	-4.01	-4.46
Pre-weaning mortality (+1%)	-5.96	-5.73	-4.11	-4.56
Fattening mortality (+1%)	-8.23	-7.88	-6.40	-6.72
Adult mortality (+1%)	-8.92	-7.34	-5.08	-4.90
<i>Production traits</i>				
Pre-weaning average daily gain (+0.01 kg/d)	2.56	2.84	2.55	2.83
Fattening young animals average daily gain (+0.01 kg/d)	2.65	2.99	2.67	3.01
Culled cow in fattening average daily gain (+0.01 kg/d)	2.47	1.63	1.55	1.18
Culled cow dressing carcass percentage (+1%)	3.09	2.42	1.93	1.75
Culled cow price (+0.06 €/kg)	4.59	3.59	2.61	2.61
Carcass conformation score (+1 class of SEUROP classification)	16.39	15.35	16.31	15.30
Dressing carcass rate of young animal (+1%)	18.22	18.23	18.19	18.19
Age at slaughter (+0.01 kg)	0.27	0.44	0.21	0.14
Carcass growth of young animal (+0.01 kg)	9.00	10.09	9.07	10.03

and hence led to higher income per SYAs and cows. Increased fattening average daily gain also affected energy requirements and, consequently, fattening cost for constant age at slaughter. An increase of 0.01 kg/day in average daily gain also increased the cost of meeting energy requirements in fattening young animals by 6.15 and 6.14 UFC per slaughtered animal per year and 1.08 kg in carcass weight for both herds. The higher carcass conformation score and dressed weight directly increased carcass weight and value and, hence, income per animal. A 1% increase in dressed weight led to an increase of 4.69 kg and 4.36 kg in carcass weight and increased income per slaughtered animal per year by 18.63 € and 19.04 €, respectively. Augmented carcass growth produced an increase of 14.21 € and 15.01 € in income per young animal per year and also 5.21 € and 5.01 € in increased fattening cost. Carcass conformation and carcass growth economic values were not affected by shortening the non-productive periods in both herds.

The main differences between Herd A and Herd B in terms of economic values were in mortality and carcass traits and also in culled cow traits, but culled cow traits had lower economic importance. When optimal scenarios were considered, the economic values for CI were similar to a 0.01 €/day difference between Herd A+ and Herd B+. For 0-48h mortality, Herd A+ was 0.45 €/1% lower,

and also showed a pre-weaning mortality difference of 0.45 €/1% and a fattening mortality difference of 0.32 €/1% over Herd B+, due to higher costs. For Herd A+, culled cow traits had higher economic values due to higher income from heavier culled cows. The economic values of production traits were similar for the two herds, with growth traits being more important in Herd B+ than in Herd A+, in pre-weaning average daily gain (2.80 € per + 0.01 kg/d) and fattening average daily gain (3.38 € per + 0.01 kg/d). Differences in carcass-related traits were mainly in carcass growth (1.14 € per + 0.01 kg/d) due to higher growth and carcass conformation score (0.96 € per + 0.06 €/kg) in Herd B.

Discussion

Profit function is expressed per SYA per year and offers a “realistic” scenario for the three stages of production. Other studies measured profit per farm per year or per cow per year (Phocas *et al.*, 1998; Albera *et al.*, 2004) or both (Kluyts *et al.*, 2004). The aim of showing results per SYA was to optimize results (production and fattening cost and incomes) in each part of the production system (production, fattening and slaughter) by comparing different situations at herd level. Roughsedge *et al.* (2005)

identified key beef profitability drivers that were similar to the two cases presented. This possibility was also shown by Wolfová *et al.* (2005a,b) as a tool for optimizing mating, culling and other management and marketing decisions. In this work adaptation was shown by shortening the non-productive periods, CI and AFC because this is one of the main factors in increasing herd profitability. Reducing CI and AFC led to decreased production costs as per other authors (Bourdon & Brinks, 1983; Day & Nogueira, 2013). This is due to the increase in the number of SYAs per year that share the production cost of the heifers and dams of the herd. In Herds A and B, improved fertility led to an increase in profit per SYA (937% and 137% for Herds A and B, respectively) through cost reduction (30.6% and 20.4% in production cost decrease, respectively). Costs included were purchased feed costs, of critical economic importance to beef farms (Albera *et al.*, 2002) where most is done in extensive conditions, and pasture availability is normally seasonally uncertain (Olea & San Miguel, 2006; Etienne *et al.*, 2008).

This adaptation of the different stages of the production system should include breeding goals in beef cattle. Ponzoni & Newman (1989) pointed out that correctly defining breeding objectives is vital in an effective genetic program. Recent breeding programs (<https://www.icbf.com/wp/>) have been giving higher priority to the economic perspective in determining breeding objectives (De Haas *et al.*, 2013). Bio economic model approaches were discussed by Nielsen *et al.* (2014) to estimate economic values needed to determine correct breeding objectives. Some studies show robust breeding systems to be an error in regard to economic values due to the variation of prices and market conditions (Ronningen, 1971; Hirooka & Sasaki, 1998; Hirooka *et al.*, 1998; Kulak *et al.*, 2003). Suitable breeding objectives must show the adaptation of animal type to production system and this is the purpose of the model developed here. The bio-economic model evaluates the adaptation of sucklers, heifers and young animals to their production systems by determining economic values for two groups of traits, functional and production. Suckler adaptation is measured by functionality traits such as energy requirements (mature weight as indicator), fertility and survival traits. Improved fertility traits showed that animals are more adapted than as shown by the decrease in economic values of all functionality traits. For example, the economic value at mature weight decreased around 25%. Mature weight is associated with the size of the suckler, similar to the model proposed by Amer *et al.* (1996, 2001). It was used as an indicator of feed intake as per Pravia *et al.* (2014), due to the fact that cow weight is highly heritable and easier to collect than feed intake. Nielsen *et al.* (2014) defined mature size as a key driving variable for many aspects of animal

performance, including growth rates. This determines the growth and maintenance energy requirements of heifers, the maintenance energy requirements of suckler cows and the requirements of culled cows at feedlot. Mature weight could be predicted by other recorded traits, such as calf type evaluation, carcass weight and adult live weight in order to optimize herd feeding cost. An increase of 1 kg in mature weight produced an economic impact of -0.43 € and -0.38 € per SYA due to the increase in production cost. Young animals need to undergo optimal growth in fattening so as to achieve higher carcass value and the traits involved made up the production traits. Optimal adaptation needs to be achieved through reaching a balance between income and production cost per animal. Hence, economic values were determined for the production system as a whole (integrated pre-weaning and feedlot), similar to Hirooka *et al.* (1998), and they were expressed by product unit according to Dickerson *et al.* (1970) and Smith *et al.* (1986).

Functionality traits have a major influence on profitability of extensive-raised beef herds due to their impact on productivity (number of SYAs per cow per year). Despite their low heritability (Minick Bormann & Wilson, 2010), their inclusion in breeding objectives should be considered in current breeding programs. Aby *et al.* (2012) found they have economic importance and need to be included in breeding objectives even for intensive breeds. Pravia *et al.* (2014) also showed the importance of reproduction traits. Our study showed the importance of the CI, AFC, mature weight and survival traits, especially in poorer fertility conditions. CI is associated with non-productive days and hence with the decrease in the number of SYAs per cow and year. An increase in adult mortality directly raises the replacement rate and hence rearing cost (0.45 € and 0.22 € per SYA for Herd A and B) and brings about a loss in culled cow sales. Calf mortality in 0-48 hours, pre-weaning and feedlot decreases the number of young animals slaughtered per cow per year (productivity) and increases the production cost per animal slaughtered. Economic weights for CI, AFC, and mature weight and survival traits decreased when the optimal fertility target was achieved. For CI, economic values decreased by 16% and 12% respectively for Herds A and B. For AFC, they decreased by 46% and 36%, and 0-48h mortality economic values decreased by 31% and 32%. Also, mature weight economic value decreased by 30% and 21% for Herds A and B, respectively. These changes were due to the fact that when the optimal fertility goal is achieved changes and other traits need to be focused on increasing the profitability of production traits.

In regard to production traits, carcass growth is the most representative production trait with high economic value, as it summarizes other growth traits and associates them with carcass value (income) and costs (fattening cost). Carcass growth is measured from birth to slaughter and related to more saleable carcass weight at a set age and a higher conversion index for growth from birth to slaughter. Further research needs to be done to relate carcass growth and weaning weight to mature weight as Roughsedge *et al.* (2005). In order to include predicted carcass data for the large replacement population, calf carcass quality needs to be systematically recorded and evaluated. Young animals in some purebred populations are normally qualified at weaning by their breeding programs at 4 to 10 months of age. This value of pre-slaughter muscular scores shows high correlation to the carcass conformation score (0.94) and carcass weight, with 0.72 correlation to carcass meat production (Conroy *et al.*, 2010). Some Spanish slaughterhouses already are recording carcass weight, conformation and fat scores.

One of the prerequisites of the data used in the model was that it be easily recorded. Currently, extensive conditions make it difficult to gather data and the traits included in the model need to be able to be easily recorded at low cost in order to enable working with a large population. Moreover, it is important to consider using official data regarding dates and slaughter traits when developing breeding and management strategies. Phocas *et al.* (1998) pointed out the need to integrate on-farm records to evaluate cow fertility and calf survival. A large data set and sire registration is a prerequisite for improving traits with low heritability. Multi-breed analysis is crucial for improving phenotypic and genetic traits. Inclusion of data from crossbred animals would improve result accuracy (icbf.com). In Spanish beef cattle production crossbreeding systems are normally used (MAPAMA, 2014) in large beef populations.

The inclusion of functional and production traits would make possible suitable matings between specialized sires and dams to obtain replacement heifers or young animals for slaughter. Two different sub-indexes can be developed from the economic weights determined by the model: a replacement index for obtaining future heifers and a terminal index for obtaining young animals for slaughter, similar to the Irish program (MacNeil & Newman, 1994; Amer *et al.*, 2001). Further studies are needed in order to introduce new traits as profit function. Traits such as diseases, docility problems or calving ease need to be introduced

into the current model. Profit function should be an open tool for maximizing profit per slaughtered animal, in which more advanced data collection on related costs (veterinary and labor) and income will be needed.

In conclusion, the bio-economic model developed is suitable for establishing improvement programs with data available for a large population and determining different management, genetic and nutritional options. Most of the traits included in the bio economic model are already available and other traits can be recorded at low cost. Other data can be used, such as growth traits able to be predicted by age at slaughter and carcass weight. Type evaluations for skeletal and muscle at weaning can be done by trained professionals and farmers to predict growth and carcass traits for the animal without their own carcass traits. The model allows comparisons to be established as for the two herds of study. Further studies should be done relating to multiple types of animal genetic evaluations. Also, derived efficiency values should be studied in order to rank different types of animals. Since some Spanish regions are already recording the traits included in the proposed model, such model could provide economic results for objective recommendations to be made in multi-breed improvement programs at the national level.

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References

- Aby BA, Aass L, Sehested E, Vangen O, 2012. A bio-economic model for calculating economic values of traits for intensive and extensive beef cattle breeds. *Livest Sci* 143 (2): 259-269. <https://doi.org/10.1016/j.livsci.2011.10.003>
- Agabriel J, D'Hour P, 2007. Alimentations des vaches allaitantes. In: *Alimentation des bovins, ovins et caprins*. INRA, Paris. pp: 58-65.
- Albera A, P. Carnier P, Groen AF, 2002. Economic values for beef traits in Piemontese cattle. *Proc VII World Congress on Genetics Applied to Livestock Production, Montpellier (France)*, Aug. pp: 0-4.
- Albera A, Carnier P, Groen AF, 2004. Definition of a breeding goal for the Piemontese breed: economic and biological values and their sensitivity to production circumstances. *Livest Prod Sci* 89: 67-78. <https://doi.org/10.1016/j.livprodsci.2003.12.004>

- Amer P, Lowman B, Simm G, 1996. Economic values for reproduction traits in beef suckler herds based on a calving distribution model. *Livest Prod Sci* 46: 85-96. [https://doi.org/10.1016/0301-6226\(96\)00016-4](https://doi.org/10.1016/0301-6226(96)00016-4)
- Amer P, Simm G, Keane M, Diskin M, Wickham B, 2001. Breeding objectives for beef cattle in Ireland. *Livest Prod Sci* 67: 223-239. [https://doi.org/10.1016/S0301-6226\(00\)00201-3](https://doi.org/10.1016/S0301-6226(00)00201-3)
- Berry DP, Garcia JF, Garrick DJ, 2016. Development and implementation of genomic predictions in beef cattle. *Anim Front* 6: 32-38. <https://doi.org/10.2527/af.2016-0005>
- Bourdon R.M, Brinks JS, 1983. Calving date versus calving interval as a reproductive measure in beef cattle. *J Anim Sci* 57: 1412-1417. <https://doi.org/10.2527/jas1983.5761412x>
- Charfeddine N, 1998. Selección por mérito económico global en el ganado vacuno frisón en España. Tesis doctoral, Dpto. Producción Animal, ETSI Agrónomos, UPM, Madrid.
- Conroy SB, Drennan MJ, Kenny DA, McGee M, 2010. The relationship of various muscular and skeletal scores and ultrasound measurements in the live animal, and carcass classification scores with carcass composition and value of bulls. *Livest Sci* 127: 11-21. <https://doi.org/10.1016/j.livsci.2009.06.007>
- Day ML, Nogueira GP, 2013. Management of age at puberty in beef heifers to optimize efficiency of beef production. *Anim Front* 3: 6-11. <https://doi.org/10.2527/af.2013-0027>
- Daza-Andrada A, 2014. Vacuno de carne con criterios económicos. Editorial Agrícola Española, Madrid.
- De Haas Y, Veerkamp RF, Shalloo L, Dillo P, Kuipers A, Klopčič M, 2013. Economic values for yield, survival, calving interval and beef daily gain for three breeds in Slovenia. *Livest Sci* 157: 397-407. <https://doi.org/10.1016/j.livsci.2013.08.015>
- Dickerson G, 1970. Efficiency of animal production-molding the biological components. *J Anim Sci* 30: 849-859. <https://doi.org/10.2527/jas1970.306849x>
- Etienne A, Martínez Valderrama J, Díaz-Ambrona H, Gregorio C, 2008. Productive model of evergreen oak and annual pastures in Extremadura (Spain). Proc XII Meeting of the FAO-CIHEAM sub-network on Mediterranean pastures and fodder crops, Zaragoza (Spain), pp: 65-68.
- Fernández-Perea M, Alenda-Jiménez R, 2004. Economic weights for a selection index in Avileña purebred beef cattle. *Livest Prod Sci* 89: 223-233. <https://doi.org/10.1016/j.livprodsci.2004.01.004>
- Gutiérrez JP, Alvarez I, Fernandez I, Royo LJ, Diez J, Goyache F, 2002. Genetic relationships between calving date, calving interval, age at first calving and type traits in beef cattle. *Livest Prod Sci* 78: 215-222. [https://doi.org/10.1016/S0301-6226\(02\)00100-8](https://doi.org/10.1016/S0301-6226(02)00100-8)
- Harris DL, 1970. Breeding for efficiency in livestock production: Defining the economic objectives. *J Anim Sci* 30: 860-865. <https://doi.org/10.2527/jas1970.306860x>
- Harris DL, Newman S, 1994. Breeding for profit: synergism between genetic improvement and livestock production (a review). *J Anim Sci* 72: 2178-2200.
- Hirooka H, Sasaki Y, 1998. Derivation of economic weights for carcass traits in Japanese Black cattle from field records. *J Anim Breed Gen* 115 (1□6): 27-37. <https://doi.org/10.1111/j.1439-0388.1998.tb00325.x>
- Hirooka H, Groen AF, Hillers J, 1998. Developing breeding objectives for beef cattle production 1. A bio-economic simulation model. *Anim Sci* 66 (3): 607-622. <https://doi.org/10.1017/S1357729800009188>
- INRA, 1988. Alimentation des bovins ovins & caprins; Jarrige R (ed). Institut National de la Recherche Agronomique, Paris.
- Kluyts JF, Naser FWC, Bradfield MJ, 2004. Development of breeding objectives for beef cattle breeding: derivation of economic values: review article. *S Afr J Anim Sci* 33: 142-158. <https://doi.org/10.4314/sajas.v33i3.3768>
- Kulak K, Wilton J, Fox G, Dekkers J, 2003. Comparisons of economic values with and without risk for livestock trait improvement. *Livest Prod Sci* 79 (2): 183-191. [https://doi.org/10.1016/S0301-6226\(02\)00155-0](https://doi.org/10.1016/S0301-6226(02)00155-0)
- Lowman BG, Scott N, Somerville S, 1976. Condition scoring of cattle, *rev. ed.* Bull. East of Scotland College of Agriculture, No. 6.
- MacNeil MD, Newman S, 1994. Selection indices for Canadian beef production using specialized sire and dam lines. *Can J Anim Sci* 74 (3): 419-424. <https://doi.org/10.4141/cjas94-060>
- MAPAMA, 2014. Estudio del sector español de vacas nodrizas. Datos SITRAN 2014. Subdirección Gene-ral de Productos Ganaderos. Ministerio de Agricul-tura, Alimentación y Medio Ambiente, Gobierno de España.http://www.mapama.gob.es/es/ganaderia/temas/produccion-y-mercados-ganaderos/estudio_nodrizas_2014_tcm7-267234.pdf
- Minick Bormann J, Wilson DE, 2010. Calving day and age at first calving in Angus heifers1. *J Anim Sci* 88: 1947-1956. <https://doi.org/10.2527/jas.2009-2249>
- Moav R, 1973. Economic evaluation of genetic differences. In: *Agricultural genetics: selected topics*; pp: 319-352. John Wiley and Sons, NY.
- Nielsen HM, Amer PR, Byrne TJ, 2014. Approaches to formulating practical breeding objectives for animal production systems. *Acta Agric Scand A - Anim Sci* 64 (1): 2-12.
- NRC, 2000. Nutrient requirements of beef cattle, update 7th rev. ed. Natl Acad Press, Washington DC, USA.
- Olea L, San Miguel-Ayanz A, 2006. The Spanish dehesa. A traditional Mediterranean silvopastoral system linking production and nature conservation. XXI General Meeting of the European Grassland Federation, Badajoz (Spain). pp: 3-13.

- Phocas F, Bloch C, Chapelle P, Bécherel F, Renand G, Ménessier F, 1998. Developing a breeding objective for a French purebred beef cattle selection programme. *Livest Prod Sci* 57: 49-65. [https://doi.org/10.1016/S0301-6226\(98\)00157-2](https://doi.org/10.1016/S0301-6226(98)00157-2)
- Ponzoni RW, Newman S, 1989. Developing breeding objectives for Australian beef cattle production. *Anim Prod* 49: 35-47. <https://doi.org/10.1017/S0003356100004232>
- Pravia MI, Ravagnolo O, Urioste JI, Garrick DJ, 2014. Identification of breeding objectives using a bioeconomic model for a beef cattle production system in Uruguay. *Livest Sci* 160: 21-28. <https://doi.org/10.1016/j.livsci.2013.12.006>
- Ronningen K, 1971. Tables for estimating the loss in efficiency when selecting according to an index based on a false economic ratio between two traits. *Acta Agric Scand* 21: 33-49. <https://doi.org/10.1080/00015127109433425>
- Roughsedge T, Amer PR, Thompson R, Simm G, 2005. Genetic parameters for a maternal breeding goal in beef production. *J Anim Sci* 83 (10): 2319-2329. <https://doi.org/10.2527/2005.83102319x>
- Sanz A, Bernués A, Villalba D, Casasús I, Revilla R, 2004. Influence of management and nutrition on postpartum interval in Brown Swiss and Pirenaica cows. *Livest Prod Sci* 86: 179-191. [https://doi.org/10.1016/S0301-6226\(03\)00165-9](https://doi.org/10.1016/S0301-6226(03)00165-9)
- Short RE, Staigmiller RB, Bellows RA, Greer RC, 1990. Breeding heifers at one year of age: Biological and economical considerations. *Proc. 39th Annu. Beef Cattle Short Course*. Univ. of Florida, Gainesville, USA. pp: 93-106.
- Smith C, James JW, Brascamp EW, 1986. On the derivation of economic weights in livestock improvement. *Anim Prod* 43: 545-551. <https://doi.org/10.1017/S0003356100002750>
- Tess MW, Davis KC, 2002. Gordon Dickerson: Defining economic efficiency of beef production *Proc. Beef Improvement Fed Res Symp Annu Meeting*. Omaha (USA). pp: 21-31.
- Vermorel M, 1978. Feed evaluation for ruminants. II. The new energy systems proposed in France. *Livest Prod Sci* 5: 347-365. [https://doi.org/10.1016/0301-6226\(78\)90030-1](https://doi.org/10.1016/0301-6226(78)90030-1)
- Wolfová M, Wolf J, Příbyl J, Zahrádková R, Kica J, 2005a. Breeding objectives for beef cattle used in different production systems: 1. Model development. *Livest Prod Sci* 95: 201-215. <https://doi.org/10.1016/j.livprodsci.2004.12.018>
- Wolfová M, Wolf J, Zahrádková R, Příbyl J, Daňo J, Krupa E, Kica J, 2005b. Breeding objectives for beef cattle used in different production systems: 2. Model application to production systems with the Charolais breed. *Livest Prod Sci* 95: 217-230. <https://doi.org/10.1016/j.livprodsci.2004.12.019>