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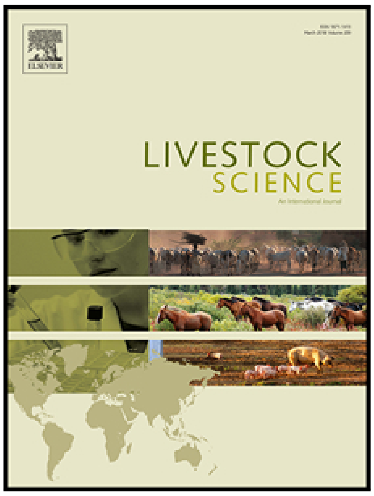

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Highlights

- Economic values are widely used in the development of breeding objectives internationally.
- The economic value of a trait in a breeding objective can be defined as the change in profit value of a unit change in an individual trait, while keeping all other traits constant.
- A total of fourteen traits of economic importance representing maternal, lambing, production and health characteristics were calculated within a whole farm bio-economic model.
- Results from this study will enable the implementation of new economic values within the national terminal and maternal Irish sheep breeding objectives which highlights the traits of importance for increasing overall farm profitability.

Deriving economic values for national sheep breeding objectives using a bio-economic model

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Abstract

The economic value of a trait in a breeding objective can be defined as the value of a unit change in an individual trait, while keeping all other traits constant and are widely used in the development of breeding objectives internationally. The objective of this study was to provide a description of the development of economic values for the pertinent traits included in the Irish national sheep breeding objectives using a whole farm system bio-economic model. A total of fourteen traits of economic importance representing maternal, lambing, production and health characteristics were calculated within a whole farm bio-economic model. The model was parameterised to represent an average Irish flock of 107 ewes with a mean lambing date in early March, stocked at 7.5 ewes per hectare and weaning 1.5 lambs per ewe joined to the ram. The economic values (units in parenthesis) calculated for maternal traits were: €39.76 for number of lambs born (per lamb), €0.12 for ewe mature weight cull value (per kg), -€0.57 for ewe mature weight maintenance value (per kg), -€0.09 for ewe mature weight replacement value (per kg) and -€0.84 for ewe replacement rate (per %). The economic values calculated for lambing traits were: €54.84 for lamb surviving at birth (per lamb), -€0.27 and -€0.30 for direct lambing difficulty in single and multiple-bearing ewes, respectively (per %); the corresponding values for maternal single and multiple lambing difficulty (per %) were -€0.25 and -€0.27, respectively. The calculated economic values for production traits were: -€0.25 for days to slaughter (per day), €3.70 for carcass Conformation (per EUROP grade) and -€0.84 for carcass fat (per fat score). The economic values for health traits were: -€0.24 for ewe lameness (per %), -€0.08 for lamb lameness (per %), -€0.25 for mastitis (per %), -€0.34 for dag score (per dag score) and -€0.08 for faecal egg count (per 50 eggs/g). Within the two Irish breeding objectives, the terminal and replacement breeding objective, the greatest emphasis was placed on production traits across both the terminal (62.56%) and replacement (41.65%) breeding objectives. The maternal and lambing traits accounted for the 34.19% and 23.45% of the emphasis within the replacement breeding objective, respectively. Results from this 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.

Keywords: ovine; breeding objectives; computer simulation

Introduction

A clear and well defined breeding objective is critical to allow for simultaneous genetic improvement across a selection of traits (Dekkers and Gibson, 1998). A prerequisite to the designing an effective breeding objective is knowledge of the traits of interest, and secondly the economic importance of each trait within the production system, thereby ensuring each trait is optimally weighted within the objectives. Economic values are often used within breeding objectives to calculate the economic importance of each trait; the economic value of a trait is defined as the value of a unit change in the trait while keeping all other traits constant (Hazel, 1943). Economic values can be calculated using a multitude of approaches, including a trait-by-trait approach using profit equations (Nielsen et al., 2014) or using a multi-trait bio-economic model approach. 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 such an approach has been described as simplistic as it fails to account for the complex biological relationships that can occur between traits (Nielsen et al., 2014). Bio-economic models are commonly used to calculate economic values across dairy (Veerkamp et al., 2002), beef (Aby et al., 2012) and sheep (Wolfová et al., 2009) production systems; this approach tends to expand the level of representation of biological inter-relationships relative to simple profit equations (Groen et al., 1997). A whole farm bio-economic model has been developed and validated across a range of Irish production systems (Bohan et al., 2016), but heretofore has not been used to calculate economic values for the national sheep breeding objectives.

As an animal's performance and profitability is dependent on a plethora of traits, multiple trait selection indexes are the most common method for defining breeding objectives for sheep production (Conington et al., 2004; Byrne et al., 2012) and other species (Veerkamp et al., 2002; Aby et al., 2012). To date most studies on the calculation of economic values for sheep systems have focused on a number of common traits including fertility, such as number of lambs born, (Kosgey et al., 2003; Conington et al., 2004; Wolfova et al., 2009), lambing traits (Byrne et al., 2010; Byrne et al., 2012; Quinton et al., 2014), carcass quality (Byrne et al., 2012; Conington et al., 2004; Quinton et al., 2014) and ewe weight (Kosgey et al., 2003; Wolfova et al., 2009; Byrne et al., 2010).

The objective of this study was to develop economic values for pertinent traits to the Irish sheep industry using a bio-economic model; these economic values will be included in the national sheep breeding objectives.

Materials and methods

Description of bio-economic model

The Teagasc Lamb Production Model (TLPM) is a whole farm bio-economic simulation model that calculates the physical, financial and economic outputs of Irish sheep systems (Bohan et al., 2016). The model is capable of simulating institutional, technical and economic change, and assessing the resulting effects on farm productivity and profitability. The model was built using actual Irish farm data from multiple sources, including national research data and input from industry experts. Simulated within the model is the annual production cycle of a sheep flock, commencing at mating. The default scenario simulated in the current study represents the average Irish flock with a flock size of 107 ewes, a mean lambing date in early March, stocked at 7.5 ewes per hectare and weaning 1.5 lambs per ewe joined to the ram.

Net energy (NE) requirement of the flock for maintenance, growth, body condition change, pregnancy and lactation were calculated based on equations developed by O'Mara (1996). Unité fourragère du lait (UFL) was the unit of energy used in the NE system, with one UFL equating to one kg of air dried barley (Jarrige, 1989). Total flock NE requirement was portioned into grazed grass, grass silage and concentrate depending on time of the year and stage of production. In times of energy deficit additional grazing was rented in or silage and/or concentrates were introduced to meet flock energy requirements. The cost of grass was calculated based on cost of production with no land opportunity cost included. Fertiliser, lime and reseeding levels were dependent on grass production to meet flock demand. The flock's energy demand was supplied by grazed grass over the grazing period with the flock housed during the winter months (mid-December to early-March) and fed grass silage. Breeding ewes were supplemented with concentrates for a period of six to eight weeks pre-lambing and lambs were supplemented from October onwards.

Lamb drafting weight was based on either a target live weight or carcass weight and kill out percentage; the number of lambs slaughtered monthly was determined by the drafting sub model. Industry data for the years 2006 to 2016 (Bord Bia, 2017) and real farm data (Creighton, 2014) were used to calculate monthly carcass prices, which included bonuses, or penalties for all conformation and fat classes. The average monthly price for culled ewe lambs, hoggets, mature ewes and rams was based on historical prices from January 2010 to December 2016 (Carty, pers. comm., 2017).

All variable costs and fixed costs (concentrates, fertiliser, reseeding, machinery hire, silage making, veterinary medicine, animal housing, farm vehicle, electricity, telephone, and depreciation) were based on Irish industry prices in 2017.

Biological inputs for the default scenario including: farm size, animal numbers, animal performance, grass growth, fertiliser use and concentrate use (Table 1) were used to calculate the physical and financial outputs in the model. The key economic outputs from the model include: annual cash flow, profit and loss, and a balance sheet. The key physical outputs from the model are: feed supply and demand, livestock trading schedule and physical ratios such as the proportion of concentrate fed and number of lambs slaughtered. Net profit is presented in a multitude of ways including on a total farm basis, as well as, per hectare, per ewe joined to the ram, per lamb slaughtered and per kg of carcass sold.

The flock in the default scenario (Table 1) has a replacement rate of 20%, with 22 ewe lambs retained to maintain ewe numbers. Similar to industry standards (Bohan et al., 2017) the replacement females are mated at 18 months of age to lamb for the first time at two years of age. The labour cost in the default scenario is based on a labour requirement of eight hours per ewe annually which represents a typical Irish sheep farm (Connolly, 2000), with labour valued at €12.50 per hour. The default scenario assumed animals are handled for routine management practices once a month. The TLPM was used to calculate the economic values for individual traits that are pertinent to Irish sheep production systems. Economic values were generated by simulating a one unit change in each trait independently and comparing the net profit in the changed scenario with a net profit in a default scenario, while all other traits remained constant in the model.

Maternal traits

Number of lambs born. The economic value of number of lambs born (NLB) was defined as the value of one additional lamb born. In the default scenario, the average number of lambs born per ewe joined was 1.63 lambs; in a second scenario (increased NLB) the number of lambs born per ewe joined was increased to 1.93 lambs. The increased NLB scenario had repercussions on the pregnancy energy requirement of the ewe, with the energy requirement for pregnancy alone increasing from 18.5 UFL in the default scenario to 20.6 UFL in the increased NLB scenario. In addition, the average lamb birth weight reduced from 4.53 kg in the default scenario to 4.24 kg in the increased NLB scenario. As litter size increased lamb mortality from pregnancy scan to sale increased from 13.06% in the default scenario to 14.40% in the increased NLB scenario (Benoit, 2014). The increased litter size was associated with greater milk production potential of the ewe (Oravcová et al., 2006) which resulted in the energy requirement for lactation alone increasing from 151.5 UFL (default scenario) to 161.5 UFL (increased NLB scenario) over the 14 week lactation period. Despite the greater overall milk production of the ewe in the increased NLB scenario, the total milk volume received by each individual lamb reduced in energy terms from 50.3 UFL per lamb in the default scenario to 45.8 UFL per lamb in the increased NLB scenario. This reduced lamb growth rate (305 g/day v 289 g/day) which in turn increased the average number of days to slaughter for the flock thereby increasing flock feed demand and costs. The increased grass demand was supplied by renting additional land for grazing. The greater number of lambs in the increased NLB scenario resulted in greater veterinary costs and also resulted in a reduction in the average carcass price due to a lower carcass price per kg for later finishing lambs reflecting the annual lamb price pattern which is lowest during the late autumn. All the above changes were due to a change in the proportion of single, twin and triplet lambs in the flock rather than changing multiple traits together.

Ewe mature weight. Ewe mature weight was defined as the value of a one kilo increase in ewe mature weight. The economic value for ewe mature weight was calculated by increasing the average ewe mature weight from 70 kg in the default scenario, to 80 kg in the increased ewe mature weight scenario. The increase in ewe mature weight resulted in greater annual mature ewe maintenance costs (+39 UFL per ewe annually, +€8.39 per ewe) compared to the default scenario. In the increased ewe mature weight scenario a greater ewe cull value was obtained as a result of the greater carcass weights achieved. The increase in mature ewe weight resulted in a greater growth and maintenance requirement of the replacement females from birth to first mating at 18 months of age (+21.4 UFL), as well as a higher growth requirement of the hogget ewes during their first lactation (i.e. 18 to 30 months old). In the increased ewe weight scenario, replacement hoggets were 8 kg heavier at first mating compared to the default scenario (58.5 kg), which equated to 80% of their mature live weight (Teagasc, 2017).

Ewe replacement rate. Ewe replacement rate was defined as the value of a one percentage increase in ewe replacement rate. The economic value for ewe replacement rate was calculated by increasing the ewe replacement rate from 20% in the default scenario to 30% in an increased replacement rate scenario. Across both scenarios (default and increased replacement rate scenario) all replacements were sourced from within the flock. The increased replacement rate scenario resulted in increased cull ewe sales (+7 ewes), costs associated with dead ewe disposal (+€84) and number of replacements retained (+11 replacements). This resulted in a reduction in income (despite higher cull ewe sales) due to the retention of a greater number of replacement females. The increased replacement rate resulted in a change in the age profile of the flock, with a greater proportion of younger ewes in the flock, this reduced overall flock performance on average (McHugh et al., 2016; 2017a) such as a reduction in the number of lambs born, increased lamb mortality and lambing difficulty, reduced lamb growth rates due to lower milk yield potential and reduced weaning weight compared to the default scenario.

Lambing traits

Lambing difficulty. Lambing difficulty was defined as the value of a one percent increase in lambing difficulty. In Ireland, lambing difficulty is subjectively scored by producers, at the ewe level, on a scale of 1 to 4 as: 1 = no lambing assistance/unobserved, 2 = voluntary assistance, 3 = slight assistance and 4 = significant assistance (including caesarean section; Table 2). Lambing difficulty measured for single and multiple bearing ewes were considered as separate traits in the current study as the genetic correlation between both traits is less than unity (McHugh et al., 2017a). The proportion of ewes in each of the four lambing difficulty categories for the default scenario was determined based on national data separately for single and multiple bearing ewes (McHugh et al., 2016; Table 2). A second scenario examining a change in lambing difficulty (hereon referred to as increased lambing difficulty scenario) was simulated whereby the proportion of ewes requiring slight and significant assistance (i.e. category 3 and 4) was increased by a total of 1%. Across all categories and scenarios, it was assumed that labour and veterinary costs per ewe did not differ between single and multiple bearing ewes. However the proportion of ewes within each lamb difficulty category differed between single and multiple bearing ewes in both the default and the increased lambing difficulty scenario (Table 2). To avoid double counting between the calculations of the economic value of lamb survival and lambing difficulty the cost of lamb mortality was not included in the calculation of the economic value for lambing difficulty. A direct (effect of the lamb) and maternal (effect of the ewe) component were calculated separately for lambing difficulty, in single and multiple bearing ewes, in the national breeding objectives (Santos et al., 2015). The cost of ewe mortality related to lambing difficulty was accounted for in the direct lambing difficulty trait and not the maternal lambing trait as the increased ewe mortality is associated with the sire rather than the ewe herself.

Lamb Survival. The economic value of lamb survival was defined as the value of one additional lamb surviving to 24 hours postpartum. In the default scenario, total lamb mortality from pregnancy scanning to lambing was 13.06% (Benoit, 2014), with 7.84% occurring at parturition. A second scenario was modelled whereby lamb mortality at parturition was decreased by 1% to 6.84%, this equated to an additional 1.82 live lambs at birth, compared to the default scenario. The increased lamb survival at birth resulted in increase in revenue due to additional lamb sales, whilst the overall costs of the maintaining the ewes were not increased. The change in net profit was divided by the 1.82 lambs to give the value per lamb. A recent study highlighted that the pre-weaning growth potential of a lamb is affected by both the lamb's birth and rearing type (McHugh et al., 2017b) therefore, the growth potential of a litter was also considered in the calculation of the economic value for lamb survival.

Production traits

Days to slaughter. Days to slaughter was defined as the value of an increase in days to slaughter by one day. The economic value for days to slaughter for each lamb was calculated based on a target lamb live weight at slaughter. The target live weight was based on industry standards changing each month as the lamb aged. The carcass weight was calculated using the live weight at slaughter and a predicted kill out percentage. The age at which the lamb reached this target live weight was dependent on the lamb's growth rate. In the default scenario, the average lamb growth rate across lambs reared as singles, twins or triplets was

221 g per day (Earle et al., 2017). In the increased days to slaughter scenario the average lamb growth rate was reduced by 5% to 210 g per day. The reduced average lamb growth rate resulted in an increase in the feed costs, as slower growing lambs remained on the farm longer and hence required additional feed to reach the optimal live weight for slaughter. In addition, a greater proportion of lambs remained on the farm when grass supply reduced in the autumn; this resulted in additional concentrate feeding and veterinary costs associated per lamb. This increase in costs was also compounded by a lower carcass price per kg obtained by the later finishing lambs due to annual price pattern experienced in Ireland which is lowest in late autumn.

Carcass conformation. Carcass confirmation was defined as the value of an increase in carcass confirmation by one grade. In Ireland Carcass conformation is graded using the EUROP grid system (E = excellent and P = poor; Russo et al., 2003). R grade carcasses receive the base price with E and U grade carcasses receiving a bonus and O and P grade carcasses receiving a penalty. The extent of these bonuses and penalties vary between abattoirs but for the purpose of this study a 10 cent bonus or penalty per kg was assumed. In the default scenario, the proportion of lambs within each EUROP class was calculated based on Irish abattoirs data and equated to 0.5%, 22.5%, 69%, 7% and 1% of carcasses graded as E, U, R, O and P, respectively (Byrne et al., 2010). For the purpose of this study the EUROP grades were converted to 1 to 5 for E to P, respectively. To calculate the economic value for carcass conformation, the average carcass conformation grade in the default scenario (3.15 corresponding to a EUROP grade of R) was increased by one unit to an average grade of 4.15 (corresponding to a EUROP grade of U). This unit increase in carcass conformation resulted in a quality bonus payment of 10 cent per kg of carcass. The higher conformation resulted in an improvement in lamb kill out percentage (+1%), which resulted in an increase in average carcass weight (+0.4kg) and therefore increased carcass value.

Carcass fat. Carcass fat was defined as the value of an increase in carcass fat by one fat score. In Irish abattoirs the external fat score of each carcass is measured and is scored using a 1 to 5 scoring system in order of increasing fatness (1 = low fat cover; 5 = high fat cover) (Russo et al., 2003). Carcasses with a fat score of 3 receive the base price with over fat and under fat carcasses receiving a penalty. The extent of the penalty varies between abattoirs but for the purpose of this study a 10 cent penalty per kg was assumed. In the default scenario, the proportion of lambs within each fat score was representative of data from Irish abattoirs and resulted in 1%, 14%, 73%, 11% and 1% of carcasses categorised as fat score 1, 2, 3, 4 and 5, respectively (Byrne et al., 2010). To calculate the economic value for carcass fat, the average carcass fat score in the default scenario (2.98) was increased by one unit of carcass fat (3.98). The fatter carcasses were penalised by 10 cent per kg due to excessive fatness. Increased fat scores increased the kill out (+1%) percentage achieved by each lamb which in turn resulted in greater carcass weights leading to a greater overall carcass value. A greater energy requirement (+2%) per kg of live weight gain was required for each lamb to reach the optimal carcass weight in the increased carcass fat scenario; this increased the feed costs per lamb.

Health traits

Ewe lameness. Ewe lameness was defined as the value of a one percent increase in ewe lameness. A recent Irish study highlighted that the genetic correlation between ewe and lamb lameness is less than unity (O'Brien et al., 2017) therefore an economic value for lameness was calculated for lambs and ewes separately. Lameness was measured on a three point scale as: 0 = not lame, 1 = mildly lame and 2 = moderately to severely lame (O'Brien et al., 2017). To calculate the economic value of lameness in ewes, lameness was simulated at two varying incidences, 5% (default scenario) and 20% (high prevalence). In the default scenario, it was assumed that ewes were not herded specifically for lameness; instead ewes were foot bathed using zinc sulphate six times per year, as part of standard management practices. In the high prevalence scenario (i.e. prevalence of lameness of 20%) it was assumed ewes were herded to the handling facility every two weeks from four weeks post lambing (April) to winter housing in December. This equated to the herding of the flock an additional eight times per annum. Irrespective of the scenario under investigation, it was assumed that of the lame ewes, 20% were classified as mildly lame and 80% were classified as moderately to severely lame (Conington et al., 2008a). In both scenarios ewes classified as moderately to severely lame received individual antibiotic treatment; ewes classified as mildly lame were foot bathed. It was assumed that the change in cost was linear between the two scenarios. The additional costs associated with the increased prevalence of lameness included the additional labour cost to herd, foot bath and treat individual ewes (Table 3), as well as, the cost of footbath solution (€0.10 per ewe per treatment), antibiotic spray (€0.20 per ewe per treatment) and a long acting antibiotic injection for ewes severely affected by lameness (€1.35 per ewe per treatment).

Lamb lameness. Lamb lameness was defined as the value of a one percent increase in lamb lameness. The economic value for lamb lameness was modelled using two varying incidence of lameness, 5% (default scenario) and 20% (high prevalence scenario). Lamb lameness was measured on the same three point scale as ewe lameness (i.e. 0 to 2; O'Brien et al., 2017). In the default scenario it was assumed that all lambs were routinely treated for lameness using foot bathing with zinc sulphate five times per year. In the high prevalence scenario it was assumed that lambs were herded for treatment every two weeks from April to November, which resulted in the herding of the flock an additional five times per annum specifically for the treatment of lameness. In the default scenario it was assumed that 2% of lame lambs required an antibiotic treatment, this figure increased to 8% of lame lambs at the high prevalence scenario (Byrne et al., 2010). In the default scenario and high prevalence scenario 0.75% and 3% lambs, respectively, were treated with a long-acting injectable antibiotic as they were considered severely lame (Conington et al., 2008a). The remaining lambs classified as lame in both scenarios (i.e. 1.25% in the default scenario and 5% in high prevalence scenario) receive an antibiotic spray treatment (Conington et al., 2008a). It was assumed that the change in cost was linear between the two scenarios.The additional costs associated in the increased lameness scenario included: the labour cost of herding, foot bathing and treating individual lambs (Table 3), as well as, the cost of footbath solution (€0.07 per lamb per treatment), antibiotic spray (€0.20 per lamb per treatment) and long acting antibiotic injection (€0.72 per lamb per treatment).

Mastitis. Mastitis was defined as the value of a one percent increase in mastitis. Previous studies have shown that the incidence of clinical mastitis in sheep flocks ranges from 1% to 15% across a multitude of ewe breeds and farm systems (Winter, 2001; Onnasch et al., 2002; Koop et al., 2010). The economic value of mastitis was calculated in the TLPM by simulating two scenarios, the default scenario with an average flock prevalence of clinical mastitis of 5% and a high prevalence scenario with an average flock prevalence of clinical mastitis of 20%. It was assumed that ewes with sub-clinical mastitis were identified through udder palpation and culled post-weaning and were not selected for mating in the subsequent breeding season; the cost of this was ignored in the mastitis EV to avoid double counting with ewe replacement rate. In the default scenario ewes were spot treated during routine management procedures where an incident of mastitis was identified. In comparison at the high prevalence of clinical mastitis (i.e. 20% prevalence), ewes were herded to a handling facility specifically for the treatment of mastitis an additional four times across the production year. For each reported incident of clinical mastitis, each affected ewe received an antibiotic injection for three consecutive days (€3.75 per ewe) and an intra-mammary antibiotic tube (€2.50 per ewe). The labour costs associated with the high prevalence of mastitis included: the herding of ewes to the handling facilities for additional treatment, the examination and palpation of each ewes udder and the labour associated with the restraining and treatment of each individual ewe (Table 3). The reported incidence of ewe mortality associated with clinical mastitis is 4% (Winter, 2001; Onnasch et al., 2002), however ewe mortality was not included in the economic value for mastitis as it is accounted for in the replacement rate trait. It was assumed that milk yield of the ewe decreased dramatically where a case of clinical mastitis was identified; therefore it was assumed that one lamb would be removed from the ewe and was sold at the market value depending on the live weight of the lamb at removal.

Dag score. Dag score was defined as the value of an increase in dag score by one score. Dag score is measured on a six-point scale (0-5) based on increasing severity of dagginess or faecal soiling around the hindquarter of an animal (McHugh et al., 2014). Dag score was simulated across two varying scenarios; a flock with an average dag score of two (default scenario) and a flock with an average dag score of five. Across both scenarios it is assumed that all lambs were treated for the prevention of blow-fly strike pre weaning. In the default scenario it was assumed that no lambs were fined at the point of slaughter for faecal contamination of the hide, however 8% of lambs were shorn over the summer months to remove excess faecal material and an additional 1% of lambs were spot treated for blow-fly strike. In the high incidence of dagginess scenario, it was assumed that 30% of lambs were penalised at point of slaughter for faecal contamination of the hide at a cost of €0.90 per carcass, 50% of lambs were shorn over the summer months to remove excess faecal material and a further 20% of lambs were spot treated for blow-fly strike. It was assumed that the change in cost was linear between the two scenarios. The increased average dag score resulted in the herding of the flock an additional 3 times over the summer months. The additional labour costs associated with the increased dag score include: herding, shearing lambs for excessive dagginess, penalties at slaughter and treatment of lambs for blow-fly strike (Table 3).

Faecal egg count. Faecal egg count was defined as the value of a one unit (50 eggs/gram) increase in faecal egg count. The gastrointestinal nematode infection burden in individual animals or flocks is assessed using faecal egg counts (FEC) and are used as a management support tool to determine the optimal time for the treatment of nematode infections (Kenyon et al., 2016). The faecal egg count test calculates the number of gastrointestinal worm eggs per gram of faecal matter, with a range from a low burden level of <250 eggs per gram to a high worm burden of >750 eggs per gram. Faecal egg counts of 500 eggs per gram or greater have been shown to have an effect on lamb performance (Leathwick et al., 2006). The economic value for FEC was calculated by simulating two scenarios, the default scenario where the average FEC of the flock was assumed to be 300 eggs per gram, and a high FEC scenario where the average FEC was 800 eggs per gram. In the default scenario lambs were routinely treated for nematode infection five times between two and eight months of age. In the high FEC scenario three additional oral anthelmintic drenches were administered to the lambs across the year. This resulted in greater labour requirements for the herding and administration of the additional drenches (Table 3).

Sensitivity analyses

To assess the robustness of the calculated economic values across varying input costs and prices, sensitivity analysis was undertaken. Sensitivity analysis was conducted by increasing the prices of key input and output variables and assessing their effect on the economic values. The model was adjusted so that fertiliser costs, concentrate costs, lamb price and labour cost could all be fluctuated by ±10% separately to assess which variable had the greatest effect on the economic value. These four variables were chosen for sensitivity analysis as they are they four variables that have the greatest effect on flock profitability in a grass based sheep production system (Bohan et al., 2018).

Selection Index Methodology

Selection indexes were developed to access the impact of the newly derived on the national sheep breeding objectives which includes both a terminal and replacement breeding goal (Santos et al., 2015). Genetic and phenotypic parameters for each trait were available from Irish data for lambing (McHugh et al., 2017a), health (O'Brien et al., 2017), and growth (McHugh et al., 2017b) traits; estimates of the genetic parameters for fertility, lamb carcass and ewe mature weight was derived from the literature by Santos et al. (2015).

For the calculation of the selection indexes the vector of optimal index weights (**b**) was calculated for the breeding objective as **b** = $\mathbf{P^{-1}Ga}$ where $\mathbf{P^{-1}}$ **=** the inverse of the phenotypic (co)variance matrix of the traits in the selection index and accounts for the number of progeny used within the selection index, **G** = the genetic covariance matrix between all traits included in the selection index, and **a** = the vector containing the economic values calculated in the current study. The correlated response to selection for each trait in both the replacement and terminal breeding objective was calculated as:

$$CR = \frac{\boldsymbol{b'Ga}}{\sqrt{\boldsymbol{b'Pb}}}$$

where *CR* = the correlated response to selection, ***b*** **=** the vector containing the index weights, ***G*** = the genetic (co)variance matrix, and ***a*** = the vector containing the economic values, and ***P*** **=** the phenotypic (co)variance matrix.

The relative emphasis was calculated for each trait, within both the terminal and replacement breeding objective, as the economic weight times its standard deviation divided by the sum of the absolute values of these products and then multiplied by 100 (Van Radan, 2002). For the calculation of the relative emphasis of each trait, discounted genetic expressions (DGE) were calculated bases on the assumptions by Byrne et al. (2010) to calculate the economic weight of each trait.

Results

Maternal traits

The economic value for number of lambs born was €39.76 per additional lamb born (Table 4). The number of lambs born trait resulted in a substantial change to the feed budget with an additional 9,370 kg/DM of grass and 1,046 kg/DM of concentrates required across the farm. The higher litter size also increased lamb mortality with 27 of the additional 32 lambs surviving to slaughter. Total lamb sales increased by €2,535, while feed costs increased by €1,041 and veterinary costs increased by €131 compared to the default scenario. This increase in lamb sales, feed costs and veterinary costs increased farm net profit by €1,273 (Table 6). Ewe mature weight was calculated as three separate economic values having a different discounted genetic expression (Table 4). The economic value for ewe cull value was €0.116 per kg increase in ewe mature weight, annual ewe maintenance costs was -€0.570 per kg increase in ewe mature weight and -€0.089 per kg increase in ewe mature weight for the growth associated with the replacement ewe.. The increased ewe size resulted in heavier cull ewe carcass and increased total cull sales income by €124 across the farm. The increased energy requirement resulted in an additional €705 feed costs across the flock. The increased receipts, costs and resulting net profit change associated with ewe mature weight are presented in table 6. The economic value for a 1% increase in ewe replacement rate was -€0.843. The increased replacement rate resulted in an increase in cull sales (€463), a reduction in lamb sales (€1,253) and an increase in feed costs (€249) due to retaining extra replacements. Farm receipts reduced by €7.21 per ewe, total cost of production increased by €1.22 per ewe and thus net profit per ewe declined by €8.43 (Table 6). The greater replacement rate also resulted in a change in the age profile of the flock with a greater proportion of hogget ewes retained in the flock as replacement; this resulted in a reduction in flock performance due to reduced average scanning rate, reduced average milk production and reduced average lamb growth rate.

Lambing traits

A 1% increase in lambing difficulty of a single bearing ewe had an economic value of -€0.272 and an economic value of -€0.299 for a multiple bearing ewe (Table 4). The economic value for maternal lambing difficulty was -€0.250 for a single bearing ewe and -€0.270 for a multiple bearing ewe. Increasing lambing difficulty by one unit increased labour costs by €0.14 per single bearing ewe lambing and €0.13 per multiple bearing ewe lambing. In addition veterinary costs increased by €0.13 per single bearing ewe lambing and €0.16 per multiple bearing ewe lambing. The effect of lambing difficulty on farm receipts, cost of production and net profit per ewe are presented in table 6. The economic value for increasing lamb survival was €54.84 per lamb (Table 4). Increasing lamb survival resulted in an additional 1.82 lams surviving which increased farm receipts by €170, increased costs by €70 and therefore increased net profit by €100 (Table 6).

Production traits

A one day increase in days to slaughter equated to an economic value of -€0.251. In the default scenario the average days to slaughter was 201 days, the reduction in growth rate by 5% increased the average days to slaughter to 230 days. The increase in average days to slaughter, by 29 days, increased total flock feed costs by €1,046. The increased days to slaughter resulted in an increase in cost of production of €7.76 per lamb and a reduction in receipts of €0.60 per lamb which combined reduced net profit per lamb by €7.16 (Table 6). The economic value for carcass conformation was calculated as €3.701 per conformation grade increase. Increasing the average carcass conformation grade by one unit resulted in an average increase in carcass weight of 0.4kg and bonus payment of 10c per kg resulting in an increase of €504 in lamb sales across the farm. The improvement in carcass conformation increased receipts and net profit by €3.70 per lamb (Table 6). The economic value of carcass fat score was calculated as -€0.842 per fat score increase. Increasing the average fat score by one unit resulted in in an average increase in carcass weight of 0.4kg and penalty of 10c per kg, reducing lamb sales income by €56.28 across the farm. In addition an increased energy requirement, and thereby feed cost (€58.51 across the flock), was associated with producing fatter carcass in the increased carcass fat score scenario. The increase in fat score reduced receipts by €0.41 per lamb, increased cost of production by €0.43 per lamb and thus reduced net profit per lamb by €0.84 (Table 6).

Health traits

A 1% increase in ewe lameness resulted in an economic value of -€0.240 (Table 4). The increased incidence of ewe lameness resulted in increased veterinary costs (€244) and increased labour costs (€140). Increasing ewe lameness increased cost of production by €3.60 per ewe and in turn reduced net profit by €3.60 per ewe (Table 6). The economic value for lamb lameness was -€0.078 per percentage increase (Table 4). Similar to ewe lameness, the increase in the veterinary costs of the flock (€66) and additional labour requirements were the major contributors to the reduction in the net profit of the increased lameness relative to the default scenario. Increasing lamb lameness increased the cost of production by €1.17 per lamb and in turn reduced net profit per lamb by €1.17 (Table 6). The economic value for a

1% increase in the incidence of clinical mastitis was -€0.253 (Table 4). The greater veterinary costs (+€92) associated with the increased incidence of mastitis, as well as, the greater labour costs (+€47) were key contributors to the reduced net profit in the increased mastitis scenario. However, the reduction in lamb sales, due to a lamb being removed from the ewe with mastitis, (-€330) had the greatest impact on farm profitability. Increased prevalence of mastitis reduced farm receipts by €2.63 per ewe, increased cost of production by €1.16 per ewe and reduced net profit per ewe by €3.79 (Table 6). Increasing the average flock dag score by a one unit had an economic value of -€0.342, the increased labour and abattoir penalties increased cost of production and reduced net profit by €1.02 per lamb (Table 6). A one unit increase in the faecal egg count had an economic value of -€0.076 (Table 4). The additional worm drenches that the lambs received increased the veterinary cost by €47 and the labour costs by €56 which increased the cost of production by €0.76 per lamb and reduced net profit per lamb by €0.76 (Table 6).

Sensitivity analyses

The effect of varying fertiliser, concentrate, lamb and labour prices on each economic value are presented in Table 5. Varying the aforementioned input parameters had little impact on the economic value for ewe mature weight. A variation in labour costs changed the economic values for ewe lameness, lamb lameness, dag score, faecal egg count, lambing difficulty, maternal lambing difficulty and ranged from ±4% to ±7% (Table 5), but these traits were not affected by variation in fertiliser, concentrate or lamb price. The economic value of ewe replacement rate varied based on lamb price (±14%) and labour costs (±4%); fertiliser and concentrate price had little impact on ewe replacement rate (±0.2% and ±0.3%, respectively). Mastitis was affected by both lamb price and labour price variation had an effect on the mastitis economic value and mastitis was the only health trait affected by lamb price (±16%; Table 5). The economic values of carcass conformation and carcass fat are both affected by lamb price only, with varying lamb price having twice the effect on carcass conformation compared to carcass fat. The economic value of days to slaughter was affected by variation in all four variables. Fertiliser price had a marginal effect on the economic value for lamb survival (±1%), but lamb price had the greatest impact on lamb survival (±17%). A variation in fertiliser, concentrate and labour price did affect the economic value of number of lambs born however, as with lamb survival; lamb price had the greatest effect at ±20%.

Selection Index Methodology

The economic values, genetic standard deviations and the economic weights for each trait for both the replacement and terminal breeding objectives are presented in Table 4. In the replacement breeding objectives, the economic weights for maternal traits ranged from -€0.33 for ewe mature weight to €9.58 for number of lambs born. For lambing traits, within the replacement and terminal breeding objectives, the economic weights for direct and maternal lamb survival were €28.68 and €25.23, respectively. Carcase conformation (direct and maternal effects) had economic weights of €1.55 and €1.18, respectively (Table 4); the corresponding economic weight calculated for days to slaughter was -€0.10. Smaller economic weights were associated with all the health traits and ranged from to -€0.15 (dag score) to -€0.03 (faecal egg count; Table 4) in both the replacement and terminal breeding objectives.

In the terminal breeding objective, the inclusion of the new economic values and the health traits (assuming 0.22 genetic standard deviation change per year), resulted in a reduction in direct (-2.68 days) and maternal (-0.83 days) days to slaughter as well as carcass fat score (-0.03 score). This corresponded to a slight increase in the genetic gain for ewe mature weight (0.73 kg) and maternal carcass conformation (0.02 grade). However the inclusion of the new economic value had no impact on the genetic gain for health or lambing traits. In the replacement breeding objective the inclusion of the new economic values resulted in a reduction in the genetic gain for direct (-1.72 days) and maternal (-1.57 days) days to slaughter, carcass conformation (-0.01 score) and fat (-0.02). The genetic gain for ewe mature weight (0.45 kg), numbers of lambs born (0.01 lambs), maternal carcass conformation (0.03) and fat (0.04) increased in the replacement breeding objective. The genetic gain achieved in the lambing and health traits was small but in the desired direction.

In the terminal breeding objective the greatest emphasis was placed on production traits (62.56%) followed by lambing traits (35.81%; Figure 1). In the terminal breeding objective, the greatest emphasis was associated with days to slaughter trait (47.37%), with 34.17% of the weighting placed on lamb survival. Health traits accounted for 1.64% of the terminal breeding objective (Figure 1). Similarly, the greatest emphasis (albeit with lower emphasis values) in the replacement breeding objective was placed on the production traits (41.65%; Figure 1). Maternal and lambing traits also accounted for a large proportion of the replacement breeding objective, with 34.19% and 23.45% emphasis placed on the trait groups, respectively. On an individual trait basis the greatest emphasis in the replacement breeding objective was associated with number of lambs born (18.19%), maternal days to slaughter (12.09%) and maternal lamb survival (8.98%). The contribution of health traits to the replacement breeding objective was small (0.71%; Figure 1).

Discussion

Economic values for pertinent traits in sheep production systems have been calculated for many countries including the UK (Conington et al., 2004), New Zealand (Byrne et al., 2012, Amer et al., 1999a) and Canada (Quinton et al., 2014) and across a multitude of sheep production systems including lowland (Byrne et al., 2010), hill (Conington et al., 2004), dairy (Tolone et al., 2011) and meat sheep (Wolfová et al., 2009) systems. The use of a whole farm system bio-economic model to develop economic values has been used across many production systems including dairy (Veerkamp et al., 2002), beef (Aby et al., 2012) and sheep (Wolfová et al., 2009) but prior to the current study no whole farm system bio-economic model was available to calculate economic values for an Irish sheep production system. Previous calculations of economic values for Irish sheep production (Byrne et al., 2010) used a trait by trait approach which may not account for all the biological interrelationships between traits (Nielsen et al., 2014). In addition the use of a bio-economic model has been described as a superior approach when calculating economic values compared to using simple profit equations, particularly for traits such as health and survival traits, which impact the flock age structure and dynamics which have been described as difficult to capture outside of a bio-economic model (Nielsen et al., 2014). Calculating economic values for health traits is difficult especially quantifying the effects on production. In this study the economic values for health traits did not include the effect on production as these effects are captured in the economic values of production traits such as days to slaughter and this was done to avoid double counting as described by Ostergaard et al (2016).

Economic values were calculated as the change in profit caused by a one unit change in a trait while all other traits remained constant. This study used multiple unit changes in traits such as ewe mature weight where the trait was increased from 70 kg to 80 kg (10 units); the change in profit was then divided by 10 units to find the economic value. This change of ten units was decided by a steering committee as it realistically reflected ewe mature weight differences between breeds and is acceptable as the trait is linear. Some traits however, such as lambing difficulty, are not linear and that may impact the economic value however this non linearity is accounted for in the discounted genetic expressions when calculating economic weights and relative emphasis.

The economic values generated for traits in the current study ranged from positive, for traits such as the number of lambs born, lamb survival and carcass conformation to negative, for traits that reduced profitability such as greater days to slaughter, lambing difficulty and ewe mature weight. The greatest economic value was calculated for lamb survival in the current study, followed closely by the number of lambs born. These two traits directly contribute to the lamb output per ewe which has previously been described as a key factor influencing output and profitability of prime lamb production systems (Keady and Hanrahan, 2006, Bohan et al., 2018). Discounted genetic expressions were used to calculate the economic weights of each trait which can then be used when ranking the traits in terms of their economic importance to farm profitability as they take into account the proportion of the flock that will express each trait. Number of lambs born is a key trait to a sheep production system as it is the starting point of the potential output of the system. Many studies have calculated an economic value of number of lambs born (Byrne et al., 2010) or a variation of the trait such as ewe prolificacy (Amer et al., 1999a; Byrne et al., 2012), litter size (Wolfova et al., 2009; Kosgey et al., 2003) or number of lambs weaned (Conington et al., 2004; Quinton et al., 2014). Byrne et al. (2010) calculated an economic value of €19.53 per lamb born compared to €39.76 in the current study, however a recent update of the costs and prices for the economic values of the trait in the Irish breeding objective has increased this value to €33 (Pabiou, Pers. Comm., 2017) which is in line with the findings of this study.

Lambing difficulty was calculated in two previous studies, in Ireland (Byrne et al., 2010) and Canada (Quinton et al., 2014). Lambing difficulty was calculated separately for single and multiple bearing ewes, as there was a significant difference in the labour and veterinary requirement for each category. A greater (negative) economic value was calculated for multiple bearing ewes compared to single bearing ewes which is logical as when lambing difficulty increases, a greater proportion of multiple bearing ewes require significant assistance, compared to single bearing ewes, resulting in a high labour and veterinary cost. A single economic value for lambing difficulty was calculated by Quinton et al. (2014) across both single and multiple bearing ewes; however this economic value also accounted for ewe culling and mortality and is therefore not comparable to the current study.

The economic value of lamb survival has been calculated across an array of studies (Amer et al., 1999a; Conington et al., 2004; Wolfova et al., 2009). Similar to the current study, lamb survival has been shown to be of greater economic importance than the number of lambs born in sheep production systems (Conington et al., 2004; Byrne et al., 2010). The ratio of the economic values of lamb survival to number of lambs born in the current study is 1:1.4 which is lower when compared to the corresponding ratio calculated by Byrne et al. (2010; 1:2), however the trait definition of lamb survival differed in both studies as Byrne et al. (2010) defined lamb survival to weaning whereas in the current study the trait was defined as lamb survival at birth. The trait definition used in the current study is in line with the phenotypic data available for the national breeding objective whereby currently only lamb survival at birth is recorded (McHugh et al., 2017c).

Days to slaughter is a measure of the growth rate of the lamb and the time-period for a lamb to reach its desired slaughter weight. Although many studies have calculated economic values for lamb performance most have tended to focus on traits such as: weaning (Conington et al., 2004; Byrne et al., 2012), sale (Quinton et al., 2014) or 12 month (Kosgey et al., 2003) weight. In Ireland lambs are generally slaughtered at a fixed live weight (Earle et al., 2017) as heavier carcasses can be penalised. Therefore the value of faster growth is captured in the reduced days to slaughter which helps to identify the more efficient animal rather than the heaviest animal on a given date. In the current study the economic value for carcass fat score was found to be marginally negative while the economic value of carcass conformation was roughly four times greater and in the opposite direction (i.e. a positive value). This differs from previous studies across similar grass based systems which have shown the premium for increased carcass conformation to be roughly equivalent to the penalty for increased fat (Conington et al., 2004; Byrne et al., 2010). The penalty for fatter carcasses in this study was partiality offset due to the increased kill out percentage of carcasses resulting in a heavier and more valuable carcass.

Ewe mature weight is an important trait in grass based systems as it impacts the maximum carrying capacity of the farm and therefore has been calculated in many studies (Kosgey, et al., 2003; Conington et al., 2004; Byrne et al., 2010). Similar to the current study a negative economic value for ewe mature live weight has been calculated across most studies (Conington et al., 2004; Byrne et al., 2012; Wolfova et al., 2009), although Kosgey et al. (2003) calculated a positive economic value for ewe mature weight, albeit in a contrasting production system where the ewe mature weight was 30 kg (as opposed to 70 kg in the current study) and feed costs were not included in the calculation of the economic value.

Ewe replacement rate is a critical trait for sheep production; approximately 20% of the national ewe flock is replaced annually with an average estimated replacement cost of €17 per ewe joined to the ram (McHugh, 2010). Although ewe replacement rate has not been included in the Irish national breeding objectives due to lack of available phenotypic data, it has previously been included in sheep breeding objectives for both meat (Wolfová et al., 2009) and dairy (Tolone et al., 2011) sheep production systems. The use of dam survivability is also included routinely in beef (Amer et al., 2001) and dairy (Veerkamp et al., 2002) breeding objectives. In the current study the increased replacement rate of ewes resulted in the retention of additional replacements, with a subsequent change in flock demographics and performance. Conington et al. (2004) also accounted for the effect of younger ewes on the flock performance, albeit, using slightly different parameters in a hill production system. Although a previous study has calculated a greater economic value for ewe replacement rate than both pre and post weaning lamb survival (Kosgey et al., 2003) in the current study lamb survival at birth had a much larger economic value (€54.84) compared to ewe replacement rate (-€0.84). This may be partially attributed to the unit of trait measurement, for example lamb survival is expressed per lamb while ewe replacement rate is expressed a one percent change in ewe replacement rate. Despite the development of an economic value for ewe replacement rate the trait will not be included in the Irish sheep breeding objectives due to lack of phenotypic data on the trait, however it will be included when more data becomes available.

Mastitis is the single largest reason for premature culling in UK flocks (Conington et al., 2008b) and can lead to reduced performance as well as significant labour and veterinary costs. The use of mastitis as a trait in breeding objectives is rare in sheep indices, Legarra et al. (2007) assessed the economic weights of somatic cell count in dairy sheep but no other study has estimated an economic value for mastitis in meat producing sheep in a whole farm system. In the present study a similar economic value was calculated for both mastitis (€0.25) and ewe lameness (€0.24), indicating that both traits are equally as important within Irish sheep production systems. In the present study the economic value of lamb lameness was notably lower than the economic value ewe lameness due to the lower veterinary and labour costs associated with treating lambs compared to ewes. The economic value calculated for ewe and lamb lameness in the present study is similar to the values previously calculated by Byrne et al. (2010). Dag score is an important trait as it is genetically and phenotypically correlated with blow-fly strike (Greeffe et al., 2014), a common ectoparasite affecting sheep in Europe (Bisdorff and Wall, 2008) and is a significant animal welfare concern (Pickering et al., 2011). Dag score is also a financial burden due to increased labour and financial penalties at the abattoir as a result of fleeces being contaminated with faeces. Despite the economic importance of dag score across all sheep production systems only one study (Byrne et al., 2012) has calculated an economic value for the trait heretofore. Gastrointestinal nematode infection represents a major threat to the health, welfare and productivity of grass based sheep production systems (McRae et al., 2015) and considerable genetic variation has been reported in sheep in their ability to limit and resist worm infections (Bishop and Morris, 2007). Faecal egg count has been used as a trait to represent gastrointestinal nematode infection in many sheep breeding objectives including: New Zealand (Amer et al., 1999b; Byrne et al., 2012), Australia (Amer et al., 1999b) and Ethiopia (Gizaw et al., 2010). Despite the fact that 49% of Irish farms have some level of anthelmintic resistance (Keegan et al., 2017) anthelmintic resistance was ignored in the current study due to insufficient data. A previous study reported that farms with anthelmintic resistance could expect the economic value of faecal egg count to increase by up to five times (Amer et al., 1999b), this will be considered in future Irish economic value calculations when more phenotypic data on anthelmintic resistance is available.

The primary objective of Irish sheep production systems is to maximise lamb carcass output per hectare to maximise net profit (Earle et al., 2017), this is reflected in the large relative emphasis placed on production traits such as days to slaughter and carcass characteristics in both the terminal (63%) and replacement (42%) breeding objectives. Similar to the New Zealand maternal breeding objective (Santos et al., 2015), the Irish replacement breeding objective is primarily driven by traits that maximise profit, these include (relative emphasis in parenthesis) days to slaughter direct and maternal (31%), number of lambs born (18%) and lamb survival direct and maternal (23%). The relative emphasis for the Irish replacement and terminal breeding objectives was also calculated by Santos et al. (2015), albeit using different economic values. The current study places greater emphasis on number of lambs born and lamb survival (24% versus 2%) based on the new economic values. Similarly for the terminal breeding objective greater relative emphasis will be placed on lamb survival in the current study (34%) compared to the relative emphasis calculated by Santos et al. (2015; 1.3%). Although the relative emphasis placed on health traits in both the replacement (0.71%) and terminal (1.64%) breeding objectives is low it is in the desired direction indicating that selecting animals on either the replacement or terminal breeding objectives will not reduce the robustness or healthiness of the national sheep population.

Conclusion

The development of new economic values using a whole farm systems model, will enable the continued improvement of the Irish national sheep breeding objectives using up to date inputs and a holistic approach. Irish sheep production is undergoing a period of change with a shift in markets such as the decline of the Mediterranean market for light lamb carcasses (Hynes, 2014). In addition the exit of the UK from the European Union has also created uncertainty for the Irish sheep sector, as almost 30% of sheep meat exports are destined for the UK (Bord Bia, 2016). Due to the level of uncertainty for the future direction of sheep production in Ireland the industry must be flexible and have the ability to evolve rapidly as markets change. The use of the TLPM to calculate economic values will allow for a rapid response to market changes and enable researchers to redirect the focus of breeding objectives easily, if required. The inclusion of a wide range of traits covering lambing, maternal, production and health improves the robustness of the national breeding objectives. The use of a bio-economic model to develop the economic values will provide an opportunity for future investigation into the effect of system changes on the breeding objectives and allow for updates as input and output values fluctuate and will also allow for additional traits to be included the future.

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Table 1. Description of the base farm scenario and default flock performance

Hectares (ha)	13.27
Stocking rate (ewe/ha)	7.51
Ewes Joined to the ram	107.00
Ewes lambed per ewe joined	101.80
Lambs scanned per ewe joined	1.70
Lambs weaned per ewe joined	1.48
Total lambs slaughtered	136.38
Average lamb price (€/lamb)	94.25
Total concentrate usage (kg/ewe)	44.23
Total grass grown (kg DM/ha)	7,565.36
Total N usage (kg/ha)	79.93
Ewe culling rate (%)	14.74
Ewe mortality rate (%)	5.26
Lamb mortality rate (%)	13.06

Table 2. Percentage of single and multiple bearing ewes in each lambing difficulty score (1 to 4) estimated across national data, as well as, the labour and veterinary costs associated with each category

		Lambing difficulty score			
Litter type	Costs	No Assistance	Voluntary	Slight	Significant
Single		62.69%	24.40%	9.37%	3.54%
Multiple		65.86%	24.75%	7.53%	1.86%
	Labour (hours)	0	0.20	0.85	1.75
	Labour (€)	0	2.50	10.63	21.88
	Vet costs (€)	0	0	0	90.00

Table 3. Number of seconds required per lamb and per ewe for each labour requirement associated with a health treatment (Creighton, Pers. Comm., 2017)

Labour Requirement	Seconds per lamb	Seconds per ewe
Herding to handling facility	24	24
Isolation and treatment of foot rot	40	45
Foot bathing	12	20
Isolation and treatment of mastitis	-	56
Dosing for worms	7	-
Treating for fly strike	105	-
Shearing for excessive dagginess	55	-

Table 4. Economic values, genetic standard deviation (σ_g) and the associated economic weight for each trait (and their units) in both the terminal and replacement breeding objective.

Trait Group	Trait[1]	Unit	Economic value	σ_g	Economic weight Terminal	Economic weight Replacement
Maternal	Number of lambs born	Lamb	€39.76	0.16	-	€9.58
	Ewe mature weight	Kg		4.11	-	-€0.33
	Ewe replacement rate	%	-€0.84	0.11	-	-€0.20
Lambing	LD single	%	-€0.27	0.24	-€0.14	-€0.14
	LD single (mat)	%	-€0.25	0.07	-	-€0.14
	LD multiple	%	-€0.30	0.16	-€0.13	-€0.13
	LD multiple (mat)	%	-€0.27	0.06	-	-€0.12
	Lamb survival	Lamb	€54.84	0.04	€28.68	€28.68
	Lamb survival (mat)	Lamb	€54.84	0.03	-	€25.23
Production	Days to slaughter	Day	-€0.25	15.16	-€0.10	-€0.10
	Days to slaughter (mat)	Day	-€0.25	12.68	-	-€0.08
	Carcase conf	Grade	€3.70	0.25	€1.55	€1.55
	Carcase conf (mat)	Grade	€3.70	0.25	-	€1.18
	Carcase fat	Score	-€0.84	0.35	-€0.35	-€0.35
	Carcase fat (mat)	Score	-€0.84	0.35	-	-€0.27
Health	Lameness ewe	%	-€0.24	0.08	-	-€0.06
	Lameness lamb	%	-€0.08	0.12	-€0.04	-€0.04
	Mastitis	%	-€0.25	0.04	-	-€0.06
	Dag Score	Score	-€0.34	0.33	-€0.15	-€0.15
	Faecal egg count	50 eggs/g	-€0.08	0.30	-€0.03	-€0.03

[1]Where mat refers to the maternal component for the trait, conf refers to conformation and LD refers to lambing difficulty

Table 5. The percentage change in each economic value from the sensitivity analyses, where the base economic value for each trait was compared to a 10% increase or decrease in fertiliser costs (Fert), concentrate costs (Conc), lamb survival (Lamb) and labour costs (Labour).

Trait Group	Trait[1]	Base EV	Fert	Conc	Lamb	Labour
Maternal	Number of lambs born	39.76	±2.1%	-2.8%	+19.9%	±0.1%
	Ewe mature weight (Cull)	0.12	±0.0%	±0.0%	±0.0%	±0.0%
	Ewe mature weight (Maintenance)	-0.57	±0.2%	±0.0%	±0.0%	±0.0%
	Ewe mature weight (Replacement)	-0.09	±0.3%	±0.0%	±0.0%	±0.0%
	Ewe replacement rate	-0.84	±0.2%	±0.3%	±13.9%	±4.0%
Lambing	LD single	-0.27	±0.0%	±0.0%	±0.0%	±4.3%
	LD single (mat)	-0.25	±0.0%	±0.0%	±0.0%	±5.3%
	LD multiple	-0.30	±0.0%	±0.0%	±0.0%	±3.4%
	LD multiple (mat)	-0.27	±0.0%	±0.0%	±0.0%	±4.5%
	Lamb survival	54.84	±0.8%	±0.0%	±17.0%	±0.0%
Production	Days to slaughter	-0.25	±0.3%	±3.2%	±0.4%	±0.3%
	Carcase conformation	3.70	±0.0%	±0.0%	±10.0%	±0.0%
	Carcase fat	-0.84	±0.0%	±0.0%	±4.9%	±0.0%
Health	Lameness ewe	-0.24	±0.0%	±0.0%	±0.0%	±3.6%
	Lameness lamb	-0.08	±0.0%	±0.0%	±0.0%	±5.8%
	Mastitis	-0.25	±0.0%	±0.0%	±16.1%	±1.2%
	Dag score	-0.34	±0.0%	±0.0%	±0.0%	±7.4%
	Faecal egg count	-0.08	±0.0%	±0.0%	±0.0%	±5.4%

[1]Where LD refers to lambing difficulty and mat refers to the maternal component for the trait.

Table 6. Trait units, unit change, receipts change, costs change, net profit change

Trait[1]	Unit	Unit change	Receipts change[2]	Costs change[2]	Net profit change[2]	Economic value
Number of lambs born	Lamb	32	€2,534.65	€1,261.24	€1,273.41	€39.76
Ewe mature weight (Cull)	Kg	10	€1.16	€0.00	€1.16	€0.12
Ewe mature weight (Maintenance)	Kg	10	€0.00	€5.70	-€5.70	-€0.57
Ewe mature weight (Replacement)	Kg	10	€0.00	€0.89	-€0.89	-€0.09
Ewe replacement rate	%	10	-€7.21	€1.22	-€8.43	-€0.84
LD single	%	1	-€0.03	€0.23	-€0.27	-€0.27
LD single (mat)	%	1	€0.00	€0.25	-€0.25	-€0.25
LD multiple	%	1	-€0.03	€0.26	-€0.30	-€0.30
LD multiple (mat)	%	1	€0.00	€0.27	-€0.27	-€0.27
Lamb survival	Lamb	1.82	€170.08	€70.27	€99.81	€54.84
Days to slaughter	Day	29	€0.60	€7.76	-€7.16	-€0.25
Carcase conf	Grade	1	€3.70	€0.00	€3.70	€3.70
Carcase fat	Score	1	-€0.41	€0.43	-€0.84	-€0.84
Lameness ewe	%	15	€0.00	€3.60	-€3.60	-€0.24
Lameness lamb	%	15	€0.00	€1.17	-€1.17	-€0.08
Mastitis	%	15	-€2.63	€1.16	-€3.79	-€0.25
Dag Score	Score	3	€0.00	€1.02	-€1.02	-€0.34
Faecal egg count	50 eggs/g	10	€0.00	€0.76	-€0.76	-€0.08

[1]Where LD refers to lambing difficulty and mat refers to the maternal component for the trait.

[2]Presented on a per ewe or per lamb basis depending on the trait

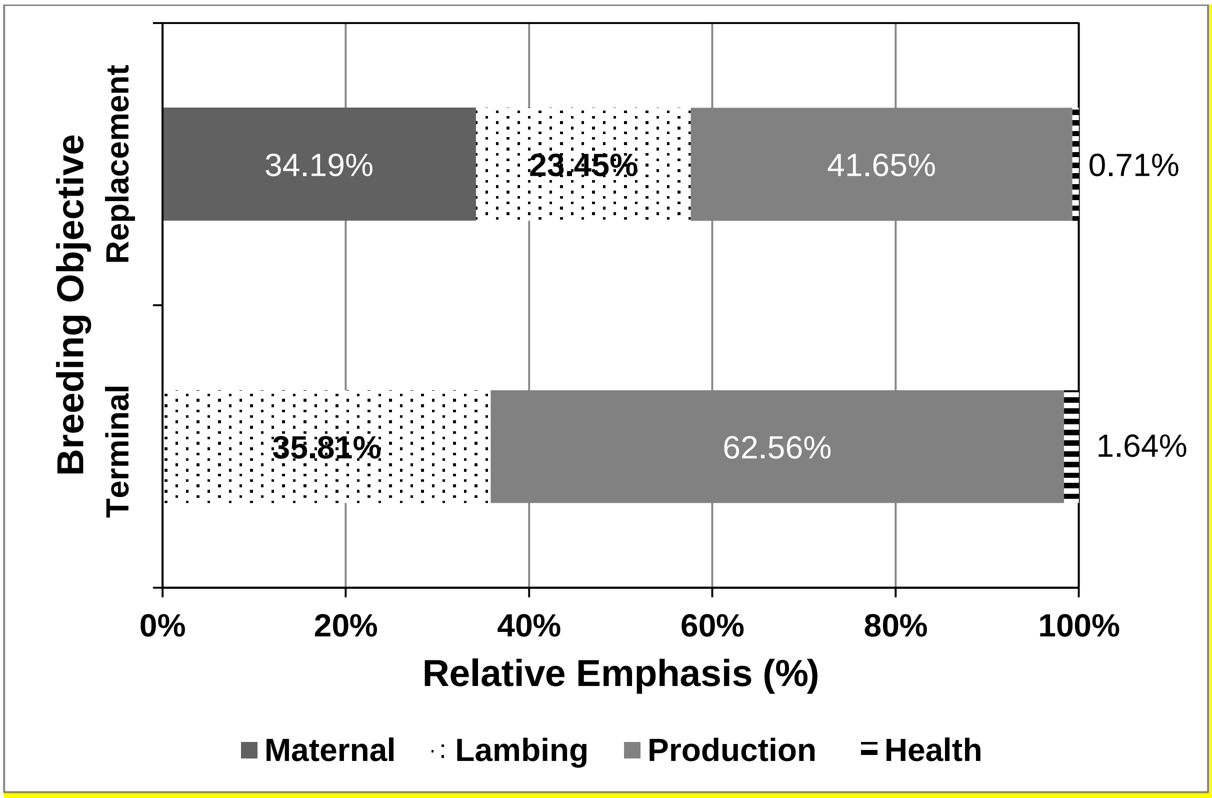

Figure 1. Relative emphasis based on the economic contribution for each trait group (maternal, lambing, production and health) in the national terminal and replacement breeding objective.