OPTIMISING MATURE WEIGHT FOR FARM EFFICIENCY AND PROFITABILITY (P61110077) – BEEF & SHEEP

Prepared for

Kim Matthews[1], John Richards[2], Doug Bell[3]

[1]AHDB Beef & Lamb

[2] Hybu Cig Cymru - Meat Promotion Wales

[3]Quality Meat Scotland

By

Tom Kirk, Natalie Howes, Peter Amer, Cheryl Quinton, and Tim Byrne

AbacusBio Limited

Mike Coffey and Eileen Wall

Scotland's Rural College

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AbacusBio International Limited
Roslin Innovation Centre
Easter Bush
Edinburgh EH25 9RG

Phone: +44 (0) 131 6519671
Mobile: +44 (0) 772 9894807
Email: tbyrne@abacusbio.co.uk
Website: www.abacusbio.com

Executive Summary

To determine the implications of differences in breeding female mature weight, we first evaluated how changing cow and ewe breeding female mature weight impacts other biological traits in the farm system and then modelled the costs and revenues on farm, associated with all the traits implicated (breeding female mature weight included).

Costs and revenue per animal were calculated (breeding female, replacement female, or slaughtered progeny), and scaled to reflect a herd or flock of 100 breeding females. The age distribution of breeding females, the replacement rate, and the slaughter offspring produced are representative of typical beef and sheep farms in the UK. Costs were subtracted from revenues across the entire herd or flock at each breeding female mature weight, to identify changes in margin over feed across a range of breeding female mature weights.

The avenues (i.e. traits) by which mature weight affects total annual cost and revenue can be defined as direct or indirect. The direct effects, which are a function of breeding female mature weight, are the annual maintenance cost, replacement heifer/hogget cost, and the cull carcase revenue. The indirect traits are the number and value of slaughtered progeny. The degree of change in costs and revenue depends on the biological relationship between breeding female mature weight and each trait. Indirect traits include the number of progeny (cow fertility, ewe number of lambs born) and the value of those progeny that are slaughtered (carcase weight and carcase quality).

For beef and sheep, we describe the base system performance, direct trait changes, and indirect trait changes associated with a 100kg (beef) and 10kg (sheep) difference in breeding female mature weight. The impact of a 100kg (beef) and 10kg (sheep) difference in breeding female mature weight is calculated, so that the scale of differences can be presented, before a breakdown of revenue and cost components, and margin over feed for a farm of 100 breeding females, across a range of breeding female mature weights is reported. Differences in breeding female mature weight will result in different overall levels of feed demand; this requires additional land for pasture and thus incurs rental costs. To capture the cost of this, the number of breeding females has been adjusted down to reflect the limited pasture resource; this is assumed to be equivalent to the cost of renting additional land.

Outcomes were assessed for sensitivity to differences in progeny slaughter practices (constant carcase weight rather than a constant age), the phenotypic correlation between breeding female mature weight and progeny carcase weight, processor penalties for heavy carcasses, the average feed cost for all feed types (+/-20%), the average feed cost for concentrate only (+/-20%), the diet over winter for cows/ ewes (inclusion of silage and concentrate for 100% of the diet), and the diet over winter for cows/ ewes (inclusion of silage and concentrate for 100% of the diet) combined with differences in the average feed cost for all feed types (+/-20%).

Beef

With increasing breeding female mature weight, cull cow revenue increases, while cow maintenance costs, replacement costs, and progeny feed costs all increase. Breeding females heavier than 700kg require higher quality and higher cost feed, which accounts for maintenance and replacement costs increasing at a faster rate above 700kg. Increasing breeding female mature weight up to 725kg significantly increases prime carcase revenue (when progeny are slaughtered on an age constant basis). After 725kg, prime carcase revenue plateaus (to 785kg) and then decreases slightly, due to lower fertility (less progeny being slaughtered) and because heifers and bulls are also being penalised for weighing over 440kg.

The optimum breeding female mature weight for a typical beef production system is 680kg (rescaled), which for a 100-breeding female herd is associated with a total margin over feed of £25,281.

The optimum breeding female mature weight (rescaled) was not sensitive to weight constant versus age constant slaughter practices.

For phenotypic correlations, between breeding female mature weight and progeny carcase weight, from 0.90 to 0.20 there is some sensitivity for the optimum breeding female mature weight, which alternates between 680kg and 695kg over this range. The optimum breeding female mature weight is sensitive to the phenotypic correlation between breeding female mature weight and progeny carcase weight, albeit in a narrow range when considering realistic phenotypic correlations (0.60 to 0.90 and 680kg to 695kg).

The optimum breeding female mature weight is not sensitive to changes in the penalty structure, when that change represents carcase weight over 440kg paid for (but the -£0.40 per kg of carcase weight still applies).

As feed prices decreas, the margin over feed increases at every breeding female mature weight. However, the optimum breeding female mature weight was not sensitive to changes in feed costs, remaining at 680kg regardless of feed costs. This might seem counterintuitive, but it stems from the fact that the rate of change in overall cow feed cost with the introduction of a mixed diet is only slightly greater than the rate of change in a grass-based diet, as mature weight increases. The additional increase in overall cow feed cost is not great enough to offset the additional revenue from the heavier progeny carcase, and for this reason the optimum does not change.

Sheep

With increasing breeding female mature weight, cull ewe revenue increases, while ewe maintenance costs and replacement costs increase. Breeding females heavier than 75kg require higher quality and higher cost feed, which accounts for maintenance and replacement costs increasing at a faster rate above 75kg. Total progeny feed costs increase over the range of ewe mature weights; this is because per animal feed savings (weight constant slaughter) are slightly less than the increase in total feed demand resulting from increases in the number of lambs available for slaughter, as ewe mature weight increases. Progeny revenue increases significantly from 45kg to 55kg mature weight. This increase is associated with increased ovulation rates and increased number of lambs born, and thus increased lambs slaughtered per 100 ewes.

The optimum breeding female mature weight for a typical sheep production system is 55kg (rescaled), although there is very little difference in re-scaled margin over feed for breeding female mature weights of 55kg to 65kg. The optimum breeding female mature weight for a 100-breeding female flock is associated with a total margin over feed of £8,060.

The "flatness" of this optimum breeding female mature weight line is the result of several elements. Firstly, there is very little difference in progeny carcase value across the range of ages, when slaughter is at a constant carcase weight; approximately £1/ carcase. When combined with a lower (compared to beef) phenotypic correlation between breeding female mature weight and progeny carcase weight, little value is gained by increasing ewe mature weight in terms of progeny carcase value. Secondly, the reproductive rate effect manifests primarily over the range of 45kg to 55kg. Thus, little value comes from increases in fertility associated with breeding female mature weight above 55kg. Cost and revenue more-or-less increase in proportion as breeding female mature weight increases and, as such, the optimum could be said to sit between 55kg and 65kg.

For phenotypic correlations from 0.90 to 0.10 there is some sensitivity for the optimum breeding female mature weight, which decreases from 57kg at 0.90, to 55kg at 0.20, and then to 51kg at 0.10. The optimum breeding female mature weight is sensitive to the phenotypic correlation between breeding female mature weight and progeny carcase weight, albeit in a narrow range when considering realistic phenotypic correlations.

For grass-based systems, the optimum remains at 55kg with increases and decreases in feed price. For mixed diets systems, the optimum is 51kg under normal pricing, but increases to 55kg when prices are 20% lower, and decreases to 50kg when prices are 20% higher. In a situation where feed is limiting (i.e. feed costs are higher, because they have to be purchased in), e.g. hill farming, the optimum appears to be closer to 50kg.

The optimum breeding female mature weight was sensitive to changes in feed costs. Similar to beef, the rate of change in overall ewe feed cost with the introduction of a mixed diet is only slightly greater than the rate of change in a grass-based diet, as mature weight increases. However, the additional increase in overall cow feed cost is greater than the additional revenue from the heavier progeny carcase, and for this reason the optimum does change i.e. this "flatness" (driven by little variation in revenue from progeny carcases) means that the optimum is sensitive to feed costs, when average feed costs are high.

Industry-wide impact

Beef

A 100kg difference in mature weight (651.4kg to 751.4kg) would yield 17,000 tonnes of carcase but reduce margin over feed by £208.9m, when progeny are slaughtered at a constant age. A 100kg difference in mature weight would reduce output by 50,500 tonnes of carcase, but reduce margin over feed by £82.2m, when progeny are slaughtered at a constant weight. In theory, the total production of prime carcase weight should not change between the base and optimum mature weights when prime carcases are slaughtered at a constant carcase weight. However, this is not the case, as production at the optimum mature weight results in a 10.4% decrease in the number of breeding females, therefore total production also decreases.

Sheep

A 10kg difference in mature weight (61.8kg to 71.8kg) would yield 8,690 tonnes of carcase and £61.3m in additional margin over feed. Though fertility decreases the number of lambs slaughtered per ewe, the increase in total production is explained by the increased ewe numbers (rescaling).

Summary and Communication

This analysis shows that, for a typical UK beef farm, there is an optimum breeding female mature weight in the range of 680kg to 725kg for cows, depending on assumptions about the cost per unit of feed for heavy cows. In a situation where marginal feed costs are high and/ or heavy cows (>700kg) can't be maintained on the feed resource available (e.g. hill country/ upland farms, where bigger cows might need to be fed an imported higher quality and cost diet), then the optimum is 680kg. In a situation where heavy cows (>700kg) can be maintained on the grass resource available, then the optimum is 725kg. This optimum is also heavily influenced by the weight at which penalties are applied for over-weight progeny carcases.

For a typical UK sheep farm, there is an optimum breeding female mature weight ranging from 50kg, in a situation where marginal feed costs are high and/ or heavy ewes can't be maintained on the feed resource available (e.g. hill country/ upland farms, where bigger ewes might need to be fed a higher quality and cost imported diet) to 65kg, in a typical lowland system where ewes can be maintained on the grass resource available. The optimum mature weight for the typical lowland system could be said to range from 55kg to 65kg; this is the result of very little difference is progeny carcase value across the range of ages at a constant carcase weight and, also, a lower (compared to beef) phenotypic correlation between breeding female mature weight and progeny carcase weight.

Best tools and techniques and their use

When assessing the tools and techniques available, genetics offers the greatest opportunity. Breeding female mature weight has a very high heritability (0.40 to 0.60), meaning variation is very highly influenced by genetics. However, mature weight is also very antagonistically genetically correlated with early growth potential (0.60 to 0.90 depending of stage of early growth). There is therefore a trade-off between the value of additional growth and the cost of additional breeding female mature weight. There are tools available that could create clear signals to breeders and subsequently commercial farmers about the value of sires with different genetic merit for breeding female mature weight and growth potential. Importantly, these tools can be created/ augmented to reflect the information available on optimum mature weights (non-linear functions etc.). These tools are economic selection indexes, which provide the appropriate rankings of bulls/ rams, based on the principles outlined above to manage breeding female mature size. Underpinning the robustness of estimates of genetic merit is quality data. Therefore, an increase in mature weight data recording (or indeed assigning sire to progeny, who go on to have cow/ ewe carcase weight records) by the breeder tier of the industry, or via a scheme, or from commercially recorded systems would add significant value to the genetic evaluation system(s) and support accuracy of EBVs and selection indexes.

In the first instance these tools would be made available to breeders and with the correct implementation, the benefits would flow to commercial bull/ ram buyers. Breeders could also make use of EBV combinations to fine-tune selection for the right combination growth and breeding female mature weight; this does however require a clear understanding of EBVs and would likely require technical input from a specialist.

Commercial farmers are best to access genetics by buying from the bull/ ram breeder that best delivers on their commercial farm needs. Selection indexes, encompassing the appropriate weightings on early growth and mature weight (non-linear etc.), can be used as tools for breeders to communicate value to commercial farmers. With the appropriate methodology, responses to selection can be predicted for all traits in the index (including growth and breeding female mature weight); this provides clear messages to both breeders and commercial farmers regarding the implications of selection using an economic index (specifically, what it means for changes in mature weight).

While genetics offers permanent and cumulative (and potentially industry-wide) impact on the direction of the entire industry, the multiple, primarily non-economic, indexes (beef and sheep) and multiple evaluation systems (beef) create challenges in terms of ease of implementation of these tools. Implementation via an exemplar breed (beef) or in the industry combined breed analysis selection indexes (sheep) would represent excellent case studies.

While there are some management tools available to control increases in mature weight, significant practice change is required to implement these management tool/ techniques. Strategies, like more widespread use of AI (in commercial beef herds for example) using the “right” bulls would significantly increase the realised rates of genetic gain in the beef industry. Better use of maternal genetics and terminal genetics (in commercial sheep flocks for example) in combination within sheep flocks would enable the benefits of hybrid vigour to be realised, while controlling ewe mature weight. The ability of commercial farmers to control increase in breeding female mature weight through feeding (under-feeding) is likely to be unfeasible in terms of animal welfare and farming best practice.

Key messages for communicating to industry

Breeders

Key messages include:

- Where available, make use of selection indexes that have penalties applied to breeding female mature weight EBVs; this controls the increase in mature weight, associated with selection for early growth,
    - The availability of these indexes is clearly at the discretion of the breeding society and genetic evaluation service provider.
- Record sire of all calves (especially those that go on to be herd replacements), record mature weight and include that data in the genetic evaluation system,

- Engage breed societies and genetic evaluation service providers about the need for selection tools, which account for the non-linear nature of value from increases in carcase weight and the cost associated with breeding female mature weight, and
- Communicate with commercial farmers to understand the needs in the context of breeding female mature weight, with an understanding that bigger is not always better.

Commercial farmers

Key messages include:

- Buy sires where it is possible assess the size/ weight of the breeding females and gather more intelligence about the genetic merit of the males for growth, mature weight and other genetic merit estimates,
- Work to build a relationship, and communicate, with a breeder(s) that is/ are producing the types of sires you need for your farming business,
- Where possible, use an index to select sires for use in commercial flocks (needs to be made available by the breeder),
- Make use of maternal genetics and terminal genetics in combination within herds/ flocks to capture the benefits of hybrid vigour, while controlling breeding female mature weight,
- Engage breeders and breed societies about the need for selection tools, which account for the non-linear nature of value from increases in carcase weight and the cost associated with breeding female mature weight, and
- Weigh breeding females regularly and be informed about the right mature weight for the farming system.

Contents

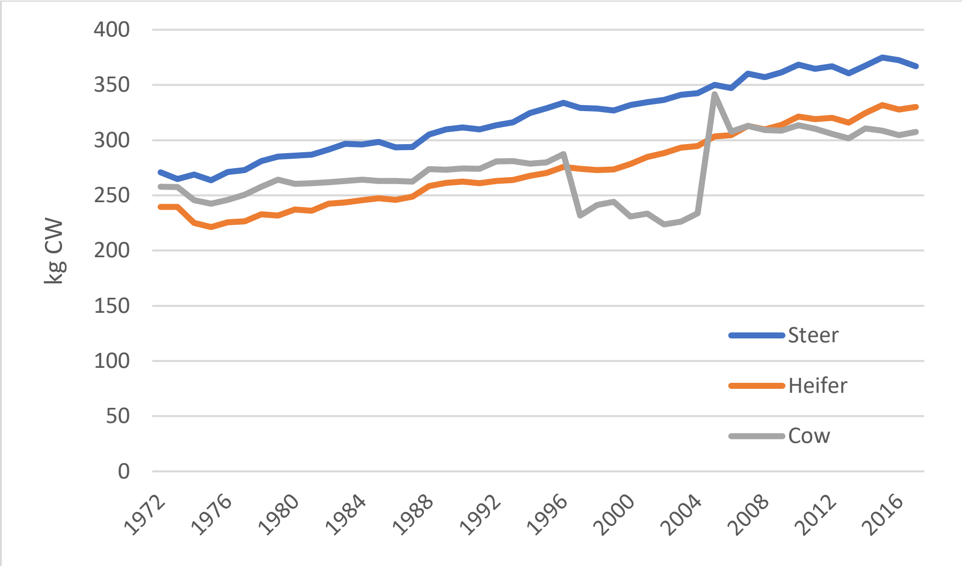
Introduction

Breeding flocks and herds represent the backbone of lamb and beef production in the United Kingdom (UK), and the productivity and profitability of these enterprises must be improved to ensure they remain sustainable. While there are many parameters that determine the productivity and profitability of a breeding business, it has long been recognised that the profitability of such enterprises is related to the productivity of the breeding female population; the mature weight of breeding females and the associated biological changes in other traits. Analysing enterprise efficiency and profitability relies on knowledge of the biological mechanisms underlying the system, the cost of inputs as well as the revenue from output. Establishing the relationships between breeding female mature weight, productivity, and profitability will support industry messaging about the implications of, and mechanism to manage, increases in breeding female mature weight. The Agriculture and Horticulture Development Board (AHDB), Hybu Cig Cymru - Meat Promotion Wales (HCC) and Quality Meat Scotland (QMS) have identified an assessment of the efficiency and profitability of breeding enterprises, linked to differences in breeding female mature weight, as an important area for their levy payers.

In the UK, data suggests that steer and heifer carcase weights have consistently increased for the past 45 years, at a rate of 2.5kg per year. Cow carcase weights increased from 1972 to 1996 at a rate of 1.5kg per year and plateaued in 2006, with little change since then[1]. This data likely includes both dairy and beef cull cows, which have both undergone increases in mature size (Carol Davis, pers. comm.). There was a sharp drop in cow carcase weight in 1997 and 2006. This was due to the Over 30 Month (compensation) Scheme, which involved slaughtering of older (heavier) animals outside the food chain (and thus the data reported), to contain BSE (Figure 1). Trends in carcase weights are indicative of a general increase in both the mature weights of breeding females, and in liveweights of slaughtered progeny, with the latter being due to an increase in age or weight at an age.

[1] Cow carcase weight data used as a proxy for mature weight of cows when culled.

Figure 1: Carcase weight for steers, heifers and cows slaughtered in the UK from 1972-2017[1]

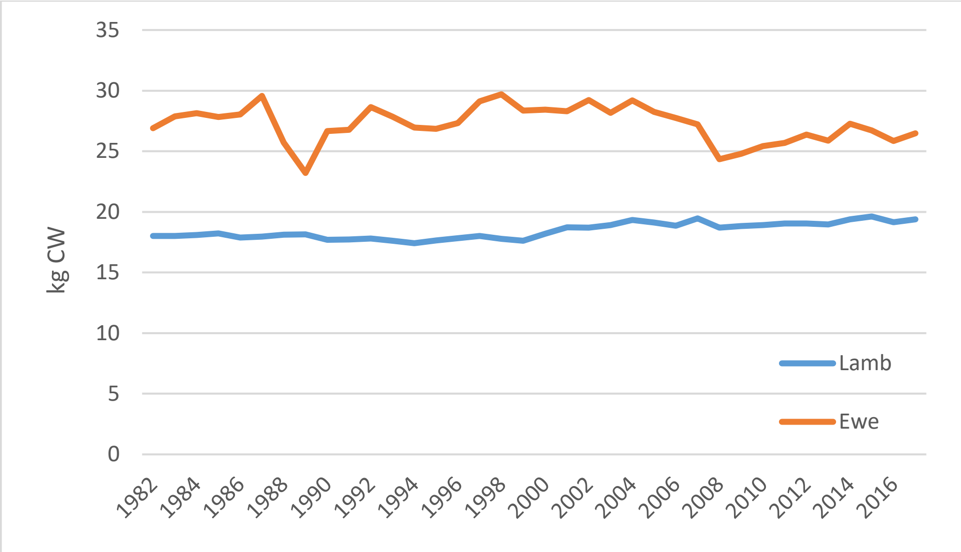


[1] Source: EUROSTAT – Bullock slaughterings; Head and Tonnes, Heifer Slaughterings; Head and tonnes, and Cow Slaughterings; Head and tonnes. Extracted 22/08/2018.

Lamb carcase weights remained relatively unchanged until 1999, after which increases occurred at a rate of 0.06kg per year. Over the 35 years for which data was available, the average annual increase in lamb carcase weight was 0.05kg (increasing from 18kg to 19.4kg over the entire period) (Figure 2). Ewe carcase weights have fluctuated dramatically over this time though, on average, have been decreasing at a rate of 0.04kg per year[2]. Lamb weights are potentially impacted by the change in the number and structure of the breeds in the UK. Stratification (hill breeds crossed with crossing sires, such as Blue Face Leister to produce lowland crossbred ewe such as Mule) of the sheep industry has decreased over the years so that it now only accounts for around 50% of the ewe breeding in the UK (Carol Davis, pers. comm.). Ewe carcase weights will have decreased due to the move away from bigger and bigger Mules (as the Blue Face Leister rams got bigger and bigger) to a more medium ewe, e.g. Lleyn UK (Carol Davis, pers. comm.).

[2] Carcase weight data used as a proxy for mature weight of ewes when culled.

Figure 2: Carcase weight for lambs and ewes slaughtered in the UK from 1982-2017[1]



[1] Source: EUROSTAT – Mutton slaughterings; Head and Tonnes, and Lamb Slaughterings; Head and tonnes. Extracted 22/08/2018.

This report provides an analysis of the impact of differences in breeding female mature weight on farm productivity and profitability in UK sheep and beef farming systems, and the implication at processor and national level. Outcomes have been tested for their sensitivity to feed costs, with low feed costs more likely to reflect extensive grazing only cow and ewe production systems, and higher feed costs reflecting more intensive systems with supplementary feeding. Using biological and economic drivers, this report includes an estimation of the optimum breeding female mature weight and provides guidance as to how producers can manage mature weight using genetics and management tools.

The sections below cover model methodology, a description of the beef and sheep trait change and profit framework, results (margin over feed) and sensitivity, processor and industry-wide impact, and genetics and management tools to manage breeding female mature weight.

Method Overview

To determine the implications of differences in breeding female mature weight, we first evaluated how changing cow and ewe breeding female mature weight impacts other biological traits in the farm system (Figure 3) and then modelled the costs and revenues on farm, associated with all the traits implicated (breeding female mature weight included).

Costs and revenue per animal were calculated (breeding female, replacement female, or slaughtered progeny), and scaled to reflect a herd or flock of 100 breeding females. The age distribution of breeding females, the replacement rate, and the slaughter offspring produced are representative of typical beef and sheep farms in the UK. Costs were subtracted from revenues across the entire herd or flock at each breeding female mature weight, to identify changes in margin over feed across a range of breeding female mature weights.

The avenues (i.e. traits) by which mature weight affects total annual cost and revenue can be defined as direct or indirect (Figure 3). The direct effects, which are a function of breeding female mature weight, are the annual maintenance cost, replacement heifer/hogget cost, and the cull carcase revenue. The indirect traits are the number and value of slaughtered progeny. The degree of change in costs and revenue depends on the biological relationship between breeding female mature weight and each trait. Indirect traits include the number of progeny (cow fertility, ewe number of lambs born) and the value of those progeny that are slaughtered (carcase weight and carcase quality).

Outcomes were assessed for sensitivity to differences in:

1) progeny slaughter practices (constant carcase weight rather than a constant age),
2) the phenotypic correlation between breeding female mature weight and progeny carcase weight,
3) processor penalties for heavy carcasses,
4) the average feed cost for all feed types (+/-20%),
5) the average feed cost for concentrate only (+/-20%),
6) the diet over winter for cows/ ewes (inclusion of silage and concentrate for 100% of the diet), and
7) the diet over winter for cows/ ewes (inclusion of silage and concentrate for 100% of the diet) combined with differences in the average feed cost for all feed types (+/-20%).

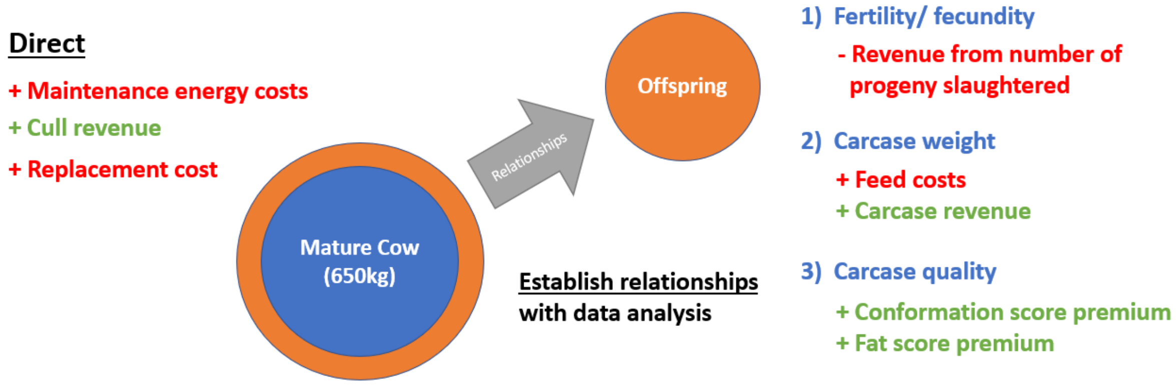


Figure 3: Summary of traits relevant to measuring the impact of increases in breeding female mature weight in beef and sheep farm systems.

Beef herd model

The sections below describe the beef herd model, including base system performance, direct trait changes, and indirect trait changes associated with a 100kg difference in breeding female mature weight. The impact of a 100kg difference in breeding female mature weight is calculated, so that the scale of differences can be presented, before a breakdown of revenue and cost components, and margin over feed for a farm of 100 breeding females, across a range of breeding female mature weights is reported.

Base system performance

The model for calculating costs and revenues, associated with changes in breeding female mature weight, is built around a base production system. This section describes the performance of the base system. Table 1 describes performance parameters for breeding females and their progeny.

Table 1: Summary of parameters for breeding females used in base beef model.

	Value
Mature weight (kg)[1]	**651.4**
Dressing percentage (%)[2]	48.4%
Carcase weight (kg)[3]	315.4
Carcase price (£/kgCW)[2]	2.20
Carcase revenue (£)	694.20
Average conception rate (%)[4]	89.3%
Calf weaning age (days)	230
Calf survival to weaning per cow mated (%)[5]	83.0%
Replacements kept (per breeding female) [6]	0.161
Slaughtered progeny (per breeding female)[7]	
Heifers	0.25
Steers	0.34
Young bulls	0.08
Total	**0.67**

[1] Mature weight = carcase weight / dressing %

[2] 2018 AHDB Beef Yearbook: average 2014-17

[3] EGENES (data sourced: 15th August 2018)

[4] Based on herd age distribution (Appendix 1: Table 30) and conception rates by parity (Appendix 1: Table 30)

[5] Based on 93% survival from birth to weaning (AHDB beef stocktake)

[6] 16.1% replacement rate at base mature weight (Appendix 1: Table 30)

[7] Heifers = 0.830/2 (surviving females) – 0.161 (replacements), Steers = 0.83/2 (surviving males) x 0.823 (proportion of males that are steers), and Bulls = 0.83/2 (surviving males) x (1 – 0.832).

The performance and margin over feed for slaughtered heifers, steers and bulls in the base production system are summarised in Table 2 below.

Table 2: Summary of margin over feed per animal for heifers, steers, and bulls in base beef model.

	Heifer	**Steer**	**Young bull**
Liveweight at slaughter (kg) [1]	581.3	696.0	631.6
Dressing percentage (%)[2]	56.5%	53.2%	53.2%
Carcase weight (kg) [2]	**328.4**	**370.3**	**335.8**
Base Price (£)[2]	3.51	3.49	3.25
Fat score (Score: 1-15) [3]	8.29	7.59	5.95
Conformation score (Score: 1-15) [3]	9.35	8.87	9.14
EUROP Premium/penalty (£)[3]	-0.04	0.06	0.05
Price (£/kgCW) [4]	**3.47**	**3.55**	**3.30**
Carcase revenue (£)	**1,139.65**	**1,314.23**	**1,106.88**
Age at slaughter (months) [5]	24.5	24.8	14.8
Total energy required (MJME)[6]	58,956	67,316	42,391
Total cost of feed (£)[7]	**624.28**	**723.97**	**716.11**
Margin over feed/animal (£)	**515.37**	**590.26**	**390.77**

[1] Liveweights at slaughter = carcase weight / dressing %

[2] 2018 AHDB Beef Yearbook: average 2014-17

[3] Based on EUROP price grid (Appendix: Table 27) and distribution of animals corresponding to carcase weights of base heifers, steers and bulls (AHDB, confidential data)

[4] Price (£/kgCW) = Base price + EUROP premium/penalty

[5] EGENES (data sourced: 15th August 2018)

[6] Calculated according to growth profiles (Appendix 2) and energy requirements (Appendix 3)

[7] Calculated according to daily MJME required and feed costs (Appendix 4: Table 38)

Table 3 summarises the average cost of feed per unit of energy (in the base model). Diets and feed costs are detailed in Appendix 4.

Table 3: Average cost of feed per unit of energy for breeding females and slaughtered progeny.

	Cost of feed (£/MJME)
Heifers	0.0106
Steers	0.0108
Bulls	0.0169
Mature cows	0.0038
Replacments[1]	0.0056

[1] Note that replacement heifers are fed a slaughtered heifer diet until age 455 days, after which they are fed a mature cow diet.

Direct trait changes

For each direct trait, the costs and revenues are calculated per animal, as a result of a 100kg increase in breeding female mature weight.

Mature cow maintenance and body condition score feed costs

Increasing breeding female mature weight increases maintenance energy requirements for the breeding female, thus increasing feed costs. In addition, higher average feed costs are included for heavier breeding female mature weights. The argument is that in order to supply the energy required to meet body condition score (BCS) targets throughout the year, higher quality and higher cost feed is required as mature weight increases; this is because the volume of energy required cannot be supplied through lower quality feed (Appendix 4). Table 4 presents maintenance energy requirements, average feed costs, and annual maintenance and BCS feed costs per breeding female, for breeding female mature weights of 651.4kg and 751.4kg, respectively. Differences are also presented.

Table 4: Maintenance energy requirements, average feed costs, and annual maintenance and BCS feed costs per breeding female, for breeding female mature weights of 651.4kg and 751.4kg, along with the differences.

Trait	*Mature weight*		Δ/100kg MW
	651.4kg	**751.4kg**	
Daily energy required for maintenance (MJME) [1]	83.81	93.29	9.48
Average feed price (£/ MJME)[2]	0.0038	0.0064	0.0025
Annual maintenance and BCS feed cost (£)	**117.71**	**216.55**	**98.84**

[1] $0.65 * MW^{0.75}$

[2] Refer to Appendix 4: Table 38 for feed costs (feed cost increases at higher MWs to maintain BCS)

Cull breeding female carcase revenue

Increasing breeding female mature weight increases the cull breeding female carcase weight, thus increasing revenue. Cull breeding female carcases earn a flat price per kilogram of carcase weight (Table 1). Table 5 presents carcase weight and cull breeding female carcase revenue per breeding female, for breeding female mature weights of 651.4kg and 751.4kg, respectively. Differences are also presented.

Table 5: Carcase weight and cull breeding female carcase revenue, per cull breeding female, for breeding female mature weights of 651.4kg and 751.4kg, along with the differences.

Trait	*Mature weight*		Δ/100kg MW
	651.4kg	**751.4kg**	
Carcase weight (kg)[1]	315.4	363.8	48.42
Cull female revenue (£)[2]	**694.20**	**800.77**	**106.57**

[1] See Table 1 for dressing percent

[2] See Table 1 for price per kgCW

Replacement female growth energy costs

A replacement female growing to a heavier breeding female mature weight requires more feed for maintenance and growth during the growth period. In addition, higher average feed costs are included for replacement heifers growing to heavier breeding female mature weights. The argument is that in order to supply the energy required to meet weight and BCS targets for first parity mating, higher quality and higher cost feed is required as mature weight increases; this is because the volume of energy required cannot be supplied through lower quality feed (Appendix 4). Replacement heifers take 1460 days to reach mature weight. The growth profile is based on the percentage of mature weight at each calving is presented in Appendix 2. Table 6 presents energy requirements (MJME) and average cost of feed associated with replacement female growth per replacement female, for breeding female mature weights of 651.4kg and 751.4kg, respectively. Differences are also presented.

Table 6: Energy requirements, feed requirements, and cost of feed associated with replacement female growth (to 4 years), per replacement, for breeding female mature weights of 651.4kg and 751.4kg, along with the differences.

Trait	*Mature weight*		Δ/100kg MW
	651.4kg	**751.4kg**	
Total energy required (MJME)[1]	118,551	132,723	14,172
Average feed price (£/ MJME)[2]	0.0056	0.0074	0.0019
Total feed cost (£)	**658.02**	**985.27**	**327.26**

[1] For calculation of energy requirements (MJME) refer to Appendix 3

[2] Refer to Appendix 4: Table 38 for feed costs

Indirect trait changes

For each indirect trait, the costs and revenues are calculated per animal, as a result of a 100kg increase in breeding female mature weight. Calculation of the biological relationships between breeding female mature weight and indirect traits (those affecting progeny) are presented in Appendix 1.

Progeny carcase revenue and costs at a constant slaughter age (carcase weight, conformation score, and fat score)

Increasing breeding female mature weight increases the carcase weight of slaughtered progeny, thus impacting both feed costs and carcase revenue. Carcase value is determined by the carcase weight and the price per kg, which is in turn determined by carcase conformation score and carcase fat score. Therefore, the costs and revenues associated with carcase weight, carcase conformation score, and carcase fat score per slaughtered animal, as a result of a 100 kg increase in breeding female mature weight, are combined into progeny carcase value. Calculation of the biological relationships between breeding female mature weight and carcase weight, carcase conformation score, and carcase fat score are presented in Appendix 1.

Data suggests that faster growing progeny, as a result of increased breeding female mature weight, are slaughtered at a constant age (EGENES data sourced: 15th August 2018). This approach to capturing the value of faster growth rate has an impact on revenue and costs per carcase.

The price per kg of carcase weight is determined by a base price, and a premium or penalty applied according to each carcase's conformation and fat score on the EUROP grid. Revenue is also affected by penalties applied to carcase weights under or over certain thresholds (Appendix 1: Table 28). Carcase weights over 440 kg earn no additional revenue per kg carcase weight and are penalised at £0.40/ kg CW; this can be seen in Figure 4 below, as the carcase revenue above 440 kg decreases, due to the increased penalty, then plateaus.

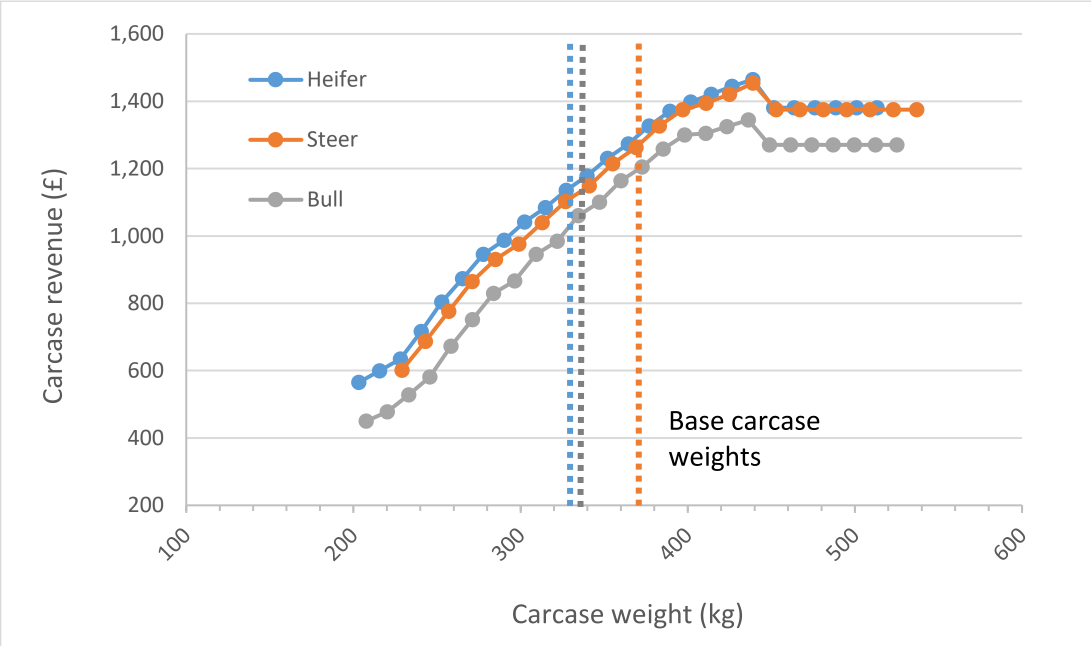


Figure 4: Total carcase revenue for slaughtered steers, heifers, and bulls based on carcase weight and price received per kgCW (sum of base price, EUROP penalty/premium and size penalty; Appendix 1). Vertical lines represent carcase weights at base.

Table 7 presents carcase weight, carcase conformation score, carcase fat score, average price per kg of carcase weight, carcase revenue and total feed costs per slaughtered progeny, for breeding female mature weights of 651.4kg and 751.4kg, respectively, when animals are slaughtered at a constant age. Differences are also presented.

Table 7: Carcase weight (constant age), carcase conformation score, carcase fat score, average price per kg of carcase weight, carcase revenue, total feed costs and margin over feed per slaughtered progeny, for breeding female mature weights of 651.4kg and 751.4kg, along with the differences, when animals are slaughtered at a constant age.

Trait		*Mature weight*		Δ/100kg MW
		651.4kg	**751.4kg**	
Carcase weight (kg)				
	Heifers	328.4	411.1	82.68
	Steers	370.3	463.6	93.33
	Bulls	335.8	420.4	84.64
Conformation score (1-15)				
	Heifers	9.35	11.11	1.76
	Steers	8.87	11.14	2.27
	Bulls	9.14	11.52	2.38
Fat score (1-15)				
	Heifers	8.29	8.33	0.04
	Steers	7.59	7.55	-0.04
	Bulls	5.95	5.90	-0.05
Price (£/kgCW)[1]				
	Heifers	3.47	3.43	-0.04
	Steers	3.42	3.12	-0.30
	Bulls	3.17	3.13	-0.04
Carcase revenue (£)				
	Heifers	1,139.65	1,410.30	270.65
	Steers	1,267.15	1,448.67	181.53
	Bulls	1,064.05	1,314.66	250.61
Total feed cost (£)				
	Heifers	624.28	751.71	127.43
	Steers	723.97	872.31	148.34
	Bulls	716.11	872.49	156.38
Margin over feed (£)				
	Heifers	515.37	658.59	143.22
	Steers	543.18	576.36	33.18
	Bulls	347.94	442.17	94.23

[1] Price per kg determined by base price (Table 2) and premium/ penalty (Table 27).

Changes in margin over feed, with increasing mature weight, cannot be reported per animal (i.e. the weighted average of steers, heifers, and bulls), without considering the changing herd distribution (detailed below).

Progeny carcase revenue and costs at constant slaughter weight (carcase weight, conformation score, and fat score)

While data suggests that faster growing progeny, as a result of increased breeding female mature weight, are slaughtered at a constant age (EGENES data sourced: 15th August 2018), they can also be slaughtered earlier, at a constant carcase weight. Under a constant slaughter weight assumption, improved margin over feed is driven by lower feed costs. Because faster growing animals are slaughtered earlier, they have lower total maintenance energy requirements over their lifetime.

As above, the price per kg of carcase weight is determined by a base price, and a premium or penalty applied according to each carcase's conformation and fat score on the EUROP grid. Because carcase weight does not change, there is far less variation in the revenue earned by carcases slaughtered at a constant weight compared to carcases slaughtered at a constant age (Figure 4 vs Figure 5). Differences in revenue per carcase at a constant weight are determined by the relationship between age at slaughter and carcase conformation and fat score (Appendix 1). Animals which are slaughtered earlier are less mature and will have different conformation and fat scores than older animals of the same weight. Scores tend to be worse for progeny slaughtered younger (faster growing animals), resulting in lower revenue. Revenue is not affected by penalties applied to underweight or overweight carcases, because all carcases are finished at the base weight.

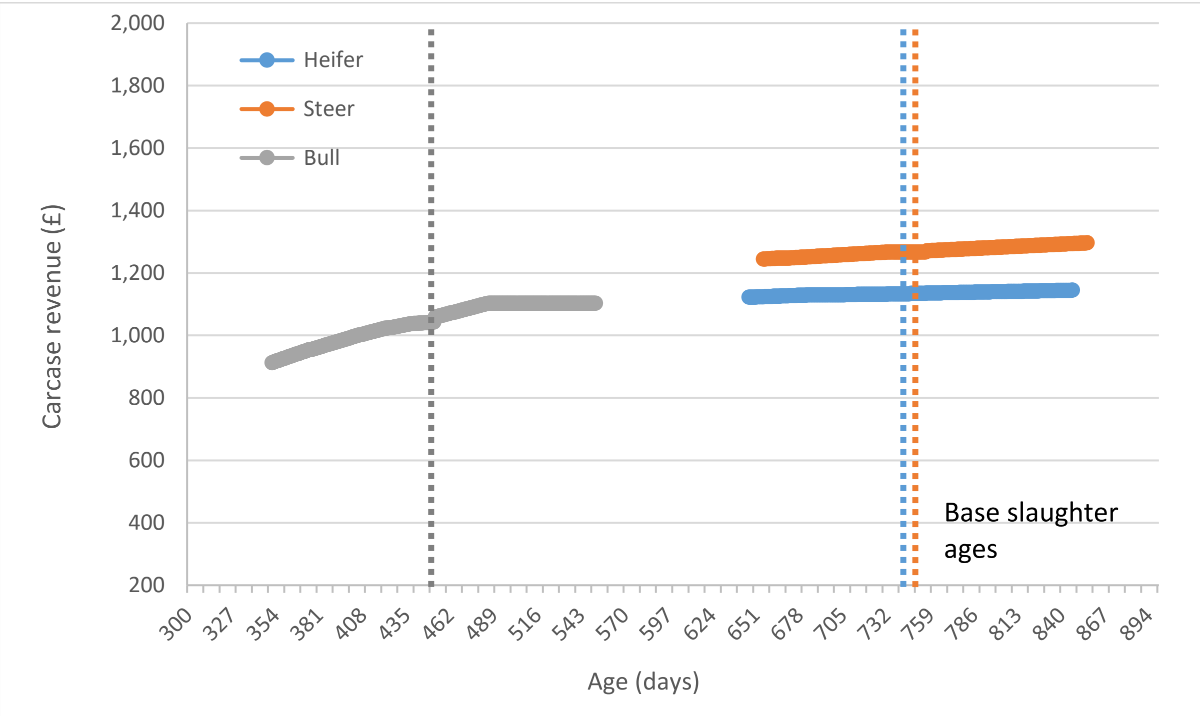


Figure 5: Total carcase revenue for slaughtered steers, heifers, and bulls based on age at slaughter at a constant carcase weight and price received per kgCW (sum of base price, EUROP penalty/premium and size penalty; Appendix 1). Vertical lines represent age at slaughter at base.

Table 8 presents carcase weight, age at slaughter in days, carcase conformation score, carcase fat score, average price per kg of carcase weight, carcase revenue and total feed costs per slaughtered progeny, for breeding female mature weights of 651.4kg and 751.4kg, respectively, when animals are slaughtered at a constant weight. Differences are also presented.

Table 8: Carcase weight (constant weight), age at slaughter in days, carcase conformation score, carcase fat score, average price per kg of carcase weight, carcase revenue, total feed costs and margin over feed per slaughtered progeny, for breeding female mature weights of 651.4kg and 751.4kg, along with the differences, when animals are slaughtered at a constant weight.

Trait		*Mature weight*		Δ/100kg MW
		651.4kg	**751.4kg**	
Carcase weight (kg)				
	Heifers	328.4	328.4	-
	Steers	370.3	370.3	-
	Bulls	335.8	335.8	-
Age at slaughter (days)[1]				
	Heifers	747	544	-203
	Steers	756	563	-193
	Bulls	452	370	-82
Conformation score (1-15)				
	Heifers	9.35	7.65	9.35
	Steers	8.87	7.26	8.87
	Bulls	9.14	7.83	9.14
Fat score (1-15)				
	Heifers	8.29	7.96	8.29
	Steers	7.59	7.09	7.59
	Bulls	5.95	7.98	5.95
Price (£/kgCW)[2]				
	Heifers	3.47	3.35	-0.12
	Steers	3.42	3.29	-0.14
	Bulls	3.17	2.82	-0.35
Carcase revenue (£)				
	Heifers	1,139.65	1,099.44	-40.21
	Steers	1,267.15	1,216.59	-50.56
	Bulls	1,064.05	945.72	-118.33
Total feed cost (£)				
	Heifers	624.28	419.11	-205.17
	Steers	723.97	474.46	-249.52
	Bulls	716.11	532.40	-183.71
Margin over feed (£)				
	Heifers	515.37	680.33	164.96
	Steers	543.18	742.13	198.96
	Bulls	347.94	413.32	65.38

[1] The number of days saved per 100kg MW are equal to the difference between LW at slaughter (constant age) and LW at slaughter (constant weight), divided by the marginal growth rate (kg/day at day of slaughter). For example, for bulls (790.84kg – 631.63kg)/1.93kg = 82 days.

[2] Price per kg determined by base price (Table 2) and premium/ penalty (Table 27).

Changes in margin over feed, with increasing mature weight, cannot be reported per animal (i.e. the weighted average of steers, heifers, and bulls), without considering the changing herd distribution (detailed below). Changes in margin over feed under the assumption of constant slaughter weight are discussed in the sensitivity section of herd margin over feed below.

Conception rate at second mating cost

Increased breeding female mature weight is assumed to affect fertility by reducing the conception rate at second mating (Appendix 1). While additional feed costs could be included to overcome this problem in heavier breeding females, there are challenges associated with a) the short window available to lift breeding female into a reproductive state after calving, through feeding, b) preferentially feeding the breeding female when the calf is at foot, and c) farm resource allocation focused on raising young stock rather than preferentially feeding heavier breeding females. Thus, heavier breeding female mature weight is assumed to manifest in fewer calves, and forgone slaughter progeny profit (carcase revenue, less feed costs), from second parity breeding females rather than additional feed costs.

First parity conception rate is dependent on the % of mature weight and body composition of the heifer at time of mating; first parity heifers are assumed to be fed sufficiently to conceive at 15 months-of-age (albeit a management decision to submit heifers for mating). The additional cost of this in heifers growing to higher breeding female mature weights and required condition score is captured through higher average feed costs (see replacement female growth energy costs section above).

Lower conception rate at second mating also increases replacements costs, because the breeding females that fail to conceive at second mating need to be culled. Thus, increases in mature breeding female weight changes the herd profile, due to an increasing number of second parity females getting culled, and lower number of progeny born (Appendix 1).

Table 9 presents conception rate at second mating, number of progeny slaughtered (heifers, steers, and bulls), herd replacement rate and replacement cost per breeding female, for breeding female mature weights of 651.4kg and 751.4kg. Differences are also presented.

Table 9: Conception rate at second mating, number of progeny slaughtered, herd replacement rate and replacement cost per breeding female, for breeding female mature weights of 651.4kg and 751.4kg, along with the differences.

Trait	*Mature weight*		Δ/100kg MW
	651.4kg	**751.4kg**	
Conception rate at second mating (%)[1]	90.0%	85.6%	-4.4%
Number of progeny slaughtered			
Heifers	0.25	0.24	-0.01
Steers	0.34	0.34	0.00
Bulls	0.08	0.08	0.00
Herd replacement rate (%)	16.1%	16.8%	0.7%
Cost of replacement (£)	106.20	165.88	59.68

[1] See Appendix 1

Costs of a changing herd distribution, with increasing mature weight, cannot be reported per animal, without considering the changes in carcase value for the slaughtered progeny (detailed above).

Herd distribution

Table 10 summarises the herd profile (number of breeding females, replacements and slaughtered progeny for breeding female) for mature weights of 651.4kg and 751.4kg. Differences are also shown.

Table 10: Number of breeding females, replacements and slaughtered progeny for breeding female mature weights of 651.4kg and 751.4kg, along with the differences.

Number of animals (total)	*Mature weight*		Δ/100kg MW
	651.4kg	**751.4kg**	
Breeding females	100	100	0
Replacement females[1]	16.14	16.84	0.7
Number of cull cows[1]	15.74	16.42	0.68
Number of progeny slaughtered			
Heifers	25.36	24.32	-1.0
Steers	33.87	33.58	-0.3
Bulls	7.63	7.57	-0.1

[1] Cull cows are equal to the number of replacements, multiplied by a salvage rate of 97.5%.

Rescaling

Differences in breeding female mature weight relative to the base production system, will result in different overall levels of feed demand. This requires additional land for pasture and thus incurs rental costs. Production at 751.4kg breeding female mature weight requires 15.1% more pasture (kgDM, system-wide) than production at the base scenario at 651.4kg. To capture the cost of this, the number of breeding females has been adjusted down to reflect the limited pasture resource; this is assumed to be equivalent to the cost of renting additional land.

Results

Herd margin over feed

Table 11 presents revenue and cost elements associated with mature cow maintenance and body condition score, cull breeding female carcase, replacement female growth and condition energy, and progeny carcase value (carcase weight, conformation score, and fat score), for mature weights of 651.4kg and 751.4kg in a 100-breeding female herd. Overall herd margin over feed is also presented. Note that differences in conception rate at second mating, manifest in differences in replacement rate and the proportion of steers, heifer, and bulls slaughtered (Table 10); these components are captured in the revenue and cost items for replacement growth and carcase value, respectively, in Table 11.

Table 11: Revenue and cost elements associated with mature cow maintenance and body condition score, cull breeding female carcase, replacement female growth energy, progeny carcase value (carcase weight, conformation score, and fat score), for mature weights of 651.4kg and 751.4kg for a 100-breeding female herd, when progeny are slaughtered at a constant age.

Animal	*Mature Weight*			
	651.4kg		**751.4kg**	
	Cost	**Revenue**	**Cost**	**Revenue**
Maintenance energy	11,771.22	-	21,655.10	-
Cull cow	-	10,924.32	-	13,144.90
Replacement growth	10,620.47	-	16,588.29	-
Heifer carcase value	15,834.24	28,906.13	18,278.32	34,292.29
Steer carcase value	24,522.40	42,920.88	29,296.32	46,175.44
Bull carcase value	5,465.38	8,120.91	6,602.37	9,948.39
Total	68,213.70	90,872.24	92,420.41	103,561.01
Margin over feed	**22,658.54**		**11,140.61**	

[1] Farm costs and revenues are calculated based on per animal costs reported in Table 4 to Table 7, and the number of animals in each class (replacement, heifer, steer, and bull) in the herd (Table 10).

In Table 11, the base breeding female mature weight (651.4kg) and the heavier breeding female mature weight (751.4kg) are associated with positive margins over feed. Figure 6 below presents a breakdown of revenue and cost components, and total margin over feed for a 100-breeding female herd, for breeding female mature weights from 500kg to 900kg.

The optimum breeding female mature weight for a typical beef production system is 695kg, which falls between the two weights in Table 11. The optimum breeding female mature weight for a 100-breeding female herd is associated with a total margin over feed of £26,863.

With increasing breeding female mature weight, cull cow revenue increases (purple line), while cow maintenance costs (light blue line), replacement costs (orange line), and progeny feed costs (green line) all increase. Breeding females heavier than 700kg require higher quality and higher cost feed, which accounts for maintenance and replacement costs increasing at a faster rate above 700kg.

Increasing breeding female mature weight up to 725kg significantly increases prime carcase revenue (red line). After 725kg, prime carcase revenue plateaus (to 785kg) and then decreases slightly, due to lower fertility (less progeny being slaughtered) and because heifers and bulls are also being penalised for weighing over 440kg (carcase weight over a 440kg threshold is not paid, see Appendix 1: Table 28).

At the optimum breeding female mature weight, rescaling the number of breeding females by -6.4% (Figure 6, dark blue dotted line) to account for higher overall feed demand reduces the total margin over feed by the same proportion; from £26,863 to £25,151. After accounting for re-scaling, the optimum decreases from 695kg to 680kg, where the re-scaled margin over feed is £25,281.

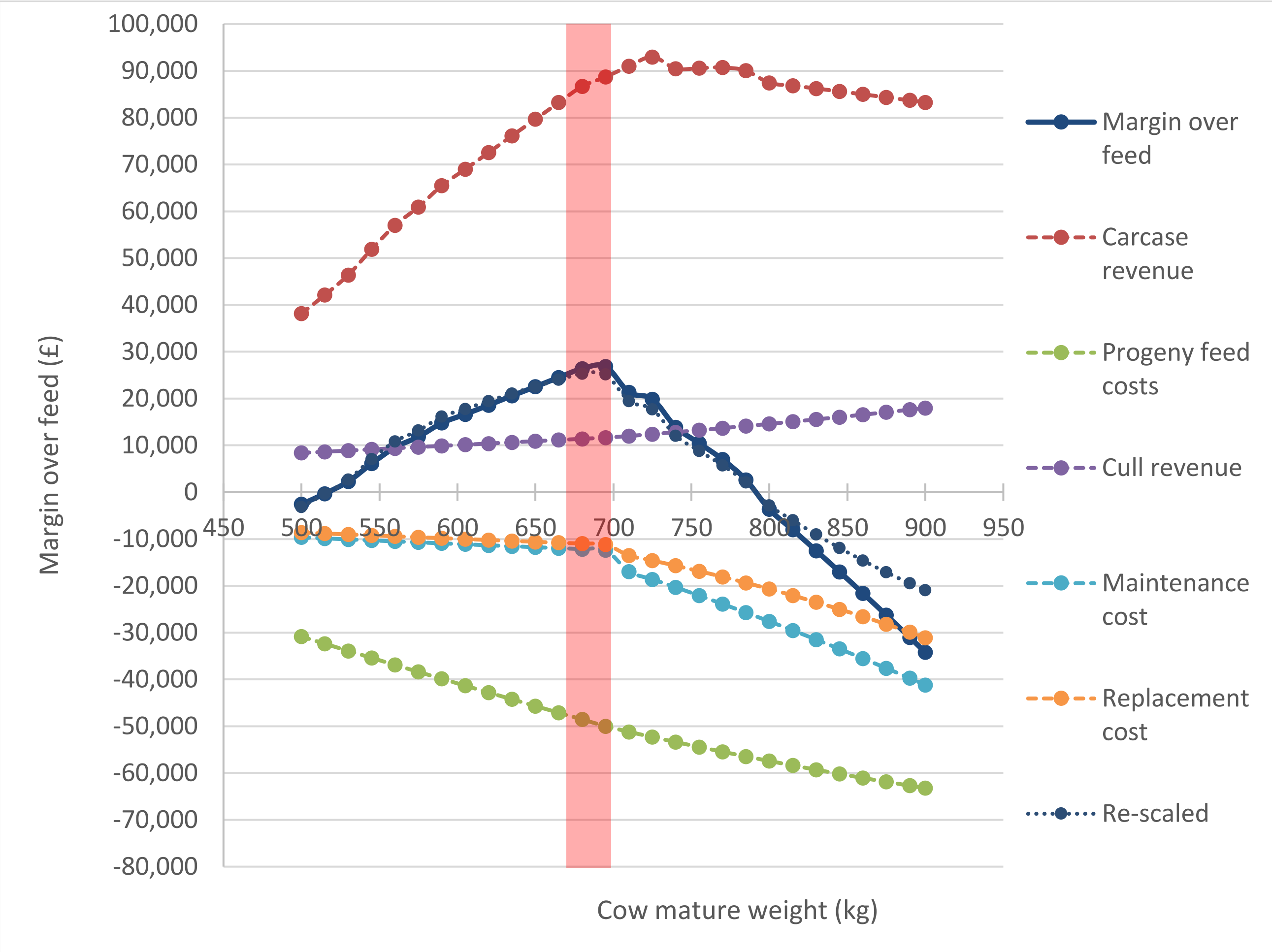


Figure 6: Breakdown of revenue and cost components (age constant), and margin over feed for a 100-breeding female herd, for breeding female mature weights of 500kg to 900kg.

Sensitivity

Slaughter at a constant carcase weight

The optimum breeding female mature weight (rescaled) was assessed for sensitivity to weight constant versus age constant slaughter. Under a constant slaughter weight production system, the revenue from heifers, steers, and bulls at 651.4kg breeding female weight is almost the same as the revenue from a 751.4kg breeding female mature weight. The small difference is due to changes in carcase conformation and fat scores, and the associated lower prices per kg of carcase weight. While, costs relating to the breeding female do not change, feed costs for slaughtered animals are much lower.

Table 12: Revenue and cost elements associated with mature cow maintenance and body condition score, cull breeding female carcase, replacement female growth energy, progeny carcase value (carcase weight, conformation score, and fat score), for mature weights of 651.4kg and 751.4kg for a 100-breeding female herd, when progeny are slaughtered at a constant carcase weight.

Animal	*Mature Weight*			
	651.4kg		**751.4kg**	
	Cost	**Revenue**	**Cost**	**Revenue**
Maintenance energy	11,771.22	-	21,655.10	-
Cull cow	-	10,924.32	-	13,144.90
Replacement growth	10,620.47	-	16,588.29	-
Heifer carcase value	15,834.24	28,906.13	10,190.93	26,733.56
Steer carcase value	24,522.40	42,920.88	15,934.39	40,858.57
Bull carcase value	5,465.38	8,120.91	4,028.81	7,156.54
Total	68,213.70	90,872.24	68,397.53	87,893.56
Margin over feed	**22,658.54**		**19,496.04**	

[1] Farm costs and revenues are calculated based on per animal costs reported in Table 4 to Table 6 and Table 8, and the number of animals in each class (replacement, heifer, steer, and bull) in the herd (Table 10).

As breeding female mature weight increases, the total progeny feed costs rapidly decrease (green line, Figure 7), due to earlier slaughter. However, the rate of decrease in feed costs diminishes. As above, females heavier than 700kg require higher quality and higher cost feed, which accounts for maintenance and replacement costs increasing at a faster rate above 700kg. The result is that the optimum breeding female mature weight occurs at the same point as for constant age slaughter; at 680kg. The optimum breeding female mature weight (rescaled) is not sensitive to weight constant versus age constant slaughter practices.

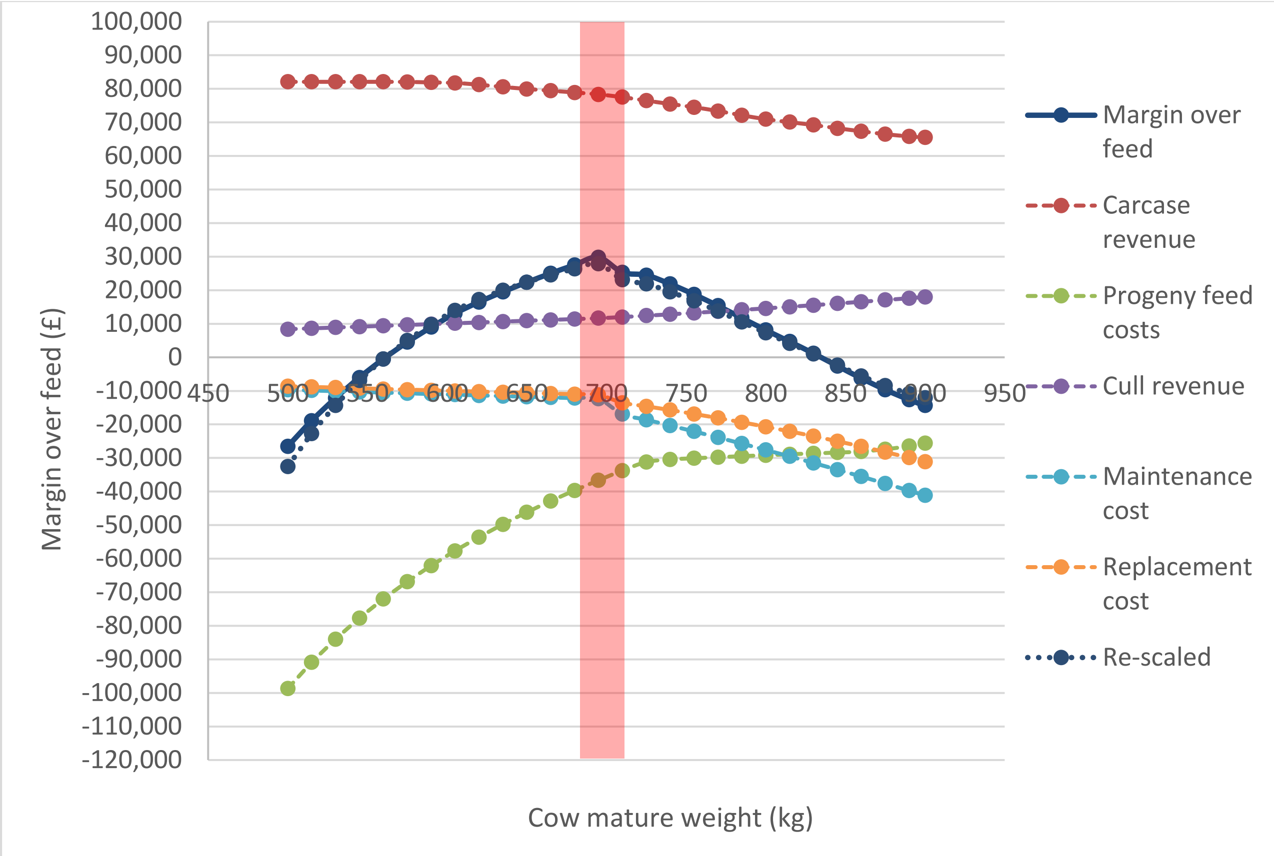


Figure 7: Breakdown of revenue and cost components (weight constant), and margin over feed for a 100-breeding female herd, for breeding female mature weights of 500kg to 900kg.

Correlation between mature weight and progeny carcase weight

The sensitivity of optimum breeding female mature weight (rescaled) to differences in the phenotypic correlation ($\beta_{CW,MW}$) between breeding female mature weight and progeny carcase weight was assessed (Figure 8).

For phenotypic correlations from 0.87 to 0.2 there is some sensitivity for the optimum breeding female mature weight, which alternates between 680kg and 695kg over this range. However, at a phenotypic correlation of 0.1 a lighter breeding female mature weight is always more optimum. The optimum breeding female mature weight is sensitive to the phenotypic correlation between breeding female mature weight and progeny carcase weight, albeit in a narrow range when considering realistic phenotypic correlations.

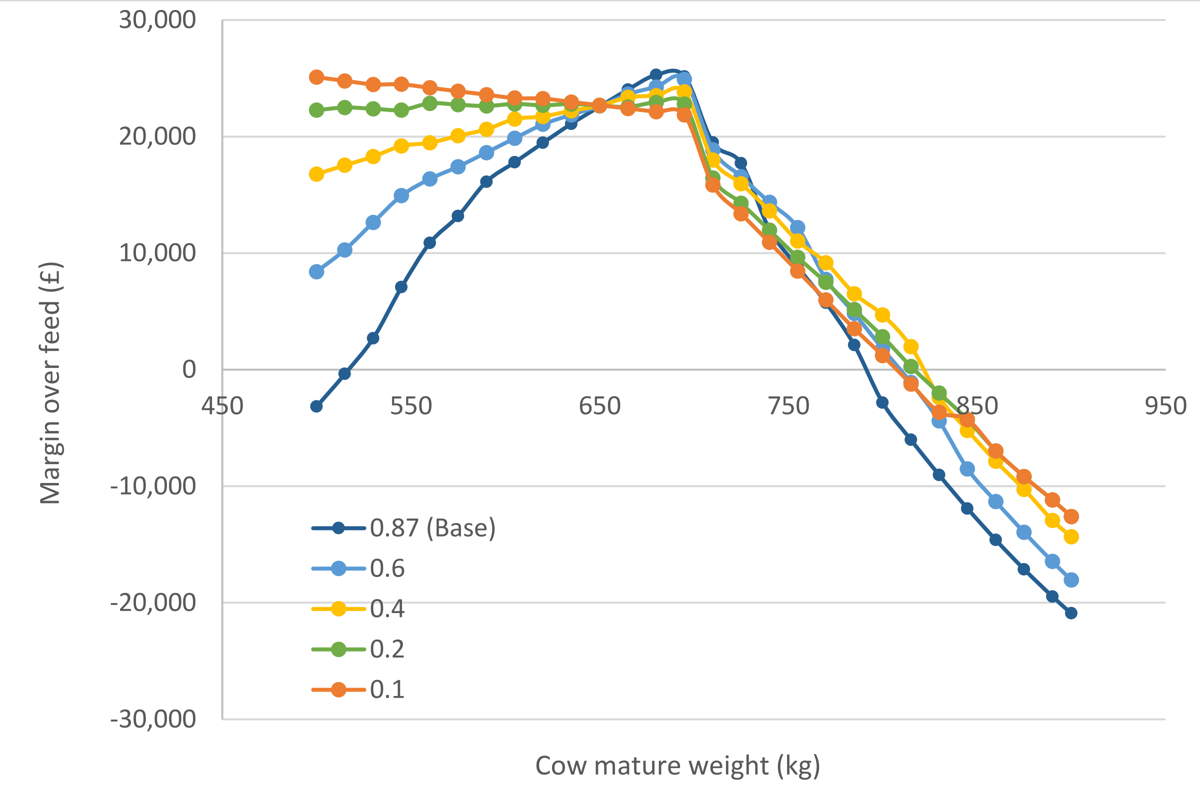


Figure 8: Re-scaled margin over feed at a range of phenotypic correlations between breeding female mature weight and progeny carcase weight, for a 100-breeding herd, for mature breeding female weights from 500 kg to 900 kg (for calculations of phenotypic correlations refer to Appendix 1).

Processor penalties for heavy carcasses

Carcases over a 440kg threshold are penalised (see Appendix 1: Table 28) at -£0.40 per kg of carcase weight, and additional carcase weight over 440kg is not paid for. Not all processors take this approach. Hence, optimum breeding female mature weight (scaled) has been assessed for sensitivity to the payment penalties applied where carcase weight over 440kg is paid for (but the -£0.40 per kg of carcase weight still applies) (Figure 9). Margin over feed, beyond 700kg breeding female mature weight, is higher when carcase weight over 440kg is paid for. However, the optimum breeding female mature weight is not sensitive to changes in the penalty structure.

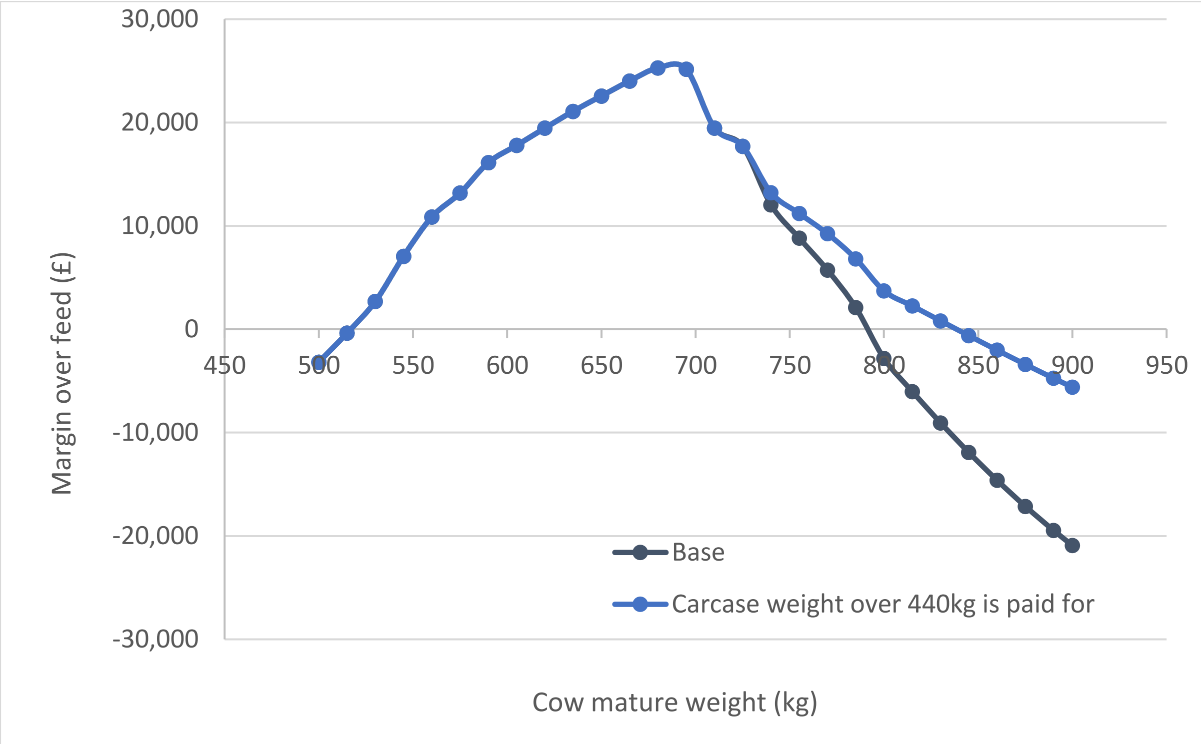


Figure 9: Re-scaled margin over under different overweight carcase penalty assumptions for a 100-breeding herd, for mature breeding female weights from 500kg to 900kg.

Feed costs and diet composition

The optimum breeding female mature weight was assessed for sensitivity to:

1) the average feed cost for all feed types (+/-20%),
2) the average feed cost for concentrate only (+/-20%),
3) the diet over winter for cows (inclusion of silage and concentrate for 100% of the diet), and
4) the diet over winter for cows (inclusion of silage and concentrate for 100% of the diet) combined with differences in the average feed cost for all feed types (+/-20%).

Sensitivities are reported in Figure 10. As feed prices decrease, the margin over feed increases at every breeding female mature weight. However, the optimum breeding female mature weight was not sensitive to changes in feed costs, remaining at 680kg regardless of feed costs. This might seem counterintuitive, but it stems from the fact that the rate of change in overall cow feed cost with the introduction of a mixed diet is only slightly greater than the rate of change in a grass-based diet, as mature weight increases. The additional increase in overall cow feed cost is not great enough to offset the additional revenue from the heavier progeny carcase, and for this reason the optimum does not change.

In addition, when concentrate prices are *relatively* more expensive (i.e. when cow diet is 100% pasture), heavier breeding female mature weights are penalized more severely (lower margin over feed), because females heavier than 700kg require an increasing proportion of their diet to be supplied by high-cost concentrate. On a 100% pasture diet, cheap pasture is replaced by more expensive concentrate, meaning costs increase at a faster rate. This is reflected in steeper rates of decline in margin over feed for mature weights over 700kg for 100% pasture diets than for mixed diets.

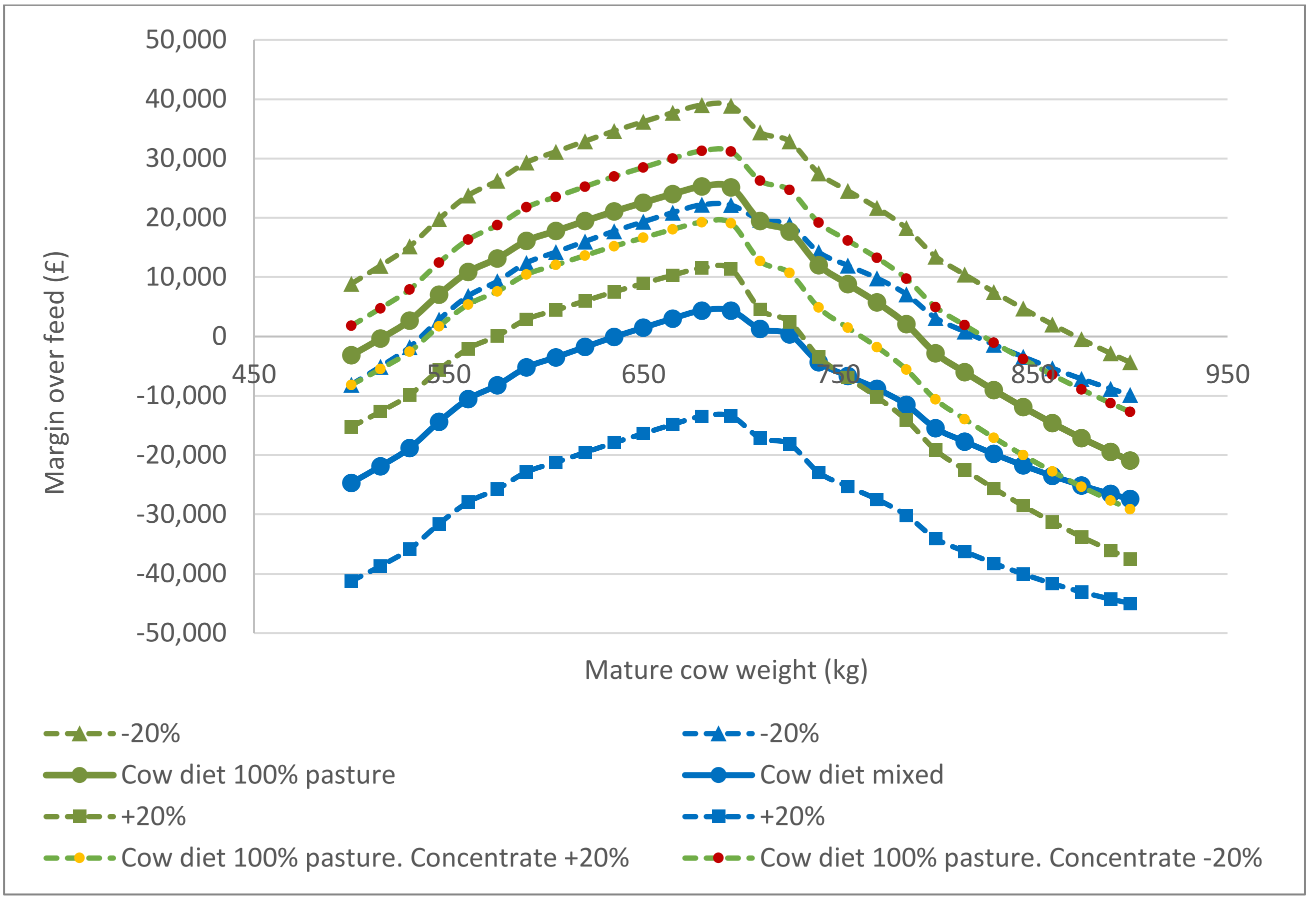


Figure 10: Sensitivity of re-scaled margin over feed to changes in diet and feed costs, for a 100-breeding female herd, for breeding female mature weights of 500kg to 900kg.

Sheep flock model

The sections below describe the sheep flock model, including base system performance, direct trait changes, and indirect trait changes associated with a 10kg difference in breeding female mature weight. The impact of a 10kg difference in breeding female mature weight is calculated, so that the scale of differences can be presented, before a breakdown of revenue and cost components, and margin over feed for a farm of 100 breeding females, across a range of breeding female mature weights is reported.

Base system performance

The model for calculating costs and revenues, associated with changes in breeding female mature weight, is built around a base production system. This section describes the performance of the base system. Table 13 describes performance parameters for breeding females and their progeny.

Table 13: Summary of parameters for breeding females used in base sheep model.

		Value
Mature weight (kg)[1]		71.80
Dressing percentage (%)[2]		40%
Carcase weight (kg)[3]		28.72
Carcase price (£/kgCW)[4]		2.32
Carcase revenue (£)		66.53
Number of lambs born (per ewe mated)[5]		1.83
Lamb weaning age (days)		100
Average survival from birth to sale[5,6]		91.8%
Replacements kept (per breeding female)[7]		0.24
Slaughtered progeny (per breeding female)[8]		
	Singles	0.12
	Twins	1.14
	Triples	0.18
	Total	1.44

[1] EGENES (data sourced: 24th January 2018)

[2] Byrne, T.J., et al., Broadening breeding objectives for maternal and terminal sheep, Livestock Science (2011)

[3] Carcase weight = Mature weight * dressing %

[4] 2018 AHDB Sheep Yearbook: average 2014-17

[5] EBLEX Sheep BRP Manual: Target ewe fertility for Better Returns, System standards (Lowland)

[6] Survival rates for singles, twins and triplets are 98%, 94%, and 73%; Byrne, T.J., et al., Broadening breeding objectives for maternal and terminal sheep, Livestock Science (2011)

[7] Flock distribution based on Byrne, T.J., et al., Broadening breeding objectives for maternal and terminal sheep, Livestock Science (2011)

[8] Based on number of lambs born of 1.83, the proportion of ewes bearing singles lambs and triplets was calculated as 25%, 67%, and 8% respectively (0.25*1+0.67*2+0.08*3=1.83) .

The performance and profitability of slaughtered single, twin and triplet lambs in the base production system are summarised in Table 14 below.

Table 14: Summary of profit per animal for single, twin and triplet lambs in base sheep model.

	Single	Twin	Triplet
Liveweight at slaughter (kg) [1]	46.59	46.59	46.59
Dressing percentage (%)[2]	41.6%	41.6%	41.6%
Carcase weight (kg) [3]	19.40	19.40	19.40
Base Price (£)[3]	4.02	4.02	4.02
Fat score (Score: 1-15) [4]	8.27	8.27	8.27
Conformation score (Score: 1-15) [4]	10.25	10.25	10.25
EUROP Premium/penalty (£)[4]	0.03	0.03	0.03
Price (£/kgCW) [5]	4.05	4.05	4.05
Carcase revenue (£)	78.63	78.63	78.63
Age at slaughter (days) [6]	162	177	185
Total energy required (MJME)[7]	2,916	2,990	3,050
Total cost of feed (£)[8]	15.19	17.86	21.92
Profit/animal (£)	63.44	60.77	56.71

[1] EGENES (data sourced: 24th January 2018). Scanning weight.

[2] Dressing % = Liveweight / Carcase weight

[3] 2018 AHDB Sheep Yearbook: average 2014-17

[4] Based on EUROP price grid (Appendix 2: Table 29) and distribution of animals corresponding to carcase weights of base lambs (AHDB, confidential data)

[5] Price (£/kgCW) = Base price + EUROP premium/penalty

[6] Byrne, T.J., et al., Broadening breeding objectives for maternal and terminal sheep, Livestock Science (2011)

[7] Calculated according to growth profiles (Appendix 2) and energy requirements (Appendix 3)

[8] Calculated according to daily MJME required and feed costs (Appendix 4: Table 39)

Table 15 summarises the average cost of feed per unit of energy (in the base model). Diets and feed costs are detailed in Appendix 4.

Table 15: Average cost of feed per unit of energy for lambs and breeding females.

	Cost of feed (£/MJME)
Single	0.0052
Twin	0.0060
Triplet	0.0072
Mature ewes	0.0038
Replacements[1]	0.0042

[1] Note that replacement ewes are fed lamb diet from birth to weaning (100 days).

Direct trait changes

For each direct trait, the costs and revenues are calculated per animal, as a result of a 100kg increase in breeding female mature weight.

Mature ewe maintenance and body condition score feed costs

Increasing breeding female mature weight increases maintenance energy requirements for the breeding female, thus increasing feed costs. In addition, higher average feed costs are included for heavier breeding female mature weights. Costs increase proportionally from 75kg mature weight. The argument is that in order to supply the energy required to meet body condition score (BCS) targets throughout the year, higher quality and higher cost feed is required as mature weight increases; this is because the volume of energy required cannot be supplied through lower quality feed (Appendix 4). Table 16 presents maintenance energy requirements, average feed costs, and annual maintenance and BCS feed costs per breeding female, for breeding female mature weights of 61.8kg and 71.8kg, respectively. Differences are also presented.

Table 16: Maintenance energy requirements, average feed costs, and annual maintenance and BCS feed costs per breeding female, for breeding female mature weights of 61.8kg and 71.8kg, along with the differences.

Trait	*Mature weight*		Δ/10kg MW
	61.8kg	**71.8kg**	
Daily energy required for maintenance (MJME) [1]	9.92	11.10	1.18
Average feed price (£/ MJME)[2]	0.004	0.004	-
Annual maintenance and BCS feed cost (£)	13.93	15.59	**1.66**

[1] $0.45 * MW^{0.75}$

[2] Refer to Appendix 4: Table 39 for feed costs (feed cost increases at higher MWs to maintain BCS)

Cull breeding female carcase revenue

Increasing breeding female mature weight increases the cull breeding female carcase weight, thus increasing revenue. Cull breeding female carcases earn a flat price per kilogram of carcase weight (Table 13). Table 17 presents carcase weight and cull breeding female carcase revenue per breeding female, for breeding female mature weights of 61.8kg and 71.8kg, respectively. Differences are also presented.

Table 17: Carcase weight and cull breeding female carcase revenue, per cull breeding female, for breeding female mature weights of 61.8kg and 71.8kg, along with the differences.

Trait	*Mature weight*		Δ/10kg MW
	61.8kg	**71.8kg**	
Carcase weight (kg)[1]	24.72	28.72	4.00
Cull female revenue (£)[2]	**57.26**	**66.53**	**9.27**

[1] See Table 13 for dressing percent

[2] See Table 13Table 1 for price per kgCW.

Replacement female growth energy costs

A replacement female growing to a heavier breeding female mature weight requires more feed for maintenance and growth during the growth period. In addition, higher average feed costs are included for replacement females growing to heavier breeding female mature weights. Costs increase proportionally from 75kg mature weight. The argument is that in order to supply the energy required to meet weight and BCS targets for first parity mating, higher quality and higher cost feed is required as mature weight increases; this is because the volume of energy required cannot be supplied through lower quality feed (Appendix 4).

Replacement females take 948 days to reach mature weight (age at second mating). The growth profile is based on the percentage of mature weight at each mating is presented in Appendix 2. Table 18 presents energy requirements (MJME) and average cost of feed associated with replacement female growth per replacement female, for breeding female mature weights of 61.8kg and 71.8kg, respectively. Differences are also presented.

Table 18: Energy requirements, feed requirements, and cost of feed associated with replacement female growth to 948 days, per replacement, for breeding female mature weights of 61.8kg and 71.8kg, along with the differences.

Trait	*Mature weight*		Δ/10kg MW
	61.8kg	**71.8kg**	
Total energy required (MJME)[1]	9,925	11,356	1,431
Average feed price (£/ MJME)[2]	0.0042	0.0042	0.00
Total feed cost (£)	**41.27**	**47.66**	**6.39**

[1] For calculation of energy requirements (MJME) refer to Appendix 3

[2] Refer to Appendix 4: Table 39 for feed costs

Indirect trait changes

For each indirect trait, the costs and revenues are calculated per animal, as a result of a 10kg change in breeding female mature weight. Calculation of the biological relationships between breeding female mature weight and indirect traits (those affecting progeny) are presented in Appendix 1.

Progeny carcase revenue and costs at constant slaughter weight (carcase weight, conformation score, and fat score)

Increasing breeding female mature weight increases the growth potential of slaughtered progeny. Carcase value is determined by the carcase weight and the price per kg, which is in turn determined by carcase conformation score and carcase fat score. Therefore, the revenues associated with carcase weight, carcase conformation score, and carcase fat score per slaughtered animal, as a result of a 10 kg change in breeding female mature weight, are combined into progeny carcase value. Calculation of the biological relationships between breeding female mature weight and carcase weight, carcase conformation score, and carcase fat score are presented in Appendix 1. Differences in revenue per carcase at a constant weight are determined by the relationship between age at slaughter and carcase conformation and fat score (Appendix 1). Differences in feed costs for single, twin and triplet lambs are presented in Appendix 4:Table 40.

Changes to the growth potential of slaughtered progeny are reflected in slower/faster growth rates to a constant carcase weight at slaughter (19.4kg for single, twin and triplet lambs). The price per kg of carcase weight is determined by a base price, and a premium or penalty applied according to each carcase's conformation and fat score on the EUROP grid. Older and younger progeny (relative to the base), at a constant carcase weight, tend to have worse carcase conformation (younger) and fat scores (older) and earn less revenue per carcase, as shown in Figure 11.

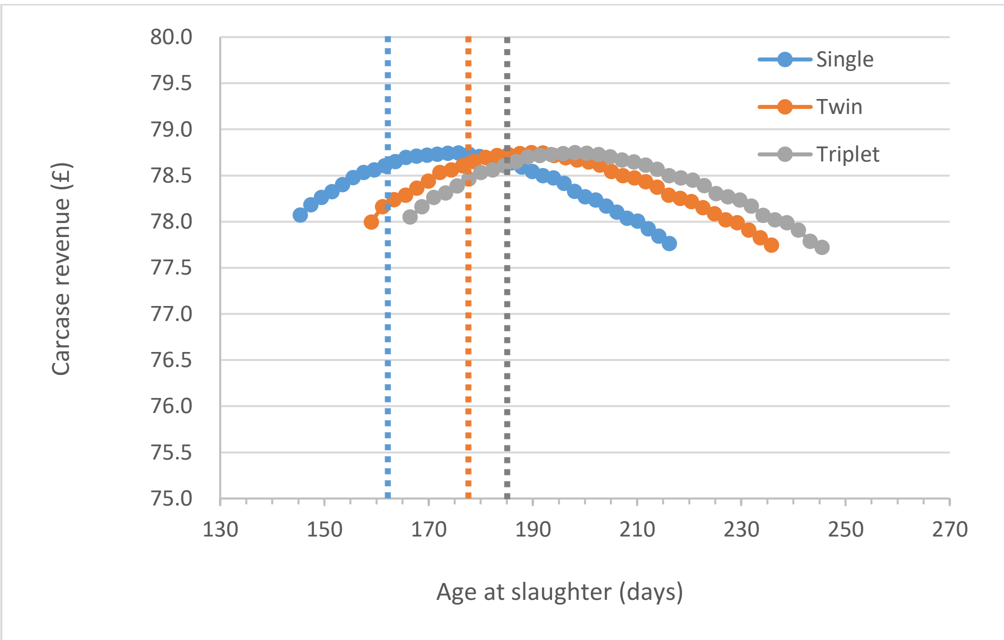


Figure 11: Total carcase revenue for slaughtered singles, twins, and triplets based on age at slaughter at a constant carcase and price received per kgCW (sum of base price, EUROP penalty/premium; Appendix 1). Vertical lines represent age at slaughter at base.

Table 19 presents carcase weight, carcase conformation score, carcase fat score, average price per kg of carcase weight, carcase revenue and total feed costs per slaughtered progeny, for breeding female mature weights of 61.8kg and 71.8kg, respectively. Differences are also presented.

Table 19: Carcase weight (weight), age at slaughter in days, carcase conformation score, carcase fat score, average price per kg of carcase weight, carcase revenue and total feed costs per slaughtered single, twin and triplet, for breeding female mature weights of 61.8kg and 71.8kg, along with the differences.

Trait		*Mature weight*		Δ/10kg MW
		61.8kg	**71.8kg**	
Carcase weight (kg)				
	Single	19.4	19.4	-
	Twin	19.4	19.4	-
	Triplet	19.4	19.4	-
Age at slaughter (days)				
	Single	182	162.0	-20.2
	Twin	199	177.0	-22.0
	Triplet	208	185.0	-22.6
Conformation score				
	Single	11.1	10.2	-0.9
	Twin	11.1	10.2	-0.9
	Triplet	11.1	10.2	-0.9
Fat score				
	Single	8.9	8.3	-0.6
	Twin	8.9	8.3	-0.6
	Triplet	8.9	8.3	-0.6
Price (£/kgCW)[1]				
	Single	4.06	4.05	0.0
	Twin	4.06	4.05	0.0
	Triplet	4.06	4.05	0.0
Carcase revenue (£)				
	Single	78.67	78.63	-0.04
	Twin	78.67	78.63	-0.04
	Triplet	78.67	78.63	-0.04
Total feed cost (£)				
	Single	15.17	15.19	0.0
	Twin	18.12	17.86	-0.3
	Triplet	22.85	21.92	-0.9
Margin over feed (£)				
	Single	63.50	63.44	-0.06
	Twin	60.55	60.77	0.22
	Triplet	55.82	56.71	0.89

[1] Price per kg determined by base price (Table 2) and premium/ penalty (Table 29).

Changes in carcase value, with decreasing mature weight, cannot be reported per animal (i.e. the weighted average of singles, twins and triplets), without considering the changing flock distribution (detailed below).

Conception rate at second mating cost

Phenotypically increasing breeding female mature weight is assumed to affect fertility by increasing the ovulation rate of ewes, and this, lifting the proportion of ewes birthing multiples (Appendix 1). Thus, heavier breeding female mature weight is assumed to manifest in increased number of lambs born, and increased slaughter progeny profit (carcase revenue, less feed costs).

The effect of increased ovulation rate is only realised in breeding females with a mature weight up to 65kg, and with diminishing effect up to that point (Appendix 1: Figure 20). For breeding females heavier than 65kg further increases in mature weight does not provide any additional benefits to ovulation rate. Table 20 presents the number of lambs born per breeding female and the percentage of ewes birthing multiples for breeding female mature weights of 61.8kg and 71.8kg. Differences are also presented.

Table 20: Number of lambs single, twin, and triplet lambs born and % of ewes birthing multiples (twins or triplets) for breeding female mature weights of 61.8kg and 71.8kg, along with the differences.

Trait		*Mature weight*		Δ/10kg MW
		61.8kg	**71.8kg**	
Number of lambs born		1.80	1.83	0.03
	Single	0.27	0.25	-0.02
	Twin	1.32	1.34	0.01
	Triplet	0.21	0.24	0.03
% of ewes birthing multiples		73.4%	74.8%	1.5%

[1] See Appendix 1

Costs of a changing flock distribution, with decreasing mature weight, cannot be reported per animal, without considering the changes in carcase value for the slaughtered progeny (detailed above).

Flock distribution

Table 21 summarises the flock profile (number of breeding females, replacements and slaughtered progeny for breeding female) for mature weights of 61.8kg and 71.8kg. Differences are also shown.

Table 21: Number of breeding females, lambs born, replacements and culls, and slaughtered singles, twins and triplets for breeding female mature weights of 61.8kg and 71.8kg, along with the differences.

Number of animals (total)	*Mature weight* 61.8kg	*Mature weight* 71.8kg	Δ/10kg MW
Breeding females	100.00	100.00	-
Number of lambs born	180	183	3
Replacement females[1]	24.33	24.33	-
Number of cull ewes[1]	23.72	23.72	-
Number of progeny slaughtered			
Single	13.19	12.34	-0.86
Twin	113.22	113.51	0.29
Triplet	15.17	17.66	2.49

[1] Cull ewes are equal to the number of replacements, multiplied by a salvage rate of 97.5%.

Rescaling

Differences in breeding female mature weight relative to the base production system, will result in different overall levels of feed demand. This requires additional land for pasture and thus incurs rental costs. Production at 61.8kg breeding female mature weight requires 3.4% less pasture (kgDM, system-wide) than production at 71.8kg. To capture this, the number of breeding females has been altered to reflect the limited pasture resource; this is assumed to be equivalent to the cost of renting additional land.

Results

Flock margin over feed

Table 22 presents revenue and cost elements associated with mature ewe maintenance, cull breeding female carcase, replacement female growth energy, and progeny carcase value (carcase weight, conformation score, and fat score), for mature weights of 61.8kg and 71.8kg in a 100-breeding female herd. Overall flock profit is also presented.

Note that differences in ovulation rate (the proportion of ewes birthing multiples) manifest in differences in the number of singles twins and triplets slaughtered (Table 21); these components are captured in the revenue and cost items for replacement growth and carcase value, respectively, in Table 22. In Table 22, a breeding female mature weight of 71.8kg and the lighter breeding female mature weight of 61.8kg are associated with very similar margins.

Table 22: Revenue and cost elements associated with mature ewe maintenance , cull breeding female carcase, replacement female growth energy, and progeny carcase value (carcase weight, conformation score, and fat score), for mature weights of 61.8kg and 71.8kg for a 100-breeding female flock, when progeny are slaughtered at a constant carcase weight.

Animal	*Mature Weight*			
	61.8kg		**71.8kg**	
	Cost	**Revenue**	**Cost**	**Revenue**
Maintenance energy	1,393.09	-	1,558.95	-
Cull ewe	-	1,358.46	-	1,578.28
Replacement growth	1,004.21		1,159.76	
Single carcase	200.11	1,037.97	187.36	970.16
Twin carcase	2,051.74	8,906.48	2,027.45	8,924.91
Triplet carcase	346.60	1,193.42	387.07	1,388.49
Total	4,995.75	12,496.33	5,320.59	12,861.85
Margin over feed	**7,500.58**		**7,541.26**	

[1] Farm costs and revenues are calculated based on per animal costs reported in Table 16 to Table 19, and the number of animals in each class (replacement, single, twin, and triplet) in the flock (Table 21).

Figure 12 below presents a breakdown of revenue and cost components, and total margin over feed for a 100-breeding female flock, for breeding female mature weights from 45kg to 80kg.

The optimum breeding female mature weight for a typical sheep production system is 65kg, although there is very little difference in re-scaled margin over feed for breeding female mature weights of 50kg to 65kg. The optimum breeding female mature weight for a 100-breeding female flock is associated with a total margin over feed of £7,597.

With increasing breeding female mature weight, cull ewe revenue increases (purple line), while ewe maintenance costs (light blue line) and replacement costs (orange line) increase. Breeding females heavier than 75kg require higher quality and higher cost feed, which accounts for maintenance and replacement costs increasing at a faster rate above 75kg.

Progeny feed costs (green line) increase over the range of ewe mature weights; this results because per animal feed savings (weight constant slaughter) are slightly less than the increase in total feed demand resulting from increases in the number of lambs available for slaughter, as ewe mature weight increases (see Appendix 1: Figure 21 for the number of progeny slaughtered, and see Appendix 4: Figure 27 for the total feed costs and feed costs per animal slaughtered with changes in ewe mature weight). Progeny revenue increases significantly from 45kg to 55kg mature weight. This increase is associated with increased ovulation rates and increased number of lambs born, and thus increased lambs slaughtered per 100 ewes.

At the optimum breeding female mature weight, rescaling the number of breeding females by 3.4% (Figure 12, dark blue dotted line) to account for lower overall feed demand, increases the total margin over feed by the same proportion; from £7,597 to £7,859. After accounting for rescaling, the optimum decreases from 65kg to 55kg, where the rescaled margin over feed is £8,060 (where the re-scaling factor increases number of breeding females by 10.1%).

The "flatness" of this optimum breeding female mature weight line is the result of several elements. Firstly, there is very little difference in progeny carcase value across the range of ages at a constant carcase weight; approximately £1/ carcase (Figure 11). When combined with a lower (compared to beef) phenotypic correlation between breeding female mature weight and progeny carcase weight, little value is gained by increasing ewe mature weight in terms of progeny carcase value. Secondly, the reproductive rate effect manifests primarily over the range of 45kg to 55kg (Figure 20). Thus, little value comes from increases in fertility associated with breeding female mature weight above 55kg. Cost and revenue more-or-less increase in proportion as breeding female mature weight increases and, as such, the optimum could be said to sit between 55kg and 65kg (Figure 12).

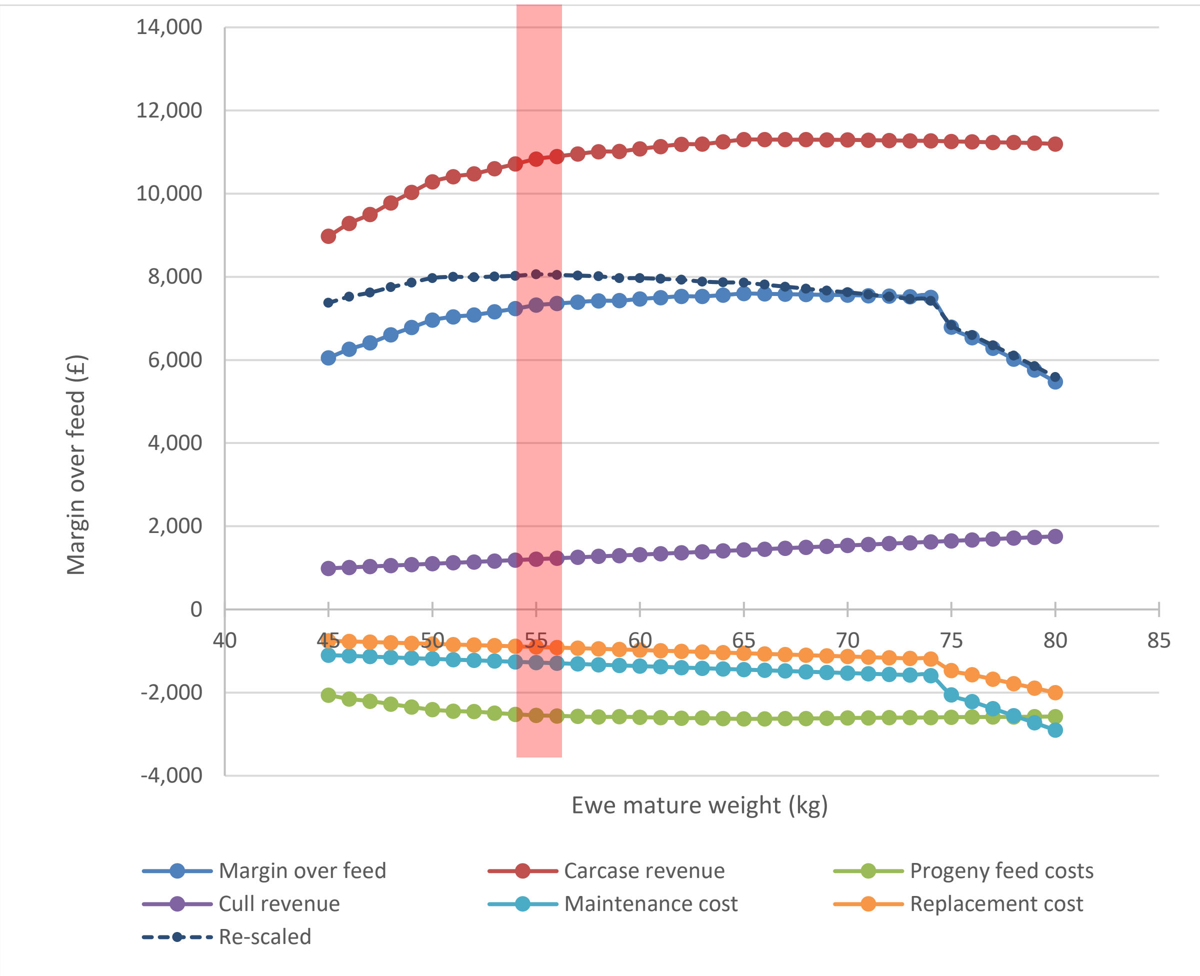


Figure 12: Breakdown of revenue and cost components (weight constant), and margin over feed for a 100-breeding female flock, for breeding female mature weights of 45kg to 80kg.

Sensitivity

Correlation between mature weight and progeny carcase weight

The sensitivity of optimum breeding female mature weight (rescaled) to differences in the phenotypic correlation (βCW,MW) between breeding female mature weight and progeny carcase weight was assessed (Figure 13).

For phenotypic correlations from 0.90 to 0.10 there is some sensitivity for the optimum breeding female mature weight, which decreases from 57kg at 0.90, to 55kg at 0.20, and then to 51kg at 0.10.

The optimum breeding female mature weight is sensitive to the phenotypic correlation between breeding female mature weight and progeny carcase weight, albeit in a narrow range when considering realistic phenotypic correlations.

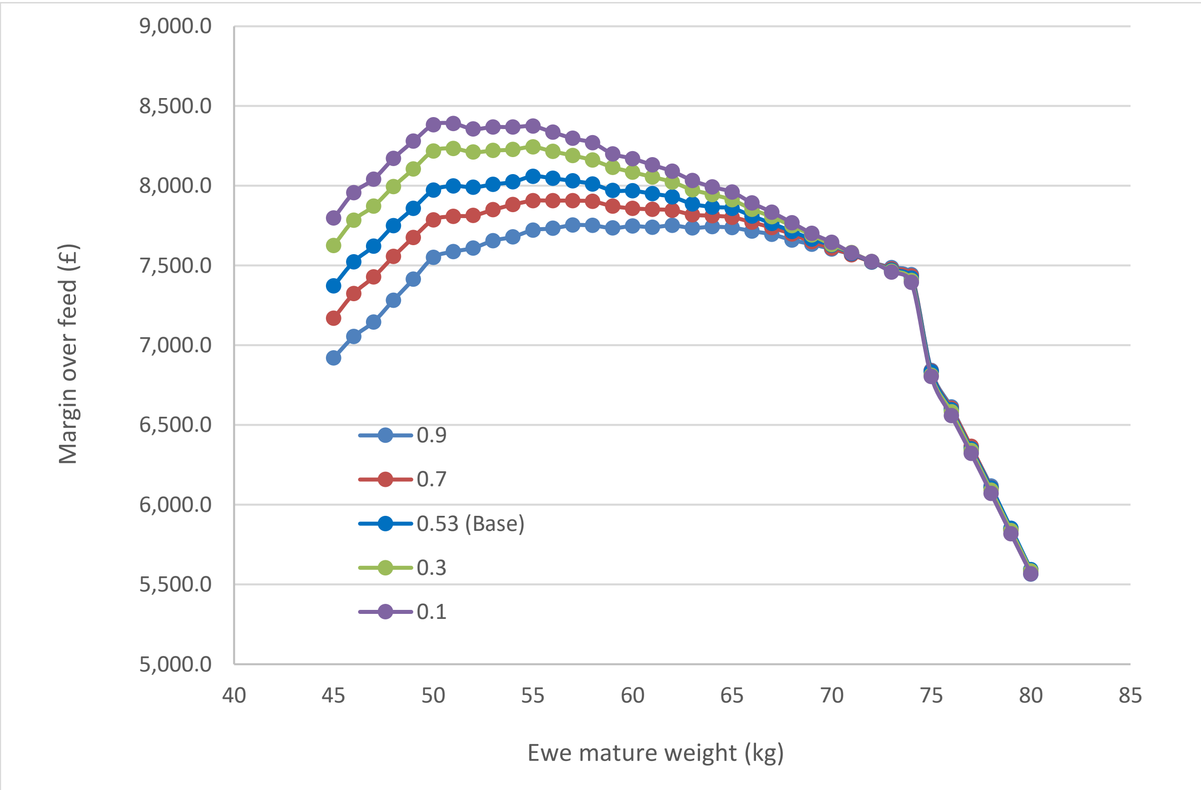


Figure 13: Re-scaled margin over feed at a range of phenotypic correlations between breeding female mature weight and progeny carcase weight, for a 100-breeding herd, for mature breeding female weights from 45kg to 80kg (for calculations of phenotypic correlations refer to Appendix 1)

Feed costs and diet composition

The optimum breeding female mature weight was assessed for sensitivity to:

1) the average feed cost for all feed types (+/-20%),
2) the average feed cost for concentrate only (+/-20%),
3) the diet over winter for ewes (inclusion of silage and concentrate for 100% of the diet), and
4) the diet over winter for ewes (inclusion of silage and concentrate for 100% of the diet) combined with differences in the average feed cost for all feed types (+/-20%).

For grass-based systems, the optimum remains at 55kg with increases and decreases in feed price. For mixed diets systems, the optimum is 51kg under normal pricing, but increases to 55kg when prices are 20% lower, and decreases to 50kg when prices are 20% higher. In a situation where feed is limiting (i.e. feed costs are higher, because they have to be purchased in), e.g. hill farming, the optimum appears to be closer to 50kg.

The optimum breeding female mature weight was sensitive to changes in feed costs. Similar to beef, the rate of change in overall ewe feed cost with the introduction of a mixed diet is only slightly greater than the rate of change in a grass-based diet, as mature weight increases. However, the additional increase in overall ewe feed cost is greater than the additional revenue from the heavier progeny carcase, and for this reason the optimum does change i.e. this “flatness” (driven by little variation in revenue from progeny carcases) means that the optimum is sensitive to feed costs, when average feed costs are high.

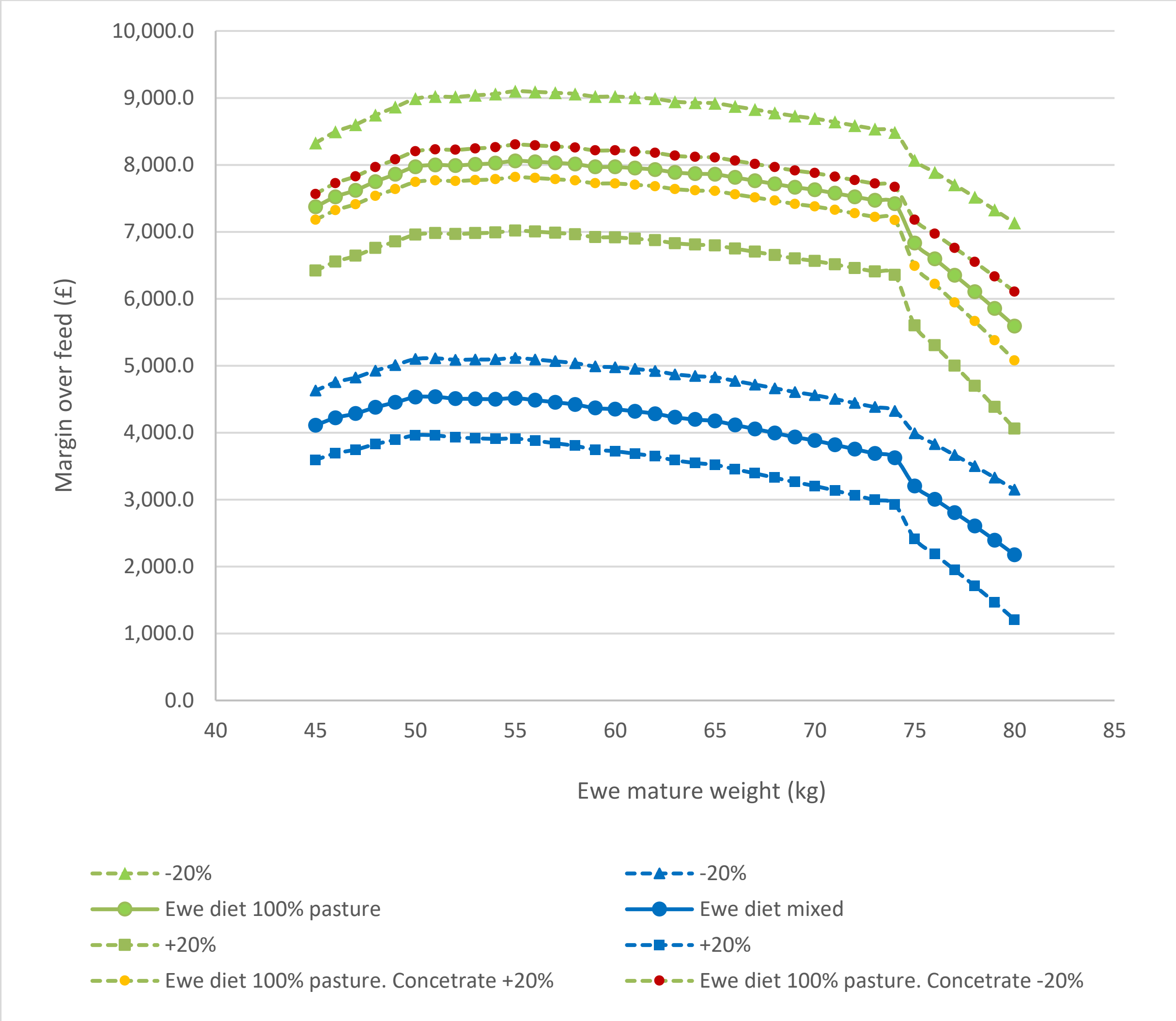


Figure 14: Total operating profit for base pasture feed costs and +20% increase in pasture feed costs, for a 100- breeding female herd, for breeding female mature weights of 45kg to 80kg.

Industry-wide impact

Beef

Table 23 presents the number of breeding females, total beef production (progeny slaughtered at a constant age), and total financial performance for UK beef industry at a base mature weight of 651.4kg and a heavier (rescaled) mature weight (751.4kg), along with the differences. A 100kg difference in mature weight would yield 17,000 tonnes of carcase but reduce margin over feed by £208.9m, due to decreased carcase revenue (lower price received per kgCW), and increased feed costs.

Table 23: Number of breeding females, total beef production (progeny slaughtered at a constant age), and total financial performance for UK beef industry at base mature weight (651.4kg) and heavier mature weight (751.4kg), along with the differences.

Number of animals (total)	*Mature weight*		Δ/100kg MW
	651.4kg	**751.4kg**	
Number of breeding females [1,2]	1.58	1.34	-0.24
Rescaling factor	na	-15.1%	na
Production ('000 tonnes)[3]			
Heifers	131.8	134.3	2.5
Steers	198.5	209.1	10.6
Bulls	40.5	42.7	2.2
Cows	78.6	80.2	1.7
Total	**449.4**	**466.4**	**17.0**
Financial performance (£m)[4]			
Revenue	1,438.1	1,391.0	-47.0
Cost	1,079.5	1,241.4	161.9
Margin over feed	**358.6**	**149.6**	**-208.9**

[1] At base MW (651.4kg), number of breeding females = 2018 AHDB Beef Yearbook: average 2014-17

[2] At heavier MW (751.4kg), number of breeding females = 1.58m *(1 + rescaling factor)

[3] Total UK Production (’000 tonnes)
= ((CW: Table 7)/1000 * Number slaughtered: Table 10) * (Number of breeding females/100))/1000

[4] Total UK performance (£m)
= (Cost, revenue, or Margin over feed: Table 11 / 1000000)*(Number of breeding females /100)

Table 24 presents the number of breeding females, total beef production (progeny slaughtered at a constant weight), and total financial performance for UK beef industry at a base mature weight of 651.4kg and a heavier (rescaled) mature weight (751.4kg), along with the differences. A 100kg difference in mature weight would reduce output by 50,500 tonnes of carcase and reduce margin over feed by £82.2m when slaughtered at a constant weight.

In theory, the total production of prime carcase weight should not change between the base and optimum mature weights when prime carcases are slaughtered at a constant carcase weight. However, this is not the case, as production at 751.4kg mature weight results in a 10.4% decrease in the number of breeding females, therefore total production also decreases. There are also fewer progeny slaughtered per breeding female at 751.4kg mature weight, due to decreased fertility, further decreasing production.

Table 24: Number of breeding females, total beef production (progeny slaughtered at a constant weight), and total financial performance for UK beef industry at base mature weight (651.4kg) and heavier mature weight (751.4kg), along with the differences.

Number of animals (total)	*Mature weight*		Δ/100kg MW
	651.4kg	**751.4kg**	
Number of breeding females (m)[1,2]	1.58	1.42	-0.16
Rescaling factor	na	-10.4%	na
Production ('000 tonnes)[3]			
Heifers	131.8	113.2	-18.6
Steers	198.5	176.3	-22.2
Bulls	40.5	36.0	-4.5
Cows	78.6	73.4	-5.2
Total	**449.4**	**398.9**	**-50.5**
Financial performance (£m)[4]			
Revenue	1,438.1	1,245.9	-192.2
Cost	1,079.5	969.5	-109.9
Margin over feed	**358.6**	**276.4**	**-82.2**

[1] At base MW (651.4kg), number of breeding females = 2018 AHDB Beef Yearbook: average 2014-17

[2] At heavier MW (751.4kg), number of breeding females = 1.58m *(1 + rescaling factor)

[3] Total UK Production ('000 tonnes)
= ((CW: Table 8)/1000 * Number slaughtered: Table 10) * (Number of breeding females/100))/1000

[4] Total UK performance (£m)
= (Cost, revenue, or Margin over feed: Table 12 / 1000000)*(Number of breeding females /100)

Sheep

Table 25 presents the number of breeding females, total lamb and sheep production (progeny slaughtered at a constant age), and total financial performance for UK sheep industry at a base mature weight of 71.8kg and a lighter (rescaled) mature weight (61.8kg), along with the differences. A 10kg difference in mature weight would yield 8,690 tonnes of carcase and £61.3m in additional margin over feed. Though fertility decreases the number of lambs slaughtered per ewe, the increase in total production is explained by the increased ewe numbers (rescaling).

Table 25: Number of breeding females, total beef production (progeny slaughtered at a constant age), and total financial performance for UK sheep industry at base mature weight (71.8kg) and lighter mature weight (61.8kg), along with the differences.

Number of animals (total)	*Mature weight*		Δ/10kg MW
	71.8kg	**61.8kg**	
Number of breeding females (m)[1,2]	16.26	17.16	0.91
Rescaling factor	na	5.6%	na
Production ('000 tonnes)[3]			
Singles	38.9	43.9	5.01
Twins	358.0	376.9	18.96
Triplets	55.7	50.5	-5.19
Ewes	110.7	100.6	-10.10
Total	**563.3**	**572.0**	**8.69**
Financial performance (£m)[4]			
Revenue	2,090.8	2,144.5	53.73
Cost	864.9	857.3	-7.57
Margin over feed	**1,225.9**	**1,287.2**	**61.30**

[1] At base MW (71.8kg), number of breeding females = 2018 AHDB Sheep Yearbook: average 2014-17

[2] At heavier MW (61.8kg), number of breeding females = 16.26m *(1 + rescaling factor)

[3] Total UK Production ('000 tonnes)
= ((CW: Table 19)/1000 * Number slaughtered: Table 21) * (Number of breeding females/100))/1000

[4] Total UK performance (£m)
= (Cost, revenue, or Margin over feed: Table 22 / 1000000)*(Number of breeding females /100)

Tools & techniques: how to achieve change?

Genetics

Non-linear index weighting on carcase weight (beef)

It is apparent from the results that, in beef, carcase value drops and plateaus, above a certain carcase weight (Figure 4), albeit that the implications of this in the context of increasing mature weight differ, depending on whether carcases are harvested at a weight constant or age constant end point. This can be reflected within bull selection index ranking tools, through the implementation of a non-linear function in the weighting applied to the carcase weight EBV[3]. The calculation would rely on an understanding of the relationship between the carcase weight EBV and the expected commercial-herd phenotype; this could be established from data in the national phenotype and EBV database (EGENES). From this it would be possible to determine the EBV that delivers the most valuable commercial carcase weight (e.g. 440kg for steers, as seen in Figure 4). The best function is likely to be “linear then asymptote”, such that the carcase weight EBV receives the same economic weighting up to the optimum point, and no additional value beyond that. For example, if the optimum carcase weight EBV was +20kg, the index value for carcase weight for a bull with an EBV of +30kg would be the same as that of a bull with an EBV of +20kg. This approach caps the growth values of individuals with above-optimum carcase weight EBV that may be over-valued with a linear economic value. When incorporated into the index, the non-linear carcase weight economic value mitigates the risk of high growth genetics driving individuals’ total index.

Strengths:

- Can be applied at the industry level (reduces fragmentation).
- Permanent and cumulative impact so will deliver long lasting outcomes for the industry.
- Complex calculations remain “behind the scene”.
- When incorporated into the economic index, the non-linear carcase weight economic value mitigates the risk of high growth genetics driving an individuals’ total index.

Weaknesses:

- Potentially difficult to explain to users.
- Difficult to implement across multiple genetic evaluation systems (EGENES/ BREEDPLAN) (beef).
- Can cause problems if different farms have very different optimums (especially in across breed situation).
- No industry-level economic selection indexes exist in which to implement a non-linear function (although it could be implemented in the Limousin index, for example).

[3] An equivalent approach can be seen in: Quinton, C., Byrne, T., and Amer, P. (2017). Nonlinear economic value for number of lambs born in New Zealand sheep indexes. Association for the Advancement of Animal Breeding and Genetics. Townsville, Australia. Volume: 22

Non-linear index weighting on mature weight (sheep and beef)

Similarly, genetic selection tools can be updated to include a non-linear function in the weighting applied to the mature weight EBV. Similar tools have been used in other industries and indeed in the ATAN function in the UK sheep industry[4]. The calculation would rely on an understanding of the relationship between the carcase weight EBV and the expected commercial-herd phenotype (as above) but that outcome would be linked to the mature weight EBV. The best function is likely to be "linear then exponential", such that the mature weight EBV receives the same economic penalty up to the optimum point and an increasing penalty beyond that, reflecting the reduction in progeny carcase value associated with higher mature weights. Note that this reduction in progeny carcase value would be only that associated with the reduction in price per kg associated with weight, not carcase conformation or fat score. For example, if the optimum mature weight EBV was +5kg, the index penalty value for mature weight for a bull with an EBV of +10kg would be more than double that of a bull with an EBV of +5kg. This approach more heavily penalises individuals with above-optimum mature weight EBVs that may be under-penalised with a linear economic value. When incorporated into the index, the non-linear mature weight economic value mitigates the risk of high growth genetics driving individuals' total index.

Strengths:

- Can be applied at the industry level (reduces fragmentation).
- Permanent and cumulative impact so will deliver long lasting outcomes for the industry.
- Complex calculations remain "behind the scene".
- When incorporated into the economic index, the non-linear mature weight economic value mitigates the risk of high growth/ high mature weight genetics driving an individuals' total index.

Weaknesses:

- Difficult to explain to users.
- Difficult to implement across multiple genetic evaluation systems (EGENES/ BREEDPLAN) (beef).
- Can cause problems if different farms have very different optimums (especially in across breed situation).
- No industry-level economic selection indexes exist in which to implement a non-linear function (although it could be implemented in the Limousin index, for example).

Sires with lower mature weight EBVs (beef and sheep)

Both approaches above should result in the use of sires, in both elite and commercial tiers of the industry, that have favourable mature weight EBVs. An alternative to the above is to use sires that have as high as possible growth EBVs in combination with mature weight EBVs as close as possible to zero, or negative if trying to reduce female size (i.e. applying selection thresholds); as selected by breeders/ farmers. It is likely that this will require the use of proven (older) sires, because higher accuracy of mature weight EBVs (i.e. daughters or half-sib records for mature weight) will be required

[4] https://www.signetfbc.co.uk/wp-content/uploads/2015/02/Breed-a-Better-Flock-2014-12Feb.pdf (accessed 18/03/2019).

to deliver high offspring growth rate without excessive mature weight. It's worth noting that selection indexes, which include a penalty on mature weight, usually still result in increases in mature weight. This is due to the strong genetic correlation between early growth and mature weight, and the magnitude of the positive contribution to profit from early growth relative to the negative contribution to profit of increases in mature size.

Strengths:

- Permanent and cumulative impact so will deliver long lasting outcomes for the industry.
- Allows custom approaches to managing genetics of mature weight.

Weaknesses:

- Requires users to have detailed knowledge of EBVs.
- Complex calculations need to be done by the users.
- Requires specific action/ behavioural change be many users.
- Likely to produce sub-optimal outcomes and may increase complexity.

Scheme linked to mature size data and selection practices (beef and sheep)

The ability to control mature weight using genetics requires accurate and plentiful mature weight data. This enables accurate genetic evaluation, and therefore the identification of animals with desirable growth and mature weight EBVs combinations (e.g. curve benders). Payment schemes to encourage the recording of mature weight data in elite herds and flocks would be beneficial in the development of genetics/ genomics tools; especially when combined with cull cow/ ewe carcase data from processors. Payment schemes linked to performance recording, the use of high merit genetics, and genomics have been successful in other industries[5] and can be used to create behavioural change; specifically, a change in the types of sires being used. Better data to evaluate the genetic merit of animals for mature weight and behavioural change related to mature weight at the elite breeder level, will allow the right sires to be delivered to industry (with mature weight at or below the optimum).

Strengths:

Can be applied at the industry level (reduces fragmentation).

- Creates collective and cohesive momentum towards a shared goal (like the "shout about the sire" project that AHDB ran).
- Would generate improved data for multiple genetic evaluation systems (EGENES/ BREEDPLAN) (beef).
- Motivates behavioural change and could be linked to subsidies.

Weaknesses:

- Significant investment and infrastructure required (although some already in place e.g. Scottish beef feed efficiency scheme), especially if genomics involved.
- Difficult to implement across multiple genetic evaluation systems (EGENES/ BREEDPLAN) (beef).

[5] e.g. Beef in Ireland: https://www.icbf.com/wp/?p=3985 (accessed 19/12/2018).
e.g. Sheep in Ireland: https://www.sheep.ie/wp/?page_id=27 (accessed 01/03/2019).

Management

Artificial insemination in commercial herds/ flock (beef and sheep)

There is a high likelihood that, generally, the sires available to commercial famers a) are not presented with information on genetic merit for mature weight and/ or b) are high genetic merit for growth and therefore likely to produce high breeding female mature weights. Farmers may also not give attention to estimates of genetic merit, but rather assess the bull/ ram based purely on phenotype. All of these factors limit the ability of the commercial farmer to access genetics to control breeding female mature weight. More widespread use of artificial insemination of heifers/ ewes in commercial herds, with semen from bulls/ rams with desirable growth and mature weight EBV combinations, is a solution to the problem of access to the “right”. This still requires accurate and plentiful mature weight data, and semen must be made available.

Strengths:

- Would create a step change in genetic merit in commercial herds/ flocks.
- Doesn’t necessarily require a change in the genetic evaluation (although would beneficial in conjunction with application of some of the genetics tools outlined above).
- Could be part of a scheme (as outline above).

Weaknesses:

- Large scale practice change required in commercial herds/ flock.
- Additional cost incurred by the farmer (could be subsidised)

Use of maternal and terminal genetics in combination (beef and sheep)

Within maternal breeding programs, penalties are applied to EBVs to control breeding female mature weight. In terminal systems, all animals are slaughtered so mature weight is not in the breeding objective. However, often terminal animals are used as replacements, which results in bigger breeding females, generally. There is an opportunity to create stronger messages to commercial farmers to target maternal and terminal genetics for different use and, as such, enable the benefits of hybrid vigour to be realised, while controlling breeding female mature weight.

Strengths:

- This strategy goes together with capturing hybrid vigour
- Easy to implement (if the flock or herd size is big enough)
- Selection index tools are readily available to support identification or maternal and terminal genetics

Weaknesses:

- Likely to be challenging in smaller flocks/ herds
- Could create some issues in defining best use of certain breeds

Restricted feeding of replacement heifers/ ewes (beef and sheep)

Restricted feeding of heifers/ ewes to stunt growth is a management option to reduce mature weight phenotype. However, this practice could lead to lower conception rates in first parity and second parity cows/ ewes and/ or lead to animal welfare issues. This is likely to be a low priority option for managing mature weight.

Use of Beef x Dairy cows (beef)

Genetic trends for breeding female mature weight are likely to be lower in dairy cows than beef cows (data needed to confirm). If this is the case, then the use of crossbred cows represents a potential opportunity to control breeding female mature weight. Genetic merit of the dairy influence associated with genetic characteristics like, for example, too much milk, poorer growth and carcase attributes would need to be understood.

Strengths:

- There is a readily available source of beef x dairy heifers.
- This strategy goes together with more use of terminal sires and maximising carcase value.

Weaknesses:

- Would require an understanding of the implications of dairy genetics expressed in a beef herd (perhaps this data is already available?).
- Large scale practice change required in commercial herds.

Summary and Communication

This analysis shows that, for a typical UK beef farm, there is an optimum breeding female mature weight in the range of 680kg to 725kg for cows, depending on assumptions about the cost per unit of feed for heavy cows. In a situation where marginal feed costs are high and/ or heavy cows (>700kg) can't be maintained on the grass resource available (e.g. hill country/ upland farms, where bigger cows might need to be fed an imported higher quality and cost diet), then the optimum is 680kg. In a situation where heavy cows (>700kg) can be maintained on the grass resource available, then the optimum is 725kg. This optimum is also heavily influenced by the weight at which penalties are applied for over-weight progeny carcases.

For a typical UK sheep farm, there is an optimum breeding female mature weight ranging from 50kg, in a situation where marginal feed costs are high and/ or heavy ewes can't be maintained on the grass resource available (e.g. hill country/ upland farms, where bigger ewes might need to be fed a higher quality and cost imported diet) to 65kg, for a typical lowland system where ewes can be maintained on the grass resource available. The optimum mature weight for the typical lowland system could be said to range from 55kg to 65kg; this is the result of very little difference is progeny carcase value across the range of ages at a constant carcase weight and, also, a lower (compared to beef) phenotypic correlation between breeding female mature weight and progeny carcase weight.

Best tools and techniques and their use

When assessing the tools and techniques available, genetics offers the greatest opportunity. Breeding female mature weight has a very high heritability (0.40 to 0.60), meaning variation is very highly influenced by genetics. However, mature weight is also very antagonistically genetically correlated with early growth potential (0.60 to 0.80, depending on stage of early growth). There is therefore a trade-off between the value of additional growth and the cost of additional breeding female mature weight. There are tools available that could create clear signals to breeders and subsequently commercial farmers about the value of sires with different genetic merit for breeding female mature weight and growth potential. Importantly, these tools can be created/ augmented to reflect the information available on optimum mature weights (non-linear functions etc.). These tools are economic selection indexes, which provide the appropriate rankings of bulls/ rams, based on the principles outlined above to manage breeding female mature size. Underpinning the robustness of estimates of genetic merit is quality data. Therefore, an increase in mature weight data recording (or indeed assigning sire to progeny, who go on to have cow/ ewe carcase weight records) by the breeder tier of the industry, or via a scheme, or from commercially recorded systems would add significant value to the genetic evaluation system(s) and support accuracy of EBVs and selection indexes.

In the first instance these tools would be made available to breeders and with the correct implementation, the benefits would flow to commercial bull/ ram buyers. Breeders could also make use of EBV combinations to fine-tune selection for the right combination growth and breeding female mature weight; this does however require a clear understanding of EBVs and would likely require technical input from a specialist.

Commercial farmers are best to access genetics by buying from the bull/ ram breeder that best delivers on their commercial farm needs. Selection indexes, encompassing the appropriate weightings on early growth and mature weight (non-linear etc.), can be used as tools for breeders to communicate value to commercial farmers. With the appropriate methodology, responses to selection can be predicted for all traits in the index (including growth and breeding female mature weight); this provides clear messages to both breeders and commercial farmers regarding the implications of selection using an economic index (specifically, what it means for changes in mature weight).

While genetics offers permanent and cumulative (and potentially industry-wide) impact on the direction of the entire industry, the multiple, primarily non-economic, indexes (beef and sheep) and multiple evaluation systems (beef) create challenges in terms of ease of implementation of these tools. Implementation via an exemplar breed (beef) or in the industry combined breed analysis selection indexes (sheep) would represent excellent case studies.

While there are some management tools available to control increases in mature weight, significant practice change is required to implement these management tool/ techniques. Strategies, like more widespread use of AI (in commercial beef herds for example) using the “right” bulls would significantly increase the realised rates of genetic gain in the beef industry. Better use of maternal genetics and terminal genetics (in commercial sheep flocks for example) in combination within sheep flocks would enable the benefits of hybrid vigour to be realised, while controlling ewe mature weight. The ability of commercial farmers to control increase in breeding female mature weight through feeding (under-feeding) is likely to be unfeasible in terms of animal welfare and farming best practice.

Key messages for communicating to industry

Breeders

Key messages include:

- Where available, make use of selection indexes that have penalties applied to breeding female mature weight EBVs; this controls the increase in mature weight, associated with selection for early growth,
    - The availability of these indexes is clearly at the discretion of the breeding society and genetic evaluation service provider.
- Record sire of all calves (especially those that go on to be herd replacements), record mature weight and include that data in the genetic evaluation system,
- Engage breed societies and genetic evaluation service providers about the need for selection tools, which account for the non-linear nature of value from increases in carcase weight and the cost associated with breeding female mature weight, and
- Communicate with commercial farmers to understand the needs in the context of breeding female mature weight, with an understanding that bigger is not always better.

Commercial farmers

Key messages include:

- Buy sires where it is possible assess the size/ weight of the breeding females and gather more intelligence about the genetic merit of the males for growth, mature weight and other genetic merit estimates,
- Work to build a relationship, and communicate, with a breeder(s) that is/ are producing the types of sires you need for your farming business,
- Where possible, use an index to select sires for use in commercial flocks (needs to be made available by the breeder),
- Make use of maternal genetics and terminal genetics in combination within herds/ flocks to capture the benefits of hybrid vigour, while controlling breeding female mature weight,
- Engage breeders and breed societies about the need for selection tools, which account for the non-linear nature of value from increases in carcase weight and the cost associated with breeding female mature weight, and
- Weigh breeding females regularly and be informed about the right mature weight for the farming system.

Appendix 1: Biological relationships between breeding female mature weight and indirect traits

Relationship between mature weight and progeny carcase weight

Beef

To calculate the relationship between breeding female mature weight and progeny carcase weight, we have used regression theory to calculate the coefficient of increases in carcase weight per unit increase in mature weight. This has been done separately for heifers, steers and bulls.

The calculations are as follows;

Heifers

$$\beta_{CW,MW} = rp_{CW,MW}{}^{6} \times (cv(CW)^{7} \times mean(CW)^{8}) / (cv(MW) \times mean(MW))^{9}$$
$$= 0.979 \times (0.16 \times 328.4kg) / (0.09 \times 691.3kg)$$
$$= 0.827$$

Steers

$$\beta_{CW,MW} = rp_{CW,MW}{}^{3} \times (cv(CW)^{4} \times mean(CW)^{5}) / (cv(MW) \times mean(MW))^{6}$$
$$= 0.980 \times (0.16 \times 370.3kg) / (0.09 \times 691.3kg)$$
$$= 0.933$$

Bulls

$$\beta_{CW,MW} = rp_{CW,MW}{}^{3,10} \times (cv(CW)^{4} \times mean(CW)^{5}) / (cv(MW) \times mean(MW))^{6}$$
$$= 0.980 \times (0.16 \times 335.8kg) / (0.09 \times 691.3kg)$$
$$= 0.846$$

Where rp is the phenotypic correlation between carcase weight (CW) and mature weight (MW) and cv is the coefficient of variation.

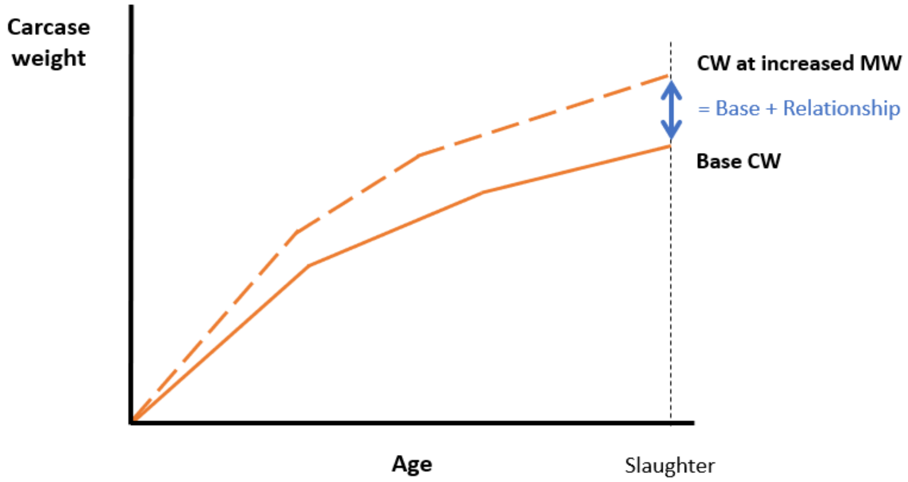
The $\beta_{CW,MW}$ indicate that for every 1kg increase in breeding female mature weight, we can expect progeny carcase weights to increase by between 0.83kg and 0.93kg (the weighted average phenotypic correlation is 0.884).

[6] EUROSTAT time series data from 1972-2017 (Figure 1), excluding 1997-2005. Cow CWs were divided by 48.4% (dressing percentage, AHDB) to calculate mature cow weight.
[7] Genetic parameters of Visual Image Analysis primal cut carcases of commercial prime beef slaughter animals, K.L. Moore et al, Animal, 2017 (source: http://openaccess.sruc.ac.uk/bitstream/handle/11262/11181/11181.pdf?sequence=2&isAllowed=y)
[8] Base heifer, steer and bull carcase weights; EGENES (data sourced: 15th August 2018).
[9] Genetic parameters for maternal breeding goal in beef production, Roughsedge et al, Journal of Animal Science, 2005.
[10] Assumed that bulls have the same Correlation $_{CW,MW}$ as steers.

As target carcase weights increase (in association with increasing breeding female mature weights), an increase in growth rate is required. To reach the necessary target carcase weights, growth each day was multiplied by a constant factor so that carcase weight on the day of slaughter is equal to expected carcase weight (based on the $\beta_{CW,MW}$ and the given breeding female mature weight).

The same logic applies to growth curves for replacement breeding females, reaching weights heavier than the base breeding female mature weight. The base growth profile is scaled to achieve 100% of the heavier mature weight at 3rd calving (1460 days). See Figure 13 below.

Figure 15: Example of scaling growth profile for slaughtered progeny based on the relationship between CW and breeding female mature weight.



Sheep

As for beef, to calculate the relationship between breeding female mature weight and progeny carcase weight, we have used regression theory to calculate the coefficient of increases in carcase weight per unit increase in mature weight.

To calculate the relationship between breeding female mature weight and progeny carcase weight, we have used regression theory (Falconer, 1960). We calculated the increase in growth potential based on the relationship between scanning weight (SW) and mature weight (MW).

The calculation is as follows;

$$\beta_{SW,MW} = rp_{SW,MW}{}^{11} \times (sd(SW)^1 / sd(MW)^1)$$
$$= 0.602 \times (5.315kg / 6.017kg)$$
$$= 0.532$$

The equation above indicates that a 1kg increase in breeding female mature weight (deviation from the base weight; 71.8kg) predicts a 0.532kg increase in lamb scan weight. Because lambs were assumed to be slaughtered at a constant carcass weight, the increased growth potential of the lamb was converted to an equivalent number of days, reducing the time taken to reach the target carcase weight (19.4kg). This is summarised in Table 26 below.

Table 26: Conversion of increased growth potential based on relationship between ewe mature weight and progeny scanning weight to days (for single lamb)

Base Ewe mature weight (kg)	71.8
Alternative Ewe mature weight (kg)	72.8
Increase in Ewe MW (kg)	**1.00**
Increase in Lamb Scanning weight (kg)[1]	0.532
Average growth rate (kg/day)	0.263
Growth savings (equivalent days)[2]	2.02
Days to target CW (days)	**159.98**

[1] Increase in Lamb Scanning weight = $\beta_{SW,MW}$ * Increase in Ewe MW
[2] Growth savings = Increase in Lamb Scanning weight / Average growth rate
[3] Days to target CW = Base days to slaughter (162, Table 2) - Growth savings

The growth profile of the slaughtered progeny is then appropriately scaled so that it reaches the target carcase weight in the calculated number of days.

For replacement females the growth profile of a was scaled to grow from a birth weight of 4kg to the target mature weight in 948 days (as described in Figure 15 above).

[11] EGENES (data sourced: 24th January 2018)

Relationship between carcase weight and EUROP conformation and fat score

Beef

The EUROP price grid is an important factor in determining the price a per kg of carcase weight. Carcases are scored for fat level and conformation (1-15). A premium or penalty, which is determined by combining both scores is applied to the base carcase price. This is described in Table 27 below.

Table 27: Price penalties and premiums for EUROP carcase conformation and fat score grid (pence per kgCW)[1].

	1	2	3	4L	4H	5L	*5H*
E	-40	5	15	15	5	-35	-85
U+	-40	5	12	12	5	-35	-85
-U	-40	0	8	8	0	-35	-85
R	-60	-5	0	0	-5	-40	-85
O+	-80	-20	-10	-10	-15	-60	-95
-O	-100	-50	-35	-35	-50	-110	-115
P+	-175	-80	-65	-65	-90	-110	-175
-P	-175	-100	-100	-100	-120	-160	-175

[1] http://www.dunbia.com/Site-Content/Payment-grid-for-all-cattle-under-36-months-effect.aspx

As carcase weight changes, the distribution of carcases on the EUROP grid shifts. The result is a substantial difference in the premiums/ penalties (£/kgCW) applied to light and heavy carcases.

Table 28 presents the average premium/ penalty (£/kgCW) applied to carcases of different weight. This relationship is summarised for heifers, steers, and bulls in Figure 16.

Table 28: Carcase weight penalties applied to carcases which are overweight or underweight[1,2].

Carcase weight thresholds (kg)		Penalty by carcase conformation score (p/kgCW)		**Average Penalty (p/kgCW)[3]**
Lower	**Upper**	**E to O+**	**O- to P-**	
-	229.9	-40	-60	-42.7
230	239.9	-30	-50	-32.7
240	249.9	-20	-40	-22.7
250	259.9	-15	-30	-17.0
260	269.9	-5	-10	-5.7
270	400	-	-	-
400.1	410	-5	-10	-5.7
410.1	420	-10	-15	-10.7
420.1	430	-15	-20	-15.7
430.1	440	-20	-25	-20.7
440.1	-	-40	-40	-40.0

[1] http://www.dunbia.com/Site-Content/Payment-grid-for-all-cattle-under-36-months-effect.aspx

[2] For carcases heavier than 440kg, weight over the 440kg threshold earns no revenue, in addition to the -40p/kgCW price penalty. This is not Dunbia practice, but does reflect other processors.

[3] Weighted average: 87% E to O+, and 13% O- to P-

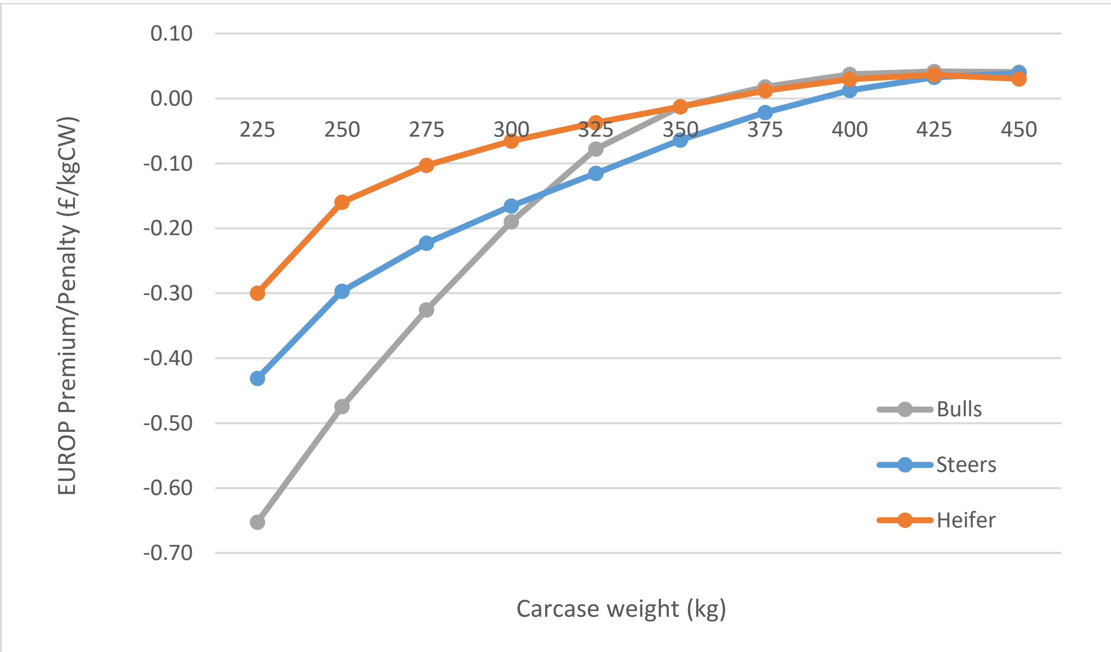


Figure 16: EUROP premium/penalty applied to base carcase price (£/kgCW) according to carcase weight for heifers, steer and bulls. Distribution of animals corresponding to carcase weights of heifers, steers and bulls (AHDB, confidential data).

Sheep

The EUROP price grid is an important factor in determining the value of a carcase. The price per kg of carcase weight is determined by a base price, and a premium or penalty applied according to each carcase's conformation and fat score on the EUROP grid. Carcases are scored for fat level and conformation (1-15). The grid applied to slaughtered lambs is applied is presented below in Table 29.

Table 29: Price penalties and premiums for EUROP carcase conformation and fat score grid (pence per kgCW)[1].

	1	2	3L	3H	4L	4H	*5*
E	9	22	21	6	-15	-40	-67
U	0	16	14	3	-20	-40	-73
R	-15	2	2	-3	-22	-43	-66
O	-60	-20	-14	-17	-32	-47	-76
P	-140	-187	-161	-214	-239	-264	-289

[1] Calculated based on reported prices on AHDB (http://beefandlamb.ahdb.org.uk/markets/deadweight-price-reports/deadweight-sheep-price-reporting/) relative to base price (£2.32/kgCW, via 2018 AHDB Sheep Yearbook: average 2014-17)

Because we have only modelled a constant carcase weight production system for sheep production, there are no penalties applied to overweight or underweight lamb carcases.

Relationship between age at slaughter and carcase conformation and fat score

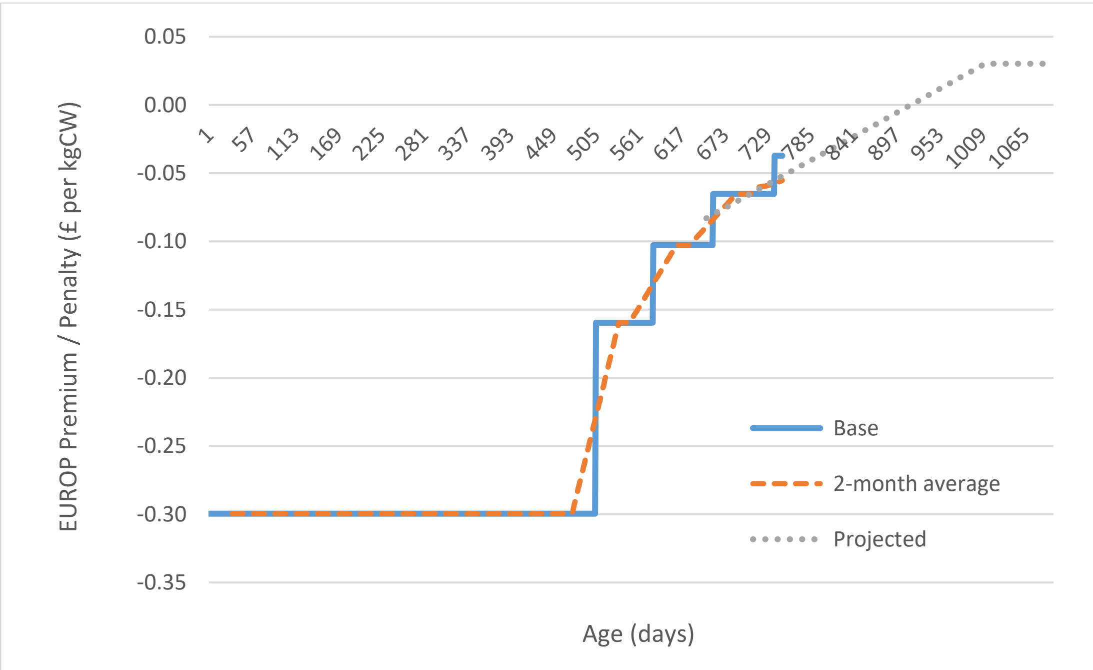
Beef

In order to capture the economic implications of slaughter at a constant carcase weight, we must calculate the carcase value to each age and then map constant carcase weight to expected age at slaughter, based on the growth profile of steers, heifers, and bulls. A heifer is used to demonstrate the concept of calculating carcase value at each age, the relationship between age at slaughter and carcase conformation and fat score, and therefore carcase value at a constant weight.

A base heifer is slaughtered at 747 days, with a carcase weight of 327.9kg. The carcase has a conformation score of 9.35, and of a fat score of 8.29 (see Table 19). Based on data supplied by AHDB, a heifer slaughtered at a carcase weight of 280kg would have a conformation score of 8.83 and a fat score of 8.17. The base heifer growth profile supports this heifer reaching a carcase weight of 280kg at 595 days. Using this approach, we can infer the conformation and fat score associated with each day of the heifer growth profile; a heifer slaughtered at age 595 days would have a conformation score of 8.83 and a fat score of 8.17. This equates to a EUROP penalty (applied to the base carcase price) of £-0.12/kgCW.

This is summarised in Figure 17 below. Note that prior to 503 days, the penalty remains at -£0.30/kgCW. This is because prior to day 503 the base carcase would weigh less than 250kg, the lowest band for which we have data.

Figure 17: Inferred EUROP premium/penalty according to age, for a base heifer growth profile to 747 days, 2-month average premium/penalty, and projected premium/penalty from day 748+.



For slower growing animals, we can estimate the conformation and fat score associated with each day *after* the base growth profile ends. Scores at each additional day are calculated by increasing the base scores (above) by the average change in conformation score/day and the average change in fat score/day.

There are maximum values for both conformation and fat score. Once predicted scores exceed these values, conformation and fat scores are held constant at their respective maximum for each day of growth.

Note that because, predictions for of conformation and fat scores are based on “stepped” data (25kg carcase weight bands), scores are based on a 60-day average age range.

For sheep, the same logic has also been applied, however, due to a much shorter finishing period (162 days vs. 25 months) a 2-week moving average has been used instead of a 2-month moving average.

Sheep

In order to capture the economic implications of slaughter at a constant carcase weight, we must calculate the carcase value to each age and then map constant carcase weight to expected age at slaughter, based on the growth profile of singles, twins and triplets.

A single is used to demonstrate the concept of calculating carcase value at each age, the relationship between age at slaughter and carcase conformation and fat score, and therefore carcase value at a constant weight.

A base single lamb is slaughtered at 162 days, with a carcase weight of 19.4kg. The carcase has a conformation score of 10.27, and of a fat score of 8.27 (see Table 7). Based on data supplied by AHDB, a single lamb slaughtered at a carcase weight of 16.5kg would have a conformation score of 8.75 and a fat score of 7.38. The base single lamb growth profile supports this lamb reaching a carcase weight of 16.5kg at 137 days. Using this approach, we can infer the conformation and fat score associated with each day of the single lamb growth profile; a lamb slaughtered at age 137 days would have a conformation score of 8.75 and a fat score of 7.38. This equates to a EUROP penalty (applied to the base carcase price) of £-0.19/kgCW.

This is summarised in Figure 18 below. Note that prior to 503 days, the penalty remains at -£0.30/kgCW. This is because prior to day 503 the base carcase would weigh less than 250kg, the lowest band for which we have data.

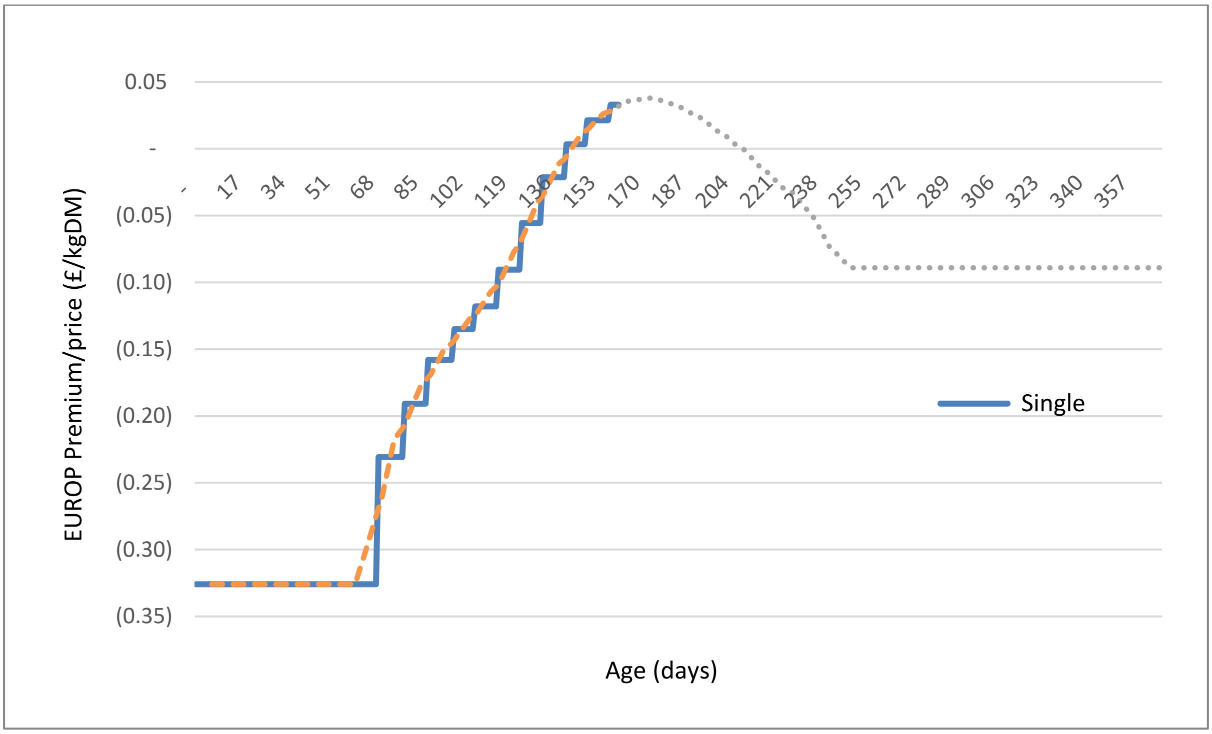


Figure 18: Inferred EUROP premium/penalty according to age, for a base single lamb growth profile to 162 days, 2-week average premium/penalty, and projected premium/penalty from day 163+.

Note that unlike beef (Figure 17), animals slaughtered later have worse premiums/penalties than those at the base. In beef, heavier animals (associated with older slaughter ages), are associated with high carcase conformation scores, and middling fat scores. Heavy lamb carcases however (associated with older slaughter ages), tend to have both high carcase conformation scores and high fat scores. The high fat scores result in the carcases being penalised, and thus lambs slaughtered later have worse premiums/penalties than lambs slaughtered at the base.

Relationship between mature weight and fertility/fecundity

Beef

Increasing breeding female mature weight is assumed to affect fertility by reducing the conception rate at second mating. This has two effects on the number and distribution of animals in the herd;

- reducing the number of slaughtered progeny, and
- decreasing the survival rate from ages 2 to 3 (cows which fail to get pregnant at their second mating are culled).

Stewart and Martin (1981) [12] reported that over the course of a cow's lifetime, 143kg of additional mature cow weight reduced lifetime calf output by 1 calf. In the base model, second calvers represent 14.5% of the herd. Dividing the proportion of second calvers in the herd, by the change in mature weight associated with 1 less calf produced per lifetime, equals the change in conception rate at second mating per kg of mature weight (14.5%/143kg = 0.10%). An assumption is made that this reduction in conception rate applies to cows with a mature weight of 700kg or heavier. Based on the replacement growth profile (Appendix 2), cows at second calving only weigh 85% of their mature weight. To account for this, the change in conception rate at second mating per kg of mature weight (0.10%) is multiplied by 0.85. Each addition kg of mature weight decreases calving rate at second parity by 0.086%. This change is summarised in Figure 19. below, where -0.086% is the slope for the conception rate. In the base production system, the conception rate at second calving in 92% (Table 30).

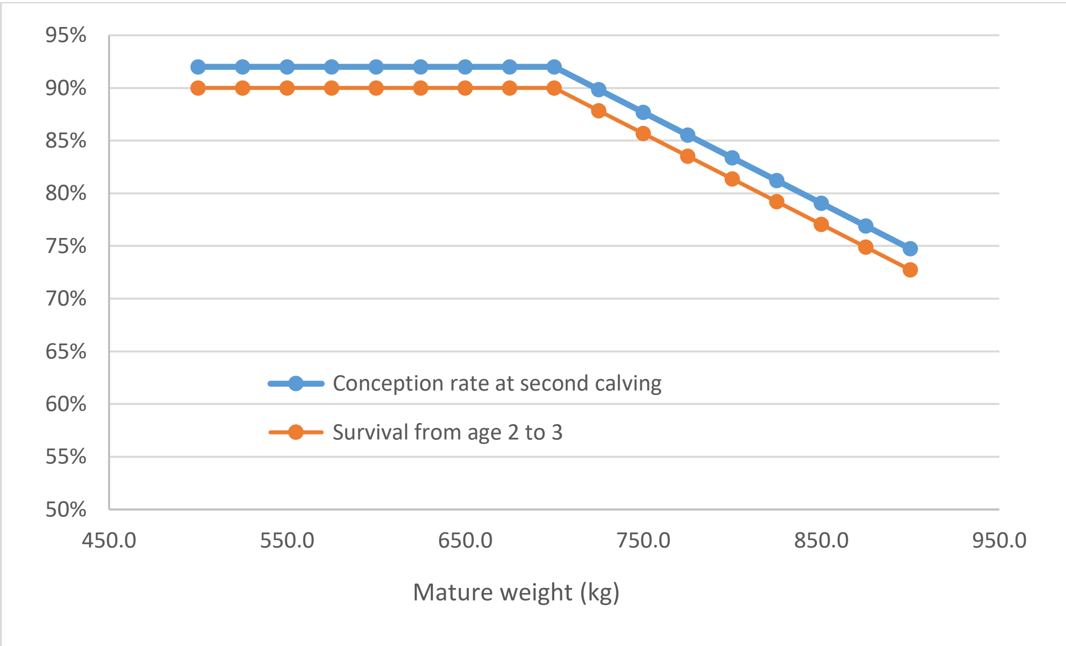


Figure 19: Conception rate at second calving and survival from ages 2 to 3 for breeding females with mature weights from 500kg to 900kg.

If a cow fails to get pregnant at second calving, it is assumed to be culled. Therefore, decreasing conception rates at second calving decreases the survival of cows from age 2 to 3. This alters the herd profile, increasing the replacement rate.

Table 30 presents herd proportions, survival rates, and conception rates by age for breeding female mature weights of 651.4kg and 751.4kg. A decrease in survival rate from age 2 to 3 by 0.086%

[12] Stewart, T. S. and Martin, T. G. (1981) *Journal of Animal Science*, 52(1), pp. 51–56. Available at: https://pdfs.semanticscholar.org/d602/b532808467da5a9d88d31b42bc9d050e6443.pdf (Accessed: 13 September 2018).

increases replacement rate by 0.014%, for every additional kg of cow mature weight above 700kg. For cows of 651.4kg and 751.4kg, respectively, this manifests in a change in replacement rate of 0.7%.

Table 30: Herd distribution, survival rates, and conception rates by age for breeding female mature weights of 651.4kg and 751.4kg.

	651.4kg			**751.4kg**		
Age	% of herd	Survival (% from previous year)	Conception rate (%)	% of herd	Survival (from previous year)	Conception rate (%)
2	16.1%	100%	75.0%	16.8%	100%	75.0%
3	14.5%	90%	92.0%	14.4%	86%	87.6%
4	13.8%	95%	92.0%	13.7%	95%	92.0%
5	12.8%	93%	92.0%	12.7%	93%	92.0%
6	11.9%	93%	92.0%	11.8%	93%	92.0%
7	10.7%	90%	92.0%	10.7%	90%	92.0%
8	8.6%	80%	92.0%	8.5%	80%	92.0%
9	6.0%	70%	92.0%	6.0%	70%	92.0%
10	3.6%	60%	92.0%	3.6%	60%	92.0%
11	1.8%	50%	92.0%	1.8%	50%	92.0%

Sheep

Increased breeding female mature weight is assumed to affect fertility by increasing the ovulation rate of ewes, increasing the proportion of ewes birthing multiples. The effect of increased ovulation rate is only realised in breeding females with a mature weight up to 65kg, and with diminishing effect up to that point, as shown in Figure 20 below.

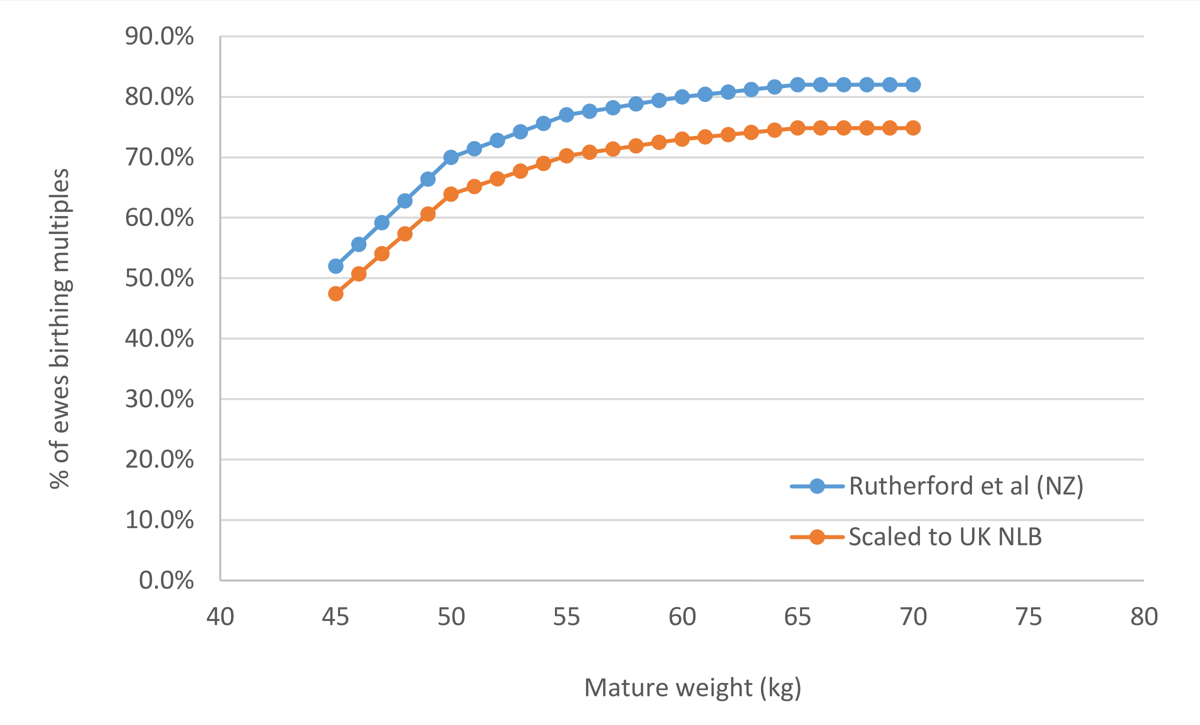


Figure 20: Relationship between breeding female mature weight and the proportion of ewes birthing multiples reported for NZ and scaled for a UK production system[1].

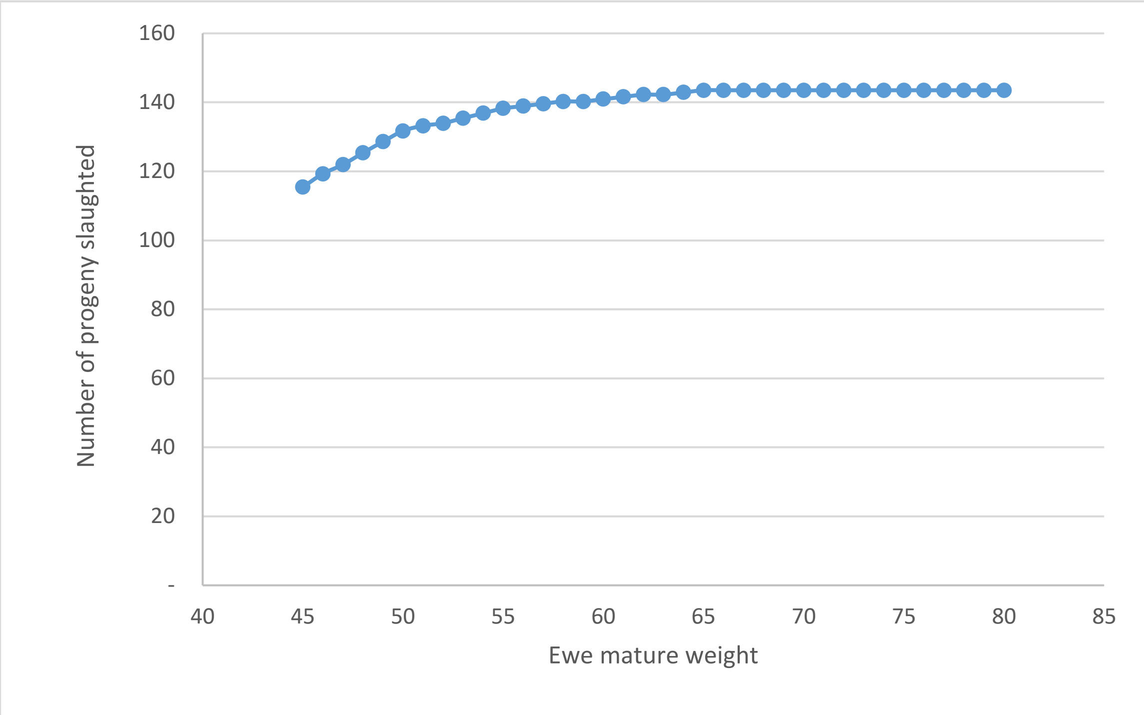
[1] Rutherford et al (NZ) source: http://www.nzsap.org/system/files/proceedings/2003/ab03034.pdf

At a mature weight of 65kg or heavier, Rutherford et al predicts that 82% of ewes will birth multiples (i.e. 82% of ewes give birth to twins or triplets). However, a rate of 82% birthing multiples corresponds to an NLB greater than the NLB for UK production (1.83, see Table 13). The NLB for UK production corresponds to 74.8% of ewes birthing multiples. To align the relationship between mature weight and the proportion of ewes bearing multiples, the relationship predicted by Rutherford et al has been scaled down.

For example, where Rutherford et al predicts at 50kg mature weight that 70% of ewes will bear multiples, this is equal to 85.4% of the maximum proportion of ewes (= 70/82). To scale this relationship, the maximum proportion of ewes birthing multiples in the UK is multiplied by 85.4% (74.8% x 85.4% = 63.9%). 63.9% of ewes birthing multiples corresponds to an NLB of 1.66.

The number relationship between breeding female weight and the number of slaughtered progeny, presented in Figure 21 closely aligns with the relationship described above.

Figure 21: Relationship between breeding female mature weight and the number of progeny slaughtered, for breeding female mature weights from 45kg to 80kg.



Appendix 2: Growth profiles

Beef

Slaughter progeny

Table 31 presents growth parameters (liveweight, growth rate, age, and length of period) for slaughtered heifers, steers, and bulls in the base production system, reaching liveweights described in Table 2. Growth periods are defined according to diet composition (see Table 37).

Table 31: Growth parameters (liveweight, growth rate, age, and length of period) for slaughtered heifers, steers, and bulls, by growing period, in the base system.

		Heifers	**Steers**	**Bulls**
Pre-weaning				
	Birth weight (kg)	45.0	50.0	50.0
	Growth to weaning (kg/day)	1.00	1.10	1.20
1st Winter				
	Age at start of period (days)	231	231	231
	Weight at start of period (kg)	276.0	304.1	327.2
	Growth rate (kg/day)	0.62	0.78	1.26
	Length of period (days)	181	181	120
Finishing				
	Age at start of period (days)	-	-	351
	Weight at start of period (kg)	-	-	478.6
	Growth rate (kg/day)	-	-	1.52
	Length of period (days)	-	-	101
	Age at finishing (days)			**452**
	Liveweight at finishing (kg)	-	-	**631.6**
Summer grazing				
	Age at start of period (days)	412	412	-
	Weight at start of period (kg)	388.4	446.0	-
	Growth rate (kg/day)	0.59	0.75	-
	Length of period (days)	184	184	-
2nd Winter (and finishing)				
	Age at start of period (days)	596	596	-
	Weight at start of period (kg)	497.3	583.3	-
	Growth rate (kg/day)	0.56	0.70	-
	Length of period (days)	151	160	-
	Age at finishing (days)	**747**	**756**	-
	Liveweight at finishing (kg)	**581.3**	**696.0**	-

Growth profiles (weight for age) are presented in Figure 22.

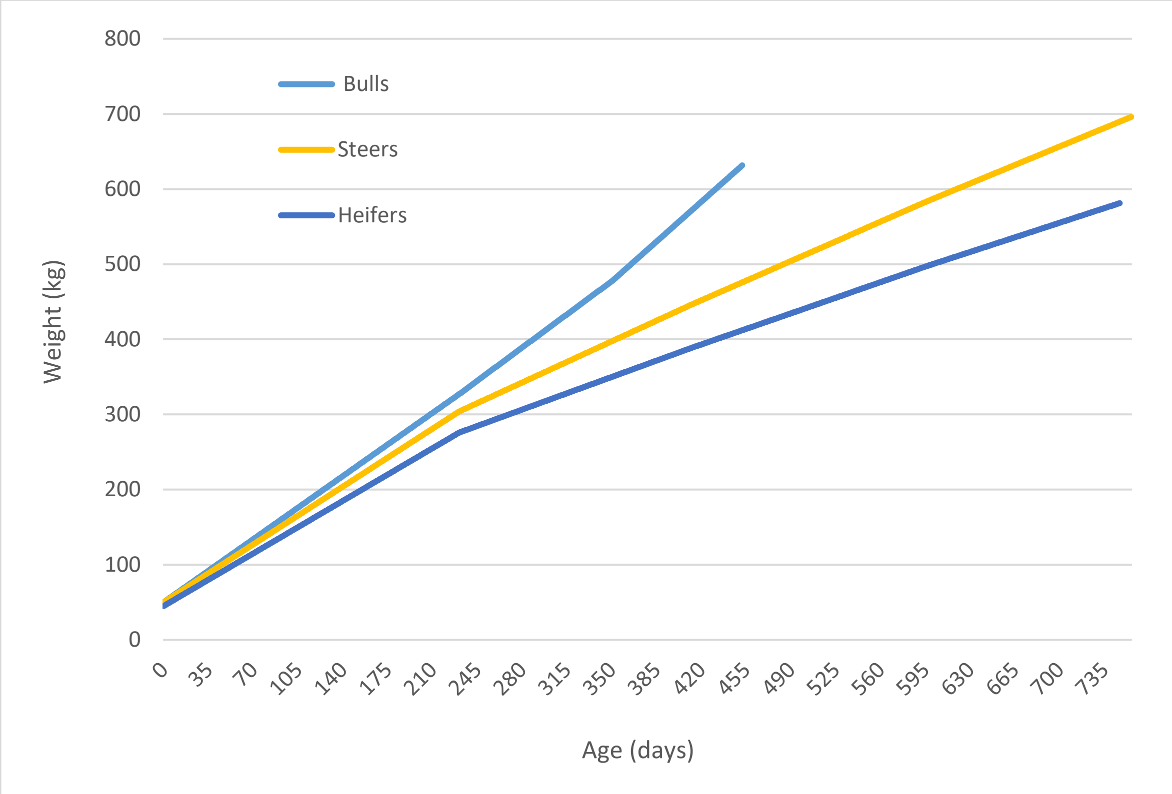


Figure 22: Growth profiles (weight for age) for slaughtered bulls, steers, and heifers.

Replacement females

Unlike slaughtered progeny, growth periods for a replacement heifer are defined by mating. In the base model, replacement breeding females follow the same growth profile as slaughtered heifers for 455 days. Their growth profiles diverge when the replacements are mated for the first time (at 63.5% of their mature weight). Because cows are mated at the same time each year, growth periods are 365 days, except for the final period, with lasts 275 days (from mating to calving).

Table 32 presents growth parameters (liveweight, growth rate, and age) for a replacement heifer in the base system.

Table 32: Growth parameters (liveweight, growth rate, and age) by calving period, for a replacement heifer in the base system.

		Replacement
1st Mating		
	Age (days)	455
	Weight (kg)	413.9
	% of MW	63.5%
	Growth rate to next mating (kg/day)	0.38
2nd Mating		
	Age (days)	820
	Weight (kg)	553.7
	% of MW	85.0%
	Growth rate to next mating (kg/day)	0.18
3rd Mating		
	Age (days)	1,185
	Weight (kg)	618.8
	% of MW	95.0%
	Growth rate to **calving** (kg/day)	0.12
3rd Calving		
	Age (days)	1,460
	Weight (kg)	651.4
	% of MW	100%

Figure 23 contrasts the growth profile of a replacement heifer and a slaughtered heifer.

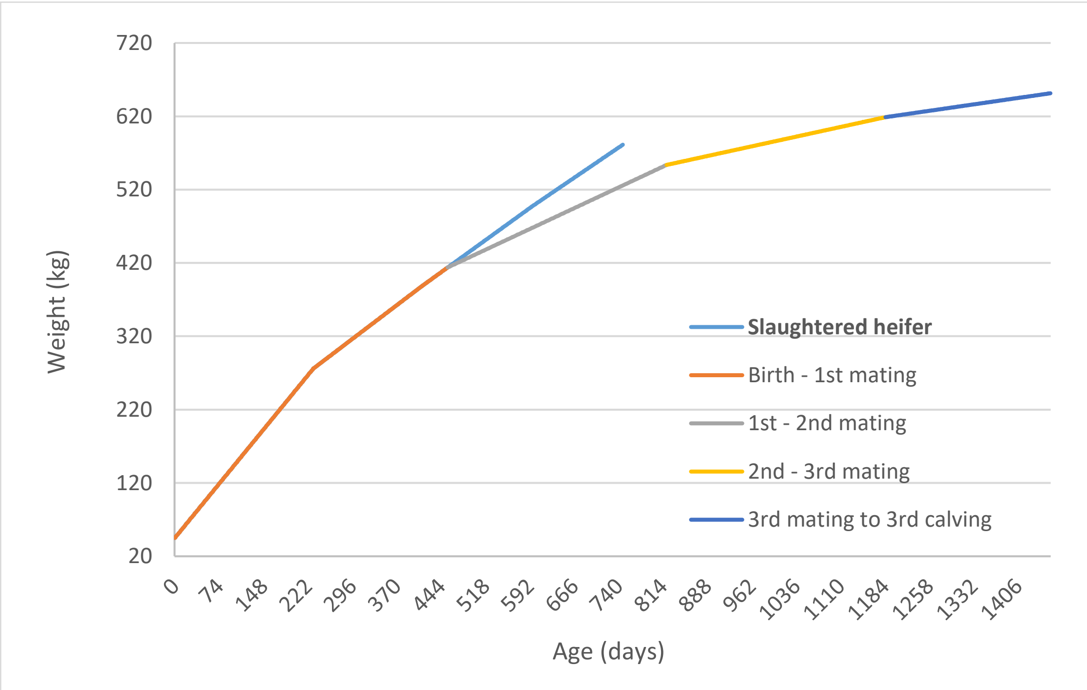


Figure 23: Comparison of growth profile for a slaughtered heifer, and a replacement female by calving period.

Sheep

Slaughter progeny

Table 33 presents growth parameters (liveweight, growth rate, age) for slaughtered single twin and triplet lambs in the base production system, reaching liveweights described in Table 14. Growth periods are defined according to diet composition (see Table 39).

Table 33: Parameters for estimating daily growth energy requirement for single, twin and triplet lambs in the sheep model.

	Single	Twin	Triplet
Pre-weaning			
Birth weight (kg)	4.0	3.7	3.0
Age at weaning (days)	100	100	100
Growth rate: birth to weaning (kg/day)	0.253	0.226	0.218
Weight at weaning (kg)	29.3	26.3	24.8
Finish			
Age at slaughter (days)	162	177	185
Growth rate: weaning to slaughter (kg/day)	0.279	0.264	0.256
Weight at finishing	46.6	46.6	46.6

Growth profiles (weight for age) are presented in Figure 24.

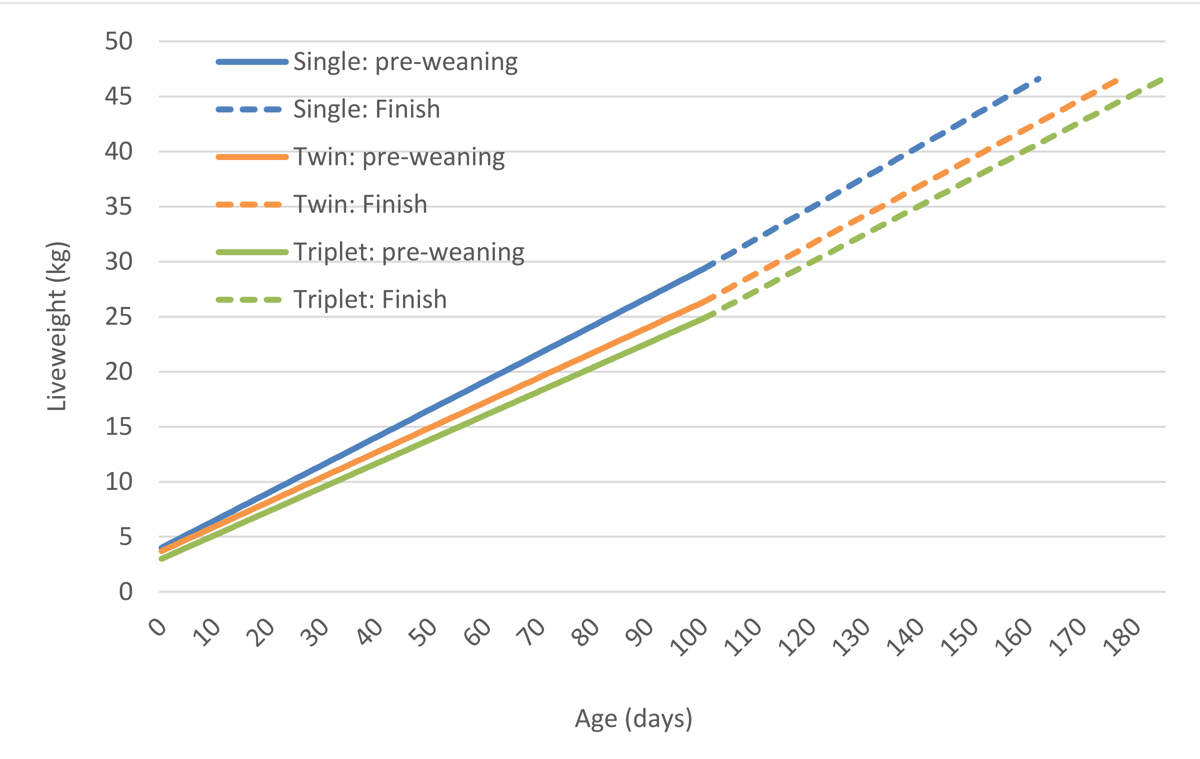


Figure 24: Growth profiles (weight for age) for slaughtered single, twin and triplet lambs.

Replacement females

Unlike slaughtered progeny, growth periods for a replacement female are defined by mating. In the base model, replacement breeding females follow the same growth profile as slaughtered progeny until weaning (for 100 days). The first mating occurs at age 583 days, allowing for ewes to lamb for the first time at age 730 days (2 years), following a 147-day pregnancy.

Table 34 presents growth parameters (liveweight, growth rate, and age) for a replacement heifer in the base system.

Table 34: Growth parameters (liveweight, growth rate, and age) by mating period, for a replacement female in the base system.

		Replacement
Weaning		
	Age (days)	100
	Weight (kg)	29.3
	% of MW	41%
	Growth rate to 1st mating (kg/day)	0.065
1st Mating		
	Age (days)	583
	Weight (kg)	61.0
	% of MW	85%
	Growth rate 2nd mating (kg/day)	0.030
2nd Mating		
	Age at 2nd mating (days)	948
	Weight (kg)	71.8
	% of MW	100%

Figure 25 contrasts the growth profile of a replacement female and a single lamb.

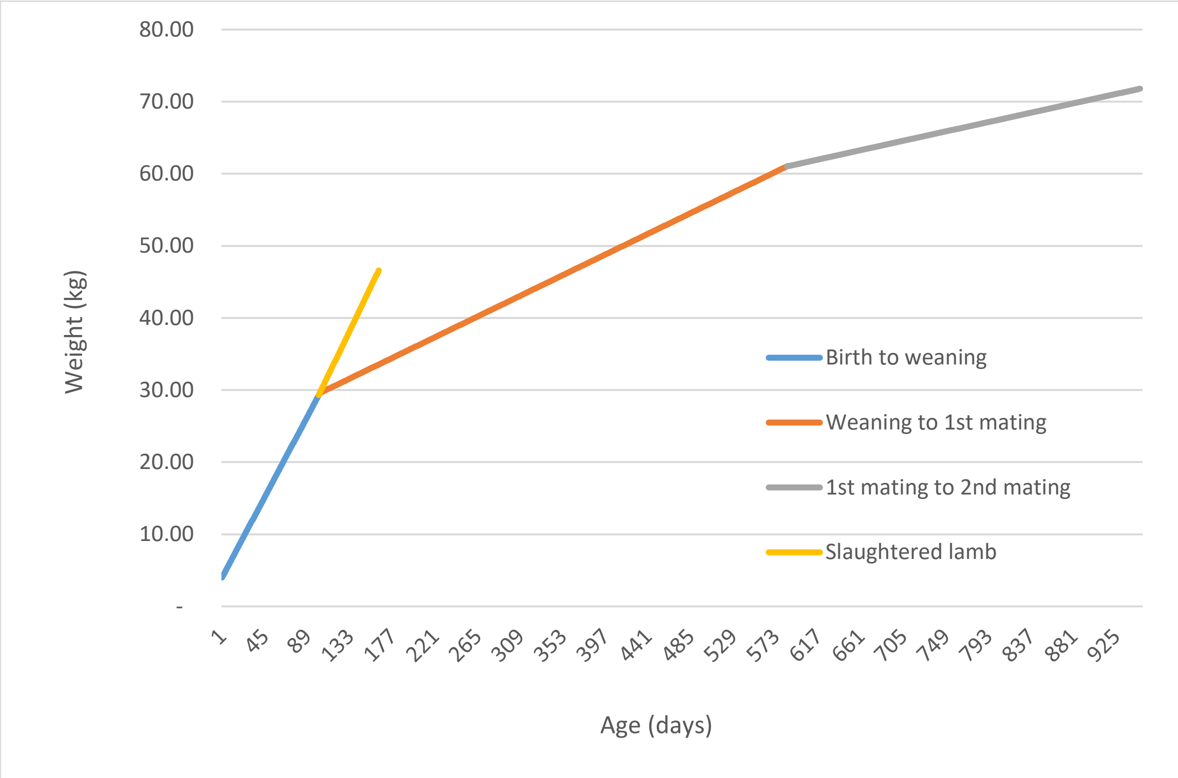


Figure 25: Comparison of growth profile for a single lamb, and a replacement female by mating period.

Appendix 3: Daily energy requirements

Beef

Daily energy requirements (MJME) for beef were calculated based on feed energy tables presented by Nicol and Brookes (2007)[13]; these models are based on cow genotypes equivalent to the UK maternal cow population. Total daily energy requirements (MJME) were calculated as the sum of daily energy required for maintenance, and daily energy required for growth. Liveweight and daily gain are measured in kg.

The maintenance energy requirement describes the amount of energy the animal must consume each day in order to survive at a constant live weight, neither gaining nor losing weight. The maintenance energy requirement equations are detailed below.

$$\text{MJME}_{\text{maintenance}} = 0.65 * \text{Liveweight}^{0.75}$$

Liveweight each day is taken as liveweight at the beginning of the day. For example, if a steer weighs 50kg at the beginning of day 1 (birth weight), for calculation of the energy required on day 1, 50kg is used as the liveweight input. On day 1 the calf grows 1.15 kg. Therefore, the liveweight at the start of day 2, and thus the input for day 2, is 51.15 kg.

The growth energy requirement describes the amount of energy the animal must consume each day in order to achieve the desired amount of liveweight gain in that day. In other words, the marginal energy requirement for change in liveweight. This requirement differs between heifers, steers and bulls. Growth energy requirement equations are detailed below.

$$\text{MJME/kg gain} = \text{Daily gain} * (\alpha + \text{liveweight} * \beta)$$

The slope parameters (α and β, Table 35) are based on a regression of the energy (MJME) required per kg of liveweight gain and the liveweight of the animal at the time of growth, where mature weight is 600kg.

Table 35: Parameters for estimating daily growth energy requirement for heifers, steers, and bulls in the beef model.

Production system	**Intercept (α)**	**Slope (β)**
Heifers (incl. replacements)	15.373	0.074
Steers	14.915	0.059
Bulls	14.915	0.059

[13] Nicol, A.M., Brookes, I.M., 2007. The Metabolisable Energy Requirements of Grazing Livestock. In: Rattray, P.V., Brookes, I. M., Nicol, A. M. (Ed.), Pasture and Supplements for Grazing Animals. New Zealand Society of Animal Production, pp. 151-172.

The positive slope (β) indicates that as liveweight increases, energy required to grow an additional 1kg also increases (diminishing returns). The degree to which the marginal energy requirement for growth increases is with respect to liveweight is discussed in the following section.

Scaling of marginal energy requirement for growth by stage of maturity

The regression parameters in Table 35: are based on the growth and energy expenditure of animals growing to 600kg. For example, the heifer regression describes the marginal energy requirement for growth, of a heifer growing to a "target" weight of 600kg.

However, for "target" weights different to 600kg, the regression parameters will not accurately predict that animals' marginal energy requirements for growth. This is due to the different maturity of animals at different weights and ages. As cattle gain weight, they lay down both fat and protein. Although as cattle mature, they lay down an increasing proportion of fat. A greater proportion of fat increases the marginal energy requirement for growth, because it is more energy dense than protein. Therefore, as cattle mature, marginal energy requirement for growth increases.

In order to reach 100% of its mature weight in 4 years (1460 days), a 700kg MW genotype cow will grow faster than a 600kg MW genotype cow. Because it grows faster, at any given weight the 700kg mature weight cow will be younger than the 600kg MW cow. Therefore, it will be at an earlier stage of maturity.

Because the faster growing animal is less mature, it will lay down a lower proportion of fat at each weight than the 600kg mature weight cow (which informs regression coefficients in Table 35). The marginal energy requirement for growth should be scaled accordingly, to reflect the differences in fat deposition at different stages in maturity.

The adjusted growth energy requirement equation applied to beef growth[14] is detailed below.

$$\text{MJME/kg gain} = \text{Daily gain} * (\alpha + \text{weight}_i * [(\text{liveweight}/\text{MW})*600] * \beta)$$

Figure 26 presents the concept of scaling of energy requirements by mature weight genotype.

[14] This has only been applied to beef, as energy requirements for growth of sheep are assumed to align with estimates from Nicol, A.M., Brookes, I.M., 2007.

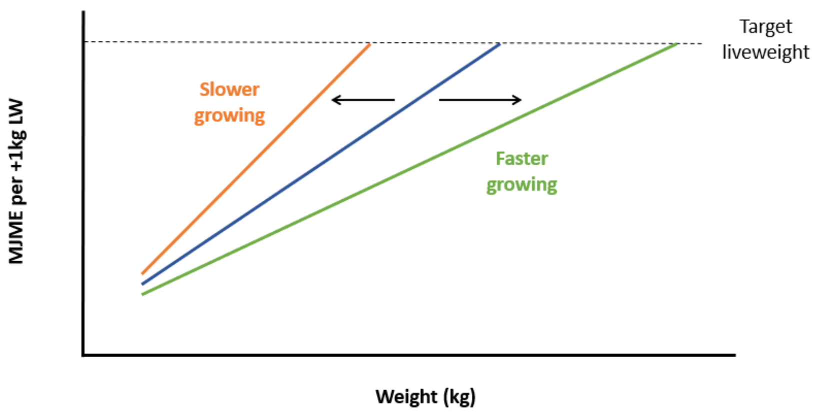


Figure 26: Scaling of energy requirements by mature weight genotype.

Sheep

Daily energy requirements (MJME) for sheep were calculated based on feed energy tables presented by Nicol and Brookes (2007)[15]. Total daily energy requirements (MJME) were calculated as the sum of daily energy required for maintenance, and daily energy required for growth. Liveweight and daily gain are measured in kg.

The maintenance energy requirement describes the amount of energy the animal must consume each day in order to survive at a constant live weight, neither gaining nor losing weight. The maintenance energy requirement equations are detailed below.

$$\text{MJME}_{\text{maintenance}} = 0.45 * \text{Liveweight}^{0.75}$$

Liveweight each day is taken as liveweight at the beginning of the day. For example, if a single lamb weighs 4kg at the beginning of day 1 (birth weight), for calculation of the energy required on day 1, 5kg is used as the liveweight input. On day 1 the calf grows 0.25kg. Therefore, the liveweight at the start of day 2, and thus the input for day 2, is 4.25kg.

The growth energy requirement describes the amount of energy the animal must consume each day in order to achieve the desired amount of liveweight gain in that day. In other words, the marginal energy requirement for change in liveweight. Growth energy requirement equations are detailed below.

$$\text{MJME/kg gain} = 50$$

[15] Nicol, A.M., Brookes, I.M., 2007. The Metabolisable Energy Requirements of Grazing Livestock. In: Rattray, P.V., Brookes, I. M., Nicol, A. M. (Ed.), Pasture and Supplements for Grazing Animals. New Zealand Society of Animal Production, pp. 151-172.

Appendix 4: Diet

Feed costs

The methodology and sources for calculation of feed costs (£/kgDM consumed) are outlined in Table 36. Concentrate and straw costs are for dry weight. Utilisation has been included because feed which is "supplied" to animals but is not eaten should be included as part of the cost. The following feed costs have been used for beef and sheep production systems.

Table 36: Calculation of feed costs (£/kgDM consumed).

	£/tonne (fresh)	**DM%**	**Utilised**[4]	**£/kgDM consumed**[5]	MJME per kgDM[7]
Silage	24.62[1]	30%[3]	75%	**0.109**	9.98
Pasture	-	-	-	**0.035**[6]	9.07
Concentrate	218[2]	87%[2]	90%	**0.278**	12.08
Straw	61.95[2]	86%[2]	75%	**0.096**	6.60

[1] Cost of silage purchased from a contractor. Department of Agriculture, Environment and Rural Affairs (DEARA) – Farm Business Data, 2018 (p19).
[2] Personal communication: Carol Davis (15th February 2019)
[3] https://www.daera-ni.gov.uk/sites/default/files/publications/dard/winterfeeding2012.pdf, Table 6
[4] AbacusBio assumption.
[5] Cost of silage, concentrate & straw (£ per kgDM) = (£ per tonne / DM%) / (1000 * utilisation).
[6] Cost of pasture: Rent per ha (Personal communication: Carol Davis 25th Feb 2019) / kgDM produced per ha of land (AHDB: Beef and Sheep Manual 8, Table 1) = £229 / 6,565gkDM
[7] energy density based on Nicol and Brookes, 2007.

Diet for heavier breeding female mature weights

Higher average feed costs are included for heavier breeding female mature weights. The argument is that in order to supply the energy required to meet body condition score (BCS) targets throughout the year, higher quality and higher cost feed is required as mature weight increases; this is because the volume of energy required cannot be supplied through lower quality feed.

As breeding female mature weight increases beyond the thresholds of 700kg for cows, and 75kg for ewes, the proportion of feed which is supplied by a high-quality supplement increases, thus increasing the average price of feed.

The proportion of diet supplied by the high-quality supplement increase by 0.25% per 1kg increase in mature weight, beginning at 10% of the diet at 700kg.

The supplemented feed is assumed to contain 25% concentrate and 75% silage. This applies all year round, and has a price of £0.0144/MJME, compared to £0.0038/MJME for pasture.

Diet composition

Beef

Table 37 summarises lifetime diet composition for slaughtered progeny, and the annual diet composition for breeding females. Except for bulls, winter diets consist of 40% concentrate and 60% silage. Bulls grow faster (and are slaughtered earlier) so receive a higher proportion of concentrate, and have straw included in their mix. During summer months, breeding females, heifers and steers all graze pasture.

Table 37: Monthly diet composition for slaughtered progeny and cows/replacements[1, 2].

<table>
<tr><th colspan="2">Month</th><th>Bulls</th><th>Steers</th><th>Heifers</th><th>Cow</th></tr>
<tr><td>-</td><td>March</td><td colspan="3" rowspan="8">Weaning (60% milk + 30% grass + 10% concentrate)</td><td>...</td></tr>
<tr><td>1</td><td>April</td><td>...</td></tr>
<tr><td>2</td><td>May</td><td>...</td></tr>
<tr><td>3</td><td>June</td><td>...</td></tr>
<tr><td>4</td><td>July</td><td>...</td></tr>
<tr><td>5</td><td>August</td><td>...</td></tr>
<tr><td>6</td><td>September</td><td>...</td></tr>
<tr><td>7</td><td>October</td><td>...</td></tr>
<tr><td>8</td><td>November</td><td rowspan="4">80% Conc.,
10% Straw,
10% Silage</td><td colspan="2" rowspan="6">40% Concentrate & 60% Silage</td><td rowspan="3">100% Silage</td></tr>
<tr><td>9</td><td>December</td></tr>
<tr><td>10</td><td>January</td></tr>
<tr><td>11</td><td>February</td><td rowspan="3">25% Conc.,
75% Silage</td></tr>
<tr><td>12</td><td>March</td><td rowspan="4">85% Conc.,
15% Straw,</td></tr>
<tr><td>13</td><td>April</td></tr>
<tr><td>14</td><td>May</td><td colspan="2" rowspan="6">Grass 100%</td><td rowspan="6">Grass 100%</td></tr>
<tr><td>15</td><td>June</td></tr>
<tr><td>16</td><td>July</td><td rowspan="10"></td></tr>
<tr><td>17</td><td>August</td></tr>
<tr><td>18</td><td>September</td></tr>
<tr><td>19</td><td>October</td></tr>
<tr><td>20</td><td>November</td><td rowspan="6">40%
Concentrate &
60% Silage</td><td rowspan="5">40%
Concentrate &
60% Silage</td><td>...</td></tr>
<tr><td>21</td><td>December</td><td>...</td></tr>
<tr><td>22</td><td>January</td><td>...</td></tr>
<tr><td>23</td><td>February</td><td>...</td></tr>
<tr><td>24</td><td>March</td><td>...</td></tr>
<tr><td>25</td><td>April</td><td></td><td>...</td></tr>
</table>

[1] Diets based on discussion and feedback from industry (Basil Lowman, David MacKenzie; pers. comm. March 2018)

[2] The cow diet here (also fed to replacement heifers) refers to the “mixed” cow diet presented in the sensitivity to feed costs Figure 10. **The base cow diet for modelling costs in all other analysis was 100% grass, all year round.**

Table 38: Average monthly cost of feed (£/MJME) for slaughtered progeny and cows/replacements[1,2].

Month		Bulls	Steers	Heifers	Cow
-	March	0.006	0.006	0.006	
1	April	0.006	0.006	0.006	
2	May	0.006	0.006	0.006	
3	June	0.006	0.006	0.006	
4	July	0.006	0.006	0.006	
5	August	0.006	0.006	0.006	
6	September	0.006	0.006	0.006	
7	October	0.006	0.006	0.006	
8	November	0.023	0.016	0.016	0.011
9	December	0.023	0.016	0.016	0.011
10	January	0.023	0.016	0.016	0.011
11	February	0.023	0.016	0.016	0.014
12	March	0.023	0.016	0.016	0.014
13	April	0.023	0.016	0.016	0.014
14	May	0.023	0.004	0.004	0.004
15	June	0.023	0.004	0.004	0.004
16	July		0.004	0.004	0.004
17	August		0.004	0.004	0.004
18	September		0.004	0.004	0.004
19	October		0.004	0.004	0.004
20	November		0.016	0.016	
21	December		0.016	0.016	
22	January		0.016	0.016	
23	February		0.016	0.016	
24	March		0.016	0.016	
25	April		0.016		

[1] Diets based on discussion and feedback from industry (Basil Lowman, David MacKenzie; pers. comm. March 2018)

[2] The cow diet here (also fed to replacement heifers) refers to the "mixed" cow diet presented in the sensitivity to feed costs Figure 10. **The base cow diet for modelling costs in all other analysis was 100% grass, all year round.**

Sheep

Table 39 summarises lifetime diet composition for slaughtered single, twin and triplet lambs, and the annual diet composition for breeding females.

Table 39: Monthly diet composition for slaughtered progeny and cows/replacements[1,2].

<table>
<tr><th colspan="2">Month</th><th>Single</th><th>Twin</th><th>Triplet</th><th>Ewe</th></tr>
<tr><td>-</td><td>March</td><td colspan="3" rowspan="4">30% grass, 10% concentrate,
60% milk (via mother)</td><td rowspan="2">75% silage,
25% conc.</td></tr>
<tr><td>1</td><td>April</td></tr>
<tr><td>2</td><td>May</td><td rowspan="6">100% grass</td></tr>
<tr><td>3</td><td>June</td></tr>
<tr><td>4</td><td>July</td><td rowspan="3">100% grass</td><td>90% grass,
10% conc.</td><td>80% grass,
20% conc.</td></tr>
<tr><td>5</td><td>August</td><td rowspan="2">95% grass,
5% conc.</td><td rowspan="2">90% grass,
10% conc.</td></tr>
<tr><td>6</td><td>September</td></tr>
<tr><td>7</td><td>October</td><td></td><td></td><td></td></tr>
<tr><td>8</td><td>November</td><td></td><td></td><td></td><td rowspan="3">100% silage</td></tr>
<tr><td>9</td><td>December</td><td></td><td></td><td></td></tr>
<tr><td>10</td><td>January</td><td></td><td></td><td></td></tr>
<tr><td>11</td><td>February</td><td></td><td></td><td></td><td>see Mar/Apr.</td></tr>
</table>

[1] Diets based on discussion and feedback from industry (Carol Davis, pers. comm. March 2019)

[2] The cow diet here (also fed to replacement females) refers to the "mixed" cow diet presented in the sensitivity to feed costs (Figure 14). **The base ewe diet for modelling costs in all other analysis was 100% grass, all year round.**

Table 40: Average monthly cost of feed (£/MJME) for slaughtered progeny and cows/replacements[1,2]

Month		Single	Twin	Triplet	Ewe
-	March	0.006	0.006	0.006	0.014
1	April	0.006	0.006	0.006	0.014
2	May	0.006	0.006	0.006	0.004
3	June	0.006	0.006	0.006	0.004
4	July	0.004	0.006	0.009	0.004
5	August	0.004	0.005	0.008	0.004
6	September	0.004	0.005	0.008	0.004
7	October				0.004
8	November				0.011
9	December				0.011
10	January				0.011
11	February				0.014

[1] Diets based on discussion and feedback from industry (Carol Davis, pers. comm. March 2019)

[2] The cow diet here (also fed to replacement females) refers to the “mixed” cow diet presented in the sensitivity to feed costs (Figure 14). **The base ewe diet for modelling costs in all other analysis was 100% grass, all year round.**

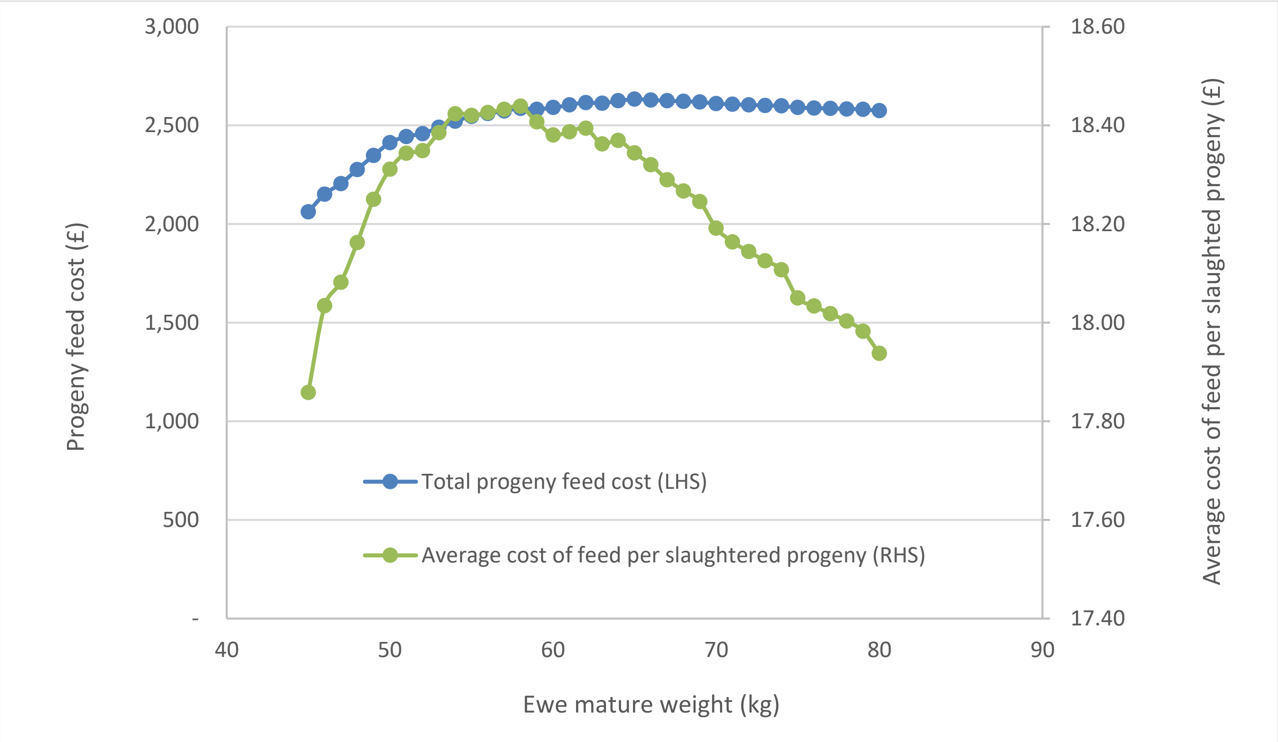
Figure 27 below summarises the how total feed costs for slaughtered progeny and the average feed cost per slaughtered progeny change in relation to breeding female mature weight.

Figure 21 (Appendix 1) shows how the number of slaughtered progeny increase with mature weight, due to improved ewe fertility. Up to 65kg, total feed costs for slaughtered progeny costs increase in the same way; as the number of progeny slaughtered increases so does the total feed cost.

Average feed costs per slaughtered animal increase rapidly from 45kg to 55kg, because as fertility improves, the number of ewes birthing multiples increases. Twins and triplets have higher average feed costs than singles, due to additional supplement required post weaning (Table 37).

As improvement to fertility diminish, the number of twins and triplets remains unchanged, while improved growth means that the lambs are finished earlier. This results in decreased total feed and average feed costs.

Figure 27: Total feed costs for slaughtered progeny in 100 breeding female flock, and average feed cost per slaughtered progeny, for breeding female mature weights of 45kg to 80kg.



Efficiency of energy via mothers' milk

The diet model calculates daily feed consumption based on the daily energy required (MJME) for growth and maintenance (Appendix 3). Therefore, to calculate the daily cost of feed, total daily energy required (MJME) is multiplied by the average cost of feed per unit of energy (£/MJME), in each given month. To calculate the average cost of feed per unit of energy (£/MJME), according to varying diet composition and feed prices, we use the following equation;

$$\frac{1}{MJMA_A * £_A + MJMA_B * £_B \ldots} * \ MJMA_A * £_A + \frac{1}{MJMA_A * £_A + MJMA_B * £_B \ldots} * \ MJMA_B * £_B \ldots,$$

where A and B represent the feed components of each diet, and $MJME_i$ and price $£_i$ represent the energy per kgDM and cost per kgDM and each feed component, respectively (Table 36). Table 38 summarises the monthly average cost of feed per unit of energy

The equation above differs adjusted slightly for calculating the cost per MJME prior to weaning (March through to October), to account for energy supplied via mother's milk. The cost of energy prior to weaning is equal to the sum of two factors; each factor is based on the equation above, however the numerator is substituted for the following values;

- 0.40 – accounting for the 40% of a calf's diet which is not supplied via the mother.
- 0.612 – accounting for the 60% of a calf's diet which is supplied via the mother (Basil Lowman; pers. comm. March 2018).

The proportion of energy (0.60) supplied by mother's milk was multiplied by 1.02, giving 0.612 for the numerator above. This figure represents the mother's relative efficiency at supplying energy to the calf. This factor of 1.02 was calculated by dividing the mothers relative feed conversion efficiency to milk (1/0.7) by the mother's relative efficiency of pasture utilisation (0.7 for mother, divided by 0.5 for calf), such that 1.02 = (1/0.7) / (0.7/0.5).