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REVIEW OF THE GENETIC IMPROVEMENT OF BEEF CATTLE AND SHEEP IN THE UK WITH SPECIAL REFERENCE TO THE POTENTIAL FOR GENOMICS

Prepared for

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Overall Summary

Genetic progress has and continues to deliver substantial genetic progress to the UK sheep and beef industries. While new genomic opportunities offer the potential to enhance these rates of progress, it is important that new industry initiatives to support genomic selection consider the ongoing need for farmer and breeder confidence in estimates of genetic merit for objective traits, and in the quantity, quality and relevance of data that contributes to these estimates. New and expanded structures where industry sires contribute to intensely recorded herds and flocks, with a strong focus on maternal trait recording, should form a significant basis of future developments. Collaboration with meat processors and encouragement of information sharing for genetic improvement purposes should open opportunities for improvements of eating quality and some disease traits. There is substantial potential to increase the rate and value of genetic progress being achieved. Because genomic prediction is not effective when applied to sets of animals distantly related to resource animals with both genotypes and phenotypes (including when trying to predict across breeds), it is important that new initiatives are not solely dependent on genomic selection delivery to achieve favourable industry outcomes.

Executive Summary

- This report has been commissioned by EBLEX with a focus on genetic improvement in the UK sheep and beef industries.
- There is a large economic benefit to UK sheep (£10.7 million annualised) and beef (£4.9 million annualised) farmers from genetic improvement.
- The realised returns from genetic improvement are substantially below their potential. In particular terminal-type breeds have been used increasingly to generate replacements for the ewe flock/ cow herd with detrimental effects on the performance of the maternal ewe flock/ cow herd.
- Consultation via a visit, as well as a substantial survey of industry participants, indicated a significant pool of engaged breeders and farmers, who believe in objective measures of prediction of genetic merit and who see potential in genomic technologies. A proviso is that visually-observed characteristics of animals are attributed comparable importance to objective measures by many survey respondents. Respondents highlighted several areas for improvement:
    - education and extension programmes underpinned by demonstration farms and informed by a demonstration of the impact that genetic improvement has on profitability of commercial farms, using simple tools (a bull test station was also mentioned);
    - a change in the way that sires are marketed, with an increase in on-farm sales (as distinct from auctions) of rams and bulls, combined with the better use of information on genetic improvement, reduced emphasis on the CAP, and direct incentivisation of ram buyers;

    - better commercial data (via progeny testing) captured using systems with very good quality control and accurate identification of animals using EID; and
    - the development of a centralised multi-species database.
- This report contains a number of recommendations that if implemented, could substantially lift the future economic benefits realised from genetic improvement.
- While considerable attention is given to the opportunities from genomics, it is important that new investment initiatives (see recommendations below), to support implementation of genomic technologies are also considered in terms of their potential to:
    - enhance conventional genetic evaluations (recommendations 3, 4, and 7),
    - generate high quality (unbiased) datasets and systems that improve the robustness and accuracy of estimates of genetic merit (recommendations 3, 4, and 12),
    - improve the understanding and recognition of the value of genetic progress across the industries (recommendations 5, 6, and 8),
    - broaden the scope of traits under improvement, with a particular focus on maternal traits such as fertility, fecundity (sheep), mature weight, and body condition score (mature female fatness level), and trait phenotypes sourced from abattoirs including both disease traits and meat quality traits (recommendations 9, 12, 13),
    - enhance communication and extension of the principles of genetic improvement, to facilitate uptake and therefore dissemination of genetically-improved males (recommendations 7, 8, and 10) , and to
    - maintain and enhance the support structures for genetic improvement including organisations providing services to breeders, and the underpinning genetic evaluation systems (recommendations 11, 15, 17, and 18).

Summary of recommendations and priorities

Recommendation	Why	Who/ leader	Dependencies	Impact/ benefit	Cost	Overall priority
Recommendation 1: Based on an assessment of the impact of genomics on current annualised returns, any future genomic selection investment in sheep should be driven by breeder (and potentially breed level) subsets of the industry, with co-investment from levy and/or national funds justified based on the magnitude of wider industry benefits that are expected to be at least £0.5 million in annualised equivalent returns. The proviso to investment by breeder (and potentially breed level) subsets of the industry is that data and results be made available for use by industry.	- To ensure adequate return on investment	- Levy bodies	- Commercial phenotypes - Genotypes - Reference populations - GE (genetic evaluation) capability	Low	Low	Low
Recommendation 2: Based on an assessment of the impact of genomics on current annualised returns, any future genomic selection investment in beef should be co-ordinated at breed level, with co-investment from levy and/or national funds justified based on the magnitude of wider industry benefits that are expected to be at least £0.7 million in annualised equivalent returns. The proviso to investment by breeder (and potentially breed level) subsets of the industry is that data and results be made available for use by industry.	- To ensure adequate return on investment	- Levy bodies	- Commercial phenotypes - Genotypes - Reference populations - GE capability	Low	Low	Low
Recommendation 3: Implement an integrated commercial sire evaluation and demonstration scheme for rams, including assessing terminal and maternal rams from both the breed society & non-society sectors, on commercial properties.	- Supply much needed commercial data - Provide centre point for demonstration - Connectedness - Gather maternal phenotypes - Genomic selection reference population	- Levy bodies - Commercial farmer group led - Consultation with breed societies - GE service providers	- Requires commercial farms - Governance	High	High	High
Recommendation 4: Build on existing commercial trials to collect commercial data from more beef cattle breeds, with the aim of building robust across-breed data sets for genetic evaluation, and to provide underpinning information to develop impact models for genetic improvement.	- Supply much needed commercial data - Provide centre point for demonstration - Connectedness - Gather maternal phenotypes - Genomic selection reference population	- Levy bodies with existing trials (Limousin and Stabilizer) - GE service providers	- Collaboration with existing commercial trials - Other service providers	High	High	High

Recommendation 5: Build an extension scheme (based on commercial data and evaluations on commercial farms) that delivers whole of farm examples of the benefits of using higher genetic merit sires from performance recording flocks/herds.	- Engagement - New method of presentation of the impact of genetic improvement (not indexes but whole farm bottom-line examples) - Showcase commercial progeny test and best practice	- Levy bodies - Commercial farmer group - Consultation with breed societies	- Recommendation 3 and 4	High	Mod	High
Recommendation 6: Review historic publications and reports on breeding objectives with a view to constructing sub-indexes and a system for simplifying the presentation of genetic merit information (bronze, silver and gold - Top 50%, 25% and 10%, respectively - categories are already in place, and represent a good starting point).	- To build a new method of presenting genetic merit information	- EBLEX/ Signet	- Other service providers	Low	Mod	Low
Recommendation 7: To generate momentum and examples for industry, target selected sheep and beef breeders who are 1) showing concern about maternal performance, 2) could benefit from implementation of new technology such as parentage testing, and 3) have an understanding of the commercial value of genetic improvement, and use these breeders as in-situ demonstrations of the use of new approaches.	- Engagement - New method of presentation of the impact of genetic improvement (not indexes but whole farm bottom-line examples) - Showcase best practice and technology use	- Levy bodies - Leading breeder engagement - Consultation with breed societies	- Identification and engagement with high performing breeders	High	Mod	High
Recommendation 8: Establish structured, regular, commercially-focused industry meetings in both sheep and beef industries in order to elicit specific and direct priorities for the development of new trait genetic evaluations, selection indexes and tools for breeders and buyers of performance recorded males, as well as provide the impetus to establish a new focus (maternal) and approach (commercial sire evaluation in sheep for example) to genetic improvement.	- New forum driven off this review - New focus - Introduce new concepts and build industry ownership	- EBLEX/ Signet - Breed societies - Commercial farmers - Leading breeders	- Align with existing meetings - Engage breed societies	Medium	Low	Medium
Recommendation 9: Build a focus on the development of wider data sets and better phenotypes in general, including data for hard-to-measure (HTM) traits.	- Genetic gains needed across a broader set of traits	- EBLEX/Signet - Breed societies - Commercial farmers - Leading breeders	- Systems for data recording - Prioritisation of traits - Other service providers	Medium	Low	Medium
Recommendation 10: Establish a process to ensure that there is an ongoing (and possibly increased) availability of services from commercial service providers, albeit assisted by a central (levy- and user-funded) body to ensure a co-ordinated approach that also provides targeted support for key initiatives, and which facilitates the provision of clear, transparent and industry-friendly communication of genetic improvement principles. It should be noted that, for legal reasons relating to the allocation of funding, it might not be possible to do some of this.	-Clearer communication to industry	- Levy bodies	- None - Other service providers	Medium	Low	Medium

Recommendation 11: Establish systems to enable the ongoing capture of data on genetic technology adoption (i.e. level of performance recording within the industries and extent to which performance recorded males are purchased, as a proportion of all males) to provide information that can be used to help target approaches to ensure the effective dissemination of genetic improvement.	- To enable a more accurate measure of the impact of genetic improvement in the future	- Levy bodies - Breed societies	- None	Medium	Low	Medium
Recommendation 12: Establish systems to provide a renewed focus on the collection of high quality, preferably commercial, phenotypes for maternal traits such as initiatives to record body condition score, increase the accuracy of phenotypes for fertility (beef), and enable the recording of mature weight.	- Generate genetic gain in commercially relevant maternal traits	- Levy bodies - Commercial farmers	- Recommendation 3 and 4 - Other service providers	High	Medium	High
Recommendation 13: Establish a research project to evaluate the potential for an industry-level programme to focus on the collection of data (phenotypes) for diseases on slaughtered animals to enable (in the longer term) the development of genomic evaluations for disease traits.	- Disease a big issue and need to generate an opportunity to genetically improve disease traits	- Levy bodies - Animal health body - Vets - Abattoirs	- Animal health body - Abattoir engagement - Vet engagement - Other service providers	Medium/ high	Medium	High
Recommendation 14: Establish a parallel research project to evaluate the potential for an industry-level programme to focus on the collection of phenotypes for eating quality traits to enable (in the longer term) the development of genomic evaluations for these traits.	- Eating quality a good foundation for future genomics work	- Levy bodies - Abattoirs - Supermarkets	- Abattoir engagement -Supermarket engagement - Other service providers	Low	Medium	Medium
Recommendation 15: Establish systems (in the beef and sheep populations) for the development of genomic selection methods including the development of new phenotypes (especially for HTM traits) that are underpinned by structures that: utilise males in ways that ensure excellent genetic connectedness between flocks/herds; utilise the inherent structure and genetic relationships within (and between) breeds; and that provide for the genotyping of influential individuals (see recommendations 3 and 4).	- Provide centre point for demonstration - Connectedness - Gather maternal phenotypes - Genomic selection reference population	- EBLEX/ Signet - Research organisations	- Recommendation 13 and 14 - Other service providers	High	High	Medium
Recommendation 16: Establish systems for the collection of DNA (and semen) from resource populations that are generated in industry demonstrations or sire evaluations, especially those with relatively small numbers of individuals per breed; the DNA would be available for the future investigation of putative genetic variants in addition to its application in genomic approaches for better prediction of relationships.	- Underpinning resource for genomic evaluation in the future	- Breed societies - Genotyping companies - Breeders	-None	High	Medium but dispersed	Medium

Recommendation 17: Take a watching brief to assess opportunities to apply genomic selection approaches in smaller breeds and populations (including initiating discussions with countries that also have small populations of relevant breeds).	-Broader industry engagement	-EBLEX/ Signet -Research organisations	- None	Low	Low	Medium
Recommendation 18: Provide for ongoing investment in genetic evaluation infrastructure to ensure that population sub-structure and contemporary group connectedness issues are accounted for, and that new genomic information is incorporated into existing evaluations as seamlessly as possible.	- Underpinning resource for genomic evaluation in the future	-EBLEX/Signet -E-Genes	- In conjunction with recommendation 3 and 4 - Other service providers	Medium	Medium	High

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Background

EBLEX (and previously MLC) has invested in the genetic improvement of cattle and sheep in the UK for several decades, leading to financial benefits to beef and sheep farmers as well as to the industry as a whole. These benefits have been estimated previously by Amer *et al.* (2007). However, as the industry has developed and the structure of the industry is changing somewhat, so too is the landscape of genetic evaluation, and in this respect, the potential for the incorporation of genomic information into breeding systems is being recognised.

The application of genomic technologies has the potential to play a major role in enhancing the overall profitability and efficiency of the sheep and suckler beef sectors in the UK. It can be expected that this would be achieved through an increase in the rate of genetic improvement through earlier identification of superior individuals for breeding, a higher accuracy of estimation of genetic merit (especially for the so-called 'hard-to-measure' traits), and through greater industry engagement. Genomics has the potential to be a disruptive technology within the sheep and beef industries – that is, it could disrupt current industry structures in a positive way.

If the current rate of adoption of conventional genetic improvement tools is sub-optimal from the perspective of industry benefits, then a disruptive technology that results in greater engagement in genetic improvement from multiple sectors of the supply chain could greatly increase industry penetration of higher genetic merit rams and bulls. The structures and resources that would be needed for the implementation of genomics are expected to differ from those in place for the current quantitative genetic evaluations.

Current quantitative approaches to genetic improvement (BLUP-based) require performance data to be collected from individuals. The reality is that many traits of economic interest are expressed in only one sex (e.g. milk production) or later in life (breeding female longevity). This is a particular problem with maternal traits in sheep and beef cattle, which are the key components that drive profitability of a breeding ewe-lamb or a breeding cow-calf enterprise. There are also traits which are very difficult or impossible to measure in the live animal, such as meat quality. Genomic technologies have the potential to address these issues, which highlights the potential value of genomic approaches (which require the analysis of a blood or tissue sample) in the earlier identification of superior individuals. However, the ability to deduce the genetic merit of an individual from DNA analysis is dependent on the development of a robust data set which can only be generated from the collection of phenotypic data (e.g. live weight by age, fertility, health status, etc.) and the associated parentage data from flocks or herds of animals. In this respect, the new genomic technologies provide both accurate parentage and the necessary genotypic data which are used in the subsequent analysis and prediction of genetic merit.

Implementation of genomic approaches at an industry level is not trivial. However both the beef and sheep industries in the UK have built up databases containing phenotypic and genetic data (via Signet, EGENES, BREEDPLAN and Breed Societies) that could provide the underpinning knowledge to enable the implementation of genomic technologies in the future.

Concern that a co-ordinated effort is required in order for the UK sheep and suckler beef industries to maximise gains from new technologies such as genomic selection have led to the commissioning of this review of the sheep and beef breeding sectors of the UK.

Terms of reference

The focus of this review is on the benefits realised from investment by the red meat industry (EBLEX, HCC, QMS breed societies, and breeders or other parties involved in the investment) in genetic improvement of beef cattle and sheep in the UK, with special reference to the potential for genomics. Further, the analysis explores the possibilities for future genetic improvement within the red meat industry. The terms of reference are summarised below.

1. Provide EBLEX with:
    a. estimates of the ***value of historic genetic gain*** through the application of genetic technologies utilising an updated version of the model developed by Amer et al. in 2007;
    b. estimates of the potential ***rate of genetic gain*** through the additional application of genomic technologies and compare this with the current quantitative approaches that utilise BLUP[1];
    c. a ***cost-benefit*** analysis for the application of genomic technologies based on #2 above.
2. Analyse the ***strengths and weaknesses*** of the breed improvement services system through:
    a. international bench-marking, with focus on phenotypic data collection (e.g. scanning services), investment in genetic R&D and the efficiency of technology transfer activities;
    b. a ***survey on genetic evaluation service system users*** to thoroughly review current service provision at point of delivery.
3. Provide a framework for the ***establishment of potential best practices*** in the use of genomic tools to accelerate genetic gain, including collection and analysis of phenotypic data, the utilisation of males for connectedness across herds, the structure of the population, and the genotyping of influential individuals.

Overview of the report

This report first addresses recent rates of genetic gain observed in the UK sheep and beef sectors. Results are somewhat differentiated by breed types and roles, although individual breed genetic trend results have been aggregated and are not presented individually, in order to preserve confidentiality. A consideration of likely changes in genetic trends with exploitation of new genomics technologies is then discussed. The historic genetic trends, and likely benefits from genomic technology are then compared with costs of investment in the context of a cost-benefit analysis. The next section of the report uses data collected as part of the visit to the UK by Tim Byrne, Peter Fennessy and Donagh Berry, along with results from an industry survey, to consider the strengths and weaknesses of the existing industry structure. This section also makes reference to several appendices which provide information for international benchmarking. Structural and research

[1] It is important to note that the performance of genomic tools will continue to improve over time due to the on-going international investment in laboratory methods and statistical methodology – this will be reflected in the accuracy of predictions of genetic merit;

challenges required for deployment of genomic selection are then considered, and recommendations made around research priorities, and implementation/funding approaches.

Genetic improvement and the rate of genetic gain – TOR 1

The focus is on the benefits realised from investment by the red meat industry (EBLEX, associated parties, breeders) in genetic improvement of beef cattle and sheep in the UK, with the output being:

a) estimates of the ***historic rate of genetic gain*** in the elite breeding sector;

b) estimates of the ***value of the genetic improvement at the commercial level*** through the application of genetic technologies utilising an updated version of the model developed by Amer et al. 2007, including an assessment of the sensitivity to key assumptions;

c) estimates of the potential ***rate of genetic gain*** through the additional application of genomic technologies and compare this with the current quantitative approaches that utilise BLUP[2];

d) a ***cost-benefit*** analysis for the application of genomic technologies based on #c above.

Historic rate of genetic gain

This section first updates the report by Amer et al. (2007) for sheep with more recent genetic trend information and with some modifications to the methodology. The methodology is presented in Appendices 1 and 2 (for sheep and beef respectively). In the course of reviewing and applying the methodology for valuing rates of genetic gain, it became apparent that the current industry structure has deviated substantially from what was assumed in the Amer et al. (2007) study. In particular, Amer et al. (2007) assumed that breeds conformed to traditional breed roles such as terminal, maternal, and crossing (for sheep only where specialised sire breeds are mated to hill ewes, and the resulting breeding females do not generate their own replacements). These formal structures are now much less prominent in sheep and beef cattle compared to the 2007 study, and so it was necessary to make major changes to the aggregation methodology. For this reason, comparisons of aggregated genetic trends and overall benefits of genetic improvement between the current study, and those reported by Amer et al. (2007) need to be treated with some caution.

Sheep

Genetic trends in recorded populations were estimated from EBV data provided by EBLEX, for hill, longwool (not crossing), crossing, shortwool, and terminal sheep breeds. Genetic trends in non-recorded populations were assumed to be either half or a quarter of that of the recorded population, depending on the level of integration of the recorded population within the breed (Appendix 1). The estimated rates of genetic gain in non-recorded populations, relative to recorded populations, were provided by EBLEX. Individual breed contributions to industry level genetic gain were based on industry structure and breed numbers from Pollott (2013).

[2] It is important to note that the performance of genomic tools will continue to improve over time due to the on-going international investment in laboratory methods and statistical methodology – this will be reflected in the accuracy of predictions of genetic merit;

A breakdown of cumulative and annualised industry benefits are presented in detail in Appendix 1. Aggregates of genetic trends across most breed types were lower than earlier estimates reported by Amer et al. (2007), with the exception of maternal ability and litter size traits which have remained relatively stable in all breed types. This is a reflection of the aggregation approach and implicit assumptions, rather than a reduction in the rate of genetic progress being achieved within the main recording breeder groups.

Mature weight trends (albeit predicted from trend in early growth traits) have increased in all breed types, which suggest that larger animals are being selectively retained, which will have a negative impact particularly on hill sheep and longwool and crossing sheep. Overall, the annual genetic trends in profit per lamb and per ewe, as realised in industry, have decreased for all breed types since 2007. This, combined with a reduction in the number of both hill sheep and longwool and crossing sheep, has resulted in annualised returns that are 60 to 80% lower than the returns reported by Amer et al. (2007). While there was a reduction in returns (30%) observed for terminal breeds also, the final impact was only modest due to the slight increase in numbers of terminal sheep. Part of the difference in realised returns between the 2007 study and the current analysis is due to differences in industry structure (Pollott and Stone, 2003; Pollott, 2013). The sum total of annualised returns across all sheep breeds was estimated at £10.7 million.

Beef

Genetic trends for terminal and dual purpose beef breeds were calculated using EBV data provided by EBLEX, BASCO and BREEDPLAN (details are in Appendix 2). Briefly, it was assumed that 80% of bull breeders used performance recording and genetic evaluation (recorded populations) and that the rate of genetic gain in non-recorded populations was 80% of that in recorded populations. The industry share for each breed was derived using industry breed composition data from Todd et al. (2011).

Two different models were applied. The first model (Model 1) assigned breeds to specific roles, and is similar to the approach taken by Amer et al. (2007). The second model (Model 2) assumed more flexible breed roles, which more closely reflects current industry practices. In the context of the current industry structure, which is very different to that reflected in the study by Amer et al. (2007), Model 2 should be considered as representing the value of benefits from investment in genetic improvement. Model 1 is provided to enable making comparisons with the results of Amer et al. (2007).

Results (Appendix 2) demonstrate that genetic progress continues to deliver benefits to the UK beef industry, with an annualised return of between £1.9 million (Model 1) and £4.9 million (Model 2). Rates of genetic gain in the terminal index have more than doubled compared to those reported by Amer et al. (2007). Rates of gain in growth and carcass traits in dual purpose breeds also doubled, but this has a detrimental effect on the genetic merit of suckler cows for maternal production efficiency. The primary reason for this is the antagonism between growth and maternal traits.

Potential rate of genetic gain through genomics

Dairy industries in many countries are realising increases in the rate of genetic progress through the application of genomics. This has come about through a reduction in generation interval (lower levels of progeny testing), rather than an increase in the accuracy of evaluation of young bulls being considered for widespread industry use.

Sheep

For sheep, the opportunities for reducing generation interval are relatively modest, and so benefits of genomic selection will need to come through improvements in prediction accuracy. The greatest opportunity is likely to be in maternal traits, including disease resistance/tolerance, and ease of care (cost-saving) traits. However, because large populations of animals that have been both phenotyped and genotyped are required to achieve accurate genomic predictions, there are challenges due to the large numbers of breeds in the UK sheep industry. Increases in rates of genetic progress by between 5% and 15% are realistic in sheep, based on the authors' experiences with work undertaken in New Zealand and Australia.

The benefits tend to be lower in breeds with a strict breeding objective focused on terminal traits. This is because these traits (with the exception of eating quality) can typically be quite accurately predicted in young selection candidates using phenotypic data alone. With current estimates of annualised benefits of genetic progress in the UK sheep industry, a 5% increase in this base rate of progress is very modest. For example, a 5% increase in the annualised benefits reported in Table 8 equates to only £0.4 million in terminal breeds. Therefore, the value of genomics would more likely be realised through a step change in industry attitudes towards genetic improvement technology, leading to more widespread impacts of the genetic progress currently only being realised in subsets of the industry. This step change would require substantial shifts in market shares of ram sales, across breeders both within and between breeds. On this basis, substantial co-investment by parties who envisage a gain in market share through adoption of new genomic technologies makes sense, and should be encouraged. There is also a potential role for service providers (DNA analysis), so long as they are engaged as partners seeking to generate value to the end-user rather than being involved in the partnership as a marketing tool to increase sales in the short term.

Beef

For beef, there is an opportunity to get AI bulls into widespread service at a younger age, and also potentially to use bulls of higher genetic merit. In particular, for breeders with a maternal focus, there could be considerable benefits from identification of young bulls for AI based on genomic predictions of disease and robustness traits, maternal milk yield, mature cow size and fertility. These young bulls will already have been evaluated for growth and physical conformation, and can be quickly assessed for calving difficulty and birth traits based on a first crop of progeny. Availability of a larger group of superior young AI sires could have a considerable and widespread impact on some of the larger beef breeds. Given that AI is quite common in the pedigree beef sector, and also acts as an efficient multiplier of elite genetics from the better performance-recorded herds, there are significant opportunities for gains to be achieved at whole breed level. For these reasons, we believe that the magnitude of the potential increase in the rate of genetic gain from genomics is much higher in beef than in sheep. The annualised benefits of a 50% increase in genetic progress in breeds making up 30% of sires (where there should be an interest in daughter maternal performance) used within the suckler beef sector would equate to approximately £0.7 million annualised extra benefit from genomics (30% x 50% x £4.8 million annualised benefit).

The importance of penetration

The above estimates of marginal benefits of genomics at current rates of penetration (adoption) are modest. However, there is potential for genomics to transform the genetic improvement industries, in particular to influence the buyers and sellers of both rams and bulls to take greater cognisance of a broader range of traits and attributes when making selection decisions. Any such disruptive transformation could result in levels of benefits at least one order of magnitude larger than those described above. This concept is addressed in greater detail under TOR 3.

Cost-benefit analysis

Expenditure

The expenditure on the provision of Signet services and on research and development in genetics and breeding by EBLEX for the period 2001-02 to 2013-14 are summarised in Table 1 with detailed summaries in Appendix 8.

Table 1: Summary of Signet expenditure for delivery of breeding services and EBLEX expenditure (£'000) on R&D in genetics and breeding

Year	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14
Signet	£622	£680	£661	£672	£606	£670	£631	£535	£360	£366	£348	£406	£336
EBLEX	£1,209	£827	£1,062	£794	£1,082	£883	£972	£632	£480	£468	£671	£565	£464

Current benefits

As reported above, the sum total of annualised returns across all sheep breeds was estimated at £10.3 million. In beef, the annualised return is estimated to be £4.9 million (Option 2)[3]. Annualised returns are calculated by working out what constant annual revenue stream would equate to having the same net present value as the benefits derived using the Amer et al. 2007 methodology. Thus, the annualised returns can be compared to annualised expenditures in a relatively straight-forward way. In this instance, a £15 million aggregate annualised benefit relative to an annual investment of between £0.8 million (recent years) and £1.5 million (historically) indicates a substantial return on the underpinning investment.

Calculations of benefits described in Appendix 1 and Appendix 2 suggest that the calculated benefits of genetic improvement under the current industry structure are less than the benefits calculated by Amer et al. (2007) where breeds had a much more rigidly defined role in structured crossbreeding systems.

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[3] Option 2 assumed breeds were more integrated and could be used as terminal & dual purpose (see Appendix 2 for details) than option 1 where it was assumed that breeds are specialised as either maternal or terminal.

Long term beneficiaries

The long term beneficiaries of sheep and beef genetic improvement in the UK are likely to be commercial sheep and beef farmers, who will need productivity improvements if they are to remain competitive in the face of global competition. More efficient production systems are also likely to lead to a sustained reduction in environmental impacts, particularly when these impacts are quantified relative to the amount of farm output achieved.

Recommendation 1: Based on an assessment of the impact of genomics on current annualised returns, any future genomic selection investment in sheep should be driven by breeder (and potentially breed level) subsets of the industry, with co-investment from levy and/or national funds justified based on the magnitude of wider industry benefits that are expected to be at least £0.5 million in annualised equivalent returns. The proviso to investment by breeder (and potentially breed level) subsets of the industry is that data and results be made available for use by industry.

Recommendation 2: Based on an assessment of the impact of genomics on current annualised returns, any future genomic selection investment in beef should be co-ordinated at breed level, with co-investment from levy and/or national funds justified based on the magnitude of wider industry benefits that are expected to be at least £0.7 million in annualised equivalent returns. The proviso to investment by breeder (and potentially breed level) subsets of the industry is that data and results be made available for use by industry.

Strengths and weaknesses of the existing structure – TOR 2

The focus is on the analysis of the ***strengths and weaknesses*** of the breed improvement services system, especially with respect to the quality of the information within the system (small contemporary groups, breeder biases, and lack of commercial data are examples), as assessed through:

a) ***consultation with a range of participants*** along with a ***survey of users of the genetic evaluation service system*** to review and gain perspectives on the current service provision at point of delivery; and

b) ***the quality of information*** (which includes an element of international bench-marking), with a focus on phenotypic data collection, investment in genetic R&D and the efficiency of technology transfer activities

Industry consultation: summary of responses to consultation questions

Consultation in the UK involved interviews with an agreed target list of industry participants (principally societies, service providers, and industry good organisations). The objective of the consultation process was to gather general information and to seek clarity around critical assumptions/inputs, especially rates of adoption (penetration or uptake), and the costs of breed improvement services. A summary of responses to six questions relating to genetic improvement in the UK industries was also compiled, and is presented below (full summary in Appendix 3).

There were wide-ranging answers to the questions. Interestingly, the participants providing feedback suggested that most people (i.e. in the participants' view of the wider industry, and generally not the participants themselves) do not have an understanding of and/ or do not trust EBVs. In contrast, the survey of end-users (Appendix 4) suggested that there was the self-perception of a high level of understanding of EBVs. This implies that the survey respondent group was biased towards those with a close association with genetic evaluation systems and/or societies, service providers, and industry-good organisations (i.e. the consultation participants) do not have a good understanding of the capability of end-users.

There is general agreement with the views of consultation participants and end-users that genomics presents a long term opportunity, and that investment to ensure that these opportunities are maximised is critically important. There is also alignment between the views of consultation participants and end-users that in general, the providers of genetic evaluation service provide a good service.

Infrastructure of the UK genetic improvement system

Users were asked to comment on the state of the infrastructure of the UK sheep and beef genetic improvement system. Generally users of the existing service providers (BREEDPLAN and Signet/ BASCO) reported that the service was good, although some users referred to inflexibility (traits and evaluations) and timeliness of feedback as issues. One theme in the feedback relating to the infrastructure of genetic improvement was a concern that the breed/breed society structure was an impediment to collaboration, and to attracting external funding. In addition, there were concerns about the lack of appreciation of the benefits of genetic improvement (linked to a need for better extension), preferential treatment of rams and bulls for sale, and the purchasing of non-recorded rams/bulls for high prices, amongst others.

Genetic progress relative to other countries

Participants reported that genetic progress in the UK was slower than in the US and Canadian (beef) industries and that the UK participants understood that rates of progress were limited by small herd size and data issues. Lower rates of gain in maternal traits (sheep and beef) were also acknowledged by service providers and some sheep breeders as an issue of concern.

Existing barriers to faster rates of genetic progress

The main barriers to achieving faster rates of genetic improvement as perceived by the consultation participants are reported as:

1) a lack of education in, and therefore understanding of, genetics, key performance indicators and drivers of profitability within commercial farm businesses (this is seen to drive poor decisions when purchasing rams and bulls);
2) systems that engender market failure/poor market signals in the genetic improvement value chain such as breed societies, the EUROP grading system, live markets, subsidies (including the Common Agricultural Policy – CAP), ram/bull management and feeding for sale, lack of provision of objective information at sale; and
3) data quantity and quality issues underpinned by a focus on terminal traits, a lack of focus on economically-important maternal traits, falsified data, small contemporary groups (herds/ flocks), lack of automation and technology use, and lack of commercial data.

Some socio-economic factors, such as the age structure of the farming population, were also reported as barriers to faster rates of genetic progress.

Overcoming barriers to faster rates of genetic progress

Participants proposed a diverse range of actions that might help overcome the barriers to achieving faster rates of genetic improvement. These can be broadly categorised to address each of the three areas outlined above, as:

1) education and extension programmes underpinned by demonstration farms and informed by a demonstration of the impact that genetic improvement has on profitability of commercial farms, using simple tools (a bull test station was also mentioned);
2) a change in the way that sires are marketed, with an increase in on-farm sales (as distinct from auctions) of rams and bulls, combined with the better use of information on genetic improvement, reduced emphasis on the CAP, and direct incentivisation of ram buyers;
3) better commercial data (via progeny testing) captured using systems with very good quality control and accurate identification of animals using EID;
4) the development of a centralised multi-species database.

Growth in the scale of farm businesses with more emphasis on profitability was also mentioned as something that might be expected to stimulate greater interest in genetic improvement and thus help overcome the barriers.

Knowledge of genomics and the opportunity it presents

Information from the consultation process indicated varying levels of knowledge of genomics and what it might offer the UK sheep and beef industries. Some participants suggested that most people would have limited knowledge of genomics, while others indicated that it has the potential to be a revolutionary tool. However there was a level of understanding of the size and scale (of phenotypes) that an industry would require in order to benefit from genomic selection and this concern was highlighted in the context of the relative fragmentation of the UK sheep and beef industries (numerous small breeds that would probably not have the scale or resources to invest and so gain the benefits). In this respect, some respondents noted that developments in genomics would be expected to favour the bigger breeds and especially those with good international links.

In terms of opportunities, genomic selection was seen as a tool to provide traceability and to provide commercial data (carcase data) for breed improvement, and also as a method of selecting for hard to measure (HTM) traits. The cost of genomics relative to the return was an issue raised on many occasions, and participants suggested that there was a case for EBLEX investment to ascertain the potential of, and how genomics might be used in practical applications.

Desire for central coordination of genetic improvement

In general, sheep breeders see the current system as centralised and relatively standardised (*one size fits all*), and believe that more flexibility (trait evaluation and timing of evaluations are examples) is required. From the perspective of management of genomic data, there are major issues with multiple databases and service providers. Interestingly, a number of participants in the consultation process suggested that there is value in involving innovators who are willing to take risks and develop stand-alone programmes. It was also noted that international collaboration is one important key to the success of the UK industries.

Survey of end-users

General findings

A sample of sheep and beef farmers from across the United Kingdom was surveyed. The survey targeted performance recording pedigree producers with an interest in performance recording. The survey was made available through Breed Societies and also advertised on the Farming Forum and Signet websites. It is important to acknowledge that there is potential for the respondent group to be biased towards those with a close association with genetic evaluation systems, and away from those who are not interested in engaging with organisations promoting the use of objective recording and EBVs. Thus, the results of the survey need to be interpreted as reflecting the characteristics, views, and perspectives of those performance recording pedigree producers and commercial (and both) producer in the UK sheep and beef industries with an interest in performance recording who were prepared to engage with the survey.

Overall, high average levels of agreement were found in the statements regarding preferences for EBVs over traditional methods, but also in the statement supporting the combined use of EBVs and other sources of information (pedigree, performance data and type traits). This means that, in general, survey respondents think that EBVs and indexes are better tools than traditional methods to estimates the performance of offspring, but that these traditional methods are needed by farmers to “visually” confirm estimates of genetic merit.

Small differences were found between sheep and beef survey respondents with beef farmer respondents having a slightly more positive attitude towards genetic improvement tools. Selection indexes are reported to be widely used and the general opinion was that they are a good way of summarizing ram/bull traits. However, most of the survey respondents reported that indexes should include a broader number of traits and weight traits differently.

Interestingly, given the complexity in the calculation of the EBVs, most of the farmers responding to the survey believe that they understand their meaning, units, and how they are calculated. Survey respondents therefore consider themselves well-informed about EBVs. This should be considered when extension activities relating to genetic improvement are being prepared for farmers.

The potential of genomic and DNA technologies to help increase rates of genetic gain in the long term was recognised by sheep and beef survey respondents as being an important opportunity that should be maximised. This suggests that participants have a broad understanding of the technology. There were above average levels of agreement with statements related to a desire to be involved in genomic evaluations. This suggests that there is a positive and open attitude toward the development of new genetic improvement tools among the survey respondents.

Finally, there was a range of opinions from sheep and beef farmers responding the survey as to the quality of genetic services provided by industry bodies (the consultation participants appeared to be more positive, compared to the survey respondents, in this respect).

Analysis

Multivariate analysis using a market segmentation approach to the analysis of responses on attitudes towards EBVs and selection indexes was applied. This identified three types of farmers whom we have defined as:

1) Pro-traditional (n=28),
2) EBV-supporter (n=173), and
3) Pro-EBVs (n=207).

It is important to note that it is highly likely that the Pro-traditional farmers are under-represented in the farmer sample in this report. Therefore, the relative proportion of farmers in each type in the survey should not be extrapolated to the UK industries. Across a range of parameters surveyed, there were differences in the attitudes of, and actions taken by, farmers in the three type groups. These differences were represented by a downward sliding scale, from Pro-EBV to Pro-traditional farmers, in terms of: engagement (meeting attendance), belief in performance recording, support for the development of new genetic improvement tools (genomics), and use of EBVs and selection indexes.

The selection criteria used when selecting bulls/rams and their relative preference for bull/ram traits also reflected the views held by each of the groups. Pro-traditional farmers gave more importance than the other farmer types to more “visual” traits such as carcase shape and mature size in sheep and retail yield and carcase weight in beef. In beef, Pro-EBVs farmers reported giving importance to a larger number of traits and in a more balanced way than Pro-traditional farmers. Also beef farmers gave very high importance to docility which is currently only included in the Limousin breeding programme.

Importantly, in the context of this study, both Pro-EBVs and EBV-supporter sheep and beef farmers reported that the reason for not providing EBVs during the sale/purchase of animals was because there was a lack of interest from the customer. Interestingly, the reason for not requesting EBVs for both Pro-EBVs and EBV-supporters sheep and beef farmers was because they were not provided by the seller. Therefore, most farmers not using EBVs attribute it to an external reason and not to a personal lack of interest.

Our overall conclusion is that there is general acceptance of genetic improvement technologies by a significant number of industry participants, and this provides a future opportunity to capture more of the potential benefits of genetic improvement.

Quality of information within the system

Estimation of genetic merit (data quality, feeding for selling, connectedness)

When purchasing breeding sires, most UK commercial sheep and beef farmers tend to make selection decisions based on a subjective assessment of the animal. This judgement tends to focus on animal size and/or muscularity. Little regard is given to the maternal traits, other than those the farmer believes can be assessed subjectively as indicators of expected functionality and performance.

In general, objective information, in the form of estimates of genetic merit, does not appear to receive attention in the purchasing process from buyers (survey results in Appendix 3 support this). This suggests that genetic merit information is not used in the sale/purchase of animals, which is also supported by consultation findings. Underlying practices that distort the phenotype of animals for the purposes of sale (i.e. preferential feeding) can in fact undermine estimates of genetic merit, because the resultant performance of the animal does not match the animal’s true genetic potential.

Subjective selection and misalignment of phenotype with estimates of genetic merit are both counter-productive to the realisation of genetic improvement. In other words, farmers do not believe that functionality is well-predicted by EBVs – that is, they ‘*know’* the phenotype that will work for them (which is an interpretation of genotype by environment interactions). Many farmers also seem to accept the *status quo* with respect to the performance of livestock on their farms and do not believe that it could be any better. In part this behaviour also seems to be due to a preference to purchase sires from the auctions as farmers are often fearful of paying above the market (albeit breeders also like auctions as they set the prices for sires). The overall consequence is that breeders and commercial farmers are often sceptical of the value of objective approaches to genetic improvement. This has implications on the use of information on genetic merit in the sale and purchase of animals.

There is also evidence of disconnection between the service provider (Egenes) for genetic evaluation and the actual client (breeders) where services are provided by UK-based organisations. The technical feedback comes from Signet and/or the breed society rather than from the technical provider (Egenes). This is a point of difference with BREEDPLAN clients where the technical service is actually provided by ABRI directly. Having said that, survey results (Appendix 3 and Appendix 4) suggest that the main genetic evaluation and reporting service providers (Signet, BREEDPLAN, Egenes) are all seen as providing a good service.

Connection between slaughter value and the value realised by sellers (live market)

A high percentage of farmers prefer to sell their animals for slaughter through the live market which rewards 'appearance' (size, fatness & muscling). Indications are that around half of the total lambs slaughtered are actually sold through the live market (AHDB, 2014)[4]. Given the subjective nature (perhaps with the exception of weight) of assessment of animal quality in the live market, there is a risk that market signals based on quantitative measures of genetic merit may be distorted through the live market. Carcase data (meat yield as an objective measure of carcase yield to replace subjective systems, fatness, pH, and (predictors of) consumer quality traits such as colour as a measure of quality (consumers see more red meat as fresher), all represent quantitative measure that are not available through the live market.

Implications – quality of information within the system

The consequences of the aforementioned issues (data quality, feeding for selling, connectedness and the live market) are manifest in a level of disconnect between estimates of genetic merit (influenced by data biases within the system), as reported by genetics service providers, and animal appearance and/or performance on commercial farms. Evidence from the consultation phase indicates that this disconnection erodes the confidence of both breeders and buyers of rams/bulls in objective estimates of genetic merit.

The key implication is that investment in projects that can clearly demonstrate the benefits of genetic improvement based on objective performance records are required to increase industry confidence in using estimated breeding values and indexes in selection decisions. Such projects will need to involve committed breeders who are active users of, and proponents of, objective recording. Within these projects there is the need to address the issue of genotype by environment interactions which farmers believe is critically important and which is often used as a justification for disregarding objectively-based data when selecting animals.

4

UK sheep 2013	**UK cattle 2013**
Live weight Sales – 58%	**Live weight Sales – 21%**
Prime lambs – 51%	Prime cattle – 17%
Cull ewes – 95%	Cull cows/bulls – 40%

Focus of the breeding tier

Focus on breeding for terminal traits

For the majority of sales of rams/bulls, insufficient account is taken of objectively-measured estimates of genetic merit. While there is information to suggest recorded animals with high genetic merit estimates are achieving a premium (at large sales), this is likely due to the fact that buyers can *'see'* the direct value of size and muscularity in slaughter animals (terminal traits reflected in the appearance of animals). In contrast, the maternal traits are more difficult to readily define and farmers don't readily assess the value proposition for higher fertility or a smaller mature size (or any other maternal trait). Growth traits also have relatively high heritabilities such that the phenotype can be expected to align relatively well with genotype; similarly muscularity is often a function of myostatin mutations, the effects of which can be readily defined and observed. Consequently breeders can readily see the benefits of selecting on phenotype for muscling and growth in terminal breeds (so there is no need for an objective genetic evaluation scheme which '*plays'* with the figures). Supermarket (or processor) payment systems and EUROP grading, both of which favour conformational traits, also have a major influence.

While a focus on terminal traits is useful for breeds that have a strictly terminal role, selection on a terminal-focused index will provide virtually no long-term benefits in a breed where significant numbers of daughters are kept as herd replacements (Roughsedge *et al.*, 2005). This is because the deterioration that occurs in maternal traits offsets the gains from improvements in growth and carcase traits. This is something that is evidenced in current index trends of sheep and beef breeds (Appendices 1 and 2).

EU payment systems

The EU payment systems which focus on environmental payments have resulted in a lesser focus on the underlying profitability of the livestock business within a farming enterprise. Hence a high percentage of farmers are not cognisant of the factors that impact the profitability of their own businesses, and are not motivated to be concerned about the profitability of their livestock enterprises because they collect so much of their income as of right through the CAP.

Consequently they do not see the value in any focus on livestock productivity, even though it is a factor over which they could have considerable control (and that directly impacts profitability). For example as a generalisation, farmers are not concerned about or are not aware of the costs of larger mature cows/ewes, or of the benefits of efficient feed management to improve performance to enable earlier turn-off, or of the scale of genetic variation within a breed. However commonly they seem to over-rate the impact of genotype by environment interactions.

Implications – focus of the breeding tier

The overall consequence of these factors is that there is a lack of focus on breeding for maternal traits (particularly for hill sheep breeds and dual purpose beef breeds) with negative implications for maternal efficiency. There is also a lack of focus on profitable animal and farm system performance and a lack of price signals to reward investment in genetic improvement (market failure).

Addressing strengths and weaknesses

Demonstration of the value of genetic improvement

It is essential that investment in this area is driven commercially. For example, in both cattle and sheep there are increasing linkages between breed groups and supermarkets which in themselves have considerable potential as powerful commercial drivers of update. However, industry level co-ordination of initiatives could greatly enhance and/or facilitate these commercial drivers.

A genetic demonstration option for sheep

We propose an integrated commercial sire evaluation of rams as part of a broader vision for British lamb production. A commercial farmer-led governance structure (perhaps bringing together representatives from existing organisations) should facilitate and drive this initiative. Both terminal and maternal rams from both the breed society and non-society sectors would be used. The project would need to run across three or more properties as a demonstration (and would also provide connectedness using multi-sire mating and DNA matching to parents[5]). This would need to be of sufficient scale to estimate potential genotype by environment interactions by comparing ram rankings across pedigree flocks with subsequent performance in a commercial setting. A preliminary power analysis study would be required to estimate the necessary scale of this commercial sire evaluation scheme, using the appropriate methodology (Falconer and McKay, 1996).

Additional benefits from this structure would be the provision of a data structure to strengthen connectedness across flocks, and an opportunity to collect data on hard-to-measure traits. Thus in addition to providing information to improve the understanding of the genetics of these traits, the structure would also help to build up information for potential future genomic selection initiatives to enable more widespread prediction of genetic merit for these traits.

Importantly, the project would provide a shop window for the benefits of objective genetic improvement.

Recommendation 3: Implement an integrated commercial sire evaluation and demonstration scheme for rams, including assessing terminal and maternal rams from both the breed society & non-society sectors, on commercial properties.

An expanded data generation option for beef cattle

We propose a scheme to build on the on-going trials to secure more commercial data at processing plants and on commercial farms; dairy-cross animals may be useful in this context.

A broadening of the Limousin (slaughter data and feed efficiency) and Stabilizer (feed efficiency) trials to include other breeds represents an opportunity to generate a multi-breed pool of data, suitable for genetic evaluation. These data should be used to inform genetic evaluations. In this

[5] While multi-sire mating prevents control of progeny numbers, the practical farm management benefits tend to outweigh the risk of some rams being under/over assessed.

respect, it is very important to avoid the connotation that there are any elements of breed comparisons in these projects. Therefore the emphasis must be on variation at the sire level and that at best, breeds provide an opportunity to match a breed feature with a particular environment. For example a smaller mature cow with excellent fertility may be more appropriate for less intensive systems. Performance data, recorded in commercial animals, are likely to be less biased (individual animals are less likely to be favourably treated) and also are likely to be in greater quantity (larger contemporary groups) than that captured in bull breeder herds. In addition to these data features, collecting commercial data (over time) allows for an assessment of potential genotype by environment interactions that may exist between bull breeder and commercial farmer herds. Effectively, the quality of data collected in a commercial setting offers an opportunity to increase the accuracy of estimates of genetic merit, which translates (assuming correct selection) into higher rates of genetic gain.

Recommendation 4: Build on existing commercial trials to collect commercial data from more beef cattle breeds, with the aim of building robust across-breed data sets for genetic evaluation, and to provide underpinning information to develop impact models for genetic improvement.

Model the impact of better genetics in whole farm models for sheep and beef

The commercial evaluations outlined above provide an opportunity to illustrate the value of genetic improvement at the whole farm level. The value lies in the ability to capture the impact of cumulative genetic change over time so that producers can be helped to understand that genetic gain is cumulative and permanent. This involves presenting the benefit of genetic improvement, not in trait or selection index changes but, in terms of the value added to farm profit as a result of using higher genetic merit sires from flocks/herds that are engaged in performance recording and objective selection.

Recommendation 5: Build an extension scheme (based on commercial data and evaluations on commercial farms) that delivers whole of farm examples of the benefits of using higher genetic merit sires from performance recording flocks/herds.

Breeding objectives & selection indices

While a case can be made to develop some good bio-economic models (as desired gains indexes are being used in sheep) and so enhance the value of breeding objectives, the reality is that historically such investment has had little impact in the UK. However there may be merit in considering the ways in which indexes are presented and how elite animals are flagged such as the use of a star system, as in Ireland, for example. As mentioned previously, presenting the benefit of genetic improvement, not in trait or selection index changes but, in terms of the value added to gross farm profit as a result of using higher genetic merit sires from performance recording flocks/ herds, will aid in increasing the level of understanding of the benefits of genetic improvement.

In addition, sub-indexes would appear to provide considerable potential for breeders as it would provide them with more control. This option is highlighted by Roughsedge *et al.* (2005).

Recommendation 6: Review historic publications and reports on breeding objectives with a view to constructing sub-indexes and a system for simplifying the presentation of genetic merit information (bronze, silver and gold (Top 50%, 25% and 10%) categories are already in place, and represent a good starting point).

Working with selected breeders

Maternal performance: There is considerable value in working with highly-motivated innovative breeders. A good example of interested breeders that became apparent during the consultation process is those in both sheep and cattle who are concerned about the current focus on terminal traits at the expense of maternal traits (fertility/fecundity, mature size and robustness/disease resistance). For example there was evidence of potential interest within Angus cattle, Texel sheep and hill sheep.

Parentage testing: Parentage testing represents one possible entry point to engender a more proactive approach to realising the value of performance recording and objective approaches to genetic improvement. For example, there is a clear value proposition for parentage of all calves in the recorded population (and not just those selected and registered by the breeders for retention or selling) if genetic improvement in recorded traits is the objective.

This approach has the potential to increase the value of recording by those who are actually recording and also to increase the overall uptake. Therefore there is an opportunity to assist those 'aware' breed societies to define the value proposition for parentage testing of all calves born and hence all bulls that enter the pedigree and commercial sectors. In this respect, the supermarkets are potential allies as they want to be able to talk about their sources, and be sure about what they are paying a premium for. Opportunities in beef include Shorthorn, Limousin, Angus, and Charolais, and in sheep Charollais, Hampshire Down, Texel, Suffolk. At the same time, it is important that such approaches are managed in a complementary way to the approach highlighted in recommendation 4 (*An expanded data generation option for beef cattle*), where it is noted that it is important to avoid the connotation that there are any elements of breed comparisons in these projects.

Recommendation 7: To generate momentum and examples for industry, target selected sheep and beef breeders who are 1) showing concern about maternal performance, 2) could benefit from implementation of new technology such as parentage testing, and 3) have an understanding of the commercial value of genetic improvement, and use these breeders as in-situ demonstrations of the use of new approaches.

Delivery of genetic improvement services

Better connection with users

There is a need to provide structured commercially-focused industry meetings in both sheep and beef industries. Such interactions would focus on eliciting specific and direct priorities for the development of new trait genetic evaluations, selection indexes and tools for breeders and buyers of performance recorded males, as well as provide the impetus to establish a new focus (maternal) and approach to genetic improvement. Therefore a forum where all industry stakeholders, including commercial farmers, can be involved and where there are opportunities for open discussion is encouraged. This represents an opportunity to establish a method/system to prioritise research and development investment although the risk of such occasions being captured by special interest groups must be managed.

Recommendation 8: Establish structured, regular, commercially-focused industry meetings in both sheep and beef industries in order to elicit specific and direct priorities for the development of new trait genetic evaluations, selection indexes and tools for breeders and buyers of performance recorded males, as well as provide the impetus to establish a new focus (maternal) and approach (commercial sire evaluation in sheep for example) to genetic improvement.

Data collection and utilisation

Supermarkets/processors as suppliers of meat products to consumers can play a major role in helping define the value proposition for genetic improvement. Importantly this is not necessarily restricted to the value of terminal traits. The direct value proposition for them to be involved is evident in terms of both securing supply and in providing valuable feedback to their farmer suppliers. The value that they perceive is evident in their breed-based procurement and marketing programmes although their basic motivation may be as much around ensuring supply in a competitive landscape as providing a quality product and story for their customers.

While at this stage, the schemes operate at the breed level, there may well be a growing realisation that definition by breed does not provide a particularly good predictor of quality. Therefore systems that will provide measures of meat quality on individually-identified carcasses and where the data can be fed back to farmer-suppliers and especially to breeders provide a major opportunity. In this respect the application of DNA technologies to enable 'DNA-enabled progeny testing' and product tracking/traceability can be expected to provide a significant value proposition to breeders and processors. However as noted previously, the importance of accounting for management groups within the analytical structure is critical (as variation due to different management/environments can be expected to 'drown out' genetic variation).

In the short term, the value of involving processors may be to help define the likely source of specific problems which in the first instance are more likely to be traced back to a particular farm than to a particular genetic origin. Although such problems are likely to be at a low frequency, two examples are disease issues (as defined by disease status of individuals) and poor meat quality (tendency to high pH, dark cutting meat, toughness). Another possibility that may help supermarket/processor buy-in is the perceived problem around the lack of 'finish' on carcasses due to the major focus on size and muscling.

Improved connections between the production and processing sectors are essential to help define the value proposition for genetic improvement. Specifically, the availability of the infrastructural systems to enable the necessary data flow (from abattoirs to the data system) is required. This development will ensure that price signals can be objectively linked to superior performance associated with genetic improvement. Two particular features, both of which would require individual (electronic) identification and tracking, which could be expected to encourage farmers to supply direct to processors are:

- carcase data (meat yield as an objective measure of carcase yield to replace subjective systems, fatness, pH, and (predictors of) consumer quality traits such as colour as a measure of quality (consumers see more red meat as fresher), and fatty acid composition, and
- health/disease status of individuals at slaughter.

Recommendation 9: Build a focus on the development of wider data sets and better phenotypes in general, including data for hard-to-measure (HTM) traits.

Delivery and implementation

There are three central features to delivery:

- systems to provide support to breeders,
- making the case for objectively-based genetic improvement, and
- providing the evidence for uptake.

The importance of making the case for objectively-based genetic improvement has already been addressed above. Therefore the section below looks at the provision of support for breeders and the need to gather data and provide evidence of update.

Support for breeders

Support for breeders is fundamental to the success of genetic improvement systems. In this respect, UK levy organisations including EBLEX, along wtih BASCO, ABRI and Breed Societies all have key roles in the delivery of genetic improvement. Experience around the world is that when delivery of services is not co-ordinated at an industry level, market failures lead to grossly sub-optimal genetic improvement outcomes. However, the efficiencies gained through competition and choice often have positive impacts on genetic improvement outcomes, and can mitigate substantial costs of monopolised central state systems. An umbrella of industry-wide support across the commercial service providers is critical to achieving effective outcomes. In addition to co-ordinating many activities as discussed throughout this report (involvement in the recommended commercial ram evaluation scheme, meeting co-ordination, and development of demonstration and extension activities are examples), striving for a "common currency" approach to communication of genetic improvement messages is highly desirable, to avoid confusion, and minimise the impacts of misleading advertising and false claims of genetic merit.

Recommendation 10: Establish a process to ensure that there is an ongoing (and possibly increased) availability of services from commercial service providers, albeit assisted by a central (levy- and user-funded) body to ensure a co-ordinated approach that also provides targeted support for key initiatives, and which facilitates the provision of clear, transparent and industry-friendly communication of genetic improvement principles.

Measuring uptake or adoption

The uptake and (rate of) adoption of improved genetics are major drivers in terms of realizing the impact of genetic improvement. Estimating adoption is fraught with uncertainties and while we have estimated adoption based on the production of sires from recorded herds/flocks and estimated usage, we have stressed the potential for large upside to benefits if greater adoption of improved genetics can be facilitated.

This discussion highlights the importance of measures of uptake which are critical to understanding and defining the impact of genetic improvement at a national level. There are two key aspects: first the sales of animals from recorded herds and flocks, and second, their use commercially. Such data could be collected through some soundly-based surveys; these would cover bulls/rams purchased, type (terminal, maternal), usage (mating ratios, years of usage) in the flock/herd. Another source of such data may be some of the farm business consultancy practices although how representative they may be is a potential issue in terms of relevance.

The cost benefit of this initiative is hard to quantify, as the benefits will come in the future from actions initiated in response to changes in rates of adoption that occur over time. Our belief though is that the benefits will be very high relative to costs, because collection and publication of such data collected every 2 to 5 years, would motivate and incentivise all participants in the genetic improvement pipeline to act in ways that increases adoption and penetration of improved genetic improvement practices.

Recommendation 11: Establish systems to enable the ongoing capture of data on genetic technology adoption (i.e. level of performance recording within the industries and extent to which performance recorded males are purchased, as a proportion of all males) to provide information that can be used to help target approaches to ensure the effective dissemination of genetic improvement.

International bench-marking

The state of sheep breeding across the more developed world was recently reviewed by Amer et al. for an FAO publication that has not yet been released. Material from the submitted report has been reproduced as Appendix 5. With the possible exception of the milking sheep industry in France, the impact of genomic selection approaches has so far been relatively modest across a number of sheep industries, despite considerable investment over a number of years. There is clear evidence of gains in genetic progress, but these are marginal gains, rather than big gains from large improvements in accuracy of selection.

To date, there have probably been greater realised benefits from investments in recording structures and resource populations. In particular, progeny testing of industry rams in New Zealand, Australia, and Ireland are good examples. There is still considerable hope and promise that genomic approaches will improve, and in particular, help broaden the set of traits in which meaningful genetic progress is achieved. In contrast to the substantial investments in structured matings and/or resource populations for genomic predictions in New Zealand, Australia, Ireland and France, investment in the UK has been much more modest. There have been substantial spin-offs for conventional genetic evaluation and improvement from these structures, sometimes designed with a main purpose to facilitate developments in genomics. Challenges encountered with delivery of genomics include the data management and statistical challenges of integrating predictions of genetic merit from multiple sources. While theoretical solutions to the problem exist, their deployment into practical and routine analysis and reporting systems is far more difficult than initially was envisaged. Furthermore, problems inherent to existing genetic evaluations such as poor connectedness, pedigree errors, and incorrect recording of contemporary groups that have gone un-noticed in routine evaluations, become exposed as more rigorous testing and validation procedures are applied to test genomic predictions. An important implication for the UK sheep industry is to ensure that any new investment targeting genomic implications, does at the same time, serve to underpin and improve conventional genetic evaluation, and to improve trust in and adoption of, performance recording approaches.

Amer and others also recently compared beef breeding structures around the world, and this was presented at the ICAR meeting held in Cork, Ireland in 2012. The written background to the presentation is presented in this report as Appendix 6. In summary, the genetic trends for growth traits in UK beef breeds are quite variable, but within the ranges observed in other countries. Globally, breed is a much greater source of variation in the rate of genetic progress observed, than the country where the breed resides. While many countries are holding potentially unfavourably correlated (with growth) birth traits in check, this was not so strongly apparent across the UK breeds which appear to be variable in the direction of their trends for calving traits.

Importation of genetic change is a significant driver of progress in beef cattle populations in New Zealand, Australia, and Ireland. It is likely that a significant proportion of genetic trend in continental breeds in the UK is driven by importation of elite foreign sires.

There has been substantial variation across countries in the level of investment in absolute terms, and also when expressed per breeding female. The majority of investment underpinning beef genetic improvement around the world comes from user-pays revenue which supports recording and sometimes genetic evaluation activity. In the international comparison (Appendix 6), it is evident that the UK is as one of the countries towards the extreme end of the user-pays structure.

New Zealand, as another country with a strong user-pays basis for beef cattle genetic improvement has recently initiated a number of new investments, including the establishment of sire evaluation structures on commercial farms using AI matings. Part of the driver of this investment is the concern of a significant genotype by environment interaction between the stud and commercial sectors, but data valuable for future genomic prediction will also be generated. Research collaboration with Australia is being actively established, as the provision of genetic evaluation across the main New Zealand beef breeds is through BREEDPLAN, and there is a lot of interchange of genetic material between New Zealand and Australia. In Australia, there has been significant investment in so-called Beef Information Nucleus (BIN) systems, involving matching investment from breed societies and federal government funds through Meat & Livestock Australia. These structures (discussed further below) provide a dual role of improved sire evaluation, and an information source to facilitate genomic predictions. It is notable that the Irish, USA and French beef industries benefit from research investment from either national tax-payer funds, or from farmer levies.

As for sheep, the problem of integrating multiple sources of genetic merit predictions has been an issue arising from attempts to deploy genomic selection in beef industries. Initially, genomics companies attempted to deliver and promote stand-alone genomic predictions of genetic merit. However, this creates a lot of tension in the market, with commercial bull buyers becoming confused by the meaning of the different tests and predictions, often on different scales and with different trait definitions to the existing industry breeding values. There is a temptation for breeders paying for the tests to use them as a marketing gimmick, rather than actually using them to make improved selection decisions. Best practice is to have the original SNP data available for the national genomic prediction engine, and largely the international genomics companies have been forced into complying with this approach. Where different companies provide competing testing services, there can be problems if these companies wish to use subsets of phenotypic information that they regard as IP to market added value products and services. In general, claims of test efficacy based on foreign phenotypic data have been disappointing, and the local phenotype resource will be critical to the success of genomic selection. The implication is that for any breed or breed group pursuing genomic selection, there should be a standard genotype platform used, and the resulting SNP data should be available for the genetic evaluation system. The core phenotypic resource used should involve a pool of animals that are closely related to the selection candidates to undergo genomic tests.

Trait improvement prioritisation

A number of factors determine the research investment priority for a given trait under genetic control. For each trait, the industry economic benefit should be quantified for a defined level of improvement (perhaps 10%). This represents a first stage in prioritising a trait for genetic improvement.

Guidelines for a methodology to assess trait improvement priority

In addition to an analysis of the economic benefits arising (above), a survey of stakeholders aimed at establishing scores (on a scale of zero to one) on the following definitions and criteria can be used to prioritise traits for improvement. The product of these scores, when combined with economic benefits, represents a measure of priority.

- Likelihood that genetic variation exists to achieve the improvement
    - If no genetic variation exists a value of zero will be assigned to the trait.
- Current scientific capability/knowledge of the trait
    - If limited scientific capability/knowledge of a trait is present it will be assigned a value closer to zero.
- Cost and ease of getting phenotypes sufficient for Genome wide selection
    - If there is a need for larger numbers of animals or if a large number of animals with existing phenotypes would need to be DNA tested with little spinoff benefit to other traits, then a figure closer to zero should be chosen.
- Historical investment versus product yield

  - If historical investment in genetic research has resulted in negligible return, a figure closer to zero should be chosen.
- Counter-factual
  - If there is a higher abundance (or ease) of alternative (non-genetic) ways to improve the trait it should be assigned a weighting closer to zero.
- Customer demand
  - If a product developed for this trait is perceived to have low customer demand then a figure close to zero should be chosen. In other words, if either breeders or commercial farmers have limited interest or incentive for improving the trait.
- Assessment as a research priority
  - If deemed a very low priority for research then a figure close to zero should be chosen, a very high priority should be close to one.

Opportunities for genomic selection (in the UK) – TOR 3

The focus in this section is on a framework for the ***establishment of potential best practices*** in the use of genomic tools to accelerate genetic gain in the UK industry. This includes investment with a particular focus on the collection and analysis of phenotypic data and the genetic structure of individual (breed) populations. As background to this section, we have provided an overview of the current state of genomics and genomic selection as Appendix 7.

The development of this framework has been informed by the strengths and weaknesses highlighted above which have been considered in terms of the potential of, and the opportunity for, the development and application of genomic selection approaches in the UK industry.

Best practice, needs and the case for investment

The application of genomics in animal breeding (genetic evaluation and genetic improvement) represents a paradigm shift. Genomic approaches promise faster rates of genetic gain overall, a much more effective way to deal with, and make improvement in, the so-called *hard-to-measure* (HTM) traits, and a potential means to integrate supply chains.

Therefore we consider the case for future investment in three specific areas: the *implications of genomic approaches, genomics investment as an investment in options,* and *delivery and implementation.* Genomics in the context of the UK sheep and beef industries is potentially disruptive leading to positive outcomes.

Implications of genomic approaches

While there is considerable potential to capture new value from genomic selection this will be limited without a change in structure of data collection and evaluation practices and further development of the technology. Therefore there is a major opportunity/necessity to develop a new framework for the development and application of genomic tools in systems to accelerate genetic gain. There are four specific issues to consider which have wide implications:

a) the critical importance of phenotypes (and hence the collection of ***phenotypic data***),
b) the density of the genotyping platform used and the role of imputation
c) recognition of the ***genetic structure*** of populations, and
d) support of the ***core infrastructure*** for the management and analysis of data.

Consequently, in respect of each, it is important to recognise the importance of:

a) the value propositions for performance recording pedigree and commercial producers, and downstream users (e.g. processors) to capture ***phenotypic data*** (tools for incentivisation); the potential of, and the value propositions for, novel phenotypes (many of which represent HTM traits such as disease resistance traits, product quality traits and greenhouse gas traits including methane and nitrous oxide);

b) the recognition of the ***genetic structure*** of the individual (breed) populations and the associated importance of connectedness across herds and genotyping of individual animals in the development of genomic tools and in the application of genomic selection; and

c) the support of the ***core infrastructure*** for the management and analysis of data including the tools for genetic evaluation (including underpinning analytical software and methodologies).

Phenotypic data

Without a change in the way that data are collected, the result could well be an increase in cost without a parallel increase in value.

There is potential for the application of genomic technologies (by defining the genotype of individuals and matching products to source) to generate additional data through the value chain. Arguably the greatest value will come from integrating data from the supply chain back into breeding and production systems. This could range from data collection such as that around meat quality and the consumer eating experience through to detailed growth and finish (marbling) performance in cattle.

This is effectively a DNA-enabled progeny-testing approach. However such approaches are critically dependent on defining and incorporating the structure of the 'progeny test' within the analysis (the environmental component which includes factors such as the property of origin, feeding group, etc). The major issue is to avoid the confounding of genotype and environment. DNA systems also provide the opportunity to identify problems that are relatively uncommon but important. These include 'symptoms' of problems such as diseases of animals in intensive growing facilities or a high incidence of poor quality meat products from a suspected common source, where a genetic link might be suspected but not detectable. Again the same issue of managing structure (property of origin, management group, etc.) is critical within the analysis.

In sheep and cattle, the need for, and the value proposition to, increase the rate of genetic gain in maternal traits represents both a particular challenge and an opportunity for breeding schemes. This applies to those groups with a focus on investment in genetic progress and who are prepared to undertake detailed recording. In this respect, practices that will facilitate uptake and encourage industry-wide adoption of genomic technologies within the sheep and beef cattle industries are critical. The realisation that the successful implementation of genomic technologies is actually due to a better description of underlying genetic relatedness is critical to understanding the opportunity. In essence, the success of genomic selection to date is largely due to the methodology that accounts for identity-by-descent.

This reality puts a premium on the on-going generation and collection of high-quality phenotypic data for performance traits such as fertility and survival that are especially important in the commercial sector. While collection of data for some HTM traits such as feed intake and new traits such as methane production are well-suited to evaluation through centralized facilities (albeit problematic in pregnant and lactating animals), other traits will require much more data. In particular, recording of breeding cow fertility, survival and performance will be critical to avoid costly unfavourable outcomes from continued selection on growth rate and potentially also residual feed intake in young growing animals. Hence this highlights the critical importance of, and the value proposition for, downstream (DNA-enabled) progeny testing.

Recommendation 12: Establish systems to provide a renewed focus on the collection of high quality, preferably commercial, phenotypes for maternal traits such as initiatives to record body condition score, increase the accuracy of phenotypes for fertility (beef), and enable the recording of mature weight.

Recommendation 13: Establish a research project to evaluate the potential for an industry-level programme to focus on the collection of data (phenotypes) for diseases on slaughtered animals to enable (in the longer term) the development of genomic evaluations for disease traits.

Recommendation 14: Establish a parallel research project to evaluate the potential for an industry-level programme to focus on the collection of phenotypes for eating quality traits to enable (in the longer term) the development of genomic evaluations for these traits.

Genetic structure

There is an inherent population structure within a breed or strain of animals. Utilising this structure is a key to realising the benefits of genomic selection in a number of ways including:

- utilisation of males to provide genetic connectedness between flocks/herds,
- utilisation of the inherent structure and genetic relationships within breeds within the beef and sheep populations,
- the genotyping of influential individuals.

Given these factors, the value of an Information Nucleus demonstration herd/flock (Saatchi *et al.*, 2013) is immediately evident. The co-ordinated collection of downstream (effectively progeny-test) data that are integrated through DNA-based relationship analysis is a major opportunity to extend the reach of the nucleus herd/flock. However the critical importance of accounting for the environmental component must be recognised in the design of the analysis (as noted previously). Genomic approaches are being successfully applied in dairy cattle – this is primarily a function of the small effective population size, the very close relationships between individuals within the population and the very high quality phenotypes. While it is reasonable to expect that genomic approaches will have a future in genetic improvement in sheep and beef cattle, there is a lot of work required and the route to the practical application of genomics in sheep and beef cattle is not yet clear. However there will be considerable value in applications for ‘hard to measure’ traits (feed efficiency) but the methodology requires further development. The essential factors in the successful application of genomics are that the relationship between the reference population (for which there are both phenotypes & genotypes) and the test population (for which there are genotypes only) must be very strong. Any claims for the application of genomics across breeds must be treated with scepticism given the now well-known importance of strong genetic relationships in determining the accuracy of genetic prediction using genomics.

SNP density and imputation

The choice of genotype density is a major area of consideration in both genomics research, and in application of genomic selection. Costs of higher density genotyping platforms, including sequencing, are constantly declining, although it also needs to be recognised that per animal test costs remain high and still constitute a significant challenge for the commercial application of genomic selection. This is particularly so in lower unit value animals such as sheep, where the value of progress achieved is less relative to the genetic impact and gains that can be associated with that test. This is in stark contrast to the value and benefits that can be considered when genotyping both proven dairy bull, and young dairy bull candidates that, once selected, can potentially go on to make a substantial genetic contribution to the population. A substantial amount of recent research has focused on **imputation** as an option for gaining a high proportion of the information available from high density platforms through statistical inference from information provided from a combination of low density information on an individual, and higher density genotype information on key ancestors. These approaches work best in situations where a large number of key ancestors have high density genotypes, and where the difference in density between the high and low density platforms is not too great. The idea behind imputation is to drive down the cost of genotyping, while maintaining predictive efficacy. An additional advantage is that they can facilitate genomic selection in situations where genotypes of different densities are available in a single population where a combined analysis would be beneficial.

Because SNP density in excess of 15 to 30k yields only relatively trivial increases in the accuracy of conventional genomic selection approaches, new approaches to genomic selection are going to be required to exploit imputation to higher density. The most likely prospect from gains achieved through imputation will likely come when the approach results in identification of genetic variants that have at least modest impacts on traits, and where these impacts hold up across populations with large effective population sizes. Similarly, if the effects of these variants are consistent across breeds and countries, they may be of value to boost the effectiveness of genomic selection in small populations and breeds. These approaches are receiving considerable research investment in many countries, but are as yet unproven.

Best practice is to make sure that key ancestors (e.g. sires within a population with many progeny and sons with progeny) in any population under consideration are genotyped at a high density of markers within the available budget. This should be at least 600k density if possible, and high quality DNA samples should be banked for potential future sequencing.

Recommendation 15: Establish systems (in the beef and sheep populations) for the development of genomic selection methods including the development of new phenotypes (especially for HTM traits) that are underpinned by structures that: utilise males in ways that ensure excellent genetic connectedness between flocks/herds; utilise the inherent structure and genetic relationships within (and between) breeds; and that provide for the genotyping of influential individuals (see recommendations 3 and 4).

The role of international collaboration in genomics

It is widely recognised that large populations of individuals with both recorded phenotypes and sampled genotypes are required to achieve genomic predictions of reasonable accuracy. This has prompted much discussion about the role of international collaboration in ensuring that populations are of sufficient size. However, when the genomic selection approach relies on better prediction of relatedness, there are significant limitations to the value of international collaboration unless there are close historic relationships between the populations. It is particularly important to note that the 'same' breeds may be very different in different countries. For example, Texels in the UK are very different to Texels in New Zealand, with only very distant relationships albeit from the same original genetic base. Similarly UK Angus cattle are quite different from those in much of the rest of the world. There are likely better opportunities for the Continental beef breeds to link in with their counterparts in France although French programmes may see little benefit to their own programmes from sharing data and information.

The higher density genotyping approaches may be more productive in the international collaboration domain. Finding variants of moderate to large effects, and ascertaining their effects in other countries is more likely to be effective than trying to do genomic selection internationally. In this context, smaller resource populations for genomic selection may still add some value for traits where genes of moderate to large individual effects are common. Litter size in sheep, and carcase conformation are examples of such traits. Where populations and initiatives are limited in size, it is important that high quality DNA is collected and stored and accurately linked to the phenotypic records. All relevant animals should be considered including dams and lambs in addition to sires.

Recommendation 16: Establish systems for the collection of DNA (and semen) from resource populations that are generated in industry demonstrations or sire evaluations, especially those with relatively small numbers of individuals per breed; the DNA would be available for the future investigation of putative genetic variants in addition to its application in genomic approaches for better prediction of relationships.

Genomics for small populations

Little research internationally has focused on the opportunity to apply genomic selection in smaller niche populations where most individuals have some relationship to a significant number of other individuals in the population. Examples of these populations include smaller niche traditional breeds, and sometimes composite breeds which have been underway for a number of generations. A watching brief should be maintained to identify opportunities to apply genomic selection in these populations. In particular, there may be opportunities where a number of key breeders within the breed have a desire to improve a particular hard to measure trait. For example, a meat and/or eating quality trait recorded on slaughtered descendants of a number of key sires might provide genomic predictions through predictions of relationships at the genomic level, across a large proportion of the population because of the extent of common relatedness.

Opportunities for smaller breeds and tightly-knit breeding programmes require less co-ordination, and could help mitigate inequities that come about because most current genomic approaches are heavily biased in favour of the predominant breeds.

Recommendation 17: Take a watching brief to assess opportunities to apply genomic selection approaches in smaller breeds and populations (including initiating discussions with countries who also have small populations of relevant breeds).

Core infrastructure

The support of the ***core infrastructure*** for the management and analysis of data is essential to realise the benefits of genomic selection. The issue of incorporating environmental factors into the analysis to avoid confounding of genotype and environment is critical as highlighted above. Experience in New Zealand and Australia is that deficiencies in conventional genetic evaluation infrastructure can undermine the potential for applications of genomics. For example, in Australia, the presence of three quite different sub-populations of Merino sheep has made delivery of genomic predictions that work effectively within sub-populations challenging. In New Zealand, uncertainties about the degree to which genetic connectedness is sufficient for accurate comparisons of sires across breeds and sub-populations of sheep differing widely in genetic merit for key traits is thought to be a contributor to lower than anticipated accuracies of genomic predictions for traits already widely recorded.

Where genomic approaches generate new information, it is important that this new information does not add excessively to the already complex array of information generated from the genetic evaluation process. Improved statistical and analytical processes for efficiently and appropriately incorporating genomic information into routine genetic evaluations and selection list reports used by breeders are therefore required.

Recommendation 18: Provide for ongoing investment in genetic evaluation infrastructure to ensure that population sub-structure and contemporary group connectedness issues are accounted for, and that new genomic information is incorporated into existing evaluations as seamlessly as possible.

Genomics investment as an investment in options

The potential opportunities are very broad and the future is very uncertain. Therefore it is important to recognize the potential for EBLEX programmes to create future options for the industry.

Central concept

The central concept is that genetic improvement provides options. In other words, it is a form of insurance that enables producers to better manage forward risks and better exploit forward opportunities.

A core objective of an investment in R&D must be one that provides some of the means to enable a much quicker response to adverse situations and/or the means to help capitalise on opportunities that arise. Some examples include changes in the market (e.g. greater competition from other countries such as those from Eastern Europe and South America in export markets, increased demand for ground beef in some markets[6]), changes in the production environment (e.g. due to new disease challenges or to a more variable climate or the requirement to farm within regulatory limits such as nutrient loading of water catchments), and changes in technologies (such as automated systems for data collection based on individual electronic identification, and applications of genomics especially in terms of the options around capturing data from commercial flocks and herds).

Value and importance of traits

There are some traits which are always likely to be important because they are fundamental to the productivity of the female and hence to the profitability of the enterprise (gain in carcase weight and weaning percentage are examples) and hence they are important for all breeds. However there are other traits which are likely to become more important in the future. These include feed efficiency, and a reduced output of methane (per unit of feed intake and ultimately per unit of product sold). There are other traits that are relatively more important for particular breeds such as meat quality. While the rate of change within a breed may be limited (by the extent of variation within that breed), there is considerable opportunity to exploit differences between breeds. In this respect two opportunities to exploit the power of genomic technologies are to:

- help define the value proposition for cross-breeding using real on-farm data, and
- defining the response of individuals within a herd to disease challenges.

Both can both be considered as applications of options thinking in that they help provide a broader range of possibilities for the future.

Potential Best Practices

Is genomics a potentially disruptive innovation?

The previous section on genomics as an investment in options provides the background for this part of the report. In particular, we consider here some ***potential best practices*** in the application of use of genomic tools to accelerate genetic gain. While undoubtedly there is considerable potential to capture new value from genomic selection this is limited without a change in structure of data collection and evaluation practices and further development of the technology. Without a change in the way that data are collected, the result could well be an increase in cost without a parallel increase in value. Hence the value proposition for the integration of genomic approaches within an established industry is that to have any impact, it is almost by 'obligation' a disruptive innovation[7]. In

[6] Rabobank AgFocus (January 2014), Ground beef nation: The effect of changing consumer tastes and preferences on the US cattle industry

[7] See The Innovators Dilemma www.claytonchristensen.com/key-concepts/#sthash.WmFx3MaZ.dpuf (Clayton Christensen); Disruptive innovation describes a process by which a product or service takes root initially in simple applications at the bottom of a market and then relentlessly moves up market, eventually displacing established competitors. Characteristics of disruptive businesses, at least in their initial stages, can include: lower gross margins, smaller target markets, and simpler products and services that may not appear as attractive as existing solutions when compared against traditional performance metrics. Because these lower tiers of the market offer lower gross margins, they are unattractive to other firms moving upward in the market, creating space at the bottom of the market for new disruptive competitors to emerge.

other words it will likely see a major change in the structure of the industry. Such changes have been seen before in the livestock breeding industries. Examples include the impact of AI in the dairy industry which completely changed the role of the bull breeder through facilitating the development of progeny testing of young bulls which lead to a corporatisation of the bull evaluation and replaced the sale of bulls with AI. The decline in sheep numbers, the availability of DNA parentage and the development of central progeny testing disrupted the NZ ram breeding industry. The limit on the number of ewes that a lambing shepherd could manage (in terms of matching dams and offspring) became irrelevant, ewes could be run in commercially-relevant environments such that the number of breeders reduced and the flock size of ram breeding flocks increased greatly. Paradoxically some breeders opted to reduce their input and set up multiplier flocks of high profile breeders and sold rams with minimal input.

Development of novel traits

Genomic selection offers opportunities to generate value from incorporation of non-traditional traits in genetic selection. Good examples include meat quality and health traits. Pre-genomic methods such as BLUP are limited by the need to generate data through the recording of phenotypes and/or progeny testing on a relatively large scale. Consequently collection of such data can be prohibitively expensive and is often limited to industries that are either vertically-integrated (pigs and poultry) or where there are well-developed artificial breeding (AB) systems that enable the widespread utilisation of elite males through AB such as with dairy cattle.

Genomics offers a paradigm shift in that a breeding programme can be structured such that data can be collected on a smaller number of animals within a well-structured nucleus population(s). These populations must be designed so that they incorporate the key sources of genetics from within the wider (e.g. breed) population so that the data and information generated are relevant to the wider population. As there is a need to sample a much smaller number of animals than in pre-genomic systems, the cost of individual assessments is much less of an issue. A good example is the use of CT (computed tomography) approaches in sheep breeding schemes.

In addition there is the opportunity to collect progeny test data through commercial ventures as accuracy of pedigree is no longer an issue as pedigree can effectively be re-constructed using genomic approaches through gBLUP. Good examples are health traits for animals in feedlots, meat quality traits at slaughter, and maternal traits such as longevity and cow health.

There is a potential advantage for genomic selection in a reduction in generation interval that is achievable given the availability of good quality phenotypic data both in the nucleus and in downstream related herds through the capture of data where the value is realised through pedigree re-construction. The Australian Merino Information Nucleus (Clark *et al.*, 2012) provides an example of the operation of the nucleus, although the utilisation of the outputs downstream through the industry is a work in progress.

How could this apply to breeders? In the context of the bull and ram breeding industry, established breeders who have captured the high-priced auction market do not see the threat at the bottom of the market. It is only when the commercial realities bite the purchaser that the established breeders realise that it is too late. In this context, new (objective) technologies have greatly impacted the NZ ram breeding industry such that the show-led approach has become virtually irrelevant.

New opportunities in evaluation

There is a major opportunity to develop a new framework for the development and application of genomic tools in systems to accelerate genetic gain. These include:

- improved processes for the collection and analysis of phenotypic data,
- utilisation of males to provide genetic connectedness between herds,
- utilising the inherent structure and genetic relationships within breeds within the cattle population,
- the genotyping of influential individuals.

Given these factors, there is a strong case for the development of Information Nucleus herds[8] and the co-ordinated collection of downstream (effectively progeny-test) data that are integrated through DNA-based relationship analysis. The need to increase the rate of genetic gain in maternal traits represents both a particular challenge and an opportunity for breeding schemes with a focus on investment in genetic progress and who are prepared to undertake detailed recording.

Role for genomic technologies through the value chain

There is potential for the application of **genomic technologies** to generate additional data through the value chain. This could include data collection such as that around disease status and meat quality. As noted above, this is effectively a DNA-enabled progeny testing approach.

There is also the opportunity to utilise genomic technologies in **traceability** of meat products. However the costs of such approaches which require that a DNA sample is taken in the processing plant and stored in the event that a product must be sourced back to its origin, means that such systems have been adopted only in specific higher value supply chains; such systems include SureTRAK (Australia), and IdentiGEN[9] (Ireland, UK and US). This blockage to widespread adoption will only be overcome when real-time DNA analysis is available at a cost that will enable its application in the meat processing plant so that data are stored rather than samples.

Arguably the greatest value will come from integrating data from the supply chain back into breeding and production systems, especially as DNA systems provide the opportunity to identify problems that are relatively uncommon but important. These include ‘symptoms’ of problems such as diseases of animals in feedlots or a high incidence of poor quality meat products from a particular meat plant where, in such cases, a genetic link might now be suspected but undetectable. DNA-based systems will enable such analysis.

Facilitating uptake

Practices that will **facilitate uptake** and encourage industry-wide adoption of genomic technologies within the beef cattle industry are critical. A critical issue that will greatly impact on the realisation of potential is the effective development of an integrated supply chain. This is important to both

[8] The value of the training set is a function of the relatedness of that set of animals to the population under evaluation. Hence it is essential that they are closely-related Saatchi, M., Ward, J., Garrick, D.J., 2013. Accuracies of direct genomic breeding values in Hereford beef cattle using national or international training populations. Journal of Animal Science.

[9] http://animalgenetics.pfizer.com/sites/PAG/nz/Documents/SureTRAK_Brochure_NZ.pdf; www.identigen.com/

provide a strong incentive for investment in genetic improvement and to the realisation of many of the benefits of genetic improvement. This can only occur in the event that the supermarket/processor can assess the potential of genetic lines of cattle to perform within their system. However this will require integration from the breeder to the cow-calf producer and arguably the development of genomic tools for marker-assisted management, where genomic analysis coupled with analysis of early life phenotype provides a predictive tool for use in selection of individuals.

Genomic technologies also provide new opportunities to increase genetic gain in crossbred populations such as Stabilizers. While genetic analysis based on DNA-based relationships offers the potential to evaluate bulls as sires for meat production, it may also offer the opportunity to dissect the contributions of parental breeds and the contribution of heterozygosity.

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Appendix 1: Estimating industry benefits of current genetic gain in the UK sheep industry

Introduction

Investment in genetic improvement required justification that a return to the industry, and/or society, is sufficient to offset the cost of the investment made. Amer et al. (2007) published a detailed cost benefit analysis for the UK sheep and beef genetic improvement industries and found significant returns from beef industry genetic progress and terminal sire sheep genetic progress up until 2004/2005. The intention of this report is to provide an update of the results presented by Amer et al. (2007), with new and more recent genetic trend information and with some modifications to the methodology used.

Methods

Estimating genetic trends

Average estimated breeding values (EBVs) were provided by EBLEX for the sheep breeds: Beltex, Beulah, Bluefaced Leicester, Charollais, Dorset, Hampshire Down, Lleyn, Meatlinc, NCC Hill, NCC Park, Scottish Blackface, Shropshire, Southdown, Suffolk, Texel, Vendeen and Welsh Mountain. Hampshire down, Suffolk and Texel had data for recorded and non-recorded flocks, while all other breeds had data for recorded flocks only. Flocks of unknown origin were removed from the analysis.

There were some potential biases created by some flocks migrating in and out of the genetic trend information over years. When poorer merit flocks drop out of recording, an artificial inflation of the genetic trend estimate might be expected. For this reason, genetic trends were calculated on a per flock and year basis (EBV difference between successive years within flock), weighted by the minimum number of lambs born by year within each pairwise comparison. The average genetic trends across all flocks, by year, were then calculated for 8 week weight, CT Fat, CT Lean, litter size, maternal ability, mature weight, scan weight and muscle depth, where data was available.

The final genetic trends used for each trait were the average of these genetic trends from 2009-2013, inclusive. The number of lambs and flocks by breed within the 2009-2013 period is presented in Table 2.

Table 2: Average annual number of lambs over the 5 year period 2009-2013, as well as number of the sum total (over 5 year period) of flocks contributing to these numbers, by breed.

Breed	Number of lambs	Number of flocks
Beltex	678	21
Beulah	1,118	6
Bluefaced Leicester (BFL)	1,412	38
Charollais	6,850	93
Dorset	4,537	25
Hampshire Down (Rec/not-recorded)	1,444/407	50/27

Lleyn	18,880	73
Meatlinc	1,413	7
North country cheviot (NCC) hill	1,281	10
NCC park	1,473	17
Scottish blackface (SBF)	5,020	29
Shropshire	899	23
Southdown	622	15
Suffolk (Rec/not-recorded)	6,637/22,809	94/1,011
Texel (Rec/not-recorded)	15,012/51,619	248/1,645
Vendeen	347	4
Welsh mountain	3,562	17

Application of genetic trend data to industry

On average, the genetic trend for 8 week weight was twice as high in the recorded compared to the non-recorded populations for Hampshire Down, Suffolk and Texel. Therefore, the model assumed that the genetic trend in non-recorded animals for all traits was half that of recorded populations for these breeds. The same assumption was made for highly integrated breeds Charollais and Dorset. With the exception of Meatlinc, where all animals are recorded, genetic trends in non-recorded animals for all other breeds were assumed to be one quarter of that in recorded populations.

The proportion of each breed making up the hill, terminal, crossing, longwool and shortwool types are presented in Table 3. For terminal breeds, it was assumed that 25% of the breed is recorded and 75% is not. For all other breed types, it was assumed that 20% were recorded. This information was used to calculate the proportion of genetic trend coming from each breed in each of the mating categories presented in Table 4.

Table 3: Proportion of each breed making up the hill, terminal, crossing, longwool and shortwool types, based on Pollott (2013).

Hill breeds							
		Beulah	NCC	SBF	Swaledale	Welsh mountain	Other
Proportion within hill breeds	Ewes	0.037	0.076	0.292	0.187	0.251	0.155
	Rams	0	0.082	0.267	0.108	0.204	0.340
Proportion recorded		0.2					
Proportion not recorded		0.8					
Terminal breeds							
		Suffolk		Texel		Other	

Proportion within terminal breeds	Ewes	0.265	0.620	0.114
	Rams	0.242	0.513	0.245
Proportion recorded			0.25	
Proportion not recorded			0.75	
Crossing breed				
		BFL		Other
Proportion within crossing breeds	Ewes	1		0
	Rams	1		0
Proportion recorded			0.2	
Proportion not recorded			0.8	
Longwool – not crossing				
		NZ Romney		Romney marsh
Proportion within longwool breed	Ewes	0.26		0.74
	Rams	0		1
Proportion recorded			0.2	
Proportion not recorded			0.8	
Shortwool				
		Easycare	Lleyn	Polled dorset
Proportion within shortwool breed	Ewes	0.16	0.73	0.12
	Rams	0.16	0.76	0.08
Proportion recorded			0.2	
Proportion not recorded			0.8	

Eight week weight, litter size, maternal ability and mature weight were calculated as ewe traits – that is the contribution of the ewe from each mating class was taken into account to derive genetic trends for these traits. Muscle depth, scan weight, lean weight and fat weight were calculated as progeny traits – that is the contribution of both the ewe and ram from each mating class was taken into account to derive genetic trends for these traits.

For direct traits within each mating category, the overall genetic trend (DGT) for each of the traits was calculated as,

$$DGT = \sum_{i=1}^{17} \left[0.5\left(g_i p_{id}(r_i + 0.5n_i)\right) + 0.5\left(g_i p_{is}(r_i + 0.5n_i)\right)\right]$$

where, i denotes each of the 17 breeds presented in Table 3, $\mathrm{g_i}$ is the genetic trend of the trait for breed i, $\mathrm{p_i}$ is the proportion of that breed in the mating category (for sires, s, and dams, d), $\mathrm{r_i}$ is the proportion of recorded animals within that breed and $\mathrm{n_i}$ is the proportion of non-recorded animals within that breed (Table 3). For direct traits, the mating categories were classed by breed type (hill, terminal and longwool/crossing) according to the ram contribution. The average genetic trend across all mating categories of a breed type was calculated and weighted by the ewe numbers within mating categories to derive the average industry genetic gain achieved for each trait within each breed type.

For maternal traits, the overall industry genetic trend (MGT) for each trait within each ewe breed type (hill, longwool/crossing and terminal) was calculated as,

$$MGT = \frac{\sum_{i=1}^{b}\left[\sum_{j=1}^{35}\left(\frac{g_i p_{ij} r_i m_j}{t}\right) + \sum_{j=1}^{35}\left(\frac{g_i p_{ij} n_i m_j}{t}\right)\right]}{c/t}$$

$$MGT = \frac{\sum_{i=1}^{b}\left[\sum_{j=1}^{35} g_i p_{ij} r_i m_j + \sum_{j=1}^{35} g_i p_{ij}(1-r_i) m_j\right]}{c}$$

where, b is the number of breeds within the breed type, i is the ith breed of that breed type, j is the jth mating category of the 35 different mating categories, gi is the genetic trend of the maternal trait for breed i, pij is the proportion of breed i in mating category j, r_i is the proportion of recorded animals of that breed, mj is the number of ewes in mating category j, c is the number of ewes in the breed type for which the trend is being calculated and t is the total number of ewes in industry. The resultant trends were therefore weighted by the impact of each mating category on the overall industry.

Table 4: Mating categories. Adapted from Pollott (2013).

Breeding	Ewe type	Ram type	Ram category	Ewes (000)
Crossbred	HillxHill	Hill	Hill	45
Crossbred	HillxHill	Others	Other	74
Crossbred	HillxHilll	Terminal sires	Terminal	44
Crossbred	LongwoolxHill (mule)	Other terminal sires	Terminal	420
Crossbred	LongwoolxHill (mule)	Others	Other	271
Crossbred	LongwoolxHill (mule)	Suffolk	Terminal	896
Crossbred	LongwoolxHill (mule)	Texel	Terminal	1455
Crossbred	Other crosses	Other terminal sires	Terminal	230
Crossbred	Other crosses	Others	Other	666
Crossbred	Other crosses	Suffolk	Terminal	185
Crossbred	Other crosses	Texel	Terminal	423
Crossbred	Other terminal sire crosses	Others	Other	300
Crossbred	Other terminal sire crosses	Other terminal sires	Terminal	330
Crossbred	Other terminal sire crosses	Suffolk	Terminal	243
Crossbred	Other terminal sire crosses	Texel	Terminal	983
Crossbred	Terminal sire x	Other terminal sires	Terminal	200

Crossbred	Terminal sire x	Others	Other	68
Crossbred	Terminal sire x	Suffolk	Terminal	71
Crossbred	Terminal sire x	Texel	Terminal	280
Crossbred	Terminal sire x Hill	Others	Other	16
Crossbred	Terminal sire x Hill	Terminal sire	Terminal	77
Purebred	Hill	Bred pure	Hill	2597
Purebred	Hill	Longwool crossing	Longwool	867
Purebred	Hill	Other	Other	134
Purebred	Hill	Other hill	Hill	122
Purebred	Hill	Terminal sire	Terminal	433
Purebred	Longwool crossing	Bred pure	Longwool	24
Purebred	Longwool crossing	Other	Other	1
Purebred	Longwool crossing	Terminal sire	Terminal	4
Purebred	Longwool ewe	Bred pure	Longwool	207
Purebred	Longwool ewe	Other	Other	30
Purebred	Longwool ewe	Terminal sire	Terminal	86
Purebred	Shortwool ewe	Bred pure	Shortwool	522
Purebred	Shortwool ewe	Others	Other	56
Purebred	Shortwool ewe	Terminal sire	Terminal	231
Purebred	Terminal sire	Bred pure	Terminal	394
Purebred	Terminal sire	Other terminal sires	Terminal	135
Purebred	Terminal sire	Others	Other	68

Indices were derived for hill, crossing (all longwool) and terminal ram types. Economic values were the same as those used in Amer et al. (2007) but adjusted for inflation and the increase in lamb price (total increase 40%).

For hill sheep the index to derive profit (£) per lamb born was,

$$I_{direct,hill} = 0.434LWscan$$

where, *LWscan* is the genetic trend of liveweight at scanning for lambs sired by hill rams. While the index to derive profit (£) per breeding ewe was,

$$I_{maternal,hill} = -0.182matureLW + 19.04litter + 0.434matA$$

where, *matureLW* is the genetic trend of mature liveweight, *litter* is the genetic trend of litter size and *matA* is the genetic trend of maternal ability for hill ewes which contains both direct and maternal elements of lamb growth.

For longwool and crossing sheep the index to derive profit (£) per lamb born was,

$$I_{direct,cross} = 0.434LWscan$$

where, *LWscan* is the genetic trend of liveweight at scanning for lambs sired by crossing rams. For crossing sheep the index to derive profit (£) per breeding ewe was,

$$I_{maternal,cross} = 0.434matAb$$

where, *matAb* is the genetic trend of maternal ability for longwool and crossing ewes. For terminal sheep the index to derive profit (£) per lamb born was,

$$I_{direct,term} = 3.724lean - 2.464fat$$

where, *lean* is CT lean and *fat* is CT fat of lambs sired by terminal rams.

The cumulative benefit achieved (as net present values, NPV) with current levels of genetic progress as achieved over a 10 year period with an impact period of 20 years was calculated using methods presented by Amer et al (2007).

Results and discussion

The weighted genetic trends for direct and maternal traits by breed types, hill, crossing and longwool and terminal are presented in Table 5 and Table 6, respectively. Terminals had higher genetic trends than hill and crossing and longwool breed types for all of the direct traits. Across all direct traits, trends were lower than those being achieved in 2007 (Table 5), a finding which was also observed for most maternal traits (Table 6). Some exceptions were maternal ability in hill and longwool and crossing breed types as well as mature weight in longwool and crossing and terminals. Mature weight genetic trends increased for the hill, longwool and crossing breed types, as well as terminals, which will have a negative economic impact on the former breed type. In this study, mature weight was not included in the index for terminal or longwool/crossing breed types and is not currently accounted for in most industry indexes either.

Table 5: Weighted genetic trends for direct traits, by breed type. Lean weight and fat weight are based on CT lean and CT fat, respectively. Comparative values from 2007 (Amer *et al.*, 2007) are presented in parentheses.

Breed type	Liveweight at scanning	Muscle depth	Lean weight	Fat weight
Hill	0.077 (0.145)	0.028(0.074)	0.024	0.025
Longwool and crossing	0.079 (0.241)	0.029 (0.095)	0.021	0.016
Terminal	0.222 (0.317)	0.068(0.110)	0.073 (0.114)	0.032 (0.040)

Table 6: Weighted genetic trends for maternal traits, by breed type. Comparative values from 2007 (Amer *et al.*, 2007) are presented in parentheses.

Breed type	8 week weight	Litter size	Maternal	Mature weight

			ability	
Hill	0.043 (0.059)	0.003 (0.006)	0.037 (0.037)	0.225 (0.220)
Longwool and crossing	0.017 (0.114)	0.001 (-0.001)	0.003 (0)	0.055 (0.013)
Terminal	0.092 (0.146)	0.001 (0.004)	-0.003 (-0.002)	0.114 (0.007)

Economic benefits per lamb born and per ewe mated for each breed type are presented in Table 7. For hill breeds, there was a decrease in profit per lamb and per ewe. The profit per lamb born for the crossing and longwool breed type, as well as terminals decreased. For the terminals, this is largely driven by the 36% reduction in lean weight genetic trend observed between 2007 and 2013. For the crossing and longwool breed type the reduction is driven by the 67% reduction in the liveweight at scanning genetic trend.

Table 7: Annual genetic trends in profit per lamb and per ewe, as realized in industry. 2007 trends by Amer et al. (2007) are presented in parentheses, adjusted for inflation.

Trait	Hill breeds	Crossing breeds	Terminal breeds
Profit per lamb born (£)	0.033 (0.045)	0.034 (0.075)	0.182 (0.233)
Profit per breeding ewe (£)	0.047 (0.065)	0.001 (-0.001)	n/a

The industry level returns for each of the breed classes (Table 8) is based on the benefits of 10 years of genetic progress, as realised over a 20 year horizon. The value of genetic progress is approximately 65% lower in hill and terminal breeds compared to that which was predicted based on 2007 levels of genetic gain (Amer et al., 2007). More substantially, the value of genetic progress in the crossing and longwool breeds has dropped dramatically, from £14.0 to £2.8 million (Table 8). This is partly due to the decrease in profit per lamb born (Table 7), but mostly due to diminishing industry share of this breed, with the number of ewes mated to crossing/longwool breeds reduced by over half (2.2 million to 1 million, Table 9). Likewise the number of industry ewes mated to hill rams has decreased by 30% and may go some way in explaining the reduction in estimated genetic progress returns since 2007. While terminal profit per lamb born has decreased since 2007, the number of ewes being mated to terminal sires in industry has increased slightly (7.1 versus 7 million ewes), which may have helped offset the effects of the reduction in profit per lamb born.

Annualised returns based on current levels of genetic progress being obtained are £1,776,000, £307,000 and £8,512,000 for hill, crossing and longwool, and terminal breed types, respectively. This means that annual investments in genetic improvement must be less than these values for a profit to be realised.

Table 8: Expected value of genetic progress over a 20-year time period resulting from 10 years of genetic improvement, with current levels of genetic gain at an industry wide level. 2007 values from are presented also (Amer *et al.*, 2007).

Breed type	**Returns (£000)**			**Annualised returns, 2013 (£000)**
	Current (2013)	**2007**	**2007 (CPI adjusted*)**	
Hill	13,354	23,291	28,550	1,776
Crossing (and longwool)	2,781	11,387	13,958	370
Terminal	64,004	76,061	93,236	8,512

*http://www.thisismoney.co.uk/money/bills/article-1633409/Historic-inflation-calculator-value-money-changed-1900.html

Table 9: Industry ewe numbers mated by ram type – 2013 values compared to 2007 values presented in Amer et al. (2007).

Industry females mated by ram type (000)	**Hill**	**Crossing**	**Terminal**
2007	3,886	2,200	7,000
2013	2,764	1,098	7,120

Appendix 2: Estimating industry benefits of current genetic gain in the UK beef industry

Introduction

Investment in genetic improvement requires justification that a return to the industry, and/or society, is sufficient to offset the cost of the investment made. Amer et al. (2007) published a detailed cost benefit analysis for the UK sheep and beef genetic improvement industries and found significant returns from beef industry genetic progress and terminal sire sheep genetic progress up until 2004/2005. The intention of this report is to provide an update of the results presented by Amer et al. (2007), with new and more recent genetic trend information and with some modifications to the methodology used.

Methods

Estimating genetic trends

Average estimated breeding values (EBVs) by year were provided by Signet for the beef breeds: Blonde d'Aquitaine, Highland, Limousin (BASCO), Lincoln Red, Red Poll, Saler, Stabiliser and Sussex. Average EBVs by year were provided by the BREEDPLAN (Agricultural Business Research Institute, ABRI) for the breeds: Angus, Charolais, Hereford, Red Devon, Shorthorn, Simmental and South Devon. British Blue data was downloaded from the ABRI website, and then edited and provided by Signet.

For all breeds, genetic trends were calculated as the weighted average of the differences in average EBVs between successive years, from 2008 to 2013. For EBLEX breeds, the trait averages were weighted by the number of animals with relevant trait records per year, from 2008 to 2013. For BREEDPLAN breeds, the trait averages were weighted by the number of animals used to produce the annual EBV averages. For the British Blue breed, the trait averages were weighted by the total number of animals within each year.

For Signet/ BASCO breeds, genetic trends were calculated for the traits: beef value (as an indicator of carcass traits), gestation length direct, calving ease direct, 400 day growth, calving interval, age at first calving, and longevity. For BREEDPLAN breeds, genetic trends were calculated for the traits: gestation length direct, calving ease direct (based on heifer calving), 400 day weight and mature cow weight. For British Blue, genetic trends were calculated for gestation length direct, calving ease direct (based on heifer calving) and 400 day weight.

As beef value trends were available for Signet/ BASCO but not BREEDPLAN breeds, they were derived from 400 day weights (400wt) trends as,

$$bfV_{BreedPlan} = \frac{400wt.\beta_{400wt,bfV} \cdot \sigma_{g.cwt}}{\sigma_{g.400wt}}$$

where, $\beta_{400wt,bfV}$ is the genetic regression co-efficient of 400 day weight on beef value, $\sigma_{g.cwt}$ is the genetic standard deviation of carcass weight and $\sigma_{g.400wt}$ is the genetic standard deviation of 400 day weight. Values for these parameters are found in Table 10. Calving ease values from BREEDPLAN breeds are expressed as levels of difficulty expected in calving heifers. To convert these to cow calving ease, calving ease was multiplied by the corresponding genetic regression co-efficient (Table 10). Mature weight trends were not available for Signet/ BASCO data. These were derived from 400 day weights, by multiplying by the genetic regression co-efficient of 1.23 (Table 10).

Application of genetic trend data to industry

The model assumed that genetic gain in non-recorded populations was 80% of that obtained in recorded populations and that 80% of breeders used performance recording. Industry share, by breed, was derived using industry breed composition data from Todd et al. (2011), where the numbers were based on those from the 2008 slaughter population in British Cattle Movements Service (BCMS)/Scottish Rural University College (SAC). Two different models were considered. The first model assigned breeds to specific roles, and is most similar to the approach taken by Amer (2007). The second model assumed more flexible breed roles, which more closely reflects current industry practices.

Model 1 – structured breed roles

Under this model, breeds were assigned specialized roles, either maternal or terminal. For the terminal index genetic trend, it was assumed that the industry breed composition was equivalent to the proportion of males out of the total number of males required across breeds. For the dual purpose index, it was assumed that the industry breed composition was equivalent to the proportion of females retained (Todd *et al.*, 2011) out of the total number of females retained across all breeds. Four breeds not represented in the Todd et al. (2011) paper that were found in sufficient numbers to warrant additional inclusion were Stabiliser, Red Devon, South Devon and Shorthorn. The corresponding numbers (both males and number of females retained) of these breeds were derived using their ratio to the Angus (included in Todd et al. (2011)) breed.

Blonde d'Aquitaine, British Blue and Charolais breeds were assumed to contribute to the terminal index. Angus, Hereford, Limousin, Red Devon, Shorthorn, Simmental, South Devon, and Stabiliser breeds were assumed to contribute to the dual purpose index.

It was assumed that 1.27 million suckler cows are mated to beef breed bulls, and under this model, 63% of these matings were attributable to the breeds denoted as maternal based on data reported by Todd et al. (2011).

Model 2 – flexible breed roles

Under this model, the genetic trend for bulls mated to breed replacements was based on relative breed contributions to suckler herd replacements as derived by Todd et al. (2011). Likewise, the genetic trend for bulls where all progeny are slaughtered were based on the relative breed contributions to females slaughtered from Todd et al. (2011). This approach recognizes that beef breeds do not conform to traditional breed roles in the UK. It was then assumed that 24% of matings would be with the intention to breed replacements to get the split of the industry impacted by maternal and terminal traits from these breeds when mated to suckler cows.

Calculating indexes

Terminal index

The terminal index ($\mathrm{Index}_{\mathrm{direct,term}}$) consisted of the traits beef value (bfV), gestation length (GL) and calving ease direct (CED), as,

$$Index_{direct,term} = \frac{£1.bfV.bp_{2013}}{bp_{1995}} + \frac{bp_{2013}}{bp_{2005}}(-£1.GL + 0.25.£2.47.CED)$$

where, bfV, GL and CED are the genetic trends of the corresponding traits, bp_{2013} is the 2013 deadweight beef price, bp_{2005} is the 2005 deadweight beef price and bp_{1995} is the 1995 deadweight beef price (Table 10). The index was adjusted in proportion to changes in the beef price between these years to convert the economic values to 2013 values (i.e. to account for inflation and changes in beef price). The economic value of calving ease was multiplied by 0.25 to account for the fact that the EV was derived under the assumption that terminal sires are not usually mated to cows with a high risk of calving difficulty (Amer *et al.*, 2007). These index values were calculated for the recorded and non-recorded populations of each breed contributing to the terminal index and the sum of these values taken as the final terminal index trend.

Dual-purpose index

The dual purpose index ($\mathrm{Index}_{\mathrm{direct,dp}}$) consisted of the traits beef value (bfV), gestation length (GL), calving ease direct (CED), calving interval (CI, Signet/ BASCO breeds only), age at first calving (AFC, Signet/ BASCO breeds only), longevity (L, Signet/ BASCO breeds only) and mature weight (MW), as,

$$Index_{direct,dp} = (1-r)\left(\frac{£1.bfV.bp_{2013}}{bp_{1995}} + \frac{bp_{2013}}{bp_{2005}}(-£1.GL + £2.47.CED)\right) + \frac{bp_{2013}}{bp_{2005}}(-£0.83.CI.e - £48.11.AFC.e + £6.63.L.e - £0.23.MW)$$

where, r is the percentage of calves kept as replacements (calculated as a weighted average by sire breed from Todd et al. (2011)) and e is an indicator variable with a value of either 0 (BREEDPLAN breeds) or 1 (Signet/ BASCO breeds). These index values were calculated for the recorded and non-recorded populations of each breed contributing to the dual purpose index and the sum of these values taken as the final dual purpose index trend.

Table 10: Model parameters

Parameter	Value
Beef value economic value (£), (Amer *et al.*, 1998)	1
Gestation length economic value (£), (Roughsedge *et al.*, 2005)	-1
Calving ease EV (£), (Roughsedge *et al.*, 2005)	2.47
Mature weight EV (£), (Roughsedge *et al.*, 2005)	-0.23
Calving interval EV (£), (Roughsedge *et al.*, 2005)	-0.83
Age at first calving EV (£), (Roughsedge *et al.*, 2005)	-48.11
Longevity EV (£), (Roughsedge *et al.*, 2005)	6.63
Genetic standard deviation of carcass weight	12.5
Genetic standard deviation of 400 day weight	29.3
2013 beef price (£), EBLEX	3.90
2005 beef price (£), provided by EBLEX	1.90
1995 beef price (£), EBLEX	2.26
Genetic regression co-efficient of 400 day weight on beef value	1.3
Genetic regression co-efficient of CED in heifers versus CED in cows	2.3
Genetic regression of 400 day weight on mature weight	1.23
Calving ease multiplier, (Amer *et al.*, 2007)	0.25
Genetic trend in the non-recorded versus recorded population	0.80
Percentage of calves kept as replacements, (Todd *et al.*, 2011)	0.236

The cumulative benefit achieved (as net present values, NPV) with current levels of genetic progress as achieved over a 10 year period with an impact period of 20 years was calculated using methods presented by Amer et al. (2007).

Results and discussion

Beef value trends, in the current analysis, were less favourable for terminal breeds than the 1999-2003 trends reported by Amer et al. (2007) under model 1 but almost equivalent with model 2, where breed information from most breeds is accounted for (Table 11). In contrast, the beef value trend was higher in the dual purpose breeds (Table 12), which reflects selection based on growth/ carcass rather than maternal traits in these breeds, with the trends being particularly high in the breeds that contribute substantially to the dual purpose index. Gestation length trends are more favourable now than they were during the 1999-2003 period, particularly in the dual purpose breeds where there is a slight negative gestation length trend. Calving ease now has a positive trend in terminal breeds (Table 11) – that is calvings are becoming easier, compared to 1999-2003 where calvings were becoming more difficult. The calving ease trend is more favourable in the dual purpose breeds than in the period 1999-2003 but it is still negative – that is, calving ease is still regressing (Table 12). Mature weight, calving interval, age at first calving and longevity trends were not available for the 1999-2003 period. The current trends suggest mature weight is increasing, calving interval is becoming longer, heifer calving age remains relatively unchanged and cows have slightly better survival.

Table 11: Weighted average genetic trends in traits and sub-indexes for terminal sire performance. Trends are adjusted for contribution of each breed, proportion recorded versus non-recorded and genetic trend in recorded versus non-recorded populations. Trends are compared to those presented in Amer et al. (2007).

Trait	**Trend (2009-2013)**		**Trend (1999-2003)**
	Model 1	**Model 2**	
Beef value (£ per calf born)	0.589	0.810	0.824*
Gestation length (days)	0.007	-0.003	0.029
Calving ease (% unassisted)	0.162	0.006	-0.277

*CPI adjusted, http://www.thisismoney.co.uk/money/bills/article-1633409/Historic-inflation-calculator-value-money-changed-1900.html

Table 12: Weighted average genetic trends in traits and sub-indexes in dual purpose breeds. Adjusted for contribution of each breed, proportion recorded versus non-recorded and genetic trend in recorded versus non-recorded population. Trends are compared to those presented in Amer et al. (2007).

Trait	**Trend (2009-2013)**		**Trend (1999-2003)**
	Model 1	**Model 2**	
Beef value (£ per calf born)	0.915	0.838	0.835*
Gestation length (days)	-0.018	-0.013	0.033
Calving ease (% unassisted)	-0.065	-0.035	-0.094
Mature weight (kg)	2.128	1.919	n/a
Calving interval (days)	0.080	0.065	n/a
Age at first calving (days)	-0.002	-0.001	n/a
Longevity (years)	0.011	0.009	n/a

*CPI adjusted, http://www.thisismoney.co.uk/money/bills/article-1633409/Historic-inflation-calculator-value-money-changed-1900.html

The rate of genetic gain in the terminal index is double that of the 1999-2003 period, at a rate of gain of £1.21/year (Table 13). This is largely driven by the increase in calving ease trend, which is now more than 1.5 times larger than that observed in the 1999-2003 period and a larger economic weighting than other traits in the terminal index.

In contrast, the dual purpose trend is making much less gain than reported by Amer et al. (2007) (Table 13). In Amer et al. (2007), the components of the dual purpose index was the same as the terminal index, with the exception of the omission of the calving ease multiplier (0.25) discussed in the methods section. The equivalent portion of the current dual purpose index is reported – terminal component trend of £0.803/year (Table 13). In this respect, the dual purpose breeds are actually performing better – that is dual purpose breeds are now making more progress in terminal traits than they were in the 1999-2003 period (£0.803 versus £0.490/year). Breeding for faster growing and larger animals tends to have an antagonist effect on maternal traits, and this is apparent when maternal traits are included in the dual purpose index. Specifically, the overall trend in genetic merit for dual purpose performance becomes negative (Table 13), which has a profound impact on the net annualized returns to industry, resulting in the current trend actually costing the industry as opposed to providing a profit. This affords an opportunity to refocus attention on maternal traits in dual purpose breeds, to produce a very positive impact on the dual purpose industry.

Table 13: Index trends for the period 2009-2013 versus 1999-2003. The terminal component (corresponding to the beef value, gestation length and calving ease index) of the dual purpose index is reported for comparison to the 1999-2003 results.

Index	**2009-2013**		**1999-2003 (CPI adjusted*)**
	Industry share option 1	**Industry share option 2**	
Terminal (£)	1.208	1.411	0.625*
Dual purpose (£)	-0.029 (0.803 terminal/ -0.832 dual purpose)	0.068 (0.827 terminal/ -0.759 dual purpose)	0.490*

*http://www.thisismoney.co.uk/money/bills/article-1633409/Historic-inflation-calculator-value-money-changed-1900.html

Table 14: Expected value of genetic progress over a 20-year time period resulting from 10 years of genetic improvement, with current levels of genetic gain at an industry wide level. 2007 values from Amer et al. (2007) are presented for comparison.

Index	**Returns (£000)**			**Annualised returns, 2013 (£000)**	
	Current (2013)		**2007 (CPI adjusted*)**		
	Option 1	**Option 2**		**Option 1**	**Option 2**
Terminal (£)	14,878	35,997	6,119	1,979	4,788
Dual purpose (£)	-763 Terminal = 21,202 Dual purpose = -21,968	665 Terminal = 8,128 Dual purpose = -7,459	22,300	-101	89

*http://www.thisismoney.co.uk/money/bills/article-1633409/Historic-inflation-calculator-value-money-changed-1900.html

In summary, genetic progress continues to deliver substantial benefits to the UK beef industry. However, rates of genetic progress are dominated by progress in growth and carcase traits which is at the same time having a detrimental effect on the genetic merit of suckler cows for maternal production efficiency.

Appendix 3: Summary of industry consultation and visit

United Kingdom industry consultation: summary of responses to consultation questions

Industry consultation was carried out in the UK involving an agreed target list of participants (principally societies, service provides, and industry good organisations). The consultation gathered information, in addition to critical assumptions, adoption rates, and costs of breed improvement services. Responses to a number of questions related to genetic improvement in the UK industries were also compiled. There were wide ranging answers to the questions, summarised in Appendix 3. Generally, the answers provided during consultation point to an understanding of the challenges in the development of a functional infrastructure, the generation of genetic gain, and the implementation of genomics. The below sections report the key findings from industry consultation.

This section summarises the information obtained from the key evaluation questions asked, with references. To maintain anonymity, participants were categorised into various groups with superscripts as follows:

[1]Service provider

[2]Industry representation body

[3]Levy body

[4]Beef breed society

[5]Sheep breed society

[6]Sheep breeder group

[7]Beef breeder

1. **What are your current thoughts and feelings about existing UK infrastructure to support genetic improvement of sheep and beef cattle (separately)?**
    - Concerned about the breed structure[1] – harder to attract funding and creates mixed messages[4]/influence of breed societies i.e. bigger proportion of bull buyers use eBVs compared to ram buyers – driven by Charolais and Limousin societies[3].
    - Small breed societies with their own breeding objectives and fragmentation make working together harder[4].
    - An increasing number of people want to be involved but very few appreciate the benefits of genetic improvement; main driver is non-recorded rams (more highly paid)[2].
    - Quite clued up[4] but need a review to improve i.e. farmer input combined with scientific expertise to ensure direction is right and practical[2]. Being involved in performance recording has taken the breed to a higher level with more exposure[5].

- Don't use the system for recording and evaluation, apart from when bringing in sires selected using Signet information[1,6]; inflexible with respect to traits available[1,6], timing of evaluations[1,6].
- Happy with Signet service[5,6] (given resources)[5], EBLEX[6] (knowledge of extension services)[4] and ABRI[4,7]. Signet should be proactive not reactive – leading science together with demonstration[2,5]. Signet also would not accept ABRI-provided data for scanning; applied to EBLEX for training scanners in Australia but heard nothing[4]. Also, issues with ability to benchmark other breeds on Signet[1,6].
- ABRI slower in terms of getting animals registered – doesn't focus on phenotypic performance feedback[7] unlike BASCO – easily register a calf with real-time phenotypic performance[7].
- Although BASCO interface is good[4], BASCO does not respond well to questions (disconnection between service provider and client) – shakes confidence. Furthermore, there is no data from EU for Limousins (which is needed). Limousin society says they are addressing issues like cheating but they are not – lack of continuity on boards[7].
- BreedPlan is good and affordable with great backup support[4]. SIL has better customer service with a wider range of eBVs (survival)[6].
- **Others:** issues with accuracy – need better extension on how the system works so they can do better, preferential treatment, connectedness[6]; carcase weight increases – too big[3]; terminal sires far ahead of maternal sires – genotype versus phenotype issue[3;] takes a bit of time to get US imported embryos evaluated – need across-country evaluation[4].

2. **How do you think rates of genetic progress compare in the UK, versus other countries, and do you believe that genetic progress is important for the competitiveness of the UK industries?**
    - Compared to the US and Canada, UK is recognised to be slower[7]. Rates of genetic progress are understood to be limited by the implications of small herd size and data issues[7].
    - With comments about the growth in the dairy industry[4], UK could do better; due to the lack of engagement between breeders and commercial farmers, UK has lower levels of gain in maternal traits and adoption, but better genetic progress in terminal traits[1,6].
    - Genetic improvement most certainly provides benefits in the whole chain[2].

3. **What are the main barriers to achieving faster and more widespread rates of genetic progress in the UK sheep or beef industries (separately)?**
    - Lack of funding[4] from government, subsidies[6]; succession issues[3]; weak link between eBV service providers and end-users[4] i.e. Egenes and breeders[6], no engagement between breeders and commercial farmers[1,3,6]. Selling of rams in markets, conservative approach to rams (high ram:ewe ratios) and ram management[3].

- Large number of small herds – hobby farmers[4,5] and hence more prone to cheating[4,7]; part-time nature of breeding[1,6].
- **Views and understanding:** short-term view of commercial farmers[5] – especially that all money should be spent on marketing and productivity is what just happens to them[2], non-commercial focus[1,6], their lack of understanding of farm business[1,2,5] and KPI's in commercial farms[5], lack of appreciation for genetic improvement[2,4,5,6] due to lack of scientific evidence[2,5]. Breeders are less innovative – focusing on growth and yield traits instead of cost traits/ functionality[1,6], social aspect of buying the "best and biggest" ram[2,4,7] – visual appraisal[5] rather than quality[5], including commercial producers' knowledge and willingness to improve[3,4].
- **Systems:** Industry mixed messages[4], age structure of farming population[5], breed society structure[3] limiting vehicle to drive R&D[1] with wrong people at the top of the pyramid, overfeeding to achieve biggest animal[4,5], flock size particularly in maternal flocks, EUROP grading system draws focus away from real issues[1,6] i.e. cost/functionality traits, grid pricing[6], stuck on terminal traits[3], need more maternal traits[4], extreme muscle and growth which meant that dysfunctional components just got worse[4].
- **Others:** falsified data[4] , inaccuracy of evaluation results[5], lack of faith in performance recording[5] in pedigree breeders and commercial farmers[2,5] that can be resolved by online automation and technology[2], little education[4] on data recording[4] and genetic improvement[5], information used at purchase – indexes not good[7].
- Need more and better data[4] with a wider range of data and traits – female and health traits[4], unavailability of information on eBVs at sale[5] or abattoir information[7], health status or prior treatment[2], particularly insufficient utilisation of available information[4,5], market signals not clear enough to drive buying better rams[5].

4. What do you think can be done to overcome these barriers?

- Money[5], funding, from EBLEX, education[4] and extension[4] for farmers[3] especially about data recording[4] for breeders – building accuracy[4] – focusing on the top-end breeders[5] i.e. case studies to learn outcomes and improve practices[6], profitability messages to educate commercial farmers[4].
- On-farm sales[7] – market hard to establish (need reputation via sales first)[4], people ask for eBVs[5], need confidence in eBVs[4], 75% sold at the gate[7], financial drivers for genetic improvement – farmers' pocket[2,6].
- Better commercial data on growth rates and carcase yields[4], data quality control through herd inspections[7], making better use of information - selection decisions based on information[5], information presentation to simplify information[5] – opening up information to the whole breed[5].
- Growth of farming businesses – dropping CAP[4] or CAP removal will make farmers realise there is a gap in real income, forcing a behavioural change[1,3,6], sector-specific rural development plan targeted at incentivising ram buyers[3], appropriate price signals[1], market signals[4].

- Demonstration farms[3], import best performance recorded genetics[5], more engagement in performance recording i.e. through younger farmers[5,6] as they are more adaptable[2], increase levels of performance recording[5], engagement between pedigree breeders and commercial farmers, getting rid of show sales[1,6].
- Demonstrate profit realised by meat yield[5] and that genetics work[5], connectedness[5] i.e. promote ram sharing[5].
- Bull testing station, single index and crossbred progeny to compare breeds[4], introgression of favourable genes from another breed (Myomax from Meatlinc)[5], new traits[6] i.e. meat eating quality and survival[5], breed comparison for growth muscling relationship[5], need EID to link live market lambs to kill sheets[6].
- Take a long-term sustainability view, base programme and software to link with Signet, build efficiency in livestock management, feed conversion and processing efficiency[2].
- Multi-species centralised database (movement, births, genetic evaluation), better phenotypes (disease data) underpinned by better collection methods[2], farmer functionality to database (animal health records); refresh Signet with use of DNA in CPT, stabiliser breed trial for RFI[3].

5. **What is your current knowledge of genomics, how it works, and what the opportunities are?**
    - **Not very aware** of genomics[4], most people wouldn't know what it is[2].
    - **Limited knowledge/reasonable understanding**[4] of it as a tool[5] with the impression that it is "revolutionary"[3,4,5,6]. Believes that it works with underpinning size and scale[6]; the industry should be pioneering it in the future, however given nature of industry, it will be slow[2] i.e. 10-12 years away before value[6].
    - Thought to be very costly[3,5] – limiting opportunity to actually apply it[4]. Information available lacks reliability[4].
    - "Wait and see" approach[7]: waiting on positive results in the US before further discussion in the Board[4], more information required on how to deliver it in the dairy sector[5], also worried about population size[4].
    - UK believed to be too small a country to lead in genomics – a need for population structure[7].
    - Currently has an investment programme in genomics with value proposition in measuring traits[1,6] i.e. early targets are meat quality and tenderness. Second-tier traits include stayability, foot issues, mastitis, entropion, testicular circumference.
    - **Other uses:** traceability and as a tool to provide commercial data (carcase data) for breed improvement[2]; working to build database capability for genotype storage[1]; taking and storing high-quality DNA samples[4]; carcase testing – increasing accuracy of prediction of hard-to-measure traits[7].
    - **Opportunities?** Don't see genomics replacing phenotyping but as another tool in the box[5]. In favour of technology as long as it doesn't impact on legislation on farms[2].

- Thought it was hard to measure traits (disease resistance traits are big)[2]; survival at birth as a target trait for genomics[5]; parentage would be good[3]; less value in high heritability traits (HTM traits are the space for value)[4].
- What traits are needed that cannot be solved with regular GE[5]; DNA parentage increasing, driven by traceability through Morrison's[4]; 2-3 quid and 5 quid as break price for DNA parentage[6].

6. Would you like to see more centralised co-ordination of genetic improvement, or do you think that it is best for innovators to take the risks, and get on and do their own thing?

- Sheep breeders generally see the current system as centralised[5]. It's good to have an overall cooperative model[2] or one system[4] that benefits everybody. However, this comes with reservations in practice[4], hence needs flexibility – one size does not fit all but too small to have two[4].
- BASCO parties would not be very keen[1]; totally against ABRI making too many assumptions and lose control[6]; limitations exist to having BASCO only in the UK especially in genomics[4]. However positive to have relationship between Signet and Sheep Ireland[6].
- Ideally for innovators to take risks and lead others[3] – taking market share and rewards for risk-taking[1,6]. They understand how genetics work and actively drive genetic gain and technology[6]. They also maintain breed-type structures in the industry[5]. They have the scale to do it[5] but it depends on funding and resources.
- **It depends:** not bothered at all as long as there is accuracy and commercial demand for bulls. If could get ICBF model to work, would be all for it[7]. Frustration with society behaviour[4] and hence happy to do it on own[4,5]. Judgement based on ICBF (did not like ICBF dealings)[4].
- International recognition of BREEDPLAN is an advantage – wider connectedness. Independence is key especially with ABRI providing service[4].
- Investment in training i.e. Nuffield and NSA's Next Generation Programme, Young Ambassadors Programme[2]. Missed opportunity when EBLEX/Signet didn't take on the GE system and train people when MLC stopped[4].

Appendix 4: Survey of the users of the genetic evaluation service system in the UK

Survey analysis

Farm and farmer profile information has been reported along with survey respondents' attitudes towards estimated breeding values (EBVs) and selection indexes, performance recording, and new genetic improvement technologies. Survey respondents' actions regarding selection criteria, trait preferences, the use of EBVs and selection indexes, and the use of different services providers are also reported. In addition to analysing the distribution of farmers for various survey parameters at the surveyed population level, patterns of survey respondents' attitudes and actions were assessed through the implementation of a multivariate market segmentation analysis. A Principal Component Analysis (PCA) followed by a Cluster Analysis (CA) of the principal components was used to investigate the patterns of relationships between farmers' attitudes, actions, and preferences for the different trait improvements and to determine if farmers could be grouped accordingly. We determined the principal components (PCs) of the trait preferences and implemented a Ward's Hierarchical CA of the first five principal components. Ward's method is one of the most used clustering techniques and commonly outperforms other clustering methods in recovering the true clustering structures (e.g. (Ferreira and Hitchcock, 2009)). The selection of the number of clusters was based on the loss of inertia (within cluster sum of squares) at each partitioning of clusters (Ward, 1963). The final number of clusters was determined by the partition with the highest loss of inertia. The soundness of the determined number of clusters was verified by analysing the interpretability of the results ((Emtage *et al.*, 2006; Dossa *et al.*, 2011)).

Respondents

Four hundred and eight UK sheep and beef farmers responded to the survey. Note that the survey targeted performance recording pedigree producers with an interest in performance recording. The survey was made available through breed societies and also advertised on the Farming Forum and Signet websites. In addition to this, Signet clients where sent a paper copy which led to a higher level of representation of Signet clients in the survey (see Table 35).

It is important to highlight that the survey outcomes should be interpreted in the light of the above sampling procedure and any extrapolation to the UK industries level should be done with extreme caution. The general description of the farm and farmer profile of the respondents is presented below.

Farm and farmer profiles

Livestock species and farm enterprises

The majority of survey respondents (65%) have only sheep, with the rest having only beef (19%) or both sheep and beef (16%) (Figure 1). A small percentage of surveyed farms (6%) have other species in addition to sheep or beef, poultry being the most common (3%) (Table 19).

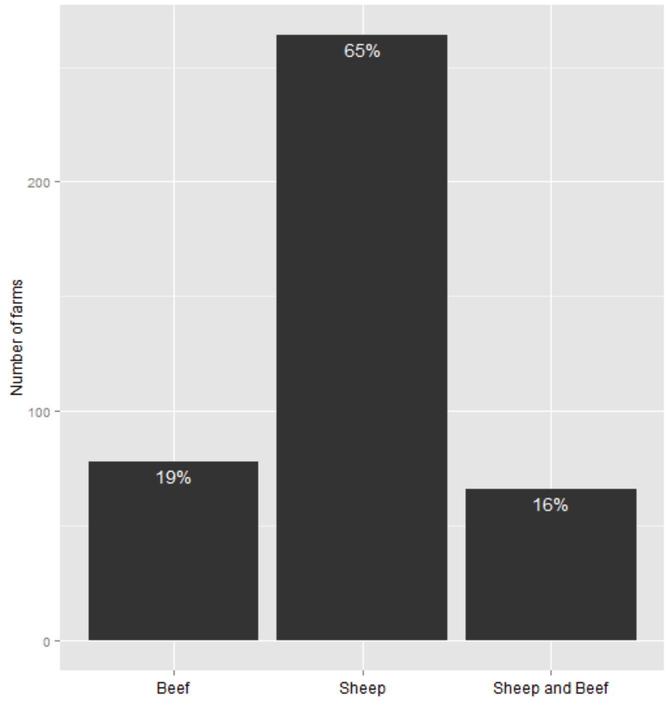

Figure 1: Sheep and beef distribution in the sampled farms

Table 15: Livestock species distribution and main enterprises of sheep and beef farms

Livestock species	Number of farms	Percentage
Sheep farms	**330**	**81%**
Breeding	125	38%
Commercial	33	10%
Breeding and commercial	172	52%
Beef farms	**143**	**35%**
Breeding	40	28%
Commercial	40	28%
Breeding and commercial	63	44%
Sheep and beef farms	**65**	**16%**
Sheep and/or beef plus other livestock	**24**	**6%**
Dairy	**4**	**1%**
Pigs	**8**	**2%**
Poultry	**12**	**3%**
Horses	**4**	**1%**

In sheep most of the survey respondents (52%) reported running a breeding and a commercial enterprise, 38% focus on breeding and 10% focus on commercial farming only (Figure 2). Conversely, in beef, commercial farm are represented in 28% of the total number of survey respondents. The most common beef farms were those running a breeding and commercial enterprise (65%). The rest of beef farms (28%) were dedicated to pure beef breeding.

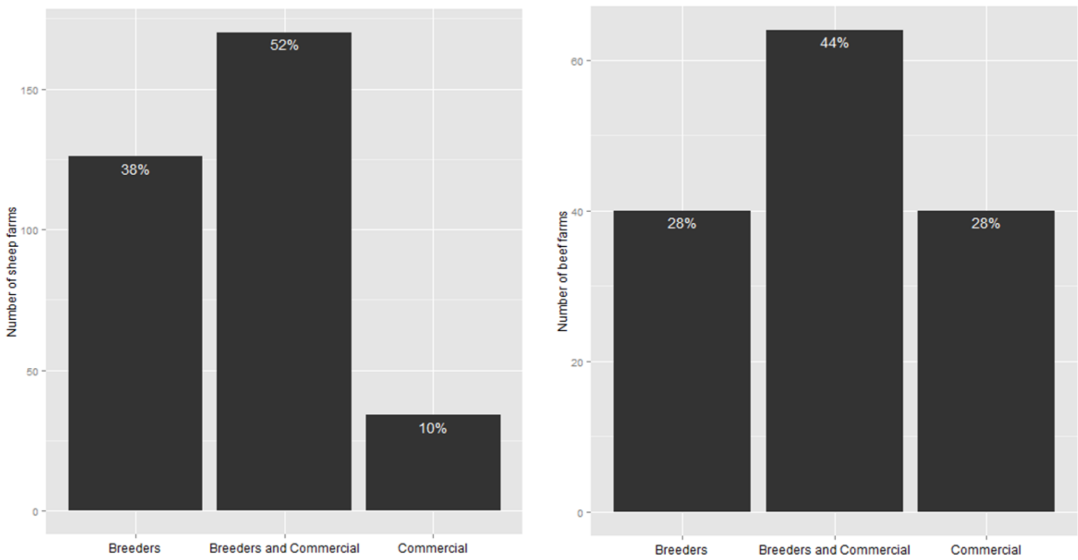

Figure 2: Number and percentage of sheep and beef farms focusing on breeding, commercial, or both

Farm sizes and breeds

Sheep farming

The average number of ewes on the surveyed sheep farms was 322 (Table 43). However, half of the sheep farms have 100 or less ewes and another 25% have between 100 and 600 ewes (Figure 3). The shape of the distribution of the number of rams sold per year per farm average over the last three years is very similar to that of the number of ewes. Note that those few farmers claiming to sell over 200 rams per year are likely to have misunderstood the question or to have typed an incorrect number.

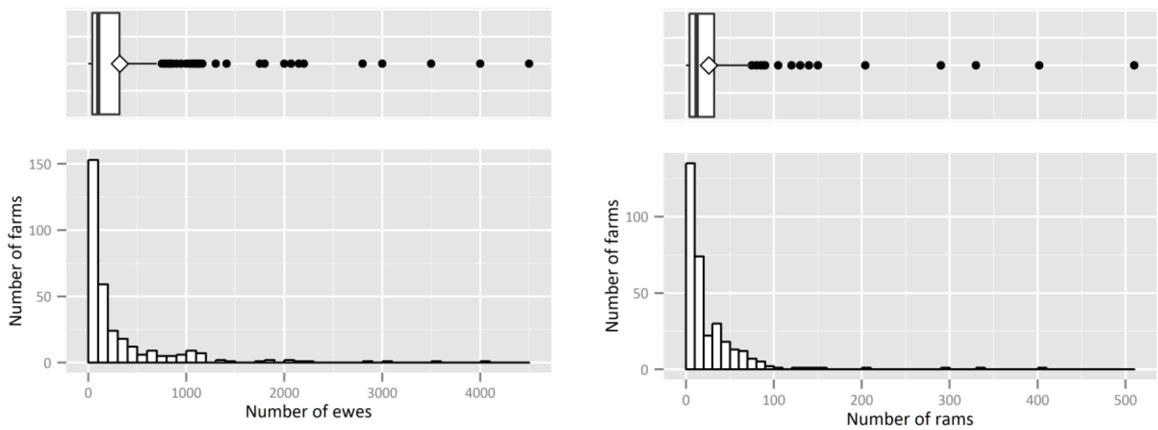

Figure 3: Distribution of the number of ewes and rams sold per year on the surveyed farms

Differences in the number of ewes between farms with different main enterprises were apparent. Commercial farms tended to have more ewes (average 718) than breeding farms (105) with the breeding and commercial farms having an intermediate size (408 ewes) (Figure 4).

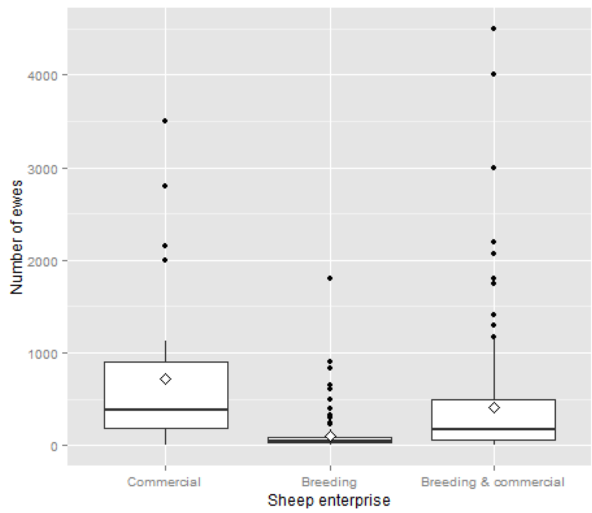

Figure 4: Number of ewes in breeding and commercial farms surveyed

Table 16: Sheep breed distribution across the surveyed farms; number and percentage of ewe and ram breeds

Sheep breeds	Main ewe breed		Main ram breed	
	Number of farms	Percentage	Number of farms	Percentage
Texel	52	16.1%	60	18.6%
Lleyn	38	11.8%	25	7.7%
Suffolk	33	10.2%	34	10.5%
Charollais	26	8.1%	30	9.3%
Others	25	7.7%	20	6.2%
Hampshire Down	19	5.9%	24	7.4%
Composite/Crosses	18	5.6%	7	2.2%
Mules	13	4.0%	0	0.0%
Welsh Mountain	11	3.4%	5	1.5%
Easycare	10	3.1%	7	2.2%
Dorset	9	2.8%	7	2.2%
Romney Marsh	9	2.8%	5	1.5%
Bluefaced Leicester	8	2.5%	16	5.0%
Scottish Blackface	8	2.5%	5	1.5%
Shropshire	8	2.5%	8	2.5%
Various	6	1.9%	3	0.9%
Wiltshire Horn	6	1.9%	5	1.5%
Southdown	5	1.6%	5	1.5%
Beulah	4	1.2%	2	0.6%
North C. Cheviot-Hill Type	4	1.2%	4	1.2%
North C. Cheviot-Park Type	4	1.2%	1	0.3%
Verdeen	3	0.9%	3	0.9%
Beltex	2	0.6%	1	0.3%
Meatlinc	2	0.6%	2	0.6%
None	-	-	44	13.6%
Total (n)	323	100%	323	100%

The number of ewe breeds is large, with 23 breeds being the main breed on the surveyed farms (Table 20). Only three breeds are the main breed in more than 10% of farms: Texel (16.1%), Lleyn (11.8%) and Suffolk (10.5%). Another three ewe breeds were the main breed in more than 5% of the farms: Charollais (8.1%), Hampshire Down (5.9%), and Composite/crosses (5.6%). The most popular ram breeds were very similar to the most popular ewe breeds, with the only difference being in composite crosses, where rams were far less common (the main ram breed in 2.2% of the farms) and the Bluefaced Leicester which was more common as a ram breed (5%) than as a ewe breed (2.5%). Usually farms had more than one breed with the majority of them having two breeds of both ewes and rams (Figure 16 in the Appendix). Although many farms sold the majority of rams off the farm (i.e. via breeding sales or at livestock markets), selling a proportion of the rams on-farm is very common (Figure 5).

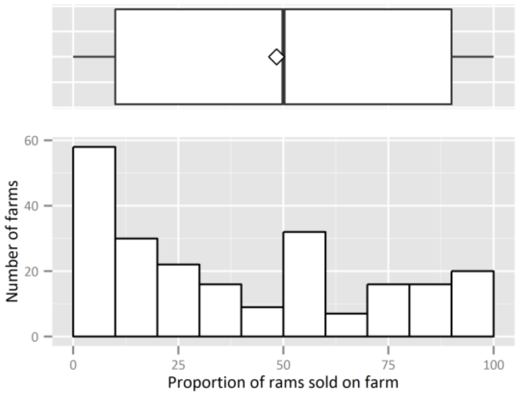

Figure 5: Proportion of rams sold on-farm on the surveyed farms

Beef farming

The distribution of the surveyed beef farms, according to size, was similar to the surveyed sheep farms; however, the average beef farm size is 83 cows and 5 bulls (Table 47 in the Appendixes). The majority of farms had less than 80 cows and sold and average of 5 breeding bulls per year, averaged for the last three years (Figure 6). However, farms of 200 cows and 10-15 breeding bulls sold were common. Note that those few farmers claiming to sell over 50 breeding bulls per year are likely to have misunderstood the question or to have typed an incorrect number. Farms with different enterprises had different numbers of cows (Figure 7); breeding and commercial farms tended to be larger (average 129 cows) than breeding (average 46 cows) and commercial (average 43 cows) farms. Finally the majority of bulls were sold off-farm (Figure 8).

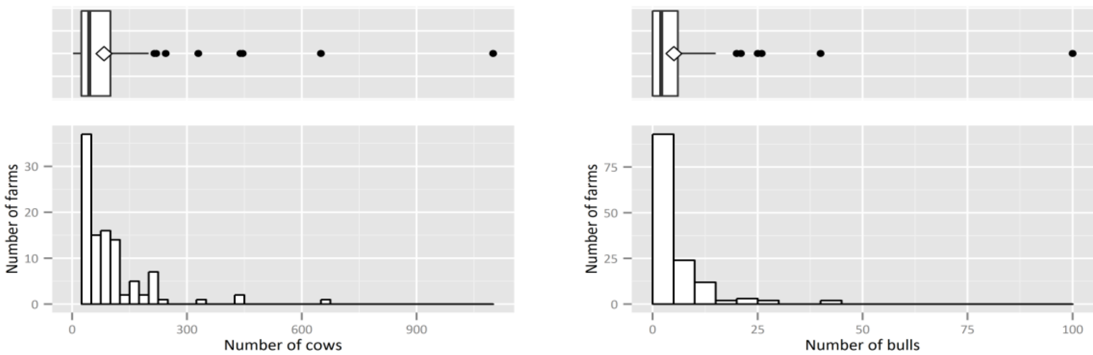

Figure 6: Distribution of the number of cows and breeding bulls sold per year on the surveyed farms

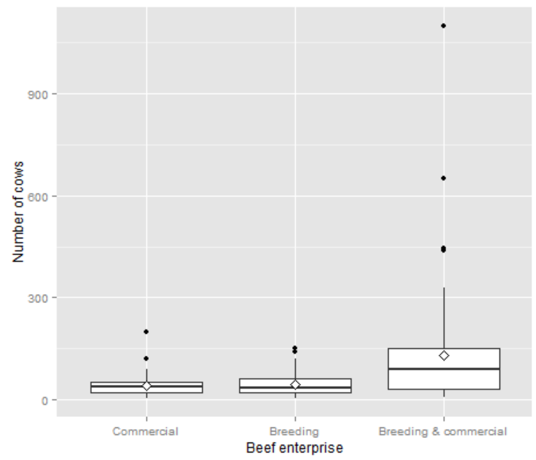

Figure 7: Number of cows on the breeding and commercial farms surveyed

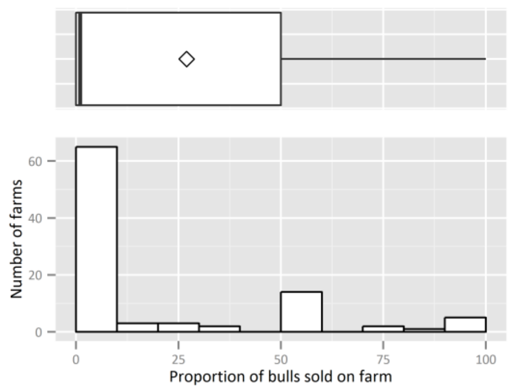

Figure 8: Proportion of bulls sold on-farm on the surveyed farms

More than 20 breeds were reported as the main breed (see Table 21) although 6 breeds accounted for the principal breed on 74.1% of the surveyed farms with Stabilizers accounting for almost 24% of the farms. The other five breeds are Limousin (11.5%), crossbreed (10.8%), Sussex (10.1%), Hereford (9.4%), and Aberdeen Angus (8.6%). Regarding bull breeds, 37% of the surveyed farms did not have any bulls on-farm and presumably use Artificial Insemination[10]. The most common bull breeds were the same as the cow breeds, except crossbred bulls that were not reported. Usually farms had one cow breed and two bull breeds (see Figure 17 in the Appendix)

[10] No question about Artificial Insemination was included in the survey

Table 17: Beef breed distribution among the surveyed farms; number and percentage of cow and bull breeds

Beef breeds	Main cow breed		Main bull breed	
	Number of farms	Percentage	Number of farms	Percentage
Stabiliser	33	23.7%	18	13.0%
Limousin	16	11.5%	10	7.3%
Crossbred	15	10.8%	0	0.0%
Sussex	14	10.1%	6	4.4%
Hereford	13	9.4%	11	8.0%
Aberdeen Angus	12	8.6%	11	8.0%
Simmental	7	5.0%	7	5.1%
Charolais	4	2.9%	5	3.6%
British Blonde	3	2.2%	3	2.2%
Others	3	2.2%	1	0.7%
Various	3	2.2%	3	2.2%
Beef Shorthorn	2	1.4%	3	2.2%
British Blue	2	1.4%	0	0.0%
Highland	2	1.4%	1	0.7%
Lincoln Red	2	1.4%	2	1.5%
Luing	2	1.4%	1	0.7%
South Devon	2	1.4%	1	0.7%
Galloway	1	0.7%	1	0.7%
Longhorn	1	0.7%	1	0.7%
Red Poll	1	0.7%	0	0.0%
Red Ruby Devon	1	0.7%	1	0.7%
Welsh Black	0	0.0%	1	0.7%
None	-	-	51	37.0%
Total (n)	139	100%	138	100%

Farmer profiles

The majority of survey respondents were from England, followed by Welsh and Scottish farmers and a small percentage of Northern Irish farmers (Table 22).

Table 18: Distribution of farms between UK countries

Country	n	Percentage
England	233	57.1%
Northern Ireland	27	6.6%
Scotland	65	15.9%
Wales	83	20.3%

The average survey respondent age was 52 years old and the distribution of age was close to normal (Figure 9). Most of the farmers (72%) came from families with a long farming tradition. The education level of farmers was reported as high; 81% of them completed technical training, university degree or post-graduate courses (Table 22). In most cases (76%), the technical training, university degrees or post-graduate courses were related to agriculture (Table 22). Furthermore, 68% of the farmers reported to have undertaken other agriculture training in addition to the studies described above.

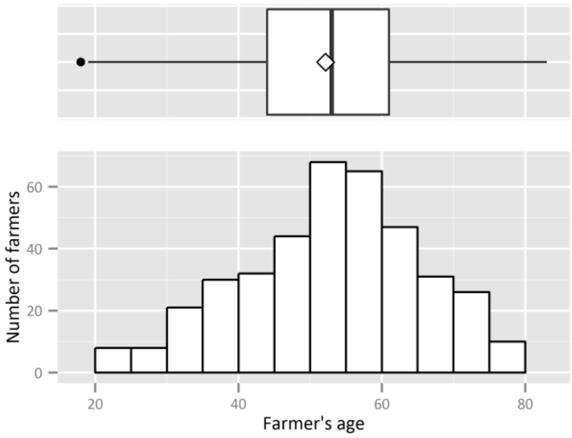

Figure 9: Distribution of farmer age

Table 19: Farmers' education level and training in agriculture

Education level	**n**	**Percentage**
Primary education	1	0.3%
Some high school	15	3.7%
High school	59	14.5%
Technical training	123	30.2%
University	154	37.8%
Post graduate studies	56	13.7%
Education related to agriculture (Technical+University+Post graduate)		
Yes	253	76.0%
No	80	24.0%

Generally speaking, the majority of farmer respondents have a strong farming network and attend farming workshops. The reported number of discussions on genetics (average 14) is lower than the reported number of farms visited (18). Results are summarized in Figures 10 and 11.

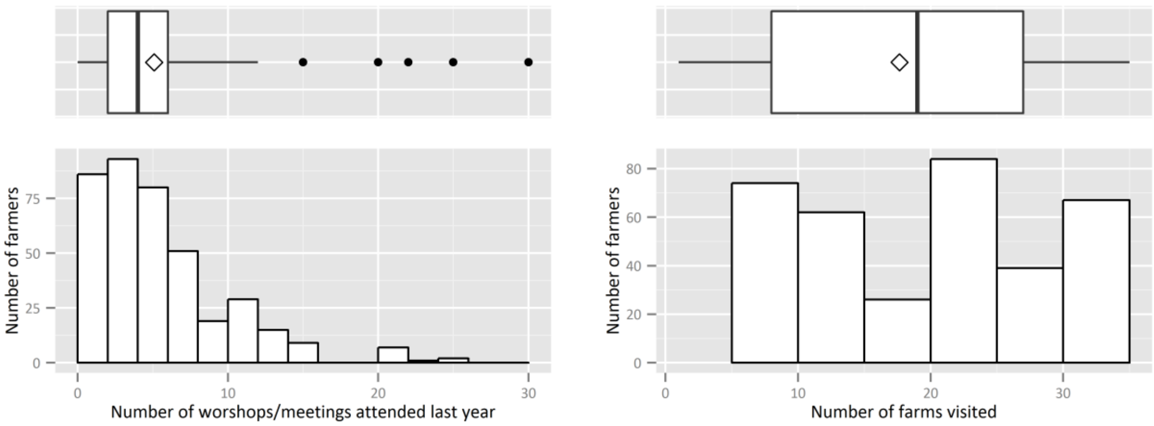

Figure 10: Reported number of workshops/meetings attended and farms visited last year

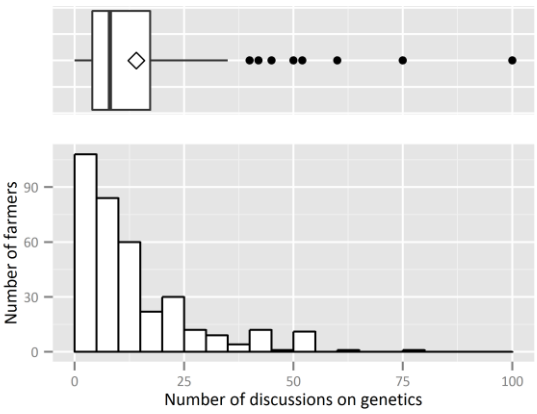

Figure 11: Reported number of discussions held on genetics with other breeders last year

Farmers' attitudes

Farmers were asked to indicate their level of agreement, on a 7-point scale (1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree") to statements related to:

1) The use of various genetic selection tools (EBVs and indexes)
2) The development of new genetic improvement tools (genomic and DNA technology), and to
3) Performance recording practices

The results to these questions are reported below, along with multivariate market segmentation analysis.

Note that the result presented in the figures and tables below, as in the rest of the report, reflect the opinions, attitudes, and actions of the surveyed farmers. The sampling procedure is clearly explained in the "Respondents" section at the beginning of the Appendix. Regarding trait preferences, result might be biased in favour breeds overrepresented in the sample surveyed (Table 16 and Table 17). In beef, preferences for maternal traits might reflect the overrepresentation of Stabilizers breeders in the sample.

EBVs and Selection indexes

Overall, survey respondents reported a positive attitude towards genetics selection tools, although results also reflected the view that traditional methods are still important and actually both sources of information are usually combined when making selection decisions (Tables 24 and 26). Small differences were found between surveyed sheep and beef farmers, although the latter seem to have a slightly more positive attitude (Tables 24 and 26, and Figure 23). Note that biases in the survey may have contributed to this result.

High average levels of agreement are found in the statements regarding preferences for EBVs over traditional methods, but also in the statement supporting the combined use of EBVS and other sources of information (pedigree, performance data and type traits). Selection indexes are reported to be widely used and the general opinion was that they are a good way of summarizing ram/bull traits. However, in most of the cases, decisions are based on EBVs and therefore indexes are used as a reference. Also most of the farmer respondents reported that indexes should include a broader number of traits and weight traits differently.

When analysing survey-wide farmer attitudes, average attitudes do not always give an accurate picture of the different ways of thinking in the farmer community. See Figures 18 to 28 in the Appendix for a more detailed description of farmer attitudes regarding genetic selection tools. For example in figure A3 (in the appendix) it can be seen that although most of the farmers think that they need EBVs to truly asses their rams/ bulls, there are a number of farmers (n=50, approx. 12% of the total) that think that they do not need EBVs at all. In addition, the use of traits for which EBVs are not available is quite important (Figure 24); around two fifths of sheep farmers and one third of beef farmers, somewhat agree or totally agree, respectively, with the statement "I select on traits for which genetic evaluations (EBVs) are not available". Finally, the vast majority of sheep and beef farmer respondents believe that they understand how EBVs are calculated and the meaning and units of the traits with EBVs.

Using multivariate market segmentation analysis we found that the previously reported attitudes are not independent but related to each other, and that different patterns of relationships somehow define different types of farmers. Three types of farmers could be found (see Table 26); we have defined these as (1) Pro-traditional, (2) Pro-EBVs, and (3) EBV-supporters. These groups have different recording practices (Table 30). Farmer respondents with a Pro-traditional attitude were the smallest group (n=28). They believe that traditional selection methods are better than EBVs and selection indexes. Conversely farmers with a Pro-EBV attitude (n= 207) completely trust EBVs and selection indexes and believe that they are better tools for selecting animals than traditional selection methods. EBV-supporters are farmers with attitudes intermediate to the two aforementioned groups. They acknowledge the power of EBVs and selection indexes but also use traditional methods. They combine both sources of information and they seem to give both equal importance.

Table 20: Attitudes towards the usefulness of EBVs

Attitude group	Attitudinal statement	Sheep farmers		Beef farmers	
		Average agreement	Standard deviation	**Average agreement**	Standard deviation
Preference of traditional selection methods	*I do not need EBVs to know how good my rams/bulls are*	2.9	2.0	2.7	1.8
	I prefer to rely on raw data (weights, muscle depth measurement, etc.) than on EBVs	3.8	1.7	3.5	1.5
	I will better off selecting on structure and type than on EBVs	3.3	1.7	3.2	1.6
Preference of genetic selection tools	*The use of EBVs increases the speed of genetic improvement compared to traditional breeding methods*	5.6	1.5	5.7	1.4
	EBVs are the best way to estimate the performance of a ram/bull's offspring	5.4	1.5	5.3	1.6
	EBVs provide poor value for money	3.0	1.7	2.7	1.6
Combination of traditional methods and genetic selection tools	*I need some extra information (pedigree, performance data, type traits) in addition to EBVs to fully assess a bull*	5.8	1.4	5.8	1.4
Methodological issues of genetic selection tools	*I select on traits for which genetic evaluations (EBVs) are not available*	4.0	1.7	3.8	1.6
	EBV accuracy is compromised by the poor quality of recording by other breeders	4.5	1.4	4.8	1.4
Understanding of genetic selection tools	*I understand how the EBVs are calculated*	5.1	1.4	5.3	1.2
	I understand the meaning and units of the traits for which EBVs are calculated	5.4	1.2	5.6	1.0

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

Table 21: Attitudes towards the usefulness of selection indexes

Species	Attitudinal statement	Average agreement	Standard deviation
Sheep	*Selection indexes are very important to me for selecting rams*	5.2	1.6
	Selection indexes are the best way I know to summarise ram features	4.8	1.6
	I would like to have new selection indexes that include a broader set of traits	4.6	1.4
	I would like to have new selection indexes that weight traits differently to the selection indexes available	4.5	1.3
	Most of my breeding decisions are based on animal's EBVs –not in their index	4.7	1.6
Beef	*Selection indexes are very important to me for selecting bulls*	5.2	1.6
	Selection indexes are the best way I know to summarise bull features	4.9	1.5
	I would like to have new selection indexes that include a broader set of traits	4.5	1.4
	I would like to have new selection indexes that weight traits differently to the selection indexes available	4.2	1.3
	Most of my breeding decisions are based on animal's EBVs –not in their index	4.9	1.6

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

Differences in farmer profile and farm features between the three farmer types were apparent in sheep farmers, but no differences could be found in beef farmers. Pro-EBV farmers were found to attend more meetings and workshops (average 5.9 per year) and visit more farms (18.3 per year) than Pro-traditional farmers (4.1 and 12.9 respectively for meetings and farm visits). EBV-supporters were in between; 4.3 and 17.8 meetings and farm visits respectively. Differences were also found for the number of years that farmers have been recording performance data on their sheep flock and whether they have done it continuously or not. Pro-EBV farmers reported recording performance for an average of 15.7 years and 87% of them have done it continuously. EBV-supporters have recorded performance for 11.7 years and 77% of them have done it continuously. Finally, Pro-traditional farmers have been recording performance for an average of 12.7 years and 59% of them have done it continuously.

Table 22: Attitudes towards EBVs and selection indexes, for the different farmer types

	Attitudinal statement	Pro-traditional	EBV-supporter	Pro-EBVs
Preference of traditional selection methods	*I do not need EBVs to know how good my rams/bulls are*	5.5	3.7	1.9
	I prefer to rely on raw data (weights, muscle depth measurement, etc.) than on EBVs	5.7	4.4	2.9
	I will better off selecting on structure and type than on EBVs	5.7	4.0	2.3
Preference of EBVs	*The use of EBVs increases the speed of genetic improvement compared to traditional breeding methods*	2.4	5.3	6.4
	EBVs are the best way to estimate the performance of a ram/bull's offspring	2.5	5.0	6.1
	EBVs provide poor value for money	5.4	3.7	1.9
Combination of traditional methods and EBVs	*I need some extra information (pedigree, performance data, type traits) in addition to EBVs to fully assess a bull*	4.7	5.9	5.8
Methodological issues of EBVs	*I select on traits for which genetic evaluations (EBVs) are not available*	4.8	4.5	3.3
	EBV accuracy is compromised by the poor quality of recording by other breeders	5.0	4.8	4.3
Understanding of EBVs	*I understand how the EBVs are calculated*	4.6	4.7	5.6
	I understand the meaning and units of the traits for which EBVs are calculated	4.7	5.1	5.9
Selection indexes	*Selection indexes are very important to me for selecting bulls*	1.9	4.8	6.0
	Selection indexes are the best way I know to summarise bull features	1.9	4.4	5.6
	I would like to have new selection indexes that include a broader set of traits	3.4	4.6	4.8
	I would like to have new selection indexes that weight traits differently to the selection indexes available	4.1	4.6	4.3
	Most of my breeding decisions are based on animal's EBVs –not in their index	3.0	4.4	5.1
Number of farmers		28	173	207

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

Performance recording

High average levels of agreement were found regarding the statement about the usefulness of an online recording system for sheep and beef. Beef farmers also gave high levels of agreement to the statement suggesting that the benefits of performance recording pay back the economic and work effort in the recording,

Pro-EBV sheep and beef farmers were found to see more value in performance recording compared to EBV-supporter and Pro-traditional farmer types (Table 28).

Table 23: Attitudes towards performance recording

Species	Attitudinal statement	Average agreement	Standard deviation
Sheep	***Performance recording*** *requires a very* ***large effort***	4.4	1.7
	The ***benefits*** *of being in a* ***performance recording*** *programme* ***pay back*** *the economic and work effort in recording*	4.7	1.7
	I think that an ***on-line recording system would help a lot*** *in recording pedigree and animal performance data*	5.1	1.3
	Costs of animal performance recording and selection *are too high and therefore* ***are a major constraint*** *to my business*	4.3	1.5
Beef	***Performance recording*** *requires a very* ***large effort***	4.5	1.7
	The ***benefits*** *of being in a* ***performance recording*** *programme* ***pay back*** *the economic and work effort in recording*	5.1	1.5
	I think that an ***on-line recording system would help a lot*** *in recording pedigree and animal performance data*	5.4	1.3
	Costs of animal performance recording and selection *are too high and therefore* ***are a major constraint*** *to my business*	3.9	1.7

Agreement scale: 1=”Totally disagree”, 2=”Disagree”, 3=”Somewhat disagree”, 4=”Neither agree nor disagree”, 5=”Somewhat agree”, 6=”Agree”, 7=”Totally agree”.

Table 24: Attitudes towards performance recording for the different farmer types

Species	Attitudinal statement	Pro-traditional	EBV-supporter	Pro-EBVs
Sheep	***Performance recording** requires a very **large effort***	4.0	4.6	4.3
	*The **benefits** of being in a **performance recording** programme **pay back** the economic and work effort in recording*	2.8	4.1	5.7
	***Costs of animal performance recording and selection** are too high and therefore **are a major constraint** to my business*	4.6	4.8	3.7
	*I think that an **on-line recording system would help a lot** in recording pedigree and animal performance data*	3.9	5.0	5.4
Beef	***Performance recording** requires a very **large effort***	4.6	4.7	4.3
	*The **benefits** of being in a **performance recording** programme **pay back** the economic and work effort in recording*	2.0	4.3	5.7
	***Costs of animal performance recording and selection** are too high and therefore **are a major constraint** to my business*	4.2	4.6	3.5
	*I think that an **on-line recording system would help a lot** in recording pedigree and animal performance data*	4.0	5.1	5.7

Agreement scale: 1=”Totally disagree”, 2=”Disagree”, 3=”Somewhat disagree”, 4=”Neither agree nor disagree”, 5=”Somewhat agree”, 6=”Agree”, 7=”Totally agree”.

Development of new genetic improvement tools

Generally, there is a positive attitude in the farmer community towards genomic and DNA technologies and crossbreeding; slightly more positive in beef than in sheep (Table 29). Sheep farmers report that genomic and DNA technology is not going to increase the rate of genetic gain in the short term but that it will do in the long term. Also, although most farmers recognise that crossbreeding is an interesting method of increasing flock/ herd profitability (Figure 33 in the Appendixes), a large number of farmers believe that it should be carefully studied and controlled (Figure 34 in the Appendixes).

Table 25: Attitudes towards the development of new genetic improvement tools

Species	Attitudinal statement	Average agreement	Standard deviation
Sheep	*Genomic and DNA technology are going to greatly increase the rate of genetic gain in the sheep industry in the short term*	4.3	1.5
	Genomic and DNA technology are going to greatly increase the rate of genetic gain in the sheep industry in the long term	5.5	1.2
	It is important that opportunities for the sheep industry from Genomic and DNA technology are maximised	5.7	1.1
	I would like to be involved in genomic evaluations	5.5	1.4
	Crossbreeding is an interesting method to increase the profitability of a sheep flock	5.3	1.6
	Crossbreeding should be carefully studied and controlled because it could have negative impacts on the sheep industry	4.3	1.8
Beef	*Genomic and DNA technology are going to greatly increase the rate of genetic gain in the beef industry in the short term*	4.8	1.6
	Genomic and DNA technology are going to greatly increase the rate of genetic gain in the beef industry in the long term	5.9	1.0
	It is important that opportunities for the beef industry from Genomic and DNA technology are maximised	6.0	1.0
	I would like to be involved in genomic evaluations	5.4	1.3
	Crossbreeding is an interesting method to increase the profitability of a beef herd	5.5	1.4
	Crossbreeding should be carefully studied and controlled because it could have negative impacts on the beef industry	3.8	2.0

Agreement scale: 1=”Totally disagree”, 2=”Disagree”, 3=”Somewhat disagree”, 4=”Neither agree nor disagree”, 5=”Somewhat agree”, 6=”Agree”, 7=”Totally agree”.

The different types of farmers were also found to have different attitudes towards the development of new genetic improvement tools (see Table 30). These attitudes are as expected; Pro-traditional farmers were less positive towards new genetic improvement tools, in general, and both Pro-EBV and EBV-supporters farmers were very positive. Interestingly, Pro-traditional farmers (especially beef farmers) were more supportive of crossbreeding than the others and think that crossbreeding should be neither monitored nor controlled, maybe because crossbreeding is in a way a traditional method (for a more detailed description of the attitudes individually, see figures 29 to 34 in the Appendix.

Table 26: Attitudes towards the development of new genetic improvement tools for the different farmer types

Species	Attitudinal statement	Pro-traditional	EBV-supporter	Pro-EBVs
Sheep	*Genomic and DNA technology are going to greatly increase the rate of genetic gain in the sheep industry in the short term*	3.4	4.1	4.5
	Genomic and DNA technology are going to greatly increase the rate of genetic gain in the sheep industry in the long term	4.5	5.4	5.8
	It is important that opportunities for the sheep industry from Genomic and DNA technology are maximised	4.8	5.6	5.9
	I would like to be involved in genomic evaluations	4.5	5.4	5.7
	Crossbreeding is an interesting method to increase the profitability of a sheep flock	4.0	5.3	5.4
	Crossbreeding should be carefully studied and controlled because it could have negative impacts on the sheep industry	4.9	4.4	4.1
Beef	*Genomic and DNA technology are going to greatly increase the rate of genetic gain in the beef industry in the short term*	3.3	4.3	5.2
	Genomic and DNA technology are going to greatly increase the rate of genetic gain in the beef industry in the long term	5.3	5.6	6.2
	It is important that opportunities for the beef industry from Genomic and DNA technology are maximised	5.0	5.8	6.3
	I would like to be involved in genomic evaluations	5.3	5.4	5.8
	Crossbreeding is an interesting method to increase the profitability of a beef herd	6.0	5.3	5.7
	Crossbreeding should be carefully studied and controlled because it could have negative impacts on the beef industry	3.3	4.2	4.1

Agreement scale: 1=”Totally disagree”, 2=”Disagree”, 3=”Somewhat disagree”, 4=”Neither agree nor disagree”, 5=”Somewhat agree”, 6=”Agree”, 7=”Totally agree”.

Farmers' actions

Farmers were asked to assess, on a 0-10 scale:

1) The relevance/importance of various criteria for selecting rams and bulls,
2) Their preference for a set of traits with EBVs available, for selecting rams and bulls, and
3) The usefulness of the specific selection index they use

Farmers were also asked to indicate:

1) Their level of use of EBVs and animal weight records
2) The reasons for the given levels of use of EBVs
3) Their level of use of genetics service providers, and
4) The usefulness of the services provided by various industry bodies (on a 0-10 scale)

The results to these questions are reported below, along with results from the multivariate market segmentation analysis.

Selection criteria

The relative importance of a set of criteria for selecting rams and bulls was assessed for sheep and beef farmers. The following fifteen traits were evaluated:

1. Traits with Estimated Breeding Values (EBVs)
2. Traits with no EBVs available
3. Accuracy values of EBVs
4. Breeding indexes
5. Traits that define correct breed type
6. Ram/bulls structural traits that affect functionality
7. Saleability of offspring based on visual criteria
8. Health status
9. Fertility certificates
10. Whether the animal has been ultrasound scanned / CT scanned
11. Gene status for major genes
12. Pedigree information
13. Reared on similar system to farm
14. Price/costs
15. Breeder

Generally, the most important selection criteria for both sheep and beef farmers was the health status of the animals, followed by the structural traits that affect functionality and traits with EBVs (Figures 12 and 13). For sheep farmers, the least important criteria were the fertility certificates and the gene status for major genes (perhaps because so few are available/useful to many sheep breeds). For beef farmer, the least important criteria were traits with no EBVs available, and the gene status for major genes. Note that traits with no EBVs available do not refer to structural traits or the visual appearance of the animals, both of which are actually very important to farmers.

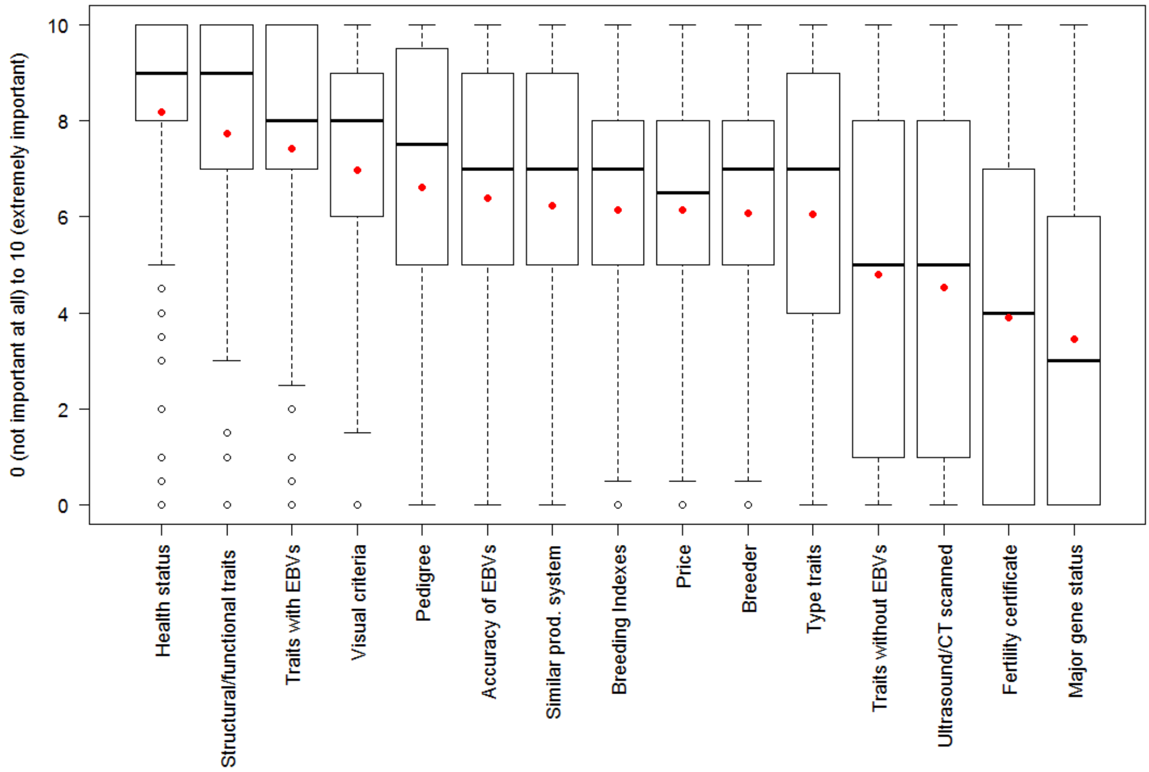

Figure 12: Importance of selection criteria for sheep farmers when selecting rams

Boxplot representing the average (black point), the median (black lines), the first and third quartiles (contained in the boxes), the dispersion (dashed line), and outliers (empty points) of the distribution of the ranks of each trait improvement

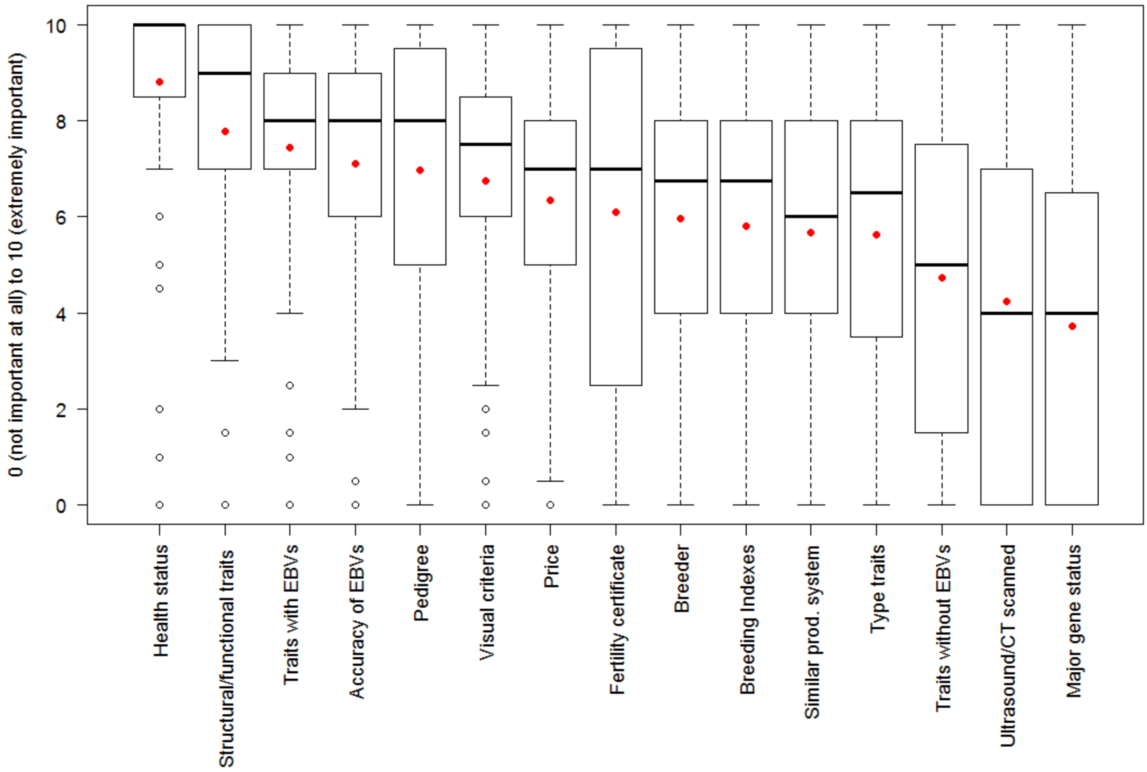

Figure 13: Importance of selection criteria for beef farmers when selecting bulls

Boxplot representing the average (black point), the median (black lines), the first and third quartiles (contained in the boxes), the dispersion (dashed line), and outliers (empty points) of the distribution of the ranks of each trait improvement

There were some differences in the relative importance that the farmer types gave to the different selection criteria (Table 31). As expected, a lower importance was given to traits with EBVs, accuracy values of EBVs and selection indexes by Pro-traditional farmers. Interestingly, pro-EBV farmers gave more importance to ultrasound scanned/ CT status and to the gene status for major genes, compared to other farmer types. These results reflect a more positive attitude towards genetic improvement technologies by pro-EBV farmers, over the other farmer types.

Table 27: The importance of selection criteria for sheep and beef farmer types when selecting rams and bulls

Criteria for selecting rams/bulls	Sheep				Beef			
	Pro-traditional	EBV-supporter	Pro-EBVs	ANOVA p. value	Pro-traditional	EBV-supporter	Pro-EBVs	ANOVA p. value
Health status	7.7	8.0	8.4		7.9	8.5	9.0	
Ram structural traits that affect functionality	7.6	7.4	8.0		5.6	7.3	8.2	0.064
Traits with Estimated Breeding Values (EBVs)	2.3	6.8	8.8	***	2.1	5.9	8.8	***
Saleability of offspring based on visual criteria	7.6	7.2	6.7		8.5	6.9	6.5	
Pedigree information	7.6	6.7	6.4		6.5	7.0	7.0	0.1
Accuracy values of EBVs	1.8	6.0	7.5	***	0.5	6.3	8.0	***
Reared on similar system to farm	6.9	6.0	6.3		2.2	5.7	5.9	
Breeding indexes	2.0	5.8	7.2	***	0.7	4.4	7.0	***
Price/costs	5.8	6.3	6.0		3.3	6.8	6.3	*
Breeder	5.6	5.8	6.4		3.9	6.1	6.0	
Traits that define correct breed type	6.3	6.1	6.0		4.9	5.6	5.7	
Traits with no EBVs available	4.7	5.0	4.7		3.2	4.5	5.0	
Whether the animal has been ultrasound scanned / CT scanned	2.6	3.8	5.5	***	1.3	3.4	4.9	**
Fertility certificates	4.4	3.5	4.2		4.4	4.6	7.2	***
Gene status for major genes	2.6	2.8	4.1	***	0.0	2.8	4.5	***

ANOVA p values: "***" = 0, "**" = 0.001, "*"= 0.01 , and "." = 0.05

Preferences for traits when selecting animals

The following fifteen traits were assessed by sheep farmers in a 0 to 10 scale:

1. Birth weight
2. Lambing ease
3. Maternal ability (milk)
4. Litter size born
5. Litter size reared
6. Eight week weight
7. Scan weight
8. Muscle depth
9. Fat depth
10. ATAN – Penalty on lack of fat
11. Carcase fat weight
12. Carcase lean weight
13. Carcase shape – Gigot muscularity
14. Mature size
15. Faecal Egg Count

The following nineteen traits were evaluated by beef farmers in a 0-10 scale:

1. 200 days weight
2. 400 day weight
3. 600 day weight
4. Age at first calving
5. Birth weight
6. Calving ease
7. Calving interval
8. Carcase weight
9. Cow mature size
10. Docility
11. Fat depth
12. Gestation length
13. IMF% (marbling)
14. Lifespan
15. Maternal 200 day weight (milk)
16. Maternal calving ease
17. Muscle depth / area
18. Retail yield
19. Scrotal circumference

Answers were standardized before being analysed to avoid biases related to differences in the use of the scale between farmers in their evaluation of the traits' importance. Overall results are presented in Figure 14 for sheep and Figure 15 for beef.

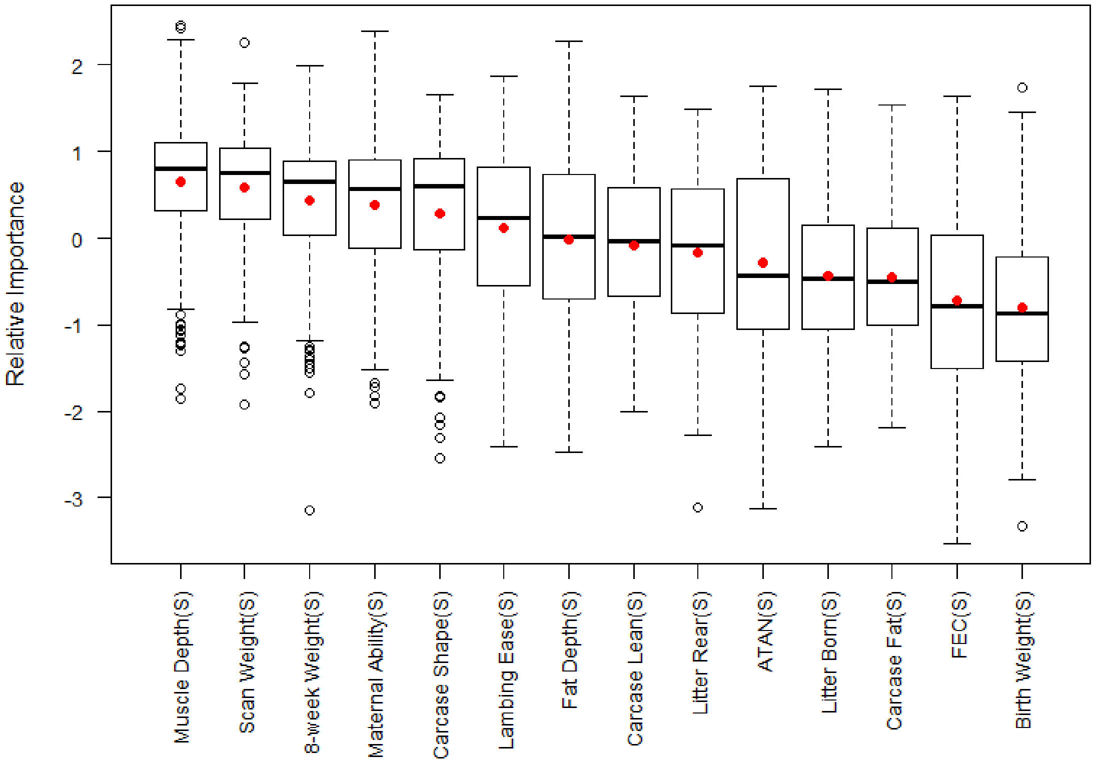

Figure 14: Relative importance of traits for selecting rams

*(S) refers to the standardized variables. That is why the relative importance varies from -4 to 2.5 instead of the original 0-10 scale.

Boxplot representing the average (black point), the median (black lines), the first and third quartiles (contained in the boxes), the dispersion (dashed line), and outliers (empty points) of the distribution of the ranks of each trait improvement

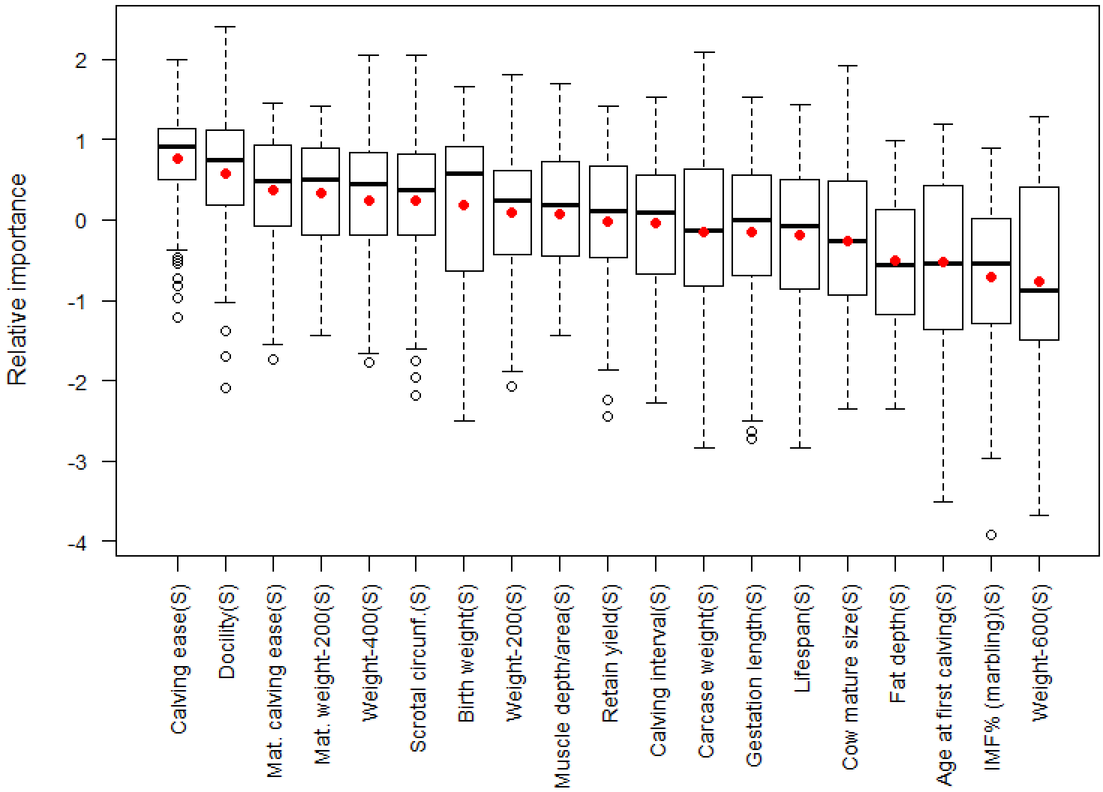

Figure 15: Relative importance of traits for selecting bulls

*(S) refers to the standardized variables. That is why the relative importance varies from -4 to 2.5 instead of the original 0-10 scale.

Boxplot representing the average (black point), the median (black lines), the first and third quartiles (contained in the boxes), the dispersion (dashed line), and outliers (empty points) of the distribution of the ranks of each trait improvement

Farmer types were found to have different preferences for a number of traits (Table 32). Carcase shape, mature size and ATAN (penalty for lack of fat) were reported as being more important for Pro-traditional sheep farmers, compared to the other sheep farmer types. Conversely, scan weight was reported as being less important for Pro-traditional sheep farmers than for the other types. In beef, retail yield and carcase weight were more important for Pro-traditional farmers when compared to the other types, while maternal 200-day weight and birth weight were reported as being less important (Table 33). Also, Pro-EBVs beef farmers reported giving importance to a larger number of traits than Pro-traditional farmers, who reported focusing primarily in only four or five traits. Finally, farmers of all the groups reported giving high importance to docility. Note that differences for some traits (docility, lifespan, cow mature size and age at first calving) could not be evaluated due to the lack of data to inform a statistical test (these traits are not widely analysed in all breeds and hence could not be scored by all survey respondents).

Table 28: Relative importance of traits for sheep farmer types when selecting rams. A large bar denotes a high relative importance of the trait.

Ram traits	Pro-traditional	EBV-supporter	Pro-EBVs	ANOVA p. value
Muscle depth	0.6	0.7	0.6	
Scan weight	-0.2	0.6	0.7	***
Eight week weight	0.2	0.5	0.4	
Maternal ability (milk)	0.3	0.3	0.4	
Carcase shape – Gigot muscularity	0.7	0.3	0.2	0.060
Lambing ease	0.1	0.1	0.2	
Fat depth	0.2	0.0	-0.1	
Carcase lean weight	0.0	-0.1	0.0	
Litter size reared	0.0	-0.1	-0.3	
Mature size	0.2	-0.2	-0.3	*
ATAN – Penalty on lack of fat	0.3	-0.4	-0.3	0.054
Litter size born	-0.1	-0.5	-0.4	
Carcase fat weight	-0.1	-0.5	-0.5	
Faecal Egg Count	-1.2	-0.8	-0.6	
Birth weight	-0.9	-0.8	-0.8	

ANOVA p values: “***” = 0, “**” = 0.001, “*”= 0.01, and “.” = 0.05

Table 29: Relative importance of traits for beef farmer types when selecting bulls. . A large bar denotes a high relative importance of the trait.

Bull traits	Pro-traditional	EBV-supporter	Pro-EBVs	ANOVA p. value
Calving ease	0.3	0.8	0.8	
Docility	0.6	0.6	0.6	NA
Maternal calving ease	0.0	0.3	0.4	
Maternal 200 day weight (milk)	-0.5	0.1	0.5	*
400 day weight	-0.3	0.1	0.3	
Scrotal circumference	-0.4	0.2	0.3	
Birth weight	-0.9	0.0	0.3	*
200 days weight	-0.3	-0.1	0.2	
Muscle depth / area	-0.3	0.2	0.0	
Retail yield	0.9	-0.2	0.0	0.092
Calving interval	-0.3	-0.1	0.0	
Carcase weight	1.1	0.2	-0.3	*
Gestation length	-1.0	-0.1	-0.1	
Lifespan	-0.2	-0.2	-0.2	NA
Cow mature size	-0.3	-0.3	-0.3	NA
Fat depth	-1.0	-0.4	-0.5	
Age at first calving	-0.5	-0.5	-0.5	NA
IMF% (marbling)	-0.5	-0.3	-0.9	
600 day weight	-0.3	-0.5	-0.9	

NA traits with NA had not enough anwers in all of any of the farmer groups to allow statistical analysis. The traits importance value that is given for this trait correspond with the overall average acroos groups

ANOVA p values: “***” = 0, “**” = 0.001, “*”= 0.01, and “.” = 0.05

Use of EBVs and animal weight records

Overall, a large proportion (above 80% in farmer types for both sheep and beef) of survey respondents reported recording weights in their flocks/ herds (Table 30). No major differences were found between farmer types in this respect. However, differences were found between farmer types in the proportion of surveyed farmers who reported sharing records; 90% of the Pro-EBVs recording sheep farmer respondents reported sharing records with recording service providers, while a lower 70% of the Pro-traditional farmers reported doing the same. Similarly, 89% of the Pro-EBVs recording beef farmer respondents reported sharing records with recording service providers, while only 75% of the Pro-traditional beef farmer respondents reported doing the same. Regarding the provision of and request for EBVs, a large proportion of farmer respondents reported that they request EBVs when purchasing rams/bulls. However, around 40% of the sellers do not provide EBVs. Generally, sheep and beef farmers were more likely to record weights and submit them to service providers, than to provide or request EBVs during the sale/ purchase of animals. There were some differences in the level of use of EBVs by the farmer types (Table 34). Pro-EBV farmers were more likely to provide or request EBVs, compared to other types of farmers. These results reflect a more positive attitude towards the use of EBVs in the sale/ purchase of animals by pro-EBV farmers, compared to the other farmer types.

Table 30: Level of use of EBVs and animals weight records

Species		Pro-traditional	EBV-supporter	Pro-EBVs	All farmers
Sheep	Provide EBVs	25%	43%	79%	59%
	Request EBVs	17%	69%	95%	78%
	Record weights	88%	88%	97%	92%
	Share weights*	70%	85%	90%	86%
Beef	Provide EBVs	20%	29%	88%	63%
	Request EBVs	20%	60%	97%	80%
	Record weights	80%	71%	95%	85%
	Share weights*	75%	82%	89%	86%

*Percentage of weight recording farmers that submit their weights to service providers.

Sheep and beef farmer respondents of both Pro-EBVs and EBV-supporter types reported that the reason for not providing EBVs during the sale/ purchase of animals was because there was not the interest from the customer. Interestingly, the reason for not requesting EBVs for both Pro-EBVs and EBV-supporters sheep and beef farmers was because they were not provided by the seller (Table 35).

As well as reporting that EBVs were not of interest to customers, Pro-traditional sheep and beef farmers gave a much broader set of reasons for not providing EBVs (compared to Pro-EBV and EBV-supporter farmers) including reporting that EBVs are not an accurate indication of ram/ bull quality, EBVs are not a useful marketing tool, the traits that are important in the sale are not covered by EBVs, and EBVs may be confusing to understand. Sheep farmers also suggested that EBVs were not provided because they were too costly (Table 36).

Pro-traditional sheep and beef farmers reported that a reason for not requesting EBVs was because EBVs are not needed to know how good a ram/ bull is and because EBVs are not an accurate indication of ram/ bull quality.

Table 31: Reasons for not providing/ requesting EBVs

Species	Reasons for	Statements	Percentage of farmers	n
Sheep	No providing EBVs	*Too time consuming*	16%	106
		Too costly	16%	106
		The traits that are important in the sale are not covered by EBVs	25%	106
		EBVs are not an accurate indication of the quality of my rams	19%	106
		I am not convinced that EBVs are a useful marketing tool	21%	106
		My customers are not interested in using EBVs to select their rams	80%	106
		I believe that EBVs are too confusing for my clients to understand	33%	106
		The EBVs for my stock don't compare favourably with others within the breed	14%	106
	No requesting EBVs	*The traits that are important to me are not covered by EBVs*	29%	66
		EBVs are not an accurate indication of the quality of the rams	39%	66
		EBVs are not provided by my ram seller	62%	66
		I am happy to trust the ram seller's judgement in providing the rams I need	14%	66
		I don't need EBVs to know how good a ram is	33%	66
Beef	No providing EBVs	*Too time consuming*	27%	37
		Too costly	19%	37
		The traits that are important in the sale are not covered by EBVs	27%	37
		EBVs are not an accurate indication of the quality of my bulls	19%	37
		I am not convinced that EBVs are a useful marketing tool	8%	37
		My customers are not interested in using EBVs to select their bulls	76%	37
		I believe that EBVs are too confusing for my clients to understand	38%	37
		The EBVs for my stock don't compare favourably with others within the breed	14%	37
	No requesting EBVs	*The traits that are important to me are not covered by EBVs*	15%	26
		EBVs are not an accurate indication of the quality of the bulls	15%	26
		EBVs are not provided by my bull seller	58%	26
		I am happy to trust the bull seller's judgement in providing the bulls I need	23%	26
		I don't need EBVs to know how good a bull is	38%	26

Table 32: Reasons for not providing/ requesting EBVs by farmer types

Species	Reasons for	Pro-traditional	EBV-supporter	Pro-EBVs
Sheep	**Not providing EBVs**			
	Number of farmers	18	75	32
	Too time consuming	6%	15%	26%
	Too costly	38%	13%	9%
	The traits that are important in the sale are not covered by EBVs	38%	22%	22%
	EBVs are not an accurate indication of the quality of my rams	50%	18%	0%
	I am not convinced that EBVs are a useful marketing tool	44%	19%	9%
	My customers are not interested in using EBVs to select their rams	63%	82%	87%
	I believe that EBVs are too confusing for my clients to understand	38%	37%	17%
	The EBVs for my stock don't compare favourably with others within the breed	0%	18%	13%
	Not requesting EBVs			
	Number of farmers	20	44	7
	The traits that are important to me are not covered by EBVs	35%	29%	0%
	EBVs are not an accurate indication of the quality of the rams	80%	21%	25%
	EBVs are not provided by my ram seller	25%	76%	100%
	I am happy to trust the ram seller's judgement in providing the rams I need	10%	12%	50%
	I don't need EBVs to know how good a ram is	70%	17%	25%
Beef	**Not providing EBVs**			
	Number of farmers	4	35	9
	Too time consuming	0%	26%	43%
	Too costly	0%	19%	29%
	The traits that are important in the sale are not covered by EBVs	33%	30%	14%
	EBVs are not an accurate indication of the quality of my bulls	67%	19%	0%
	I am not convinced that EBVs are a useful marketing tool	67%	4%	0%
	My customers are not interested in using EBVs to select their bulls	67%	78%	71%
	I believe that EBVs are too confusing for my clients to understand	33%	44%	14%
	The EBVs for my stock don't compare favourably with others within the breed	0%	15%	14%
	Not requesting EBVs			
	Number of farmers	4	20	2
	The traits that are important to me are not covered by EBVs	25%	15%	0%
	EBVs are not an accurate indication of the quality of the bulls	75%	5%	0%
	EBVs are not provided by my bull seller	0%	65%	100%
	I am happy to trust the bull seller's judgement in providing the bulls I need	0%	25%	50%
	I don't need EBVs to know how good a bull is	100%	25%	50%

Use of selection indexes

Given the large number of sheep breeds and indexes in the sample and the reluctance of many farmers to address the "evaluation of selection indexes" questions in the survey, the results presented in Table 37 should be interpreted with extreme caution. Conversely, the number of beef selection indexes is smaller than in sheep and most surveyed beef farmers assessed the indexes.

Table 33: Evaluation of selection indexes by sheep farmers

Sheep breed	Selection Index	n	Average Usefulness	Standard deviation
Percentage of farmers using selection indexes = **84%**				
Bluefaced Leicester	Lamb Growth Index	2	5.8	2.5
Charollais	Terminal Sire Index	2	8.3	2.5
Dorset	Maternal Index	2	10.0	0.0
	Terminal Sire Index	2	8.3	1.8
Easycare	Hill Index	1	7.5	-
Hampshire Down	Terminal Sire Index	9	8.3	1.4
Lleyn	Maternal Index	7	7.8	2.4
	Carcase+ Index	0	-	-
Meatlinc	Terminal Sire Index	2	5.0	7.1
North Country Cheviot Park	Hill Index	3	5.8	5.2
Romney	Carcase+ index	1	7.5	-
Scottish Blackface	Hill Index	1	0.0	-
Shedding Comp. – Scotland	Hill Index	1	0.0	-
Shedding Comp. – Exlana Group	Exlana Index	1	7.0	-
Shropshire	Maternal Index (Carcase+)	1	5.0	-
	Terminal Sire Index	0	-	-
Southdown	Terminal Sire Index	4	7.9	1.0
Suffolk	Terminal Sire Index	4	7.8	1.6
	Maternal Index	13	6.4	2.9
Vendeen	Terminal Sire Index	2	3.0	1.4
Welsh Mountain	Welsh Index	1	10.0	-
Wiltshire Horn	Wiltshire Horn Index	2	7.3	1.8
Beltex	Terminal Sire Index	0	-	-
Beulah	Welsh Index	0	-	-
North Country Cheviot Hill	Hill Index	0	-	-
Texel	Terminal Sire Index	0	-	-

Table 34: Evaluation of Selection Indexes by beef farmers[1]

Beef service provider	Selection Index	n	Average Usefulness	Standard deviation
Percentage of farmers using seletion indexes = **72%**				
Signet	Beef value	46	8.7	1.8
	Calving value	44	8.9	1.7
	Maternal value	46	8.5	2.3
Breed Plan	Terminal Sire Index	33	7.1	2.5
	Self Replacing index	31	7.0	2.8
Limousin	Beef value	9	8.7	1.2
	Calving Value	9	9.4	0.9
	Maternal value	7	7.9	2.6

[1] These usefulness rankings represent an assessment of different indexes by different users. Given this, and the small sample sizes, a statistical analysis of the differences is not appropriate.

Use of genetics service providers

The use of genetics service providers by sheep farmer respondents and by beef farmer respondents are shown in Table 39 and Table 41 respectively, and a break down by the most common breeds by sheep and beef respondents is given in Tables 40 and 42, respectively. A considerable number of respondents (16%) do not use any genetic service provider. Signet was the most used provider (56% of respondents) and 17% of the respondents reported using both Signet and Innovis. The remainder used Innovis, SIL, or another service provider. Note, that respondents were specifically asked “which sheep genetic service provider do you use?” Care is required in the interpretation of the question; some respondents may determine service provision as paying for a service (i.e. recording) while others may interpret service provision as the supply of knowledge.

Table 35: Genetic Service Provider use as reported by sheep breeders

Service provider	Number of sheep farms	Percentage
Signet	186	56%
Innovis & Signet	55	17%
Innovis	23	7%
Other	9	3%
SIL	2	1%
Signet & SIL	1	0%
None	54	16%
Total (n)	330	100%

Table 36: Genetic Service Provider use as reported by sheep farmer respondents by the most common breeds[1]

Sheep breed	n	Signet	Innovis & Signet	Innovis	Other	None
Texel	52	54%	19%	13%	4%	10%
Lleyn	38	55%	16%	11%	3%	16%
Suffolk	33	58%	24%	9%	0%	9%
HampshireDown	19	63%	32%	0%	0%	5%
Composite/Cross	18	44%	17%	11%	11%	17%

[1]Innovis also sell AI services as well as genetic evaluation services. Respondents may have indicated they use Innovis for AI services, because, for example, Innovis don't record any Suffolk sheep.

Table 37: Genetic Service Provider use as reported by beef farmer respondents[1]

Service provider	Number of beef farms	Percentage
Signet	50	35%
ABRI/Breed Plan	37	26%
Limousin	9	6%
ABRI/Breed Plan & Signet	4	3%
Other	3	2%
ABRI/Breed Plan & Limousin	1	1%
None	40	28%
Total (n)	144	100%

[1] A proportion of the 40 not using a service provider (55%) reported recording weight and not sharing the weight with service providers.

Table 38: Genetic Service Provider use as reported by beef farmer respondents by the most common breeds

Beef breed	n	Signet	ABRI/Breed Plan	Limousin	ABRI/Breed Plan & Signet	Other	None
Stabiliser	33	97%	0%	0%	3%	0%	0%
Limousin	16	6%	0%	50%	0%	0%	44%
Crossbred	15	13%	7%	7%	7%	7%	60%
Sussex	14	64%	0%	0%	7%	7%	21%
Hereford	13	0%	92%	0%	0%	0%	8%
Aberdeen Angus	12	0%	75%	0%	0%	0%	25%

Table 43 reports the value of the services provided, in three categories, by various industry bodies (on a 0-10 scale) by those sheep farmers that use or know about the service provider. There is a variation in the quality of genetic services provided by industry bodies, as reported by sheep farmers. For industry bodies with few assessments, the results should be taken with extreme caution.

Table 39: Sheep farmers' assessment of genetic services provided by Industry bodies

Industry body	*Use (or know about) the services provided*	n	Provide information and guidance[1]	Communitication of financial value[2]	Marketing support[3]
Signet	76%	252	7.5	6.1	5.9
The Breed Society	52%	173	5.5	4.8	4.9
BASCO	47%	154	7.8	4.3	4.6
NSA	41%	135	3.4	4.6	3.9
EBLEX	41%	134	5.3	6.3	5.9
EBLEX Better Return Programme	40%	131	5.2	7.1	6.6
Innovis	23%	76	5.0	5.1	5.2
Hybu Cig Cymru - HCC	14%	47	4.1	6.4	5.6
Quality Meat Scotland - QMS	13%	43	3.3	5.3	3.9
Breedplan	11%	37	7.5	4.7	5.1
Farm Connect -Wales	9%	30	4.4	4.9	3.9
NBA	8%	25	3.1	4.9	3.8
EGENES	7%	24	6.9	3.3	3.8
Pedigree Cattle Services	4%	14	7.1	4.1	4.1
SIL	2%	8	9.0	6.3	3.8

[1]Providing genetic information and guidance to pedigree breeders

[2]Communicating the financial value of breeding improvement to commercial producers

[3]Supporting the marketing of recorded animals

Significant differences were found between sheep farmer types in the value of the services provided by Signet (Table 44). Pro-EBV farmers assessed Signet as providing better services overall and in information and guidance, communication and financial value, and marketing support over EBV-supporter and Pro-traditional farmer types. This suggests that Pro-EBVs farmers that are users of Signet or know about Signet believe that Signet provides a good service.

Table 45 reports the value of the services provided, in three categories, by various industry bodies (on a 0-10 scale) by those beef farmers that use or know about the service provider. There is a variation in the quality of genetic services provided by industry bodies, as reported by beef farmers. For industry bodies with few assessments, the results should be taken with extreme caution.

Table 40: Differences between sheep farmer types assessment of genetic services provided by Signet

		Sheep farmers		
Service provider	ANOVA p-value	**Pro-traditional**	**EBV-supporter**	**Pro-EBVs**
Signet *(Use -or know about- the service provided)*	***	58%	69%	86%
[1]Provide information and guidance	***	4.3	7.1	8.2
[2]Communication of financial value	***	3.9	5.6	6.7
[3]Marketing support	***	5.2	5.3	6.5

[1]Providing genetic information and guidance to pedigree breeders

[2]Communicating the financial value of breeding improvement to commercial producers

[3]Supporting the marketing of recorded animals

Table 41: Beef farmers assessment of genetic services provided by Industry bodies

Service provider	n	*Use (or know about) the services provided*	**Provide information and guidance[1]**	**Communitication of financial value[2]**	**Marketing support[3]**
Signet	84	58%	7.5	5.2	5.6
The Breed Society	74	51%	6.1	5.3	5.6
EBLEX	55	38%	5.3	7.2	5.3
EBLEX Better Return Programme	54	38%	5.1	7.5	6.3
Breedplan	51	35%	6.8	4.8	4.7
BASCO	47	33%	8.3	5.2	5.6
NBA	38	26%	3.6	5.1	3.7
NSA	26	18%	4.0	5.5	4.0
Hybu Cig Cymru - HCC	21	15%	4.2	5.4	4.8
Innovis	19	13%	5.7	6.9	5.8
Quality Meat Scotland - QMS	17	12%	2.8	4.8	4.1
Pedigree Cattle Services	16	11%	7.3	5.0	5.7
Farm Connect -Wales	15	10%	4.9	5.1	4.0
EGENES	5	3%	5.3	3.5	4.4
SIL	1	1%	10.0	0.5	-

[1]Providing genetic information and guidance to pedigree breeders

[2]Communicating the financial value of breeding improvement to commercial producers

[3]Supporting the marketing of recorded animals

Significant differences were found between beef farmer types in the value of the services provided by Signet (Table 46). Pro-EBV farmers assessed Signet as providing better services overall and in information and guidance over EBV-supporter and Pro-traditional farmer types. This suggests that Pro-EBVs farmers that are users of Signet or know about Signet believe that Signet provides a good service in information and guidance.

Table 42: Differences between beef farmers types assessment of genetic services provided by Signet

		Beef farmers		
Service provider	ANOVA p-value	**Pro-traditional**	**EBV-supporter**	**Pro-EBVs**
Signet *(Use -or know about- the service provided)*	**	60%	42%	69%
[1]Provide information and guidance	***	1.8	6.8	8.0
[2]Communication of financial value	0.058	1.2	4.7	5.6
[3]Marketing support	0.071	5.0	4.3	6.1

[1]Providing genetic information and guidance to pedigree breeders

[2]Communicating the financial value of breeding improvement to commercial producers

[3]Supporting the marketing of recorded animals

Survey results data

Table 43: Description of the number of animals, percentage of rams and bulls sold on farm, use of Service providers and of selection indexes in sheep and beef farm

Variable	n	Average	St. Dev	Median
N of ewes	328	322	569	100
N of rams	328	26	49	12
N of ewe breeds	328	1.5	1.0	1
N of ram breeds	328	1.1	0.8	1
Perc. of rams sold on farm	280	48%	37%	50%
Perc. of farm using Innovis	408	19%	39%	0%
Perc. of farm using Signet	408	62%	48%	100%
Perc. of farm using SIL	408	1%	11%	0%
Perc. of farm using other service provider	408	4%	21%	0%
Perc. of farm not using service provider	331	16%	37%	0%
Perc. of sheep farm using selection indexes	330	84%	36%	100%
N of cows	139	83	124	45
N of bulls	139	5	11	2
N of cow breeds	139	1.4	0.8	1
N of bull breeds	193	1.7	0.6	2
Perc. of bulls sold on farm	108	27%	38%	1%
Perc. of farm using ABRI/Breed plan	144	29%	46%	0%
Perc. of farm using Limousin cattle society	144	7%	26%	0%
Perc. of farm using Signet	144	39%	49%	0%
Perc. of farm using other service provider	144	3%	16%	0%
Perc. of farm not using service provider	144	27%	45%	0%
Perc. of beef farm using selection indexes	144	72%	45%	100%

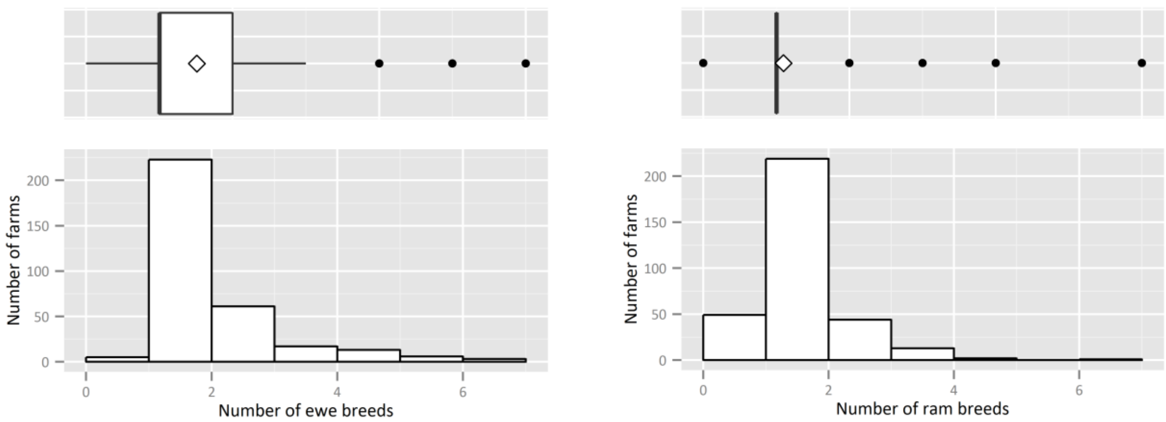

Figure 16: Number of ewe and ram breeds per farm

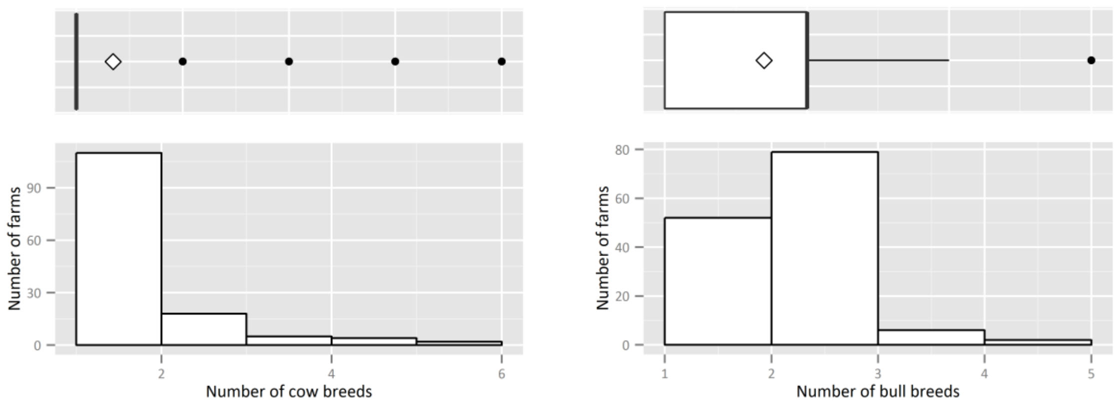

Figure 17: Number of cow and bull breeds per farm

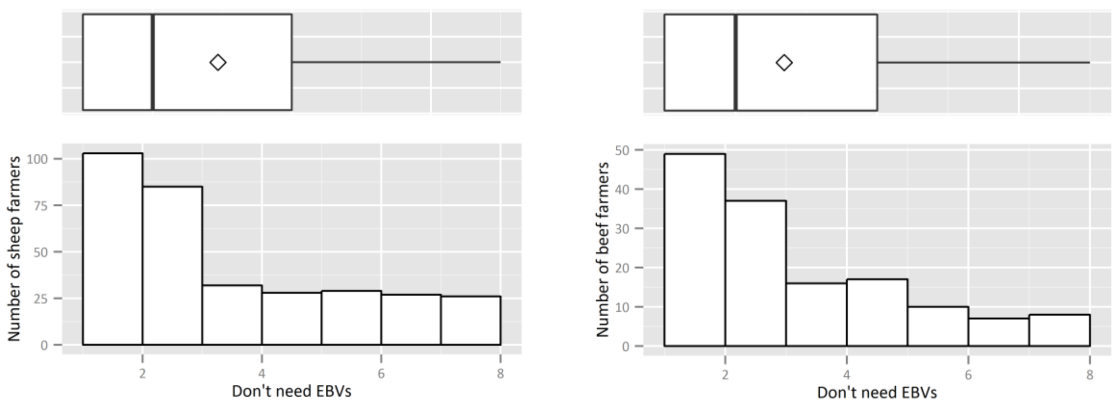

Figure 18: Farmers' attitudes towards EBVs. Agreement with statement "I do not need EBVs to know how good my rams/bulls are"

Agreement scale: 1=”Totally disagree”, 2=”Disagree”, 3=”Somewhat disagree”, 4=”Neither agree nor disagree”, 5=”Somewhat agree”, 6=”Agree”, 7=”Totally agree”.

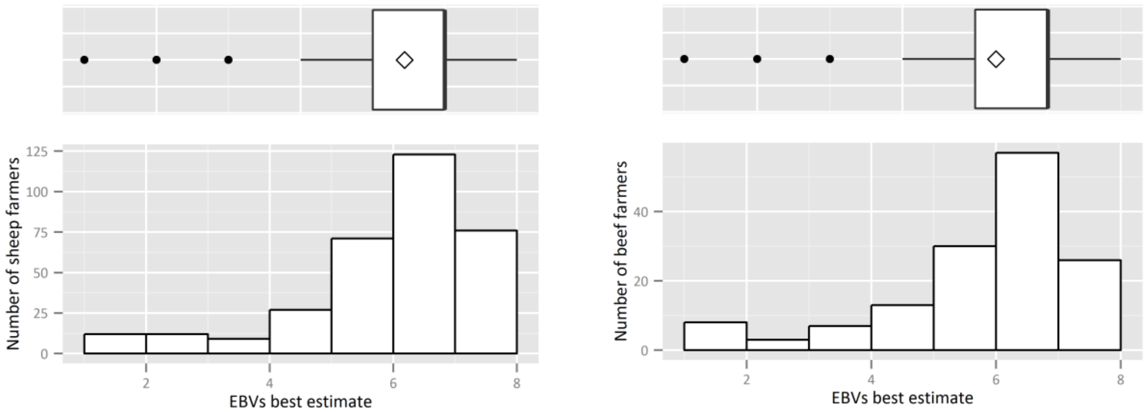

Figure 19: Farmers' attitudes towards EBVs. Agreement with statement "EBVs are the best way to estimate the performance of a ram's/bull's offspring"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

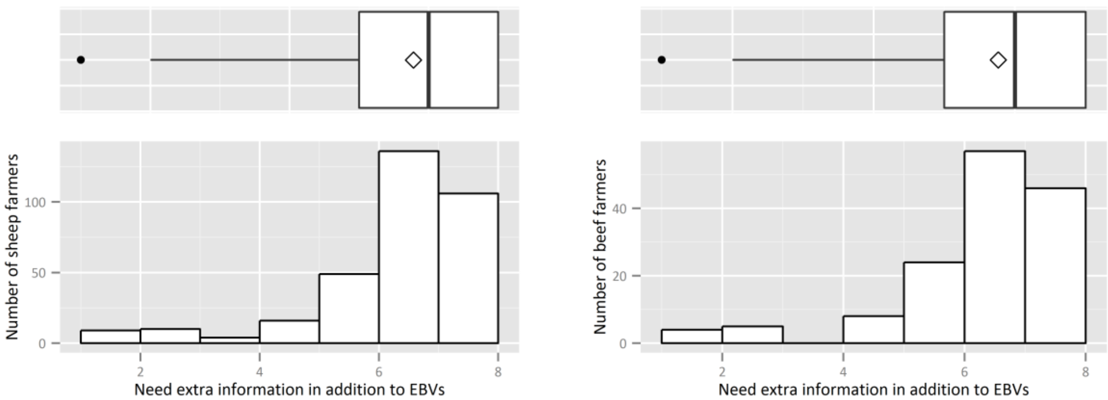

Figure 20: Farmers' attitudes towards EBVs. Agreement with statement "I need some extra information (pedigree, performance data, type traits) in addition to EBVs to fully assess a ram/bull"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

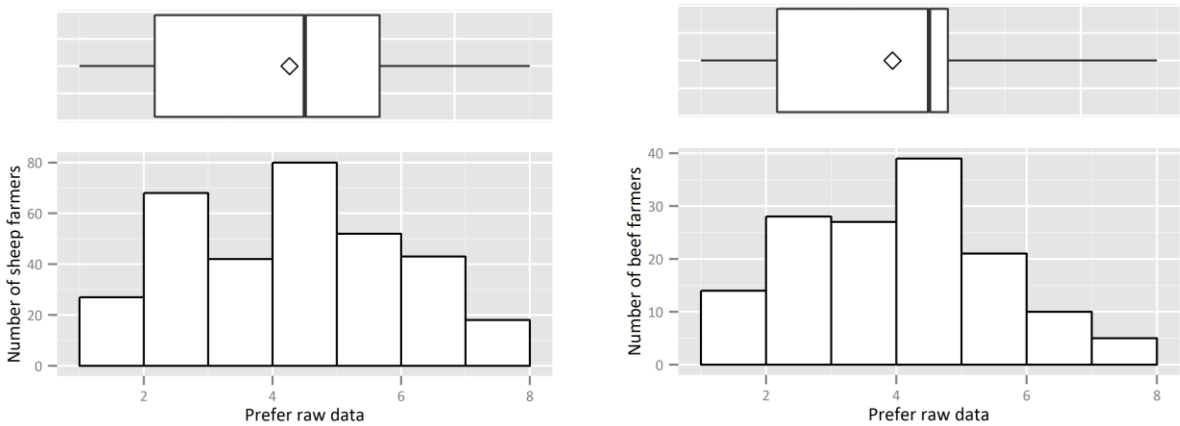

Figure 21: Farmers' attitudes towards EBVs. Agreement with statement "I prefer to rely on raw data (weights, muscle depth measurement, etc.) than on EBVs"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

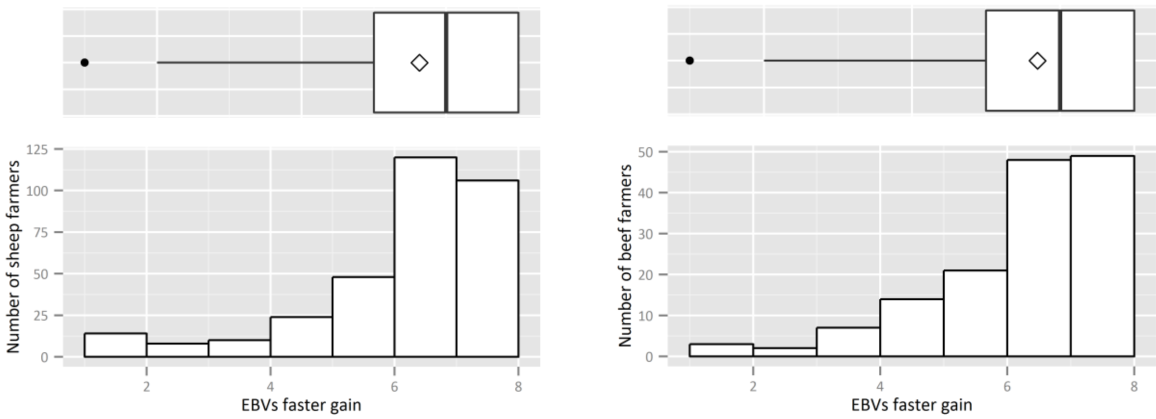

Figure 22: Farmers' attitudes towards EBVs. Agreement with statement "The use of EBVs increases the speed of genetic improvement compared to traditional breeding methods"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

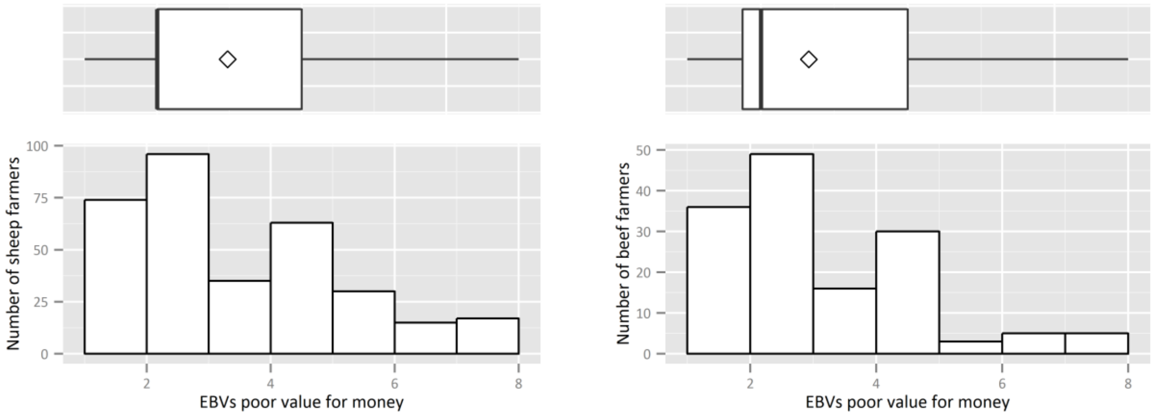

Figure 23: Farmers' attitudes towards EBVs. Agreement with statement "EBVs provide poor value for money"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

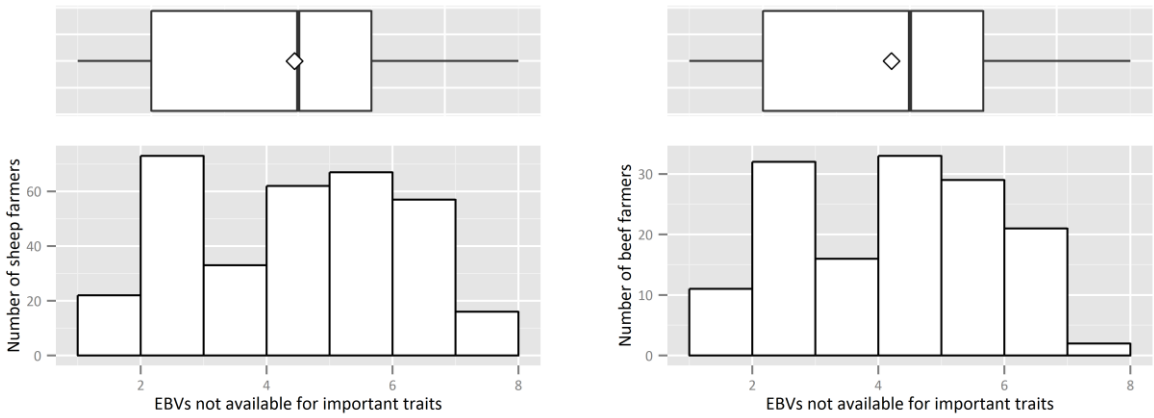

Figure 24: Farmers' attitudes towards EBVs. Agreement with statement "I select on traits for which genetic evaluations (EBVs) are not available"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

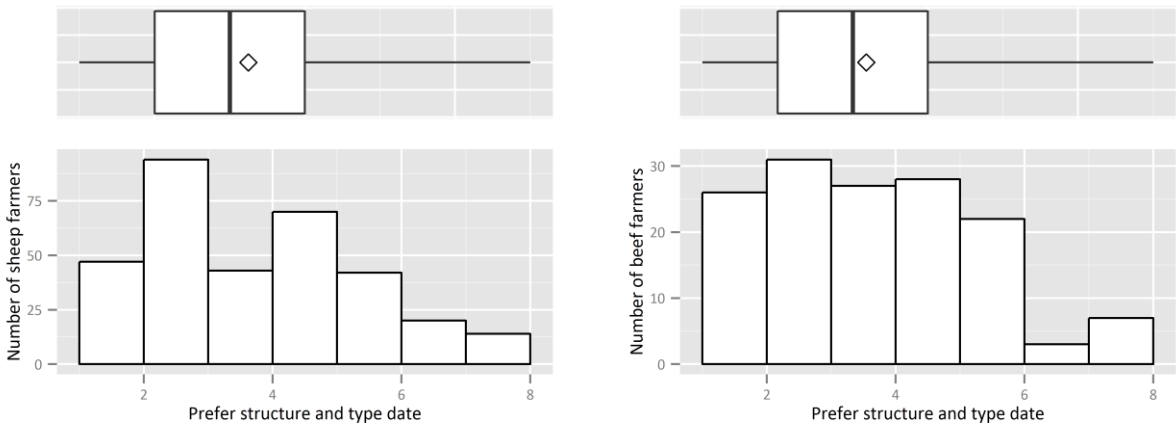

Figure 25: Farmers' attitudes towards EBVs. Agreement with statement "I will better off selecting on structure and type than on EBVs"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

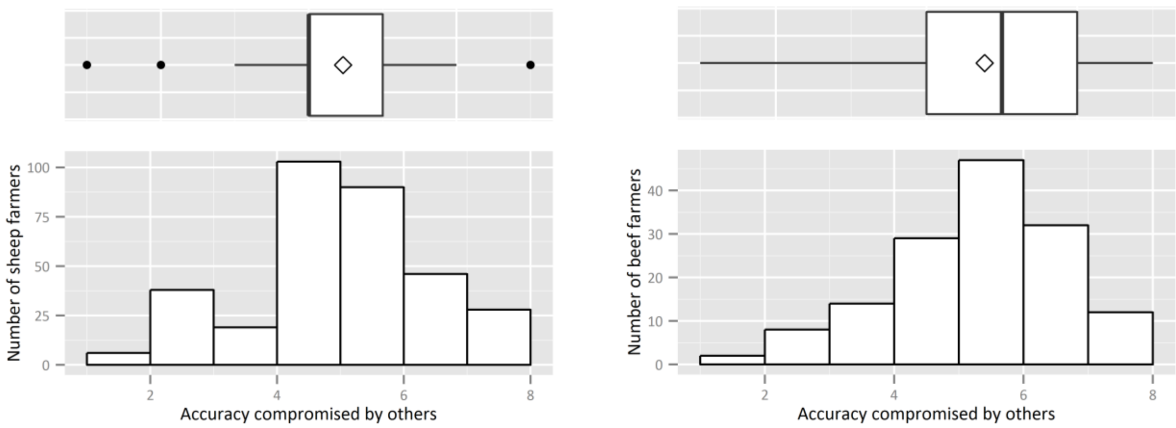

Figure 26: Farmers' attitudes towards EBVs. Agreement with statement "EBV accuracy is compromised by the poor quality of recording by other breeders"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

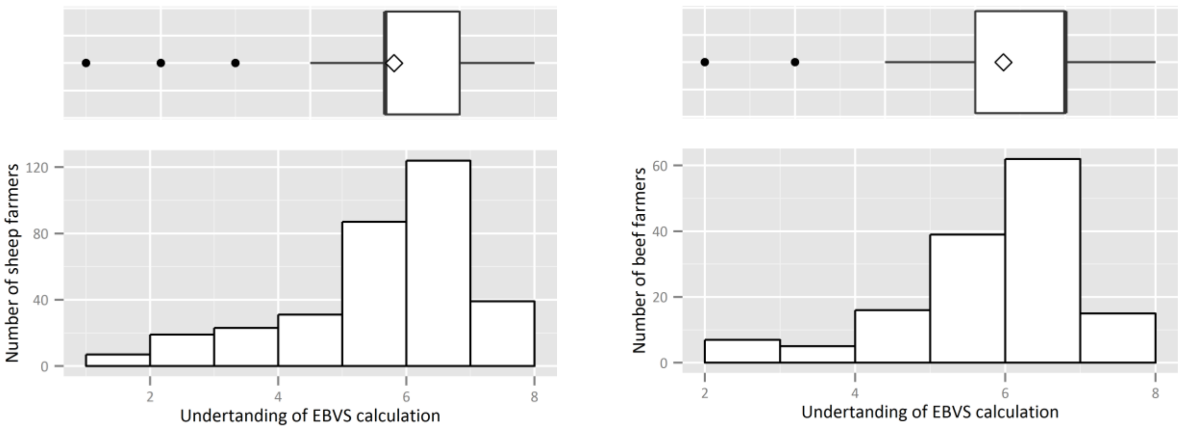

Figure 27: Farmers' attitudes towards EBVs. Agreement with statement "I understand how the EBVs are calculated"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

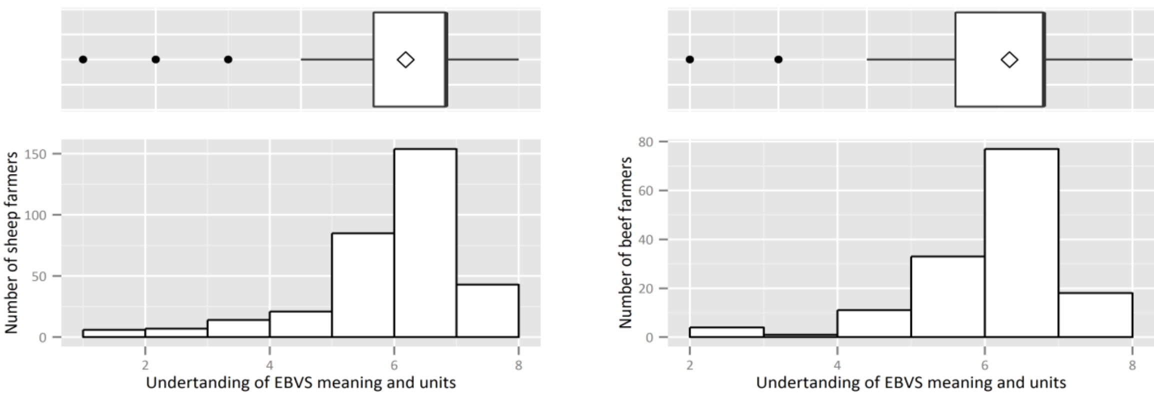

Figure 28: Farmers' attitudes towards EBVs. Agreement with statement "I understand the meaning and units of the traits for which EBVs are calculated"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

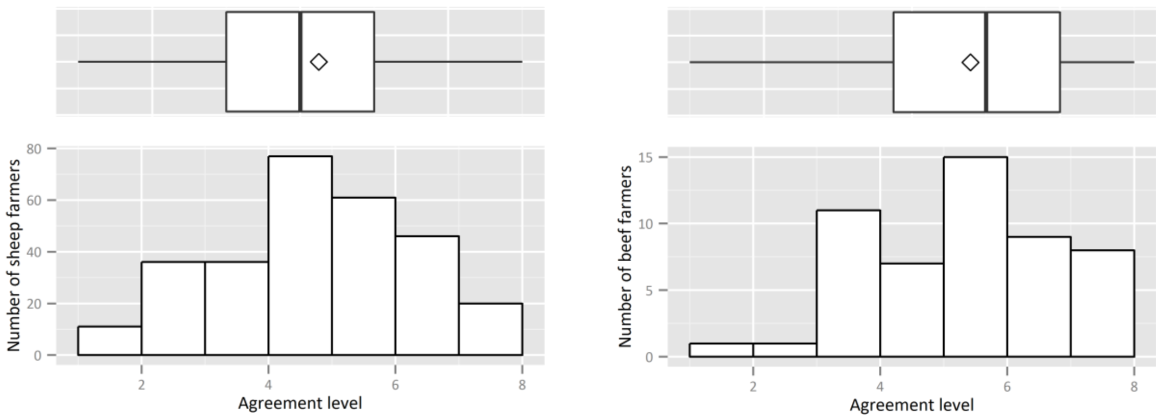

Figure 29: Farmers’ attitudes towards new genetic developments. Agreement with statement “Genomic and DNA technology are going to greatly increase the rate of genetic gain in the sheep industry in the short term”

Agreement scale: 1=”Totally disagree”, 2=”Disagree”, 3=”Somewhat disagree”, 4=”Neither agree nor disagree”, 5=”Somewhat agree”, 6=”Agree”, 7=”Totally agree”.

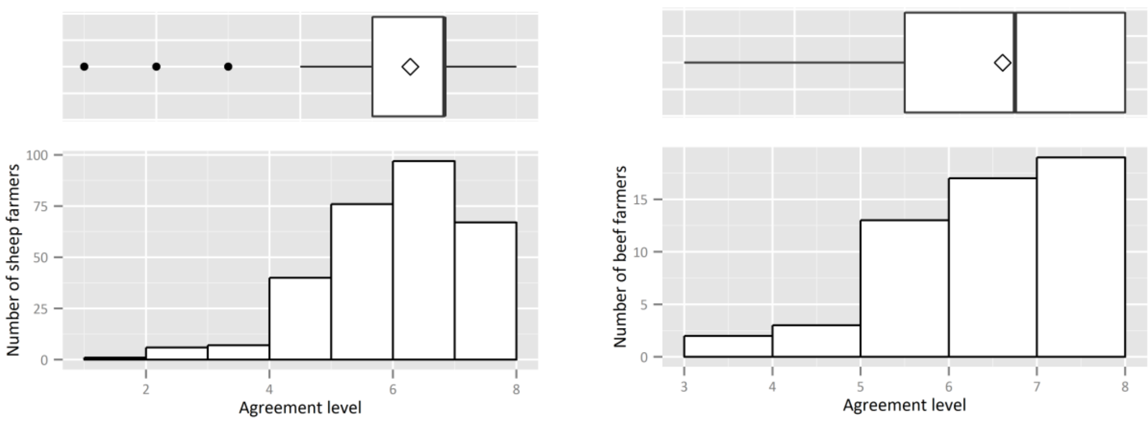

Figure 30: Farmers’ attitudes towards new genetic developments. Agreement with statement “Genomic and DNA technology are going to greatly increase the rate of genetic gain in the sheep industry in the long term”

Agreement scale: 1=”Totally disagree”, 2=”Disagree”, 3=”Somewhat disagree”, 4=”Neither agree nor disagree”, 5=”Somewhat agree”, 6=”Agree”, 7=”Totally agree”.

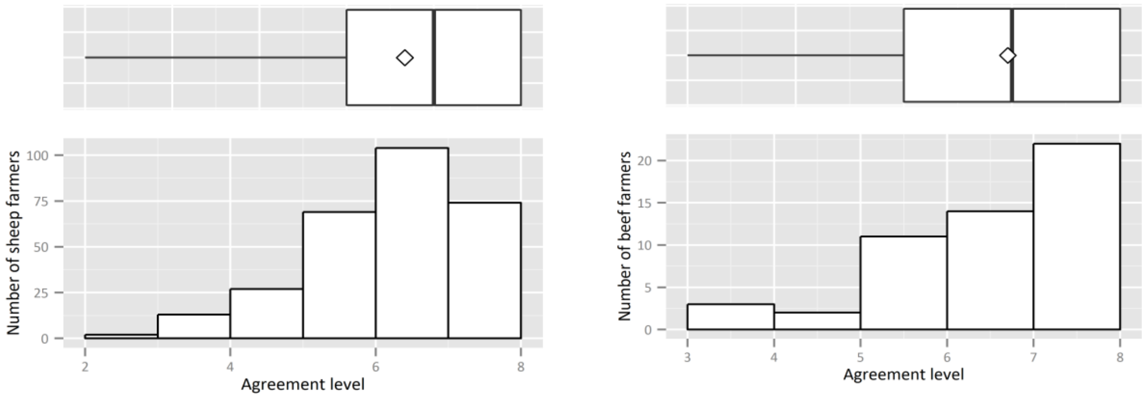

Figure 31: Farmers' attitudes towards new genetic developments. Agreement with statement "It is important that opportunities for the sheep industry from Genomic and DNA technology are maximised"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

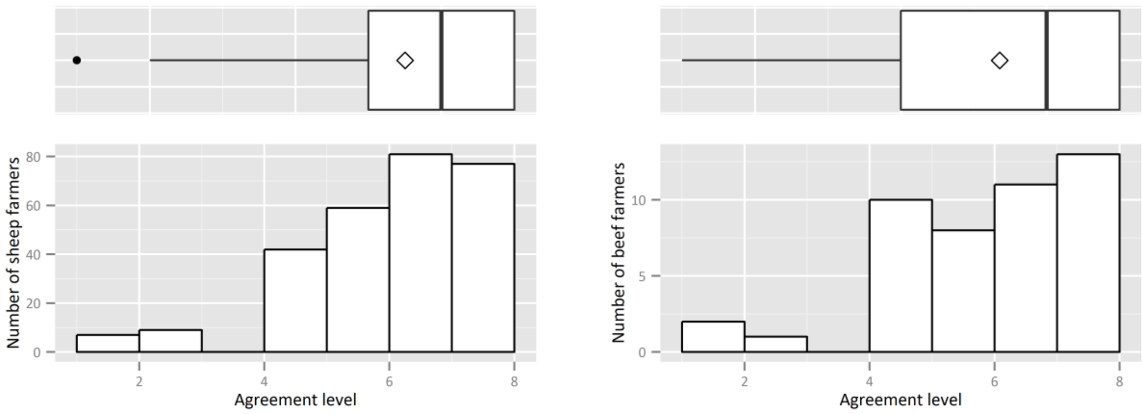

Figure 32: Farmers' attitudes towards new genetic developments. Agreement with statement "I would like to be involved in genomic evaluations"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

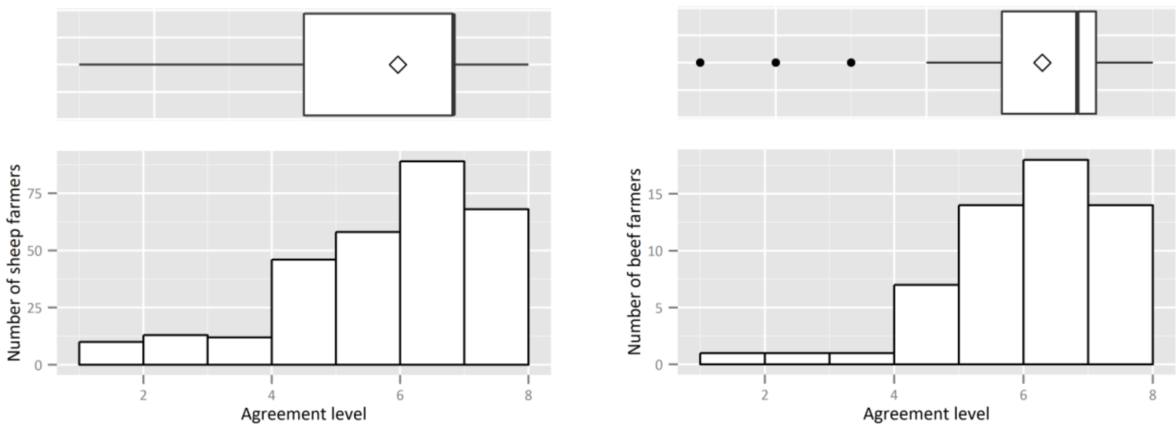

Figure 33: Farmers' attitudes towards new genetic developments. Agreement with statement "Crossbreeding is an interesting method to increase the profitability of a sheep flock"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

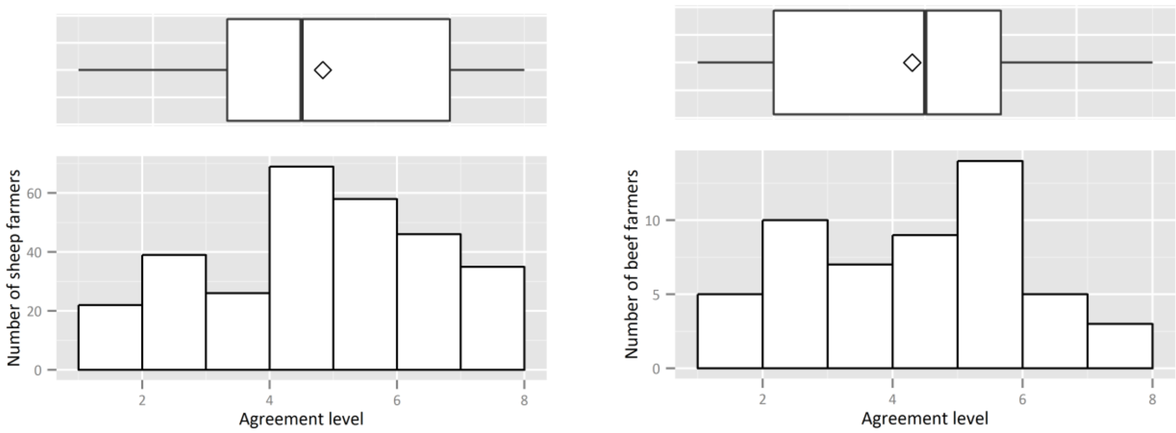

Figure 34: Farmers' attitudes towards new genetic developments. Agreement with statement "Crossbreeding should be carefully studied and controlled because it could have negative impacts on the sheep industry"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

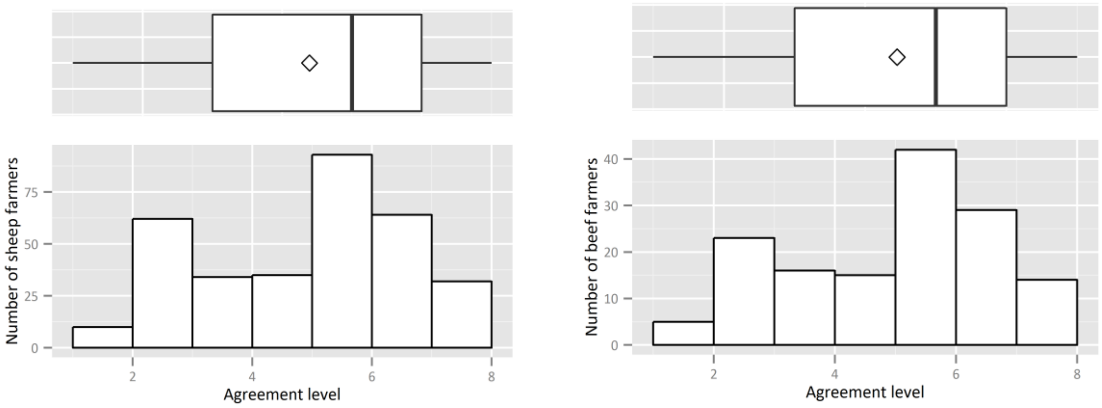

Figure 35: Farmers' attitudes towards data capture and genetic evaluation system. Agreement with statement "Performance recording requires a very large effort"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

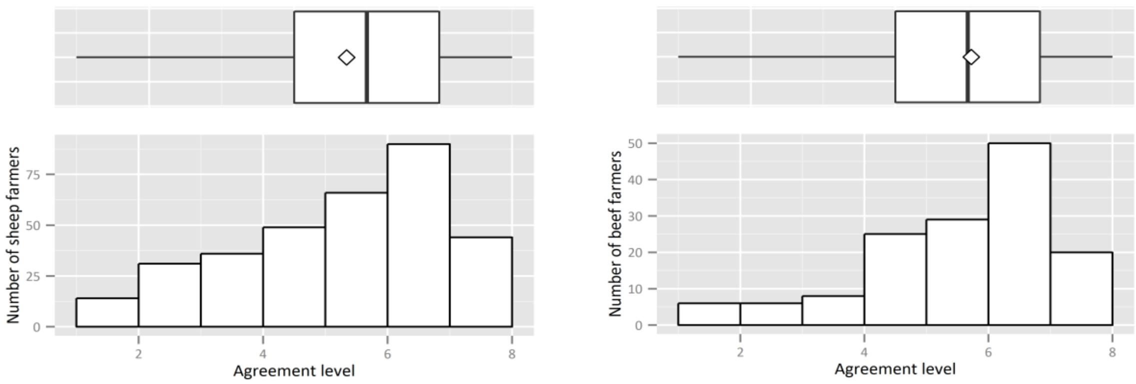

Figure 36: Farmers' attitudes towards data capture and genetic evaluation system. Agreement with statement "The benefits of being in a performance recording programme pay back the economic and work effort in recording"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

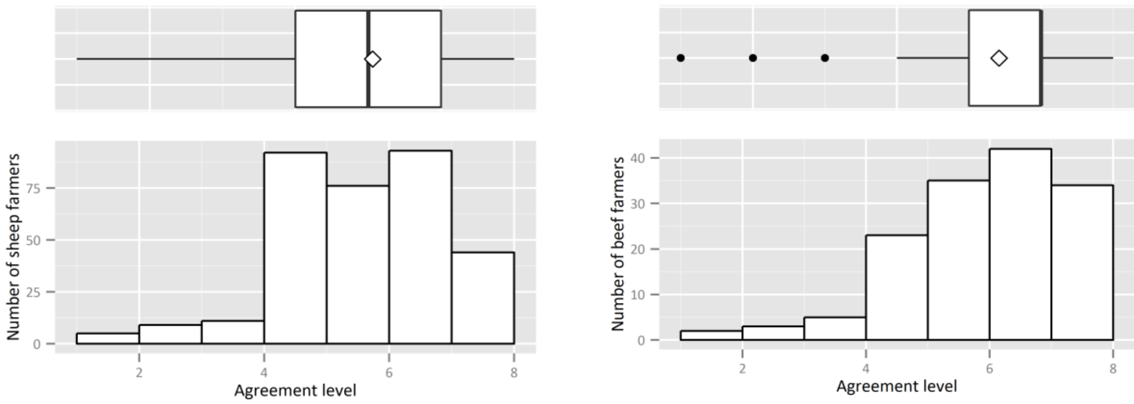

Figure 37: Farmers' attitudes towards data capture and genetic evaluation system. Agreement with statement "I think that an on-line recording system would help a lot in recording pedigree and animal performance data"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

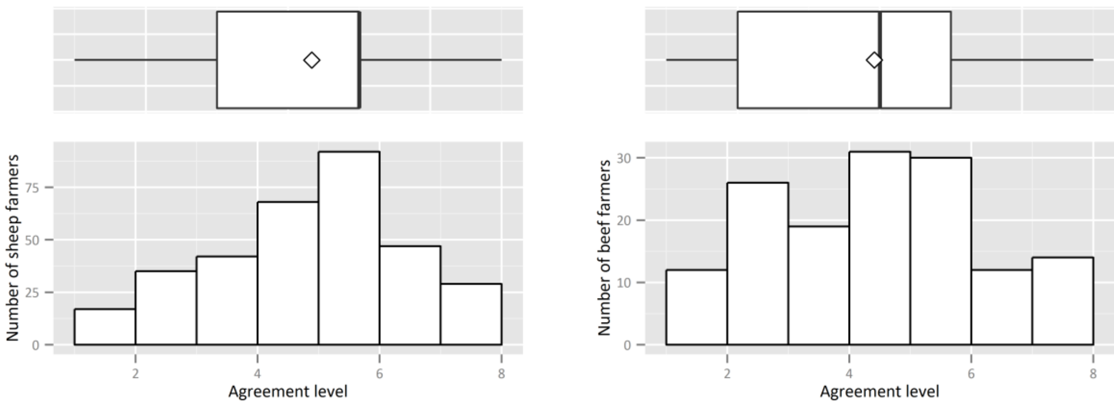

Figure 38: Farmers' attitudes towards data capture and genetic evaluation system. Agreement with statement "Costs of animal performance recording and selection are too high and therefore are a major constraint to my business"

Agreement scale: 1="Totally disagree", 2="Disagree", 3="Somewhat disagree", 4="Neither agree nor disagree", 5="Somewhat agree", 6="Agree", 7="Totally agree".

Appendix 5: Breeding programmes in high-input systems – sheep

Contributors – Peter Amer and Bruno Santos (AbacusBio, New Zealand), and Elisha Gootwine (Volcani Institute, Israel)

Developments in sheep breeding programmes for high input systems have undergone considerable change in the past decade. While developments in genomic prediction are exciting and have achieved considerable research investment in a number of countries, structural and economic impacts are also very important. In the very intensive sheep farming systems of Europe and the Middle East, where high prolificacy is economically important, use of genetic technologies such as introgression of the FECB mutation with the aid of molecular genotyping (Gootwine et al., 2008), and the advent of genomic selection (Larroque et. al. 2014), have demonstrated substantial opportunity to increase the rate of genetic progress achieved. The opportunity to exploit genomic selection is less in small milking ruminants than in Holstein dairy cows which have a larger value per animal, longer generation intervals in progeny testing schemes, smaller effective population sizes, and larger numbers of historic individuals with accurate phenotypes and genotypes. However, the simpler AI cooperative structure and operation is leading to a shift towards genomic breeding strategies in at least some French milking sheep breeding programmes (Larroque et al., 2014). In France, the genetic improvement structures are highly co-ordinated and centralised, which makes them more amenable to efficient application of genomic selection strategies, than less co-ordinated and more disbursed structures.

While in general, sheep breeding programmes have typically aimed to improve production and reproduction traits, identification of molecular markers for major genes that directly affect sheep health has led to incorporate selection for health traits. Thus, selection for the ARR haplotype at the *PRNP* locus and against the VRQ haplotype was incorporated in several countries as a means to reduce susceptibility to scrapie (Hunter, 2007). Selection against Day blindness in Awassi sheep is applying following by for the CNGA3 locus (Reicher ,2010) and resistance to Maedi Visna infection can be improved by selection for the desirable alleles at the TMEM154 locus (Heaton et al. 2012).

In New Zealand and Australia, genetic improvement has been driven partly through an opportunity to convert historic wool producing industries so that they achieve more effective meat production. Breed shifts, and the introduction of composite breed types have been transformational in both of these industries. Interestingly, in New Zealand, the higher performance composites rapidly took substantial market share following introduction of novel breeds from Europe, but much of this market share has since been recovered by breed types (including lower performance composites) identified by farmers as demonstrating higher levels of robustness in breeding ewes. In New Zealand, sheep flocks are increasingly being forced into more severe farming environments due to rapid expansion of the local dairy industry. A central progeny testing structure has been widely recognised as a key facilitator of accelerating rates of genetic progress, and the existing three test sites has recently been extended to include a further two sites which are commercial farms operating in a very harsh production environment.

Despite considerable investment in genomic approaches to breeding programmes, there are still challenges to achieving adoption of these technologies. The industry structures and dynamics and also the approaches taken to genomic selection are quite different between Australia and New Zealand. The Australian approach relies on a very large reference population with intensive phenotypic recording, while the New Zealand approach is based on industry sires as the training resource. Both approaches have demonstrated relatively modest improvements in selection accuracy compared with, for example, those shown in Holstein dairy cattle (Dodds et al. 2014; Swann et al. 2014). For this reason, in those countries adoption to date of genomic selection approaches has been limited to highly progressive breeders wishing to be at the forefront of technology, and who are content with marginal gains in the rate of genetic progress achieved. Work on how to integrate genomic predictions into novel breeding programme structures and attempts to reduce testing costs per animal, and per breeding scheme via two stage selections strategies (Sise et al. 2011) and combination with reproductive technologies have been identified as keys to increased adoption. Research into higher density chips and gene sequence is also being undertaken, although there is little evidence of practical benefits from high density genomic chips, and the exploitation of ever decreasing costs of genome sequencing remains an exciting challenge for the future.

Sheep breeding programmes in some countries where significant proportions of sheep are farmed in high input systems suffer from an absence of industry structures and co-ordinated provision of genetic improvement services such as databases and genetic evaluation systems. In the UK, co-ordinated systems exist, but conservative attitudes and a hobby mentality in the breeding sector, have led to poor rates of adoption of new technologies and very low rates of penetration into the commercial sector by rams from flocks using the technologies available (Amer et al. 2007). In Ireland, a new and modern support structure has been put in place to support sheep breeding. The initial challenge has been to engage with a breeding sector that historically relied on raw phenotypes and physical type traits as their primary selection criteria, and to overcome the barrier of having many small breeder flocks, with low levels of genetic connectedness among the flocks. A central progeny testing scheme has been established which originally had the goal of increasing levels of genetic connectedness. More recently, the focus of sheep Ireland has switched to identifying future industry sires of sires that are high performing across a balance of maternal and carcase traits (Pabiou et al. 2014). If these sires get used by AI in a wide number of ram breeding flocks, then the elite genetic material can be multiplied across a substantial proportion of the industry. This strategy is less reliant on widespread uptake of recording by all breeders, many of whom have ram breeding as a secondary source of income. In addition, Interest is growing in Ireland in the potential of genomic selection, and also imported genetics, to accelerate genetic progress.

Based on on-farm performance records, the National Sheep Improvement programme in the U.S (NSIP, www.nsip.org) provides the industry with Estimated Breeding Values (EBVs) for many traits for Elite and Young rams belonging to a range of meat and wool breeds. Some EBVs are combined to calculate indexes for specific use of animals. DNA tests are used by breeders to select against the Spider Lamb Syndrome and Scrapie susceptibility. In Canada, estimated breeding values are computed with the breeder interface via an on-line system for loading data and generating reports. Six economic indexes are under review.

Breeding programmes for improving milk production traits is carried out in several European counties. Most of the milk recording is in carried out in France, Italy and Spain, where large scale AI facilitate the breeding work. According to an ICAR survey reported in 2013, there are about two millions sheep under recording, which represent only about 10% of the dairy sheep population.

In developing countries with large potential for food production, such as Brazil and Uruguay, the adoption of sheep breeding programmes has long been neglected. This is due to the absence of well-structured support systems such as industry scale databases, genetic evaluation capability, extension support and education about the importance of animal breeding. The traditional dominance of breed societies and the cultural aspects of the "show-ring industry" are factors contributing to the current scenario. Attempts to establish genetic improvement programmes have occurred over the years. In general, the establishment of such programmes requires considerable effort from the very basics such as implementation of breeding season, animal identification and parentage control, and basic animal performance recording (Facó et al., 2011).

Whilst some regions in South America have traditionally farmed sheep for many years, there is confusion around the most appropriate genotypes for the different production systems and variety of environments. Especially in hard ecosystems where sheep have been present for a long time, production practices are improving, therefore creating opportunity for introduced breeds that are not necessarily adapted to these environments. In the absence of well-established breeding programmes to assess the effect of the introduction of "new breeds", the traditional adapted breeds are constantly threatened and productivity hardly improves.

There is also a need to establish breeding schemes to support achievement of better outcomes in intensive sheep production systems in developing countries. These are normally based on selected breeds and composites, farmed in productive grazing areas with increased stocking rates competing with other land uses. However, despite substantial and growing market demand, the current scenario has very low capacity to generate increased productivity which is partially due to the lack of suitable genotypes and appropriate breeding practices.

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Appendix 6: International comparison of beef genetic improvement

Costs and effectiveness of various national cattle breeding structures

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Abstract

Different countries have different structures to support genetic improvement of their cattle. In some instances, there is national support of genetic evaluation systems, that may span multiple breeds, multiple countries, and in the instance of Ireland, support dairy and beef cattle breeding simultaneously. There are substantial differences across countries in the amount of funds available, and the manner these funds are obtained - from breeders paying for services, levies applied to all commercial cattle farmers, or from national taxation. There are different genetic improvement outcomes across countries, in terms of extent of reliance on importation for genetic improvement, contributions to genetic progress in other countries through germplasm export, and rates of genetic progress in economically important traits. This paper compares beef and dairy genetic improvement structures and outcomes in USA, Brazil, Australia, France, UK, Ireland, and New Zealand.

Keywords: genetic trend, economic benefits, cost benefit analysis

Introduction

Genetic improvement is a powerful tool for achieving long term improvement in the performance and profitability of cattle industries. Typically, rates of genetic change achieved by dairy cattle breeding programmes have outstripped their counterparts in beef industries. However, high rates of genetic progress in intensive dairy industries can be achieved simply by importing superior sires from a country with a larger and more organised breeding industry (e.g. Gorganc et al. 2011) unless such a strategy is rendered ineffective through genotype by environment interaction. That is the case for New Zealand and Ireland whose pasture based systems require different trait emphasis compared to other countries without seasonal calving and with more reliance on concentrate feeding (e.g. Gorganc et al. 2012 this conference).

The comparative performance of beef genetic improvement is highly variable across countries, and also across breeds within countries. Genetic progress in dairy production traits is more consistently favourable, although there is substantial variation as to whether this progress is achieved through importation of improved germplasm from other countries, or from domestic improvement initiatives.

From the perspective of finding the optimal manner and level of investment in beef cattle genetic improvement, it is of interest to compare and contrast mechanisms and structures used to support improvement in different countries. Supporting structures include information systems (databases, genetic evaluation systems), breeding strategies (performance and progeny test programmes), and research infrastructure (organisations, institutions and private companies). These supporting structures may be disbursed groups within a country and funded on a user-pays basis, perhaps by a breed society (Banks and Rickards, 2012; this conference). Alternatively, they can be driven by national or even multi-national organisations with high levels of investment from cattle industry levy income, tax payers, and sometimes private shareholders of multinational companies.

This paper compares and contrasts cattle breeding structures, and attempts to make inferences about what structures may be most beneficial going forward. The main focus is on beef cattle breeding, although in most countries, dairy breeds are a significant contributor to beef output, and in some countries beef and dairy breeding and/or production are closely linked. Thus, some aspects of dairy improvement structure are topical within the general theme of this paper, and these aspects are also addressed. In a number of instances, comparisons are made among performances of breeds, and levels of investment at national level. These comparisons should be considered as approximate only, as there are many difficulties in obtaining accurate comparative data at this level. In particular, the data presented should not be treated as a league table. Despite these inaccuracies, it is useful and informative to consider the range of investment structures and outcomes, which broadly fit within the pattern of results as shown and discussed.

Genetic trends

A survey of genetic trends available on various breed society websites and industry reports indicates a wide range in rates of genetic change. From selection index theory, variation in genetic trends can be attributed to having different traits in the breeding objective, having different economic emphasis on traits in the breeding objective and due to different breeding strategies and selection criteria. The majority of documented genetic change is in growth traits, and in many breeds within countries, the nature and scope of performance recording is limited to live weight traits. Many breeds and countries lack a single clear breeding objective, and differences in breeding objectives are hard to define. Therefore, our main focus is on comparing the performance of different breeds and countries based on realised genetic trends which are concrete. Contributing factors to these differences, particularly in relation to genetic improvement investment and structures are discussed later.

Table 44: Collation of recent annual genetic trends (averaged over a 5 year period) for birth and yearling weights in 7 countries.

Country	Breed	Birth weight (kg)	Yearling weight (kg)	Other traits of interest
USA	Angus	0	2.6	
	Brahman	0	1.1	
	Charolais	-0.05	1.6	
	Hereford	0	1.7	
	Limousin	-0.06	1.8	Improved docility
	Santa Gertrudis	0	0.2	
	Simmental	-0.1	0.1	
Brazil	Brahman		0.0	Maternal traits improving
	Braford	0.03	0.0	
	Hereford	0.16	3.0	
	Nelore		0.9	Maternal traits improving
Australia	Angus	0.05	2.6	IMF% improving
	Brahman	0.10	1.0	
	Charolais	0	0.8	
	Hereford	0	1.4	
	Limousin	0.06	0.9	Improved docility
	Santa Gertrudis	0.10	0.8	
	Simmental	0	0.1	
France	Blonde d'Aquitane	-ve		Muscular development
	Charolais	0		Muscular development
	Limousin	-ve		Muscular development
UK	Angus	0.10	1.6	
	Charolais	0.05	1.0	
	Limousin	0.06	2.0	Maternal index improving
	Simmental	0.10	1.0	
Ireland	Aberdeen Angus	0.00	0.4	

	Belgium Blue	0.01	0.6	Muscular development
	Charolais	0.03	0.6	Muscular development
	Limousin	0.03	0.7	Muscular development
	Hereford	0.02	0.2	
	Simmental	0.02	0.7	Muscular development
New Zealand	Angus	0.02	1.6	
	Charolais	0.05	1.2	
	Hereford	0.10	1.6	
	Limousin	0.06	0.7	
	Simmental	0.05	1.3	

It is evident that some breeds and countries place a greater emphasis on recording and imposing selection on reduced birth weight and calving difficulty. Some countries such as the USA and Canada avoid any increases in birth weight and actively select against calving difficulty. There is less emphasis on these calving traits in New Zealand, even less in Australia, whereas in at least some breeds in European countries there is demonstrable deterioration in these traits. Several countries have a major focus on traits other than growth rate and calving difficulty, and these priorities are not reflected in Table 48. For example, Brahman and Nelore breeds of Brazil have made improvements in maternal traits such as age at first calving and calving interval, while European beef breeders place a high value on improved carcase conformation, a direct reflection of market signals provide by beef processors and butchers to commercial farmers.

In France, considerable effort is placed on recording linear scores relating to the physical development of young bulls in terms of skeletal and muscular conformation. This reflects the high demand in most European countries, and therefore slaughter premiums paid for carcases grading well for conformation. Similar recording protocols have been used for skeletal and muscular conformation in pedigree recorded herds in Ireland (McHugh et al. 2010), with additional development of more objective selection criteria from carcase records on commercial animals harvested by meat processors (Pabiou et al. 2011). However, research in both the UK (Roughsedge et al. 2005) and Ireland (Berry and Evans, 2012) suggest that the genetic correlations for growth and carcase yield traits with cow maternal traits including cow maintenance feed requirements, cow fertility and cow longevity are at least moderately unfavourable in these countries. Genetic trends across all calves born with identified sires in Ireland reveal deteriorations for calving and maternal traits while growth and carcase traits have been improving. The unfavourable correlation means that selection solely for a terminal sire index ignoring maternal traits can result in only modest net overall improvement in profit if sires that breed replacement females are also sourced from the same breeding programme (e.g. Roughsedge et al. 2005).

In Australia, the Angus breed has significantly outperformed all other breeds in terms of the rate of genetic progress being achieved (Barwick et al. 2010). Interestingly, a substantial proportion of that genetic progress has come about through importation of elite Angus sires of sires from the USA (Parnell et al, 2012 this conference).

Bos indicus influenced breeds are typically run in extensive environments and appear to have much lower rates of genetic progress than breeds run in more intensive environments. Where animals are run in extensive environments it is difficult for commercial farmers (bull buyers) to see real benefits from genetic change, because genetic difference between animals are swamped by massive environmental fluctuations. It is also not very advantageous to select for fast growing, larger genotypes, because added cow maintenance costs, and reduced cow functionality more than offset any benefits from making already slow growing progeny grow slightly faster under highly restricted nutrition (Madelena, 2012).

In both New Zealand and Ireland there is a significant dairy industry market for stock bulls, and to a lesser extent beef breed semen. These dairy industries rely on seasonal calving and late-born calves are less appealing for rearing as dairy herd replacements than are early born calves. Furthermore these countries are characterised by relatively high rates of cow survival meaning that surplus calves can be generated from the dairy herd. In addition to rearing and slaughter of surplus male calves, beef cross dairy heifers can also provide a source of breeding cows. Use of beef cross dairy cows used to be common in the UK, but has declined rapidly in recent decades due to reduced fertility and survival of dairy cows, and a greater drive for self sufficiency in sourcing replacement females in response to recent major disease outbreaks such as foot and mouth disease. Genetic selection of beef bulls for natural mating of dairy cows is predominantly for easy calving breeds that don't extend gestation length. Selection at the breed level rather than within breed perhaps reflects the risk and lack of trust in breeder records for calving difficulty traits when evaluated with relatively low accuracy for young bulls being sourced from pedigree herds. Furthermore, profit margins over slaughter beef value for bulls destined to the dairy herd are very slim in New Zealand, which is a disincentive for performance recording in breeders targeting these markets.

Models of investment for beef cattle improvement

There are three main sources of investment capital for genetic improvement of beef cattle. These include revenues collected from national taxes, farmer levies (a form of industry tax paid by commercial farmers), and user pays fees paid by beef cattle breeding farmers and companies for professional services that support genetic improvement programmes. Consideration of investment here is initially restricted to funds spent off farm in order to support data recording, data storage, genetic evaluation, applied genetics research, national breeding programmes, and extension. It should be noted that considerable additional investment is required by beef cattle bull breeders in identifying and recording the parentage of animals, and in measuring and recording trait performance.

Table 49 summarises approximately the levels of investment in genetic improvement for the same 7 countries for which genetic trends are in Table 48. These beef industries vary substantially in terms of their size and value, and also in terms of the numbers of recorded females, both overall, and when expressed in proportion to the total numbers of breeding cows in the industry.

The USA and Brazil are both very large industries with a substantial domestic focus for their beef production, while Australia and France are of intermediate size with Australia having a substantial export focus. France and UK have smaller industries with only modest net trade balances, although both these countries trade in beef products and to a lesser extent in live animals. Ireland and New

Zealand both have small beef industries with an export beef focus, although their markets and beef production systems are completely different. Beef farmers in Ireland are small scale and relatively intensive compared to New Zealand, where beef animals predominantly perform a clean-up role to maintain pasture quality in integrated sheep and beef farming systems. France has a high rate of industry participation in performance recording, while Australia has a low rate. The low rate in Australia is perhaps a reflection of the very large commercial herds run in Northern Australia where performance recording is often impractical. Brazil is characterised by extensive farming systems, but has higher rates of recording than Australia, most likely facilitated by lower labour costs for agricultural workers.

Table 45: Relative beef industry sizes and numbers of breeding females in herds where performance recording is undertaken for genetic evaluation purposes for 7 countries.

Country	Cows (M)	Industry value (€ B)	Percent beef prodn. revenue from exports	Breeding females in recorded breeding herds	
				(000's)	% all cows
USA	33.0	34.2	10%	750	2.3
Brazil	46.0	22.8	17%	2,300	5.0
Australia	13.5	6.2	60%	140	1.0
France	4.1	7.0	0%	530	12.9
UK	1.4	2.5	5%	57	4.1
Ireland	1.0	1.8	90%	36	3.6
New Zealand	1.1	0.9	90%	66	6.0

Table 50 provides a breakdown of spending on genetic improvement for these same seven countries. All currency units have been converted to Euros (€) for ease of comparison. Of particular interest is the substantial variation in investment within these industries. For example, the USA and France invest similar amounts in genetic improvement, despite a 5 fold difference in the farm gate value of their industries. The level of investment in beef cattle genetic improvement in NZ is very low, in absolute terms, but also when expressed as a percentage of industry value, and per recorded female.

Table 46: Total spend on applied genetic improvement including research, and the relative contributions to this spend from national taxes, farmer levies (taxes) and user pays services paid for by beef breeding operations.[1]

	Genetics spend				Contributors to genetics spend		
Country	Total (€ M)	% of industry value	€ per recorded female	€ per cow	National tax (%)	Farmer levy (%)	Breeder services (%)
USA	15.2	0.044	20.3	0.46	25	0	75
Brazil	2.8	0.012	1.2	0.06	0	0	100
Australia	3.6	0.058	25.6	0.27	45	11	44
France	14.5	0.207	27.4	3.54	5	26	69
UK	1.8	0.075	32.4	1.32	0	5	95
Ireland	1.9	0.108	53.2	1.92	45	21	34
New Zealand	0.4	0.047	6.5	0.39	0	0	100

[1]Costs to farmers of undertaking their own on farm measurements and investment in strategic genetics research such as genomics are not included in the figures on genetic spend.

France has a high level of investment when expressed as a proportion of industry value, although a relatively high proportion of beef farmers in France are breeders. Performance recording in France is undertaken by off farm service organisations and subject to strict regulation, rather than by the breeders themselves. They also have substantial investments in bull testing stations. Progeny testing for maternal traits is undertaken in France in a highly centralised manner, although progeny testing is being modified such that recording is undertaken in participating farms, rather than at a central site.

Ireland has a relatively high level of investment in beef genetic improvement, when viewed in total, as a percentage of industry value, or per pedigree recorded female. This is partly a reflection of the high rate of synergy in its beef and dairy genetic evaluation systems. The Irish Cattle Breeding Federation has been widely recognised by farmers as having reversed a deterioration in genetic merit of the national dairy herd due to importation of sires that were unsuited to highly seasonal and pasture based calving and production systems. The same across-breed genetic evaluation runs contribute to predictions of genetic merit for beef animals.

Both Australia and Ireland have relatively high levels of tax payer investment in beef genetic improvement. France, Ireland, and to a lesser extent Australia and the UK have moderate investments from farmer levies. Across all countries, 71% of spend as summarised in Table 50 is contributed through user pays breeder services, with 17% and 12% contributed from governments and through farmer levies respectively. In addition to this breeders incur substantial disruption to what could otherwise be a commercial farming system and have to bear many other on farm costs associated with performance recording.

High reliance on breeder services to fund genetic improvement infrastructure in countries such as USA, Brazil, UK and New Zealand suggests that market forces can create pressure on bull breeders to participate in genetic improvement. Effectively, they must record traits and pedigree information suitable for inclusion in genetic evaluations in order to participate successfully in the competitive business of selling breeding bulls. However, in these countries, it is not uncommon for bulls to be sold from pedigree registered herds where no formal performance recording is undertaken. These countries also tend to have the lowest off farm genetics spend as a proportion of total industry value. Furthermore, in most instances there have historically been high rates of taxpayer research investment in these countries to develop performance recording protocols along with significant extension efforts.

Who gets the benefits?

The international traded market for beef is substantial, not dominated by any single country. This is in contrast to sheep meat and dairy product trade, in which New Zealand has been a dominant player with disproportionately large shares of traded product. The presence of substantial global trade suggests that farm gate prices for beef in any one country are likely to be set more by the cost of production in competing industries, than the cost of production in the home country. There are arguably three different markets for beef exports based on trade barriers and quality attributes; the EU market protected by trade barriers, other high value - high quality (including hygiene and supply chain integrity) markets, and lower value markets. Even France with approximately 20% of EU27 production is unlikely to be dominant in the market, and therefore is not immune to production costs in competing EU suppliers.

This so called small country phenomenon in a larger market is important when attributing benefits of genetic improvement occurring at an individual country level. As domestic beef farmers improve their profitability through breeding for lower cost of production, and higher product quality, domestic consumers are unable to bid down the retail price paid for beef, because as they attempt this, domestic producers are able to increase their exports, forcing domestic consumers to pay a higher price in order to meet their demand. The above principles can be quantified using equilibrium displacement theory of economics (described in a genetic improvement context by Amer and Fox, 1992) which uses parameters that reflect how quantities of products either demanded by consumers or supplied by producers change in proportion to a change in the price. Thus, while consumers in all countries benefit hugely from ongoing reductions in the global average cost of production, they do not necessarily benefit directly from genetic improvement in their home country, if that country is a small part of a highly traded market.

Countries with large beef output but relatively low proportions of their product exported such as USA and Brazil are likely to be different. The large domestic consumption as a proportion of total beef output means that demand is relatively inelastic (domestic price must drop in order for more product to be sold), and as a consequence, consumers are likely to be substantial beneficiaries of genetic progress. This occurs because reductions in costs of production due to genetic improvement transfer into lower consumer prices for beef products in these countries. That is because imports and exports are not sufficiently fluid to set a domestic price that is independent of the local cost of production.

Intermediary sectors in the beef supply chain are unlikely to get substantial benefits from genetic improvement occurring at an industry level. This includes feedlots and cattle finishers that purchase calves and sell them on to processors, as well as the meat processing industries themselves. These intermediary sectors face highly competitive markets both at the procurement side of their business and when selling on to retailers. Even when traits are expressed in feedlots or as improved carcase quality, procurement and sales pressures mean that any short term profit gains achieved across these industry sectors are rapidly competed away. Thus, it can be difficult to motivate these sectors to invest in genetic improvement unless they can somehow restrict the capture of benefits to their own business, for example, via vertical integration of the supply chain.

Beef breeders are also effectively intermediaries in the beef supply chain. They supply a highly competitive market for bulls, and it is common for the price margin over the slaughter value of the lowest value breeding bulls to be quite minimal. It is therefore unlikely that beef breeders collectively benefit from genetic improvement occurring at an industry level. However, a modest proportion of individual breeders that have perceived superior animals that are in demand by other beef breeders, or semen export markets, can achieve substantially higher prices than the majority of other breeders. These breeders are often the drivers of adoption of new genetic technologies. Other breeders then become motivated to adopt the genetic technologies, particularly if they see this as a requirement to grow or maintain market share. There are reasonably high costs per recorded cow, and also some relatively high fixed costs at the bull breeding business level such as marketing and acquisition of technical knowledge. Thus breeders also benefit from being able to sell a higher proportion of their young bull crop due to their relative genetic superiority, even when they do not receive a higher price per bull sold.

Because differences in rates of genetic progress across breeders tends to result in a redistribution of income and profits within the beef breeding sector, rather than an overall increase in revenue, breeder collectives such as breed societies can be resistant to change. This can be particularly so when influential breeders within the political hierarchy of the breed society are also commercially successful. These breeders are motivated to maintain the status quo, resulting in some breed societies being highly resistant to changes to more progressive genetic improvement innovations.

Thus, the primary beneficiaries of genetic improvement are likely to be consumers in countries where the beef price is immune from the global beef market, and otherwise the owners of scarce resources required for beef production within each country. Because beef cow - calf operations are nearly always based on grazing systems, the owners of grazing land suitable for beef production will be the beneficiaries of genetic improvement. More profitable beef systems will result in higher land values for beef production, or alternatively, less profitable beef systems through a failure to maintain international competitiveness will result in lower land values unless there are alternative land uses in which cases, the land will be converted to alternative activities.

Discussion

Investment in beef genetic improvement is highly variable across countries both in terms of the amount invested, and the sources of funds. In contrast, dairy cattle breeding structures have historically been characterised by national genetic evaluation centres funded through industry or national revenue sources, and genetic improvement undertaken by commercial companies that progeny test bulls. Historically, dissemination of dairy cattle genetic improvement through AI has meant that a relatively small number of companies (often with global markets) per country are responsible for dairy cattle genetic improvement, relative to the large and geographically spread numbers of beef breeders supplying commercial farmers with breeding bulls. This perhaps along with the higher real and identified benefits to dairy farmers from genetic improvement may have made dairy breeding structures more amenable to industry level or national investment than is the case for beef improvement structures in the USA, UK and New Zealand.

Differences between countries in the sources of funds for beef cattle genetic improvement are clear, although the explanation for why these differences exist is less clear. There are almost certainly political factors at play, for example, there has been a decline in national investment in applied agricultural research in both the UK and New Zealand, as the political influence of rural industries has declined with increasingly urbanised populations. In contrast, rural regions in the USA, France, and Australia have maintained higher political influence at national level, perhaps through the way political representation is organised in these countries.

In Ireland, investment in genetic improvement up until the past decade was severely lacking. Reliance on importation for genetic material from breeding programmes in countries with substantially different feeding and production systems lead to ongoing deterioration in the genetic merit of the national dairy herd. A similar heavy reliance on imported genestocks for beef cattle genetic merit has resulted in improvement in growth and carcase traits, but a concomitant deterioration in maternal traits in the national herd has prompted substantial industry concern. Having a national breeding infrastructure under industry control is seen as being key to being able to effectively address the problem of declining fertility. While there are obvious and highly effective synergies associated with having both beef and dairy genetic evaluations run simultaneously by the same organisation in Ireland, there is not an overwhelming case for amalgamation of dairy and beef genetic evaluation centres in countries where the beef and dairy industries are less integrated. However, with long terms shortage of skills and experience, along with potential efficiency gains, further amalgamations of genetic improvement structures across industries and countries seems sensible and likely.

Studies as to who benefits from genetic improvement are scarce, and so more and better research is needed in this area. Collectively, breeders are meeting the vast majority of costs in most countries, although there is little reason to suggest that breeders collectively benefit. Because commercial farmers have difficulties seeing the benefits of beef cattle genetic improvement, it is highly likely that gross underinvestment in beef cattle genetic improvement is taking place. There is evidence that the current return on investment in beef cattle genetic improvement is high (Barwick, 2010; Amer et al. 2007) even though rates of genetic progress being achieved are typically well below theoretical expectations.

If more could be delivered with greater investment then questions about what structures should be invested in and who should pay are critically important. For countries with small to medium sized beef industries that are highly influenced by global beef prices, there is a strong case for investment via levies on commercial farmers. It seems unlikely that improved returns from investment in genetic improvement will eventuate in industries where there is little national or industry level investment, even though the current systems may be relatively efficient and low cost (such as Brazil and New Zealand). Genomic selection is an example of how co-ordinated national and international initiatives may result in improved benefits from genetic selection (Banks and Rickards, 2012, this conference). Efforts to generate substantial improvements in the rate of genetic progress through genomic selection have not yet been notably successful in situations where the technology has been driven by private multi-national companies working fully on a fee-for-service basis. Several countries have significant national investments around genomic selection for beef cattle, it remains to be seen whether or not national approaches will be more successful than the user pays, commercial approaches.

Where there is evidence that selection for a narrow range of traits is creating unfavourable trends in other economically important traits, the industry benefits from investment and co-ordination of genetic improvement over and above reliance on user pays services will likely be greater. A need for collective and co-ordinated investment in genomic selection with co-ordinated use of phenotypes and genotypes both across the industry, and potentially incorporating information from other countries may become the future conduit for ongoing additional benefits. However, first it must be demonstrated to commercial industries and/or tax payers that their money will be spent wisely and deliver real value.

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Appendix 7: Current state of genomics and genomic selection

In this appendix, we outline the current state of genomics and genomic selection in some international livestock industries.

Genomic technologies are being applied in a number of livestock industries throughout the world, but it is in dairy cattle that by far the greatest penetration has been achieved. There is a huge amount of effort going into genomic selection globally, but at this stage there is little evidence of any substantive utility, outside of dairy breeding schemes.

Current estimates of accuracies in beef cattle are well below those for dairy cattle (discussed further below). The reality is that genomic predictions of merit (genomic breeding values, GBVs) are completely dependent on the quality of the training set (i.e. the group of animals from which the relationships between phenotypes, genotypes and genetic merit have been derived). In particular, the genetic relatedness of the training set to the individuals for which the GBVs are to be estimated is an important factor that was overlooked in many early attempts at application. It is still an unknown as to how large the training population size must be for accurate genomic prediction, and there is still some debate as to whether the current prediction formulae in terms of how genomic selection improves with an increased training population size are actually appropriate. However, in general, it is widely accepted that genomic selection works best in situations where there are large training populations and the selection candidates are reasonably closely-related to the animals in the training population. For example in an analysis of the accuracies of GBVs in Hereford cattle using US or international training populations, it is clear the predictions for non-US animals were less accurate than those obtained for US Herefords; among the non-US animals, genomic predictions were more accurate for Canadian animals reflecting the greater usage of US Herefords in Canada compared with the Argentinian and Uruguayan Hereford populations (Saatchi *et al.*, 2013).

There is some indication that genomic prediction methods are working reasonably well in Black Angus in the US but these predictions do not appear to transfer to Australian Angus (see current estimates of accuracies for Angus cattle in Swan *et al.* (2012)), or to Red Angus. Several beef breed associations in the USA are progressing with genomic initiatives, although the approach of companies such as Zoetis (previously Pfizer) has shifted away from developing a "global key" marketed as having wide and generic predictive ability towards working with industry partners to develop predictors that add value in the target population.

How does genomic selection work?

The general consensus from the recent literature (Clark *et al.*, 2012; Saatchi *et al.*, 2012; Wientjes *et al.*, 2013) is that genomic selection utilises relationship data so that it actually represents a more sophisticated and 'accurate' pedigree than recorded pedigree for two reasons:

- recorded pedigree is prone to human error, and
- the genomic relationship accounts for Mendelian sampling which occurs at each conception.

The initial thinking around the likely mechanism driving predictive ability with high density marker panels and relationships was that it reflected population-wide association between markers and causative genes through linkage disequilibrium (LD). However increasingly, the contribution of LD to the predictive ability of genomic selection is regarded as minor with current approaches to genomic selection. Hence as noted above, the genetic relatedness of the training set to the individuals in which the GBVs are to be estimated is critical. Therefore this essentially precludes the use of across-breed genomic selection approaches. It is conceivable, however, that accuracies will increase with improved quality of phenotypes (more phenotypes and more accurately measured) together with improved understanding of, and estimation of, the contribution of linkage disequilibrium (LD) to the accuracy. It should be noted that the accuracies recorded for dairy cows are far higher than those recorded for beef cattle or sheep. There are three reasons:

- the pedigree structure within the various dairy breeds (and especially the Holstein-Friesian or HF),
- the population structure, and
- phenotype quality.

In terms of *pedigree structure*, the HF population features well-defined, deep pedigrees characterised by multi-generation sire lines and dam-sire lines that facilitate accurate detection of Mendelian inheritance of alleles and especially haplotype blocks across generations. Sensitivity to the depth of pedigree can be assessed through the impact of the progressive elimination of ancestral generations on the power of the analysis using gBLUP approaches where the genomic relationship matrix is substituted for the pedigree relationship.

The *population structure* or population heterogeneity has a major influence. The effective population size of the international HF population is very small; thus the haplotypes are relatively large (extensive LD) and the small population size also facilitates definition of the LD structure of the population (with relatively few SNPs). However it is these haplotype blocks which themselves are important in defining the actual Mendelian sampling.

The *quality of phenotypes* is also important. The definition of phenotypes for dairy bulls is exceptional as it is based on the (sire)-daughter data; that is the phenotype is effectively a weighted value based on daughter records rather than on the individual itself.

However while the accuracies in dairy cattle are far higher than those in beef (exceeding 0.6 for dairy production traits, noting that the square of accuracy represents reliability), there are issues with bias which means that genomic breeding values are subject to problems which must be dealt with. This is especially important when presenting results to industry stakeholders with high stakes in the outputs of genetic evaluation. Some of this bias may be due to epistatic effects (interaction between genes). In summary, while the prospects for the application of genomic selection are good, there is a strong case to review the breeding structures to ensure that genomic selection yields real value.

The opportunity for genomic selection

Bull and ram breeders are in the business of breeding and rearing sound fertile sires to sale with those investing in performance recording seeking a premium over the base product of a sound unimproved breeding sire. However the new technologies of genomic selection represent both a threat and an opportunity to breeders and to their industry. The threat comes through an ability of breeders to substitute their investment in recording with an investment in DNA testing (potentially at a lower cost).

It is a threat because, paradoxically, the development of genomic selection is dependent on the on-going collection of phenotypic data to support the development of new traits and to provide data to continually assess the accuracy of such genomic technologies. Thus if breeders using DNA-based methods only, are able to capture a significant share of the market for bulls and rams marketed as "genetically-improved", there will be a disincentive for other breeders to continue recording at higher costs.

The opportunity arises through the potential for breeders to differentiate themselves as "performance recorders" and extract extra value. The balance between threat and opportunity depends on how breeding structures within the industry change to accommodate new opportunities and the way in which structural/pricing mechanisms operate.

Genomic selection offers opportunities to generate value from the incorporation of non-traditional traits in genetic selection. Good examples include meat quality and health traits. Pre-genomic methods such as BLUP are limited by the need to generate data through the recording of phenotypes and/or progeny testing on a relatively large scale. Consequently collection of such data can be prohibitively expensive and is often limited to industries that are either vertically-integrated (pigs and poultry) or where there are well-developed artificial breeding (AB) systems that enable the widespread utilisation of elite males through AB such as with dairy cattle.

Genomics offers a paradigm shift in that a breeding programme can be structured such that data can be collected on a smaller number of animals within well-structured nucleus population(s). These populations must be designed so that they incorporate the key sources of genetics from within the wider (e.g. breed) population so that the data and information generated are relevant to the wider population. As there is a need to sample a much smaller number of animals than in pre-genomic systems, the cost of individual assessments is much less of an issue. Good examples are the use of CT (computed tomography) approaches in sheep breeding schemes, and the measurement of individual feed intake in cattle.

In addition there is the opportunity to collect progeny test data through commercial ventures as accuracy of pedigree is no longer an issue as pedigree can effectively be re-constructed using genomic approaches through gBLUP. Good examples are health traits for animals in feedlots, meat quality traits at slaughter, and maternal traits such as lifetime productivity (especially in sheep), and longevity and health in cows.

One potential advantage of genomic selection will be a reduction in generation interval that is achievable given the availability of good quality phenotypic (and genetic relationship) data both in the nucleus and in downstream related herds. While this is the case with beef, it is much less important with sheep. However the Sheep Information Nucleus (Clark *et al.*, 2012) in Australia provides an example of the operation of the nucleus, although the utilisation of the outputs downstream through the industry is a work in progress.

Appendix 8: Historical Investment in Research, Development and Services

This appendix provides a summary of investment in R&D and delivery of services to the livestock industries through EBLEX (including Signet).

Table 47: Summary of Signet expenditure for delivery of breeding services

	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
Revenue	£608,178	£682,421	£642,088	£681,738	£605,265	£638,368	£574,177
Expenditure	-£621,655	-£680,241	-£660,670	-£671,940	-£605,719	-£669,795	-£631,163
Net position	-£13,477	£2,180	-£18,582	£9,798	-£454	-£31,427	-£56,986
	2008/09	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	
Revenue	£434,518	£374,158	£372,752	£388,632	£411,844	£311,780	
Expenditure	-£534,676	-£360,000	-£366,000	-£347,699	-£406,289	-£335,522	
Net position	-£100,158	£14,158	£6,752	£40,933	£5,555	-£23,742	

Table 48: Summary of EBLEX expenditure on R&D in genetics and breeding

Year	Sheep		Beef		Generic	Operational (sheep and beef)	Total
	Research (direct)	Research (in kind)	Research (direct)	Research (in kind)			
2000			68,000				£68,000
2001			450,000			759,655	£1,209,655
2002						826,650	£826,650
2003			309,219	32,013	60,000	660,670	£1,061,902
2004	102,025		20,000			671,940	£793,965
2005			476,264			605,719	£1,081,983
2006	82,233		30,000	2,463		768,545	£883,241
2007	200,357	47,000	14,750			710,163	£972,270
2008	9,000					622,676	£631,676
2009	12,775		3,000			464,630	£480,405
2010						468,000	£468,000
2011	132,358	41,280				497,249	£670,887
2012	7,500		11,560			546,161	£565,221
2013						463,729	£463,729
2014	109,623		133,773		116,200		£359,596