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BRIDGING SCIENCE & BUSINESS

MODELLING THE BENEFITS OF BRITISH TEXEL SHEEP GENETICS

Prepared for

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By

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Executive summary

Historic industry-level economic benefits in present value terms realised through the use of the Texel breed in the UK, from both rates of genetic gain and breed expansion, have been estimated for the period 1996 to 2015. Future projected benefits up until 2035 based on *status quo* rates of genetic improvement (over the last 5 years) and ram usage (in the most recent year) have also been reported.

Historic industry-level benefits realised between 1996 and 2015 amount to £197.0 million, or £4.8 million annualised equivalent benefits[1]. The benefits can be attributed to a combination of an increasing genetic trend, increased use of rams from pedigree registered flocks (as opposed to rams from commercial flocks), and increased use of Texel rams to breed replacements.

Maternal and terminal index trends approximately doubled between 1995-1999 and 2010-2014 in recorded flocks, and more than doubled in non-recorded flocks. The absolute rate of genetic gain in recorded flocks remains higher than that of non-recorded flocks. Benefits were calculated including predicted trends for all flock types based on their estimated contributions to gene flows in the industry.

An increasing trend is apparent in the use of Texel rams from pedigree registered flocks, as opposed to Texel rams from commercial flocks. In 2015 an estimated 48% of Texel rams used, were from pedigree registered flocks, while in 1996 this figure was 29%.

An increasing trend is apparent in the proportion of Texel rams used to breed replacements. In 2015, an estimated 56% of Texel rams used were rams from which replacements were retained, while in 1996 this figure was 30%. The increasing use of Texel rams to breed replacements results in additional benefits, captured through maternal trait genetic trends.

Over the entire period, some 56% of these benefits come from rams used as terminal sires (benefits from changes in lamb performance traits only), with the remaining 44% from rams used to breed replacements (aggregate benefits from changes in both lamb and breeding ewe traits).

For future industry-level economic benefits in present value terms, the genetic trend for both terminal and maternal indexes was assumed to continue for 10 years (until 2025), beyond which the genetic trend is zero (until 2035). This results in a very conservative estimate of the cumulative benefits of genetic gain. The total present value (PV) of future benefits up until 2035 amount to £244.2 million or £23.1 million annualised benefits, from the use of the Texel breed. The higher annualised benefits when compared with historic benefits reflects both an increased penetration or market share of the Texel breed, and also accelerating rates of genetic progress in economically important traits.

Sensitivity analysis suggests that the matings per Texel ram has the largest impact on the total PV of future benefits, followed by a change in the total number of Texel rams used. Continued increases in

[1] Annualised Benefit is an equivalent constant annual payment that gives an equivalent long term return as a total Present Value.

matings per ram and further expansion of the Texel breed, in particular for maternal purposes, positions the breed to continue to deliver significant economic benefits to the UK sheep farming industry. The vast majority of these benefits are expected to be captured by commercial UK sheep farmers.

The growing importance of the maternal role of Texel genetics in the UK sheep flock indicates there may be further opportunities for economic gain, through an increased focus on maternal ewe traits for breed improvement in the future.

Key points for communication

- The historic financial benefits of genetic improvement from the use of the Texel breed have been significant.
- The financial benefits of genetic improvement between 1996 and 2015 amount to £197.0 million, or £4.8 million annually. The benefits can be attributed to a combination of an increasing genetic trend, increased use of rams from pedigree registered flocks (as opposed to rams from commercial flocks), and increased use of Texel rams to breed replacements.
    - Maternal and terminal index trends approximately doubled between 1995-1999 and 2010-2014 in recorded flocks, and more than doubled in non-recorded flocks.
    - In 2015 an estimated 48% of Texel rams used, were from pedigree registered flocks, while in 1996 this figure was 29%.
    - In 2015, an estimated 56% of Texel rams used were rams from which replacements were retained, while in 1996 this figure was 30%.
- Between 1996 and 2015, some 56% of these benefits come from rams used as terminal sires (benefits from changes in lamb performance traits only), with the remaining 44% from rams used to breed replacements (aggregate benefits from changes in both lamb and breeding ewe traits).
- The majority of the benefits in the maternal index come from genetic improvement in terminal traits.
- The future financial benefits of genetic improvement from the use of the Texel breed are predicted to be significant.
- The estimated financial benefits of genetic improvement between 2016 until 2035 (20 years) amount to £244.2 million, or £23.1 million annually. The benefits can be attributed both an increased penetration or market share of the Texel breed, and also accelerating rates of genetic progress in economically important traits.
- The growing importance of the maternal role of Texel genetics in the UK sheep flock indicates there may be further opportunities for economic gain, through an increased focus on maternal ewe traits for breed improvement in the future.

Recommendations

Based on the outcomes of this economic analysis, the following recommendations are provided. Note that these recommendations are the same as those reported in the AbacusBio report: Survey of British Texel Sheep Breeders.

1) There should be an increased focus on genetic improvement in maternal traits in the Texel breed in the future.
2) The priorities for maternal trait genetic improvement should be on foot health, lambing ease, ewe size (controlling ewe size by index selection), and mastitis, and research should focus on capturing data on, and developing EBVs for, these traits (as prioritised in the AbacusBio report: Survey of British Texel Sheep Breeders). An economic analysis and the development of a breeding objective will aid in prioritising these traits.
3) Economic selection indexes should be developed which include EBVs for existing traits and for maternal traits as identified in 2.
4) Considerable effort should be placed on educating both pedigree and commercial farmers on the importance of performance recording, EBVs, and selection indexes, as these tools are not seen as useful in the selection of rams.

Contents

Background

The use of the Texel breed in the UK has expanded significantly in the past decade (Pollot, 2012). In particular, Texel genetics have been increasingly incorporated into the breed make up of self-replacing flocks. Over the same period, genetic improvement has been made and is accelerating in a range of economically important traits (Sam Boon, Signet – pers. comm.).

An estimate of the financial impact of the Texel breed in the UK derived from genetic improvement and from breed expansion would complement research applications being developed by the UK Texel Sheep Society, which require detailed business outputs/exploitation plans.

This report provides an analysis of genetic trends and incorporates data on the penetration of genetics from Texel breeders into the UK sheep population. Outcomes have been reported in the context of expected change in genetic merit (in estimated breeding value, eBV, and index terms), combined with changes in ram usage (through expansion, not substitution[2]), to present historic industry-level economic benefits realised through the use of the Texel breed in the UK. Future projected benefits based on *status quo* rates of genetic improvement and ram usage have also been reported.

Sensitivity analysis is included, in order to understand the key drivers of the economic benefits. Recommendations, to guide the British Texel Sheep Society in the future development of the breed, are provided.

Mating structures

Estimating historic ram usage

Estimates of the Texel rams in use in any given year were made up of three categories 1) new Texel rams from pedigree-registered flocks (mated for the first time), 2) older pedigree-registered rams from previous years that have been retained, and 3) commercial rams that were retained within the farm or purchased from another commercial farm.

The number of new Texel rams used in commercial flocks annually (historic) was estimated from the number of lambs registered as being born in recorded and non-recorded pedigree registered flocks by year. The number of males sold for breeding purposes per ewe present in recorded and non-recorded flocks was derived as being 0.425. This accounts for Texel ewe prolificacy, the sex ratio, and an allowance for culling of rams unsuitable, or undesired for sale.

[2] The industry impact analysis accounts for the growth in the number of ewes mated to Texel rams over time (historical) but not an analysis of the breed substitution impacts, i.e. the impacts of the genetic merit and trends in the Texel breed have not been analysed relative to the genetic merit and trends in the breed(s) that the Texel is replacing.

The number of older rams present in any given year was calculated based on a survival between years of 0.8, with a maximum of four mating seasons.

The number of commercial rams being used was estimated by difference using details of the number of Texel rams reported by Pollot and Stone (2003) and Pollot (2012). Pollot and Stone (2003) also detailed Texel ram usage in 1996. These reports provide single year snap shots of ram usage. Thus, a linear change in Texel ram usage was assumed to occur in the years between those predicted by Pollot and Stone (2003) and Pollot (2012). From 2013 to 2015, the trend in Texel ram usage was assumed to increase at the same rate as that between 2003 and 2012. In the years before 1996, the trend in Texel ram usage was assumed to increase at the same rate as that between 1996 and 2003. Figure 1 presents estimates of the number of Texel rams from pedigree registered flocks (recorded and non-recorded) and commercial Texel rams used from 1996 to 2015. Table 1 presents estimates of the number of Texel rams from pedigree registered flocks, the total Texel rams, and commercial Texel rams used from 1996 to 2015. The percentage of rams from pedigree registered flocks has also been calculated.

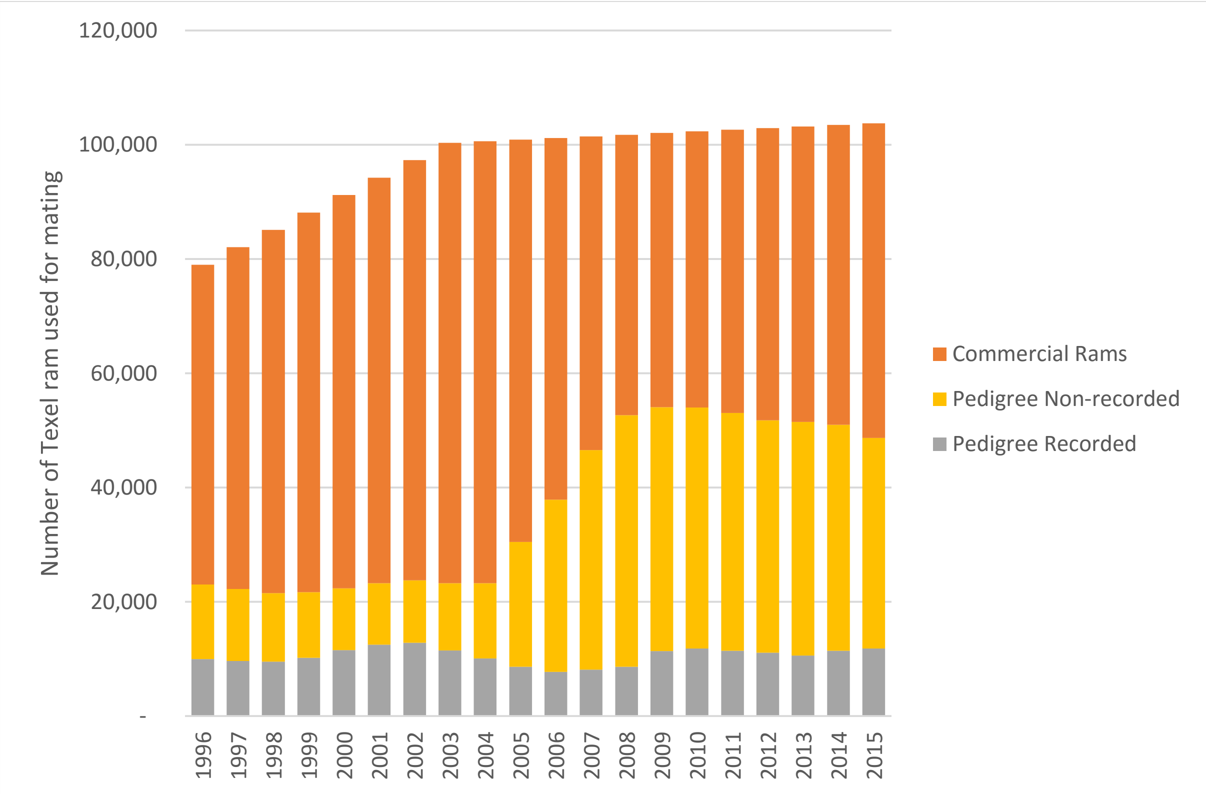

Figure 1: Estimates of the number of Texel rams from pedigree registered flocks (recorded and non-recorded) and commercial Texel rams used from 1996 to 2015. Data in 2003 and 2012 estimated by Pollot and Stone (2003) and Pollot (2012).

Table 1: Estimates of the number of Texel rams from pedigree registered flocks, the total Texel rams, and commercial Texel rams used from 1996 to 2015, including the percentage of rams used that are from pedigree registered flocks.

Year	Lambs born (pedigree registered)	New rams sold each year (pedigree registered)		Total rams in each year (pedigree registered) (a)	Total rams in each year (b)	Percentage from pedigree registered flocks (a/b)	Total commercial rams used (b-a)
		Recorded	Non-recorded				
1996*	27,910	3,288	3,689	23,028	79,000	29%	55,972
1997	31,087	3,921	3,851	22,253	82,050	27%	59,797
1998	32,754	4,703	3,485	21,536	85,100	25%	63,564
1999	32,725	4,564	3,618	21,670	88,150	25%	66,480
2000	32,010	4,158	3,845	22,384	91,200	25%	68,816
2001	29,682	2,825	4,595	23,278	94,250	25%	70,972
2002	32,056	2,807	5,208	23,767	97,300	24%	73,533
2003*	60,816	2,428	12,776	23,251	100,350	23%	77,099
2004	67,198	2,558	14,242	23,261	100,633	23%	77,373
2005	77,125	3,105	16,177	30,462	100,917	30%	70,455
2006	74,884	3,290	15,431	37,891	101,200	37%	63,309
2007	72,594	5,435	12,714	46,555	101,483	46%	54,929
2008	70,502	3,784	13,842	52,682	101,767	52%	49,085
2009	71,044	3,253	14,508	54,067	102,050	53%	47,983
2010	68,063	3,268	13,748	53,998	102,333	53%	48,336
2011	70,041	3,981	13,530	53,062	102,617	52%	49,555
2012*	68,027	4,483	12,524	51,797	102,900	50%	51,103
2013	60,748	4,030	11,157	51,514	103,183.3	50%	50,819
2014	61,490	4,232	11,140	50,999	103,466.7	50%	51,335
2015	59,539	4,282	10,603	48,711	103,750.0	48%	53,622

***** Reported by Pollot and Stone (2003) and Pollot (2012).

Estimating historic ewes mated

The number of ewes mated, by breed type, to Texel rams was calculated from data reported by Pollot and Stone (2003) and Pollot (2012). A linear change in ewes mated to Texel rams was assumed to occur in the years between those predicted by Pollot and Stone (2003) and Pollot (2012). Beyond these years, the rate of increase in mating to Texel rams was extended. This covered purebred (Texel ewe to Texel sire) and crossbred (only Texel sire) ewe matings from 2013 to 2015, and all crossbred matings from 1996 to 2002[3]. Combining estimates of ram usage and ewes mated to Texel rams, it is possible to estimate ram to ewe mating ratios (Table 3).

Texel rams mated to retain replacements

In order to account for an increasing incorporation of the Texel breed into the breed make up of self-replacing flocks, an estimate was made of the extent to which replacements are retained from Texel sires, based on data reported by Pollot and Stone (2003) and Pollot (2012).

According to Pollot and Stone (2003), some 1.332 million crossbred ewes had a Texel sire, in that year. The equivalent number in Pollot (2012) was 1.855 million crossbred ewes. After accounting for other crosses, of which a number will be Texel, the total number of ewes with a Texel sire was 1.388 million and 2.023 million in Pollot and Stone (2003) and Pollot (2012), respectively (Table 2).

Table 2: Parameters used to calculate the number of ewes mated to Texel sires from which replacements were retained (adapted from Pollot and Stone (2003) and Pollot (2012)).

	Year	
	2012	2003
Number of Texel x Hill ewes	110,000	111,000
Number of Texel x (Longwool x Hill) ewes	354,000	365,000
Number of Texel x Other ewes	1,391,000	856,000
Other Crosses (%)	0.08	0.04
Multiplier to account for “Other Crosses” that are Texel	1.09	1.04
Total ewes with a known Texel sire	1,855,000	1,332,000
Total ewes with a Texel sire	2,022,901	1,387,500
Annual female replacements required	404,580	277,500
Number of ewes mated to Texel rams to breed replacements	1,756,371	1,204,689

A linear change in the number of ewes with a Texel sire (i.e. a sire used to breed replacements) was assumed to occur between 1996 and 2003 based on numbers reported by Pollot and Stone (2003) and between 2003 and 2012 based on numbers reported by Pollot (2012.) From 2013 to 2015, the

[3]Pollot (2003) reported purebred (Texel ewe to Texel sire) matings from 1996 to 2002.

trend in number of ewes with a Texel sire was assumed to increase at the same rate as that between 2003 and 2012. The breed type make-up of these crossbred ewes is provided in Table 3.

Under the assumption that ewes are retained in the adult ewe flock for four years (i.e. enter the flock at 2 years-old and have an age at death of 6 years), the number of crossbred replacement ewes from Texel rams required in each year can be calculated (Table 2). Thus, the total number of ewes mated to Texel rams in order to produce the required number of replacements can be calculated from estimates of the proportion of females retained and the commercial lambing rate. At a replacement rate of 0.20, 0.271 of females are retained in a flock with a lambing rate of 1.7, where no specialised terminal sire rams are used. In 2012 for example, some 1.75 million ewes (52.5%) mated to Texel sires were mated to sires from which replacements were retained. The percentage of ewes mated to Texel sires from which replacements were retained, by year, is presented in Table 3.

Table 3: The number of ewes mated to Texel rams by breed type, and in total, and the number of offspring born to Texel rams from 1996 to 2015, including the estimated proportion of lambs born to Texel sires from which replacements were retained.

	Ewes mated to Texel rams by breed type					Total ewes mated by Texel rams	Matings/ Ram	Total ewes mated to Texel rams to breed replacements	Ewes mated to Texel rams to breed replacements (% of total ewes mated by Texel rams)
	Texel	**Longwool x Hill**	**Terminal sire x (Longwool x hill)**	**Other terminal sire crosses**	**Other Texel crosses**				
1996**	152,300	1,353,287	459,391	545,548	7,047	2,517,573	31.9	744,592	29.6%
1997	167,543	1,361,600	451,058	569,571	28,752	2,578,524	31.4	810,320	31.4%
1998	182,786	1,369,652	442,341	594,037	51,029	2,639,845	31.0	876,048	33.2%
1999	198,029	1,377,443	433,241	618,945	73,879	2,701,536	30.6	941,776	34.9%
2000	213,271	1,384,973	423,757	644,295	97,301	2,763,597	30.3	1,007,504	36.5%
2001	228,514	1,392,243	413,888	670,088	121,295	2,826,028	30.0	1,073,232	38.0%
2002	243,757	1,399,252	403,636	696,323	145,861	2,888,829	29.7	1,138,960	39.4%
2003*	259,000	1,406,000	393,000	723,000	171,000	2,952,000	29.4	1,204,689	40.8%
2004	252,737	1,411,444	380,444	751,889	199,000	2,995,514	29.8	1,263,534	42.2%
2005	246,473	1,416,889	367,889	780,778	227,000	3,039,029	30.1	1,322,971	43.5%
2006	240,210	1,422,333	355,333	809,667	255,000	3,082,543	30.5	1,383,008	44.9%
2007	233,947	1,427,778	342,778	838,556	283,000	3,126,058	30.8	1,443,656	46.2%
2008	227,683	1,433,222	330,222	867,444	311,000	3,169,572	31.1	1,504,922	47.5%
2009	221,420	1,438,667	317,667	896,333	339,000	3,213,087	31.5	1,566,817	48.8%
2010	215,157	1,444,111	305,111	925,222	367,000	3,256,601	31.8	1,629,350	50.0%
2011	208,893	1,449,556	292,556	954,111	395,000	3,300,116	32.2	1,692,532	51.3%
2012*	202,630	1,455,000	280,000	983,000	423,000	3,343,630	32.5	1,756,371	52.5%
2013	195,324	1,459,141	265,525	1,014,100	453,861	3,387,951	32.8	1,820,880	53.7%
2014	187,809	1,463,021	250,666	1,045,643	485,295	3,432,434	33.2	1,886,068	54.9%
2015	180,086	1,466,640	235,423	1,077,628	517,301	3,477,078	33.5	1,951,946	56.1%

*Years reported by Pollot and Stone (2003) and Pollot (2012)

**only purebred numbers reported in Pollot and Stone (2003)

Economic values and selection indexes

Economic selection indexes were calculated in order to capture the financial value of realised genetic trends, in relevant traits, for Texel rams used as maternal and terminal sires. The economic values were the same as those reported in Amer et al. (2007) but adjusted for inflation and the increase in lamb price; a total increase of 40% (Table 4). Discounted genetic expression (DGE) coefficients account for the timing and frequency of expression of traits, in the offspring and further descendants of Texel rams. For example, when a Texel ram is mated and generates ewes from which future replacements are kept, genetic superiority is passed down through multiple generations of breeding ewes and also impacts the lambs they produce, but with diminishing impacts because of halving each generation and time long time delays until benefits to be captured. Importantly, these coefficients account for trait expressions in slaughtered and retained progeny, using the method described by Amer (1999), and have the units "number of expressions of genetically improved ram's genes per commercial ewe mated". These DGE coefficients include a factor of 0.5, which accounts for the transfer of genetic merit from rams (where estimates of genetic merit are on an estimated breeding value basis) to offspring.

Table 4: Economic values, terminal and maternal DGE coefficients, and terminal and maternal economic weights for a range of traits under selection in the Texel breed.

Trait	Economic value[1]	Terminal DGE[2]	Maternal DGE[2]	Economic weight in terminal index (£/ ewe mated)	Economic weight in maternal index (£/ ewe mated)
Lean	3.724	0.646	0.828	2.41	3.08
Fat	-2.464	0.646	0.828	-1.59	-2.04
Mature live weight	-0.182	NA	0.430	NA	-0.08
Litter size	19.04	NA	0.430	NA	8.18
Maternal ability	0.434	NA	0.583	NA	0.25

[1]Amer et al. (2007) economic values adjusted for inflation and the increase in lamb price.
[2]Method from Amer (1999).

Genetic trends were calculated for an index of terminal traits and an index of maternal and terminal traits (Table 4), as detailed below.

For terminal Texel sheep the index to derive profit (£) per ewe mated was,

$$I_{terminal} = 3.724 \times DGE_{lean} \times lean - 2.464 \times DGE_{fat} \times fat$$

where, DGE_{lean} is the DGE coefficient for lean, *lean* is the estimated Texel population mean estimated breeding value in a given year for CT lean, DGE_{fat} is the DGE coefficient for fat, and *fat* is the estimated Texel population mean estimated breeding value in a given year for CT fat of lambs sired by terminal rams.

For maternally used Texel rams the index to derive profit (£) per ewe mated was,

$$I_{maternal} = -0.182 \times DGE_{mLW} \times matureLW + 19.04 \times DGE_{l} \times litter + 0.434 \times DGE_{mA} \times matA$$

where, DGE_{mLW} is the DGE coefficient for mature live weight, *matureLW* is the estimated Texel population mean estimated breeding value in a given year for mature liveweight, DGE_{l} is the DGE coefficient for litter size, *litter* is the estimated Texel population mean estimated breeding value in a given year for litter size, DGE_{mA} *is* the DGE coefficient for maternal ability, and *matA* is the estimated Texel population mean estimated breeding value in a given year for maternal ability.

Genetic trends

Estimating historic genetic trends for recorded and non-recorded flocks

Trends in estimated breeding values

Average EBVs were provided by EBLEX for the Texel breed. There were some potential biases created by some flocks migrating in and out of the genetic trend information over years. For example, 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 number of breeding rams born by year within each pairwise comparison. Data on genetic trends were available from 1975 to 2014[4]. The average genetic trends across all flocks for CT Fat, CT Lean, litter size, maternal ability, and mature weight were calculated in over 10 (1975 to 1994 period) and 5 year time intervals (over 1995 to 2014 period) intervals to capture changes in the rate of the genetic trends over time (Table 5). Trait genetic trends were calculated for recorded and non-recorded pedigree registered flocks separately. Commercial flocks selling rams were assumed to have the same genetic trend as the non-recorded pedigree flocks. This is reasonable given the flow of genetics from pedigree registered flocks to commercial flocks.

[4] Genetic trends provided by EBLEX

Table 5: Trait genetic trends[1] in estimated breeding value units for mature live weight, litter, maternal ability, CT Fat, and CT Lean in recorded and non-recorded pedigree registered Texel flocks. Note that while the genetic trends shown here date back to 1975, the benefits of genetic improvement have only been calculated for trends from 1996, the time from which ram use data is available.

	Non - Recorded				
	Mature live weight	**Litter**	**Maternal Ability**	**CT fat**	**CT lean**
1975 - 1984	0.0308	-0.0124	-0.0003	0.0100	0.0055
1985 - 1994	0.0721	0.0019	0.0069	0.0365	0.0182
1995 - 1999	0.0656	0.0038	-0.0044	0.0590	0.0200
2000 - 2004	0.0559	0.0067	-0.0365	0.0541	0.0108
2005 - 2009	0.0255	0.0054	-0.0516	0.0483	0.0043
2010 - 2014	0.0815	0.0082	-0.0355	0.1449	0.0429
	Recorded				
1975 - 1984	0.0956	-0.0066	0.0057	0.0380	0.0182
1985 - 1994	0.0518	0.0009	0.0099	0.0560	0.0308
1995 - 1999	0.0770	0.0046	0.0031	0.1187	0.0403
2000 - 2004	0.0976	0.0091	-0.0280	0.1047	0.0320
2005 - 2009	0.1002	0.0074	-0.0215	0.1232	0.0475
2010 - 2014	0.1004	0.0085	-0.0192	0.2201	0.0663

[1]Each value in this table reflects the average (within the time period indicated) increase in genetic merit from one year to the next, for each of the specified traits.

Trends in selection indexes

The genetic trends for terminal and maternal indexes were calculated in 10 year (over 1975 to 1994 period) and 5 year (over 1995 to 2014 period) intervals to capture changes in the rate of the genetic trends over time (Table 6). Rates of genetic gain have been increasing. This is depicted in Figure 2, which shows the average maternal and terminal index genetic merit (cumulative trend) in recorded and non-recorded pedigree registered Texel flocks from 1975 to 2014. The distribution of 2014 maternal and terminal index genetic trends in recorded and non-recorded pedigree registered Texel flocks are also presented (Figure 3).

Table 6: Annual genetic trend in in Terminal and Maternal indexes over 10 year (over 1975 to 1994 period) and 5 year (over 1995 to 2014 period) intervals in recorded and non-recorded Texel flocks.

	Terminal Index		Maternal Index	
	non recorded	**recorded**	**non recorded**	**recorded**
1975 - 1984	0.0155	0.0626	-0.0837	0.0011
1985 - 1994	0.0590	0.0856	0.0872	0.1153
1995 - 1999	0.1101	0.2214	0.1657	0.3162
2000 - 2004	0.1130	0.2010	0.1861	0.3176
2005 - 2009	0.1094	0.2208	0.1691	0.3308
2010 - 2014	0.2803	0.4240	0.4115	0.6006

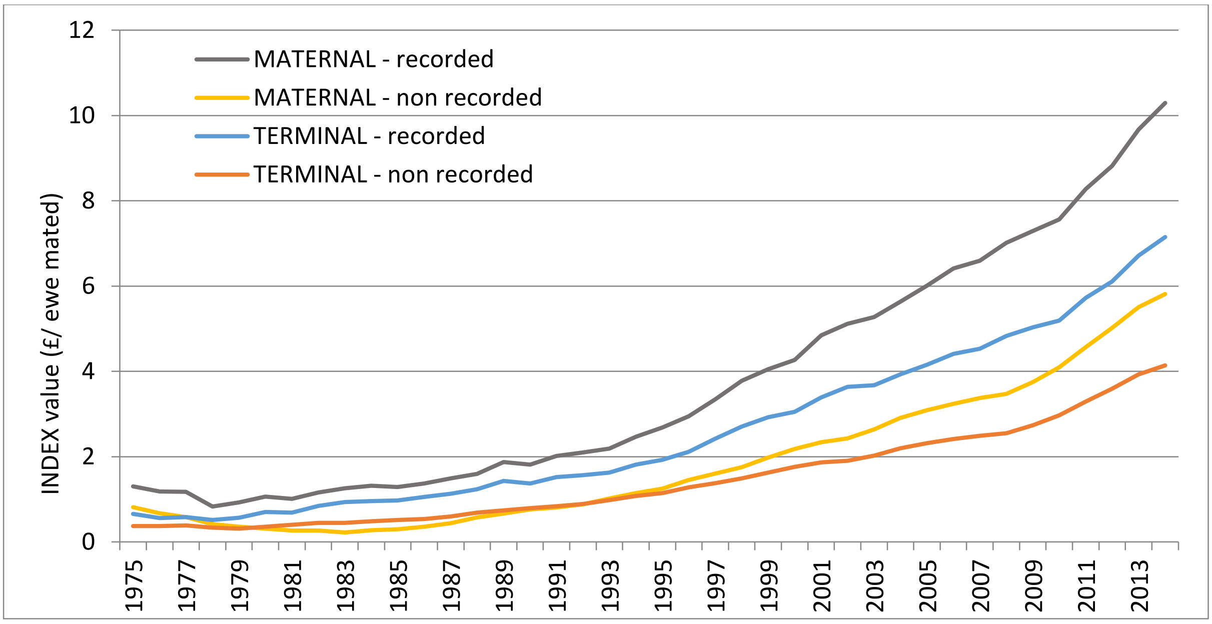

Figure 2: Average maternal and terminal index genetic merit (i.e. cumulative genetic trend) in recorded and non-recorded pedigree registered Texel flocks from 1975 to 2014.

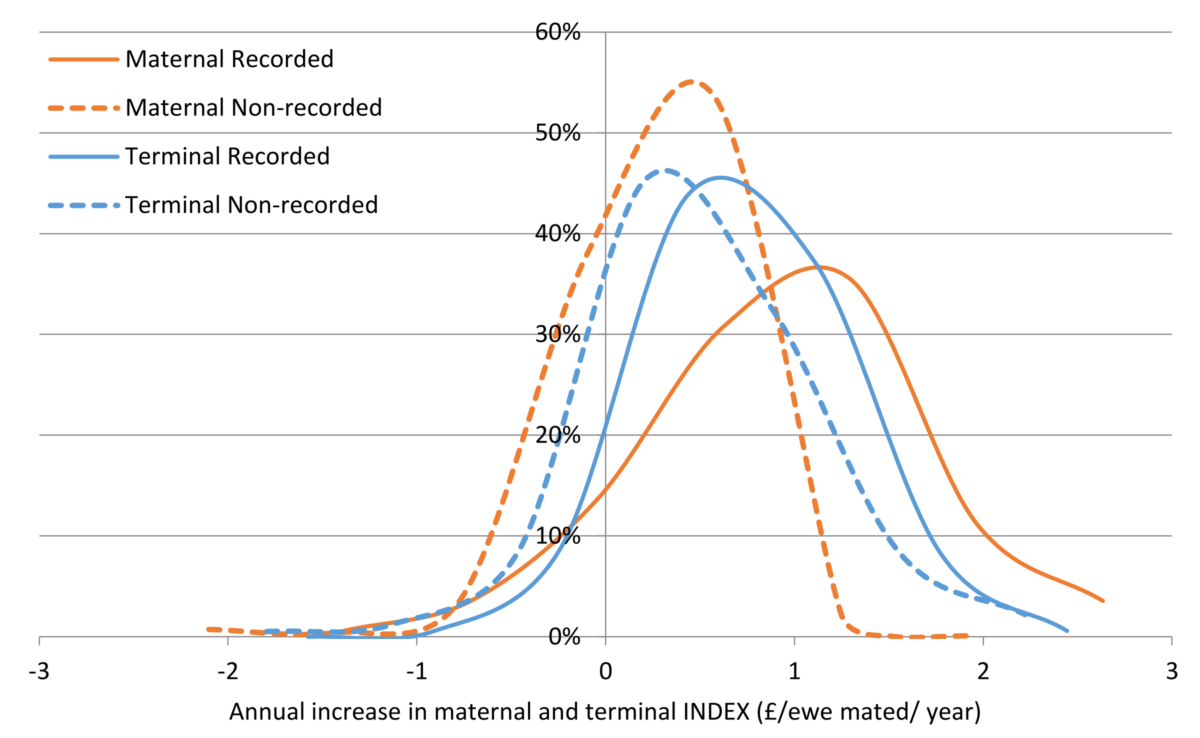

Figure 3: Distribution of 2014 maternal and terminal index genetic trends (£/ ewe mated/ year) in recorded and non-recorded pedigree registered Texel flocks.

Contribution of Terminal traits to Maternal Index gain

Though the maternal index delivers greater benefits to the industry than the terminal index, it is worth considering the drivers of this. The maternal index is calculated with DGEs greater than those for the terminal index. This is because when a ewe is mated to breed replacements, those replacement ewes also have a increased trait values, which are then passed onto that ewe's offspring. This means the cumulative benefits from superior traits are greater for the maternal index. As such, the discounted genetic expression (DGE) for the maternal index is greater than that for the terminal index (Table 4).

The result is that improving terminal traits, CT lean and CT fat, has greater impact when breeding for replacements. When looking at components of the maternal index, gains are being delivered through improved terminal traits, not improving maternal traits (maternal ability, litter size and mature live weight) (Figure 4).

Despite the low impact of maternal traits, the maternal index is more valuable than the terminal index. There is room for considerable improvement in maternal traits, which would further increase the relative superiority of the maternal index. This is true for both recorded and non-recorded populations.

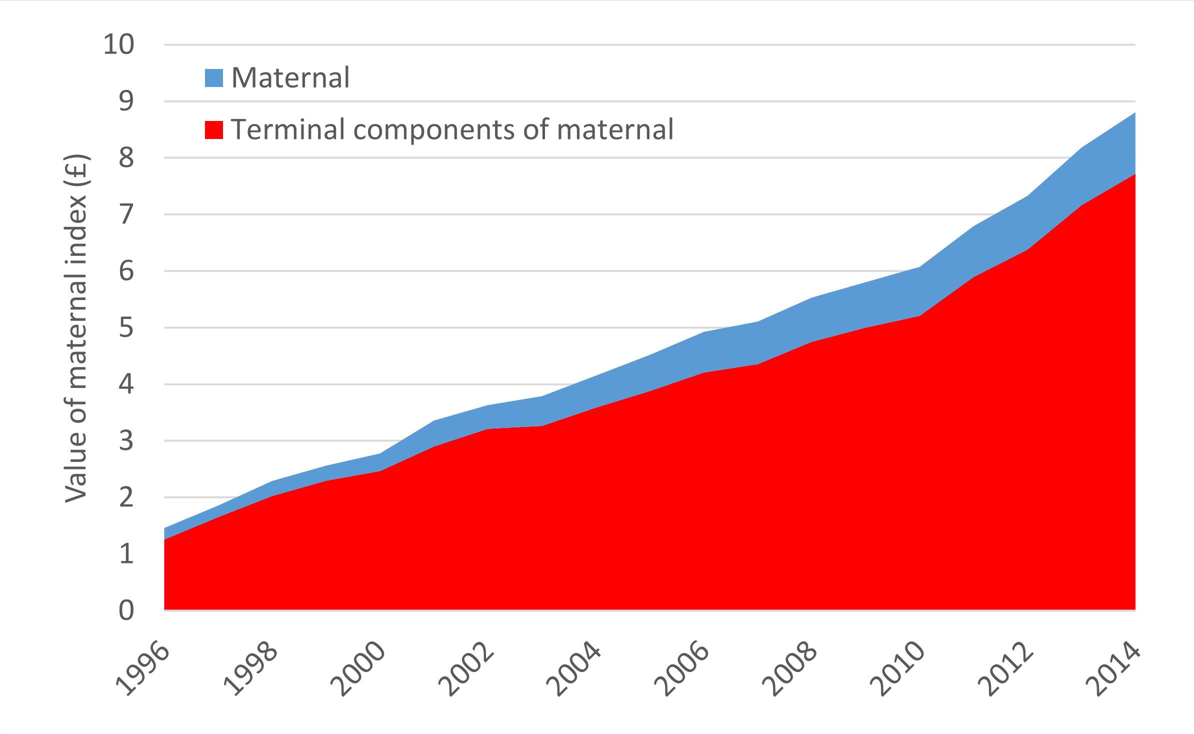

Figure 4: Value of performance recorded maternal index, for total maternal and terminal components

Historic benefits

Total cumulative present value (PV) benefits and annualised PV benefits of genetic improvement, realised from the use of the Texel breed from 1996 to 2015 are reported in Table 7. These benefits capture those realised from the use of Texel rams to breed replacements (maternal index) and also from the use of Texel rams when all progeny are slaughtered (terminal index). A discount rate of 7% is assumed. The total PV of historic benefits amounts to £196.9 million, or £4.8 million annualised benefits, from the use of the Texel breed (Table 7). Over the entire period, some 56% of these benefits come from rams used as terminal sires (benefits from changes in lamb performance traits only), with the remainder from rams used to breed replacements (aggregate benefits from changes in both lamb and breeding ewe traits). Some 56% of the benefits come from the use of commercial rams (Table 8).

Table 7: Benefits by year, and total NPV benefits over the historic period.

Time of benefit (t)	Annual Benefits			Present Value at t = x	
	Terminal	Maternal	Total	x=1995	x=2015
1996	692,560	430,032	1,122,592	1,049,151	4,059,885
1997	822,880	557,692	1,380,572	1,205,845	4,666,240
1998	1,003,948	738,307	1,742,255	1,422,199	5,503,462
1999	1,218,652	965,514	2,184,166	1,666,290	6,448,016
2000	1,453,622	1,230,053	2,683,675	1,913,423	7,404,343
2001	1,692,954	1,530,119	3,223,072	2,147,669	8,310,802
2002	1,912,877	1,842,494	3,755,370	2,338,656	9,049,861
2003	2,110,230	2,161,942	4,272,171	2,486,443	9,621,748
2004	2,262,604	2,471,497	4,734,101	2,575,037	9,964,581
2005	2,445,894	2,864,928	5,310,822	2,699,752	10,447,190
2006	2,640,594	3,290,453	5,931,047	2,817,798	10,903,988
2007	2,828,125	3,725,460	6,553,585	2,909,870	11,260,278
2008	2,987,059	4,150,648	7,137,707	2,961,895	11,461,598
2009	3,195,924	4,675,530	7,871,454	3,052,685	11,812,930
2010	3,318,366	5,114,128	8,432,494	3,056,324	11,827,009
2011	3,468,896	5,620,479	9,089,374	3,078,885	11,914,315
2012	3,663,900	6,233,612	9,897,512	3,133,299	12,124,878
2013	3,978,909	7,082,106	11,061,016	3,272,555	12,663,757
2014	4,380,259	8,148,195	12,528,454	3,464,222	13,405,446
2015	4,800,368	9,330,233	14,130,601	3,651,616	14,130,601
Annualised	**2,107,697**	**2,697,244**	**-**	**4,804,941**	
NPV				**50,903,615**	**196,980,928**

Figure 5 below illustrates the total historic (1996 to 2015) nominal benefits of genetic improvement from Texel rams mated to ewes for terminal and maternal use (based on terminal and maternal index trends). Although initially the benefits from gains in terminal and maternal indexes are similar, the benefits from the maternal index become significantly larger than those from the terminal index. This is due to a higher maternal index trend, and an increasing number of ewes mated to Texel rams to breed replacements.

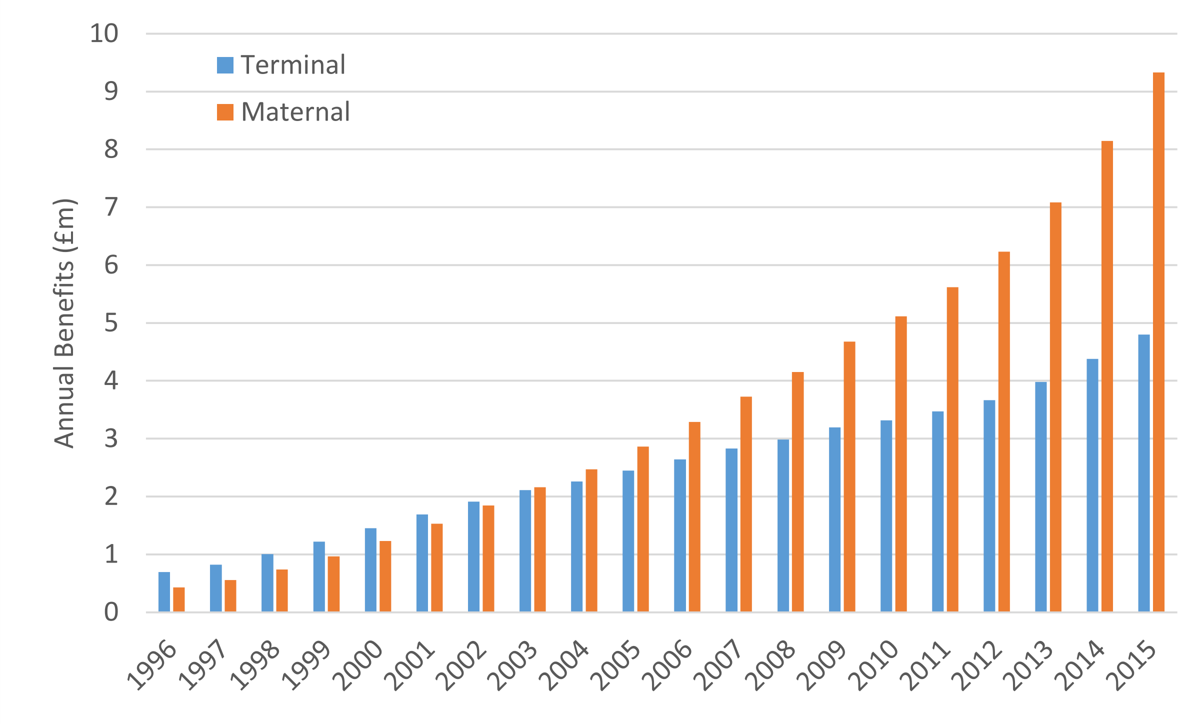

Figure 5: Annual benefits by year from 1996 to 2015, from ewes mated to Texel rams for terminal and maternal use.

Table 8: Summary of the distribution of present values of benefits of genetic improvement in year 2015, in Maternal and Terminal mated ewes.

	Terminal		Maternal	
Benefit from matings to recorded rams	14,749,292	7.5%	18,380,205	9.3%
Benefit from matings to non-recorded rams	21,992,977	11.2%	31,658,188	16.1%
Benefit from matings to commercial rams	49,663,796	25.2%	60,536,470	30.7%
PV of benefits	86,406,065	43.9%	110,574,863	56.1%
% of ewes mated	55.5%		44.5%	

Future benefits

To estimate future benefits, the average genetic trends over the most recent 5 years (£0.6 and £0.41 per ewe mated per year for maternal recorded and non-recorded respectively, and £0.42 and £0.28 per ewe mated per year for the terminal recorded and non-recorded respectively) were used. The

2015 number of ewes mated to Texel sires (3.42m) was based on the 2015 number of matings per ram (34). The proportion of ewes using a maternal index (56%) and terminal index (44%) were based on the proportions in 2015, due to the upward trend.

The genetic trend for both terminal and maternal indexes was assumed to continue for 10 years (until 2025), beyond which the genetic trend is zero (until 2035). This results in a very conservative estimate of the cumulative benefits of genetic gain (as Present Value, PV, and annualised equivalent benefits) over a period of 20 years, using methods presented by Amer et al. (2007). The total PV of future benefits amounts to £244.2 million or £23.1 million annualised benefits, from the use of the Texel breed (Table 9). Over the entire future period, some 44% of these benefits come from rams used as terminal sires (benefits from changes in lamb performance traits only), with the remaining 56% from rams used to breed replacements (aggregate benefits from changes in both lamb and breeding ewe traits) (Table 10). This increase in the benefits from maternal genetic improvement, compared to the historic period, is driven by an increasing trend in the use of Texel rams to breed replacements for self-replacing flocks.

Table 9: Benefits by year, and total NPV benefits over the future period.

	Annual Benefits			Present value 2015
	Terminal	Maternal	Total	
2016	5,207,098	9,928,555	15,135,653	14,145,470
2017	5,496,366	10,423,439	15,919,806	13,904,975
2018	5,878,105	11,236,697	17,114,802	13,970,777
2019	6,334,395	12,195,221	18,529,616	14,136,156
2020	6,793,066	13,043,634	19,836,701	14,143,293
2021	7,258,591	13,924,340	21,182,931	14,115,082
2022	7,693,424	14,697,316	22,390,740	13,943,828
2023	8,128,257	15,509,216	23,637,473	13,757,224
2024	8,563,089	16,321,117	24,884,206	13,535,359
2025	8,997,922	17,133,017	26,130,939	13,283,644
2026	9,432,755	17,944,917	27,377,672	13,006,935
2027	9,867,588	18,756,818	28,624,405	12,709,578
2028	10,155,119	19,293,684	29,448,803	12,220,206
2029	10,324,810	19,610,523	29,935,333	11,609,438
2030	10,400,228	19,751,340	30,151,569	10,928,316
2031	10,400,228	19,751,340	30,151,569	10,213,379
2032	10,400,228	19,751,340	30,151,569	9,545,214
2033	10,400,228	19,751,340	30,151,569	8,920,761
2034	10,400,228	19,751,340	30,151,569	8,337,160
2035	10,400,228	19,751,340	30,151,569	7,791,738
Annualised	**7,932,581**	**15,119,921**	**-**	**23,052,502**
NPV	**84,037,872**	**160,180,663**	**-**	**244,218,535**

Figure 6 below illustrates the total future (2016 to 2035) nominal benefits of genetic improvement from ewes mated to Texel rams for terminal and maternal use (based on terminal and maternal index values). The higher maternal genetic trend continues to deliver much greater benefits from ewes mated to Texel rams to breed replacements.

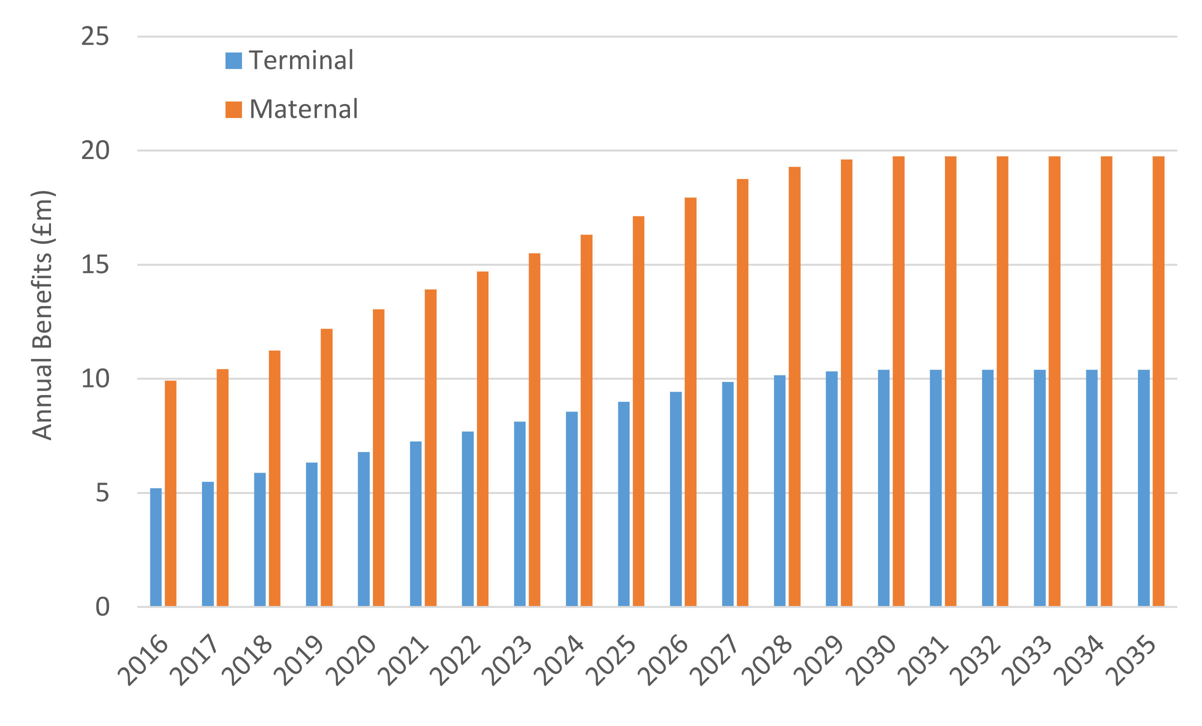

Figure 6: Annual benefits by year from 2016 to 2035, from ewes mated to Texel rams for terminal and maternal use.

Table 10: Summary of the distribution of future benefits of genetic improvement in £2015, in Maternal and Terminal mated ewes.

	Terminal		Maternal	
Benefit from matings to Pedigree recorded rams	16,213,263	19%	30,090,907	39%
Benefit from matings to Pedigree non recorded rams	27,460,792	33%	52,775,838	33%
Benefit from matings to commercial rams	40,363,817	48%	77,313,918	48%
PV of benefits	84,037,872	34%	160,180,663	66%
% of ewes mated	44%		56%	

Total benefits

Figure 7 below shows the total annual benefits from 1996 to 2035. This illustrates that for the future projections, the trend simply continues from the historic analysis. The annualised benefits are essentially a weighted average payment, that gives the same NPV in 2015 (at 7% discount rate).

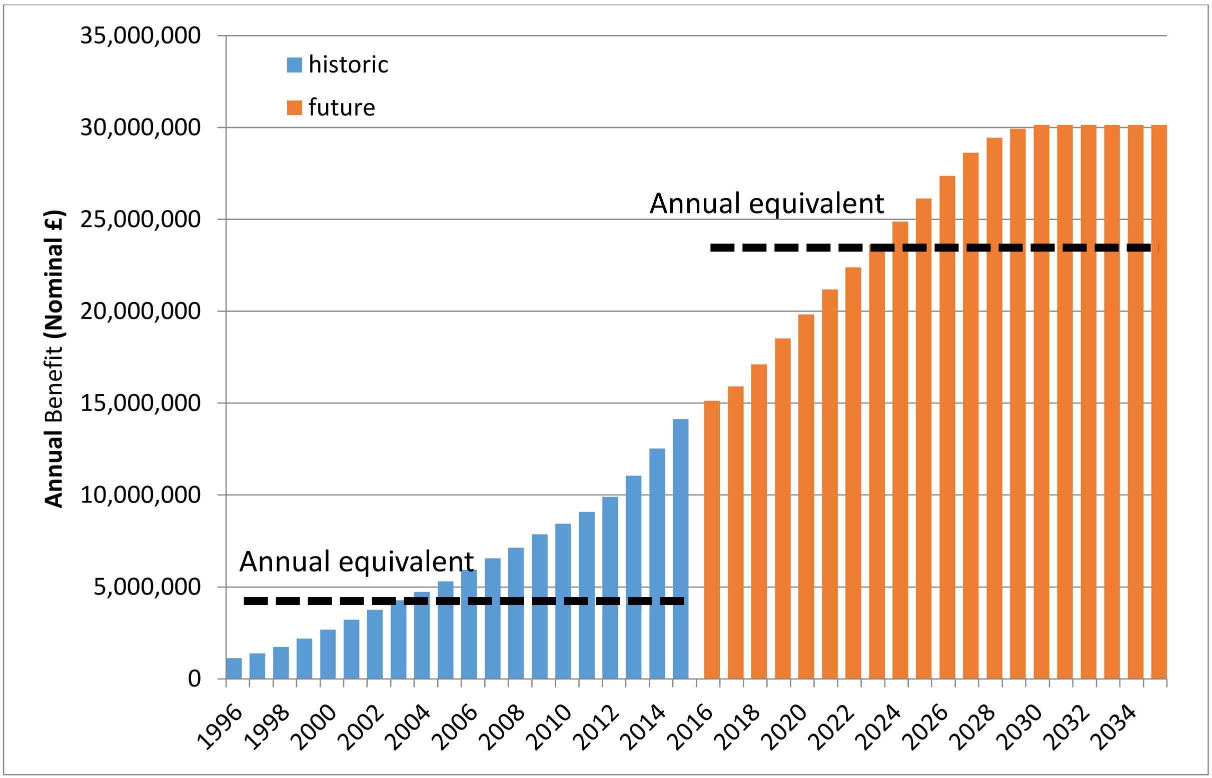

Figure 7: Total annual benefits from 1996 to 2035, and annualised benefits for historic and future projections.

Sensitivity analysis

Sensitivity of the PV of future benefits of genetic improvement to estimated input parameters has been carried out. The parameters were;

- the number of matings per ram (Table 11),
- the total number of rams (Table 12),
- the percentage of pedigree registered recorded rams used (Table 13),
- the percentage of ewes mated to Texel rams to breed replacements (Table 14),
- the annual trend in terminal (Table 15) and maternal indexes (Table 16), respectively, and,
- the number of males sold per pedigree ewe (Table 17).

The numbers of matings per Texel ram has the largest impact on the total PV of all the variables analysed. The relationship between an increase in matings per ram and NPV is 1:1. A 5% change in matings per ram is worth £12.2m in £2015 (the cumulative benefits over 20 years, discounted to 2015 at 7% p.a.) (Table 11). To increase the number of matings to greater than 34 is plausible, because the historic matings per ram had been increasing steadily from 30 in 2005, to 34 in 2015.

Table 11: Sensitivity of PV of benefits (£'000) from genetic improvement to changes in the number of matings per ram.

	-20%	**-15%**	**-10%**	**-5%**	**0%**	**5%**	**10%**	**15%**	**20%**
Matings / Ram	27	29	31	32	34	36	37	39	41
Ewes Mated ('000)	2,657	2,823	2,989	3,155	3,321	3,487	3,653	3,819	3,985
Terminal PV (£'000)	67,230	71,432	75,634	79,836	84,038	88,240	92,442	96,644	100,845
Maternal PV (£'000)	128,145	136,154	144,163	152,172	160,181	168,190	176,199	184,208	192,217
Total PV (£'000)	**195,375**	**207,586**	**219,797**	**232,008**	**244,219**	**256,429**	**268,640**	**280,851**	**293,062**
Annualised (£'000)	18,442	19,595	20,747	21,900	23,053	24,205	25,358	26,510	27,663

Changing the total number of Texel rams increases the PV of future benefits. More rams means the number of ewes mated to Texel rams increases in the same proportion. There is no change in the distribution of benefits by sire type. A 5% change in numbers of rams is worth £10.2m in £2015 (Table 12).

Table 12: Sensitivity of PV of benefits (£'000) from genetic improvement to changes in the total number of rams ('000).

	-20%	**-15%**	**-10%**	**-5%**	**0%**	**5%**	**10%**	**15%**	**20%**
Rams ('000)	78	83	88	93	98	103	108	112	117
Terminal PV (£'000)	70,250	73,697	77,144	80,591	84,038	87,485	90,932	94,378	97,825
Maternal PV (£'000)	133,068	139,835	146,610	153,392	160,181	166,976	173,777	180,584	187,396
Total PV (£'000)	**203,318**	**213,532**	**223,754**	**233,983**	**244,219**	**254,460**	**264,708**	**274,962**	**285,222**
Annualised (£'000)	19,192	20,156	21,121	22,086	23,053	24,019	24,987	25,954	26,923

Increasing the number of pedigree-recorded rams used does not affect the size of the total ram population but does increase the impact of the higher genetic trend realised in the recorded population. A 5% change in numbers of pedigree-recorded rams is worth £0.6m in £2015 (Table 13). This number if small because the range over which sensitivity is analysed, represents only a small change in the use of recorded rams.

Table 13: Sensitivity of PV of benefits (£‘000) from genetic improvement to changes in the percentage of pedigree registered recorded rams used (‘000).

	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%
Pedigree recorded (%)	10.8	11.3	11.8	12.2	12.7	13.2	13.6	14.1	14.6
Ewes mated to pedigree recorded rams (‘000)	360	375	391	406	422	438	453	469	484
Terminal pedigree recorded PV (£‘000)	13,952	14,517	15,083	15,648	16,213	16,779	17,344	17,909	18,474
Terminal non-rec pedigree & commercial PV (£‘000)	69,216	68,868	68,520	68,172	67,825	67,477	67,129	66,781	66,433
Maternal pedigree recorded PV (£‘000)	25,908	26,954	27,999	29,045	30,091	31,137	32,182	33,228	34,274
Maternal non-rec pedigree & commercial PV (£‘000)	132,755	132,089	131,422	130,756	130,090	129,423	128,757	128,091	127,425
Total PV (£‘000)	**241,831**	**242,428**	**243,025**	**243,622**	**244,219**	**244,815**	**245,412**	**246,009**	**246,606**
Annualised (£‘000)	22,827	22,883	22,940	22,996	23,053	23,109	23,165	23,222	23,278

Rams used to breed replacements are assumed to capture the benefits of genetic improvement in maternal traits (mature live weight, litter, and maternal ability), all of which are important for female performance, in addition to other traits also present in the terminal index. A 5% increase in the proportion of ewes mated to ram selected to breed replacements (about 2.5% of the number of ewes mated) will result in an extra £2.6m in £2015 (Table 14).

Table 14: Sensitivity of PV of benefits (£‘000) from genetic improvement to changes in the percentage of ewes mated to breed replacements (rams selected for maternal use).

	-20%	**-15%**	**-10%**	**-5%**	**0%**	**5%**	**10%**	**15%**	**20%**
Ewes mated to breed replacements (%)	45	48	51	53	56	59	62	65	67
Terminal PV (£‘000)	105,549	100,171	94,793	89,416	84,038	78,660	73,282	67,904	62,527
Benefits from terminal (%)	45	42	40	37	34	32	29	27	25
Maternal PV (£‘000)	128,145	136,154	144,163	152,172	160,181	168,190	176,199	184,208	192,217
Benefits from maternal (%)	55	58	60	63	66	68	71	73	75
Total PV (£‘000)	**233,694**	**236,325**	**238,956**	**241,587**	**244,219**	**246,850**	**249,481**	**252,112**	**254,743**
Annualised (£‘000)	22,059	22,307	22,556	22,804	23,053	23,301	23,549	23,798	24,046

Comparing the sensitivity analysis of the trend in terminal and maternal indexes it is clear that increases in assumed trends for maternal traits (Table 16) would deliver much greater financial benefit than those for terminal traits (Table 15). Even if the terminal index trend were to increase by 20%, only 37% of total benefits would be derived from terminal matings. A 5% increase in the terminal index trend is worth £2.5m in £2015, while a 5% change in the maternal index trend is worth £4.7m in £2015.

Table 15: Sensitivity of PV of benefits (£'000) from genetic improvement to changes in the genetic trend in the Terminal index.

	-20%	**-15%**	**-10%**	**-5%**	**0%**	**5%**	**10%**	**15%**	**20%**
Terminal PV (£'000)	73,923	76,452	78,980	81,509	84,038	86,567	89,095	91,624	94,153
Benefits from terminal (%)	32	32	33	34	34	35	36	36	37
Maternal PV (£'000)	160,181	160,181	160,181	160,181	160,181	160,181	160,181	160,181	160,181
Benefits from maternal (%)	68	68	67	66	66	65	64	64	63
Total PV (£'000)	**234,104**	**236,632**	**239,161**	**241,690**	**244,219**	**246,747**	**249,276**	**251,805**	**254,333**
Annualised (£'000)	22,098	22,336	22,575	22,814	23,053	23,291	23,530	23,769	24,007

Table 16: Sensitivity of PV of benefits (£'000) from genetic improvement to changes in the genetic trend in the Maternal index.

	-20%	**-15%**	**-10%**	**-5%**	**0%**	**5%**	**10%**	**15%**	**20%**
Terminal PV (£'000)	84,038	84,038	84,038	84,038	84,038	84,038	84,038	84,038	84,038
Benefits from terminal (%)	37	37	36	35	34	34	33	33	32
Maternal PV (£'000)	141,320	146,035	150,750	155,466	160,181	164,896	169,611	174,326	179,041
Benefits from maternal (%)	63	63	64	65	66	66	67	67	68
Total PV (£'000)	**225,358**	**230,073**	**234,788**	**239,503**	**244,219**	**248,934**	**253,649**	**258,364**	**263,079**
Annualised (£'000)	21,272	21,717	22,162	22,607	23,053	23,498	23,943	24,388	24,833

The sensitivity of the PV benefits to the number of males sold only affects the pedigree registered population of rams, about 26% of which are recorded, and have higher index trends. While the relative percentage of commercial rams used changes, the number of commercial rams used is not affected, so the total number of rams changes. It A 5% change in the number of rams being sold, affects the PV by £5.3m (Table 17). This situation reflects farmers shifting away from pedigree registered Texels, and using rams of other breeds.

Table 17: Sensitivity of PV of benefits (£'000) from genetic improvement to changes in the number of males sold per pedigree ewe.

	-20%	**-15%**	**-10%**	**-5%**	**0%**	**5%**	**10%**	**15%**	**20%**
Males sold per pedigree ewe	0.34	0.36	0.38	0.40	0.43	0.45	0.47	0.49	0.51
Commercial rams used (%)	57	56	54	53	52	50	49	48	47
Terminal pedigree recorded PV (£'000)	13,571	14,232	14,892	15,553	16,213	16,874	17,534	18,195	18,855
Terminal non-rec pedigree & commercial (£'000)	63,279	64,415	65,552	66,688	67,825	68,961	70,097	71,234	72,370
Maternal pedigree recorded PV (£'000)	25,198	26,421	27,644	28,868	30,091	31,314	32,537	33,761	34,984
Maternal non-rec pedigree & commercial (£'000)	120,925	123,220	125,512	127,802	130,090	132,376	134,660	136,943	139,224
Total PV (£'000)	**222,973**	**228,288**	**233,600**	**238,910**	**244,219**	**249,525**	**254,829**	**260,132**	**265,433**
Annualised (£'000)	21,047	21,549	22,050	22,551	23,053	23,553	24,054	24,555	25,055

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