Commercial beef farms excelling in terminal and maternal genetic merit generate more gross profit

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ABSTRACT: Validation of beef total merit breeding indexes for improving performance and profitability has previously been undertaken at the individual animal level; however, no herd-level validation of beef genetic merit and profit has been previously investigated. The objective of the present study was to quantify the relationship between herd profitability and both herd-average terminal and maternal genetic merit across 1,311 commercial Irish beef herds. Herd-level physical and financial performance data were available from a financial benchmarking tool used by Irish farmers and their extension advisors. Animal genetic merit data originated from the Irish Cattle Breeding Federation who undertake the national beef and dairy genetic evaluations. Herd-average genetic merit variables included the terminal index of young animals, the maternal index of dams, and the terminal index of service sires. The herds represented three production systems: 1) cow-calf to beef, 2) cow-calf to weanling/yearling, and 3) weanling/yearling to beef. Associations between herd financial performance metrics and herd average genetic merit variables were quantified using a series of linear mixed models with year, production system, herd size, stocking rate, concentrate input, and the two-way interactions between production system and herd size, stocking rate, and concentrate input included as nuisance factors. Herd nested within the county of Ireland (n = 26) was included as a repeated effect. Herds with young cattle excelling in terminal index enjoyed greater gross and net profit per hectare (ha), per livestock unit (LU), and per kg net live-weight output. The change in gross profit per LU per unit change in the terminal index of young animals was €1.41 (SE = 0.23), while the respective regression coefficient for net profit per LU was €1.37 (SE = 0.30); the standard deviation of the terminal index is €37. Herd-average dam maternal index and sire terminal index were both independently positively associated with gross profit per ha and gross profit per LU. Each one unit increase in dam maternal index (standard deviation of €38) was associated with a €1.40 (SE = 0.48) and €0.76 (SE = 0.29) greater gross profit per ha and per LU, respectively. Results from the present study at the herd-level concur with previous validation studies at the individual animal level thus instilling further confidence among stakeholders as to the expected improvement in herd profitability with improving genetic merit.

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INTRODUCTION

Low profitability is a characteristic of most Irish beef farms (Dillon et al., 2019). Profit is generally influenced by a series of internal on-farm factors such as animal husbandry practices and grassland management (Ashfield et al., 2013; Taylor et al., 2017b), as well as external factors such as government policy and both input and output commodity prices (Crosson et al., 2006). Crosson (2008), Crosson and McGee (2015), and Taylor et al. (2017a) all specifically documented the contributors to profit in Irish pastoral beef farms; these include farm stocking rate, grazing season length, cow reproductive performance, progeny live-weight gain, and animal genotype, all of which are under the control of the producer. The estimated contribution of farm-level factors to profitability on beef farms is usually quantified through simulations and systems modeling with a given set of assumptions underpinning the process (Finneran and Crosson, 2013); sensitivity analyses to these assumptions are, however, usually undertaken. As demonstrated by Taylor et al. (2018), supplementing these modeling outputs with actual farm-level data that accurately reflects commercial beef farms further enhances these analyses.

Several studies have validated the usefulness of breeding goals in the selection of more productive and efficient dairy (O'Sullivan et al., 2019; Berry and Ring, 2020) and beef cattle (Connolly et al., 2016; Kelly et al., 2020; Twomey et al., 2020). While several studies have related genetic merit of beef cattle to improved performance at the level of the individual animal (Connolly et al., 2016; Kelly et al., 2020; Twomey et al., 2020), no such study has been attempted at the herd level. Moreover, to quantify the association with profit, these aforementioned studies applied a monetary value to each performance metric which was assumed common across all farms (Connolly et al., 2016; Kelly et al., 2020; Twomey et al., 2020); this may not be valid as, in real terms, costs and revenues are expected to differ between farms and across time. Additionally, there was no explicit account for fixed costs in these studies. Using commercial field data from Irish dairy herds, Ramsbottom et al. (2012) demonstrated that genetically elite, spring-calving pasture-based dairy herds were, on average, more profitable than their lower genetic merit contemporary herds. The main advantages of using herd-level data over animal-level data are that the costs and income sources not directly attributable to individual animals (e.g., fixed costs) can be included in the analysis; furthermore, across-herd analyses enables the robustness of the association with genetic merit to be quantified across production systems. The main challenge with using herd-level data, however, is to properly account for differences in technical efficiencies across herds, especially if correlated with herd genetic merit; for example, beef producers who breed or purchase higher genetic merit animals may also be more technically efficient in grassland management and nutrition. Ramsbottom et al. (2012) attempted to adjust for inter-herd differences in technical efficiency in their herd-level analysis of genetic merit by also concurrently accounting for the nongenetic factors of stocking rate, herd size, and farm concentrate input as covariates in their linear mixed model. Such nongenetic factors are known to influence farm financial performance (Taylor et al., 2017a; Ramsbottom et al., 2012), and thus a similar adjustment of inter-herd technical efficiency was considered in the current study.

The main objective of the present study was to quantify the association between profitability with both herd-average terminal and maternal genetic merit across a large number of commercial Irish beef herds. Taken together with similar studies conducted at the animal-level in beef cattle (McHugh et al., 2014; Connolly et al., 2016; Twomey et al., 2020) results from this study will provide more confidence in the expected change in profitability, if any, associated with changes in herd-average genetic merit.

MATERIALS AND METHODS

All data were obtained from pre-existing databases managed separately by Teagasc and by the Irish Cattle Breeding Federation Ltd (ICBF); as such, animal care and use committee approval was not required in advance of conducting this study.

Farm Financial and Physical Performance Data

Farm financial data were obtained from the Teagasc eProfit Monitor software (Teagasc, 2020). The eProfit Monitor system is used in Ireland by farmers and their extension officers to record all farm inputs, outputs, and expenses incurred during a single production year (Teagasc, 2020). Farm-level features recorded on beef farms include farm size, farm livestock numbers, production system, stocking rate and farm live-weight output. Available farm financial variables include the value of livestock sales and purchases, as well as the total farm variable and fixed costs. Variable costs include farm contractor (custom operator) charges, veterinary expenses, fertilizer, concentrate feed, and other costs (i.e., levies, purchased forage, and miscellaneous costs). Fixed costs include machinery repairs, building and machinery depreciation, utility expenses, loan repayments and interest payable, professional fees, and casual labor. All data are self-declared but are curated so that data across years can be collated and compared.

Data on farm physical and financial performance were extracted from the eProfit Monitor database for the years 2016 to 2019, inclusive, representing 5,022 herd-years from 2,452 unique beef herds. All herds had information on farm physical and financial performance. The main beef production systems identified from the data were 1) cow-calf to beef, 2) cow-calf to weanling/yearling, and 3) weanling/yearling to beef. Beef farms were classified into one of these production systems by the farmer and their Teagasc extension officer based on the dominant production system on the farm. Several farms also had a sheep and/or arable enterprise present on the farm, but the physical performance, costs, and margins considered in the present study were those that were apportioned exclusively to the farm's cattle enterprise by the farmer and extension officer (Teagasc, 2020). In the case where some fixed costs could not be easily allocated to an individual enterprise (e.g., a hired labor unit), then these fixed costs were apportioned according to the proportion of gross revenue output contributed by that specific enterprise (Teagasc, 2020).

Gross farm revenue output is calculated within the eProfit Monitor system as the value of livestock sales minus the value of livestock purchases plus the value of any net inventory change in livestock numbers. The value of the net inventory change in livestock numbers is calculated in the eProfit Monitor system by multiplying the number of animals in a specific livestock category by a standard value for that animal category. Gross farm profit is calculated within the eProfit Monitor system as gross revenue output minus total variable costs, while net farm profit is calculated as gross profit minus total fixed costs. All financial variables are expressed on either a per cattle usable hectare, per livestock unit (LU), or on a per kg live-weight output basis; these are the primary base units used in the eProfit Monitor system (Teagasc, 2020), and in herd-level analyses within pasture-based beef systems (Taylor et al., 2017a, 2017b). Transforming cattle numbers of different ages into LU equivalents enables cattle of different life-stages to be represented on the same scale and unit, and were calculated as follows according to Teagasc (2020): beef cow = 0.9 LU, calf (0–11 months of age) = 0.3 LU, yearling (12–23 months of age) = 0.7 LU and other adult cattle (≥ 24 months of age) = 1.0 LU. Farm net live-weight output is calculated in the eProfit Monitor system as the differential between live-weight sales and purchases; this is based on a combination of 1) actual live-weight data from the sale of live cattle at livestock auctions, 2) derived live-weights based on an assumed dressing percentage when an animal is slaughtered at a registered facility, or 3) derived live-weights based on cattle age, breed, and sex for private sales in the absence of actual live-weight data. The value of concentrate consumed per ha was assumed to represent the farm's concentrate input and was calculated as the sum of the value of purchased concentrates per ha and the value of home-grown concentrates per ha. Herd size was the total LUs of the farm calculated from the ICBF database, and stocking rate was calculated as herd size divided by the farm's usable hectares attributable to the cattle enterprise.

Phenotypic carcass weight, carcass conformation, and carcass fat score (Englishby et al., 2016) extracted from the ICBF database were available for young bulls, steers, and heifers slaughtered in both the cow-calf to beef and the weanling/yearling to beef herds; these data were used to calculate herd average carcass weight, conformation, and fat for each herd-year. Similarly, the phenotypic calving interval and age at first calving for each beef cow in cow-calf to weanling/yearling and cow-calf to beef herds were available from the ICBF database and were used to calculate herd median calving interval and herd median age at first calving for each herd-year.

Genetic Merit Data

The ICBF are responsible for the beef national genetic evaluations in Ireland. All genetic evaluations are based on a multibreed population and are undertaken in the MiX99 software suite (MiX99 Development Team, 2015). All evaluations adjust for the heterosis and recombination loss coefficients of the animal as most beef cattle in Ireland are crossbred; the use of genetic groups in the evaluation account for breed differences. The national beef genetic evaluations used to derive the Irish beef indexes are described in further detail by Evans et al. (2007, 2009, 2012). The Irish terminal and maternal indexes are both economic-based with the goal of identifying genetically elite cattle. The beef terminal index is designed to identify animals excelling genetically in expected profitability of their progeny at slaughter (Connolly et al., 2016); the unit of the terminal index is euro per progeny slaughtered. The beef maternal index is designed to identify animals excelling genetically in expected profitability of their female progeny as replacement beef cows; the beef maternal index considers both maternal and terminal traits (Dunne et al., 2020), and its unit is euro per calving of each cow. Both indexes use predicted transmitting abilities (PTA) as the unit of genetic merit for each index trait, which are then multiplied by the respective trait economic weight and subsequently summed to generate a separate terminal and maternal index value per animal. The terminal index includes the traits carcass weight, carcass conformation and carcass fat cover, feed intake, docility, as well as calving performance traits such as gestation length, perinatal mortality, and direct calving difficulty (Connolly et al., 2016). The maternal index is composed of two sub-indexes, the calf maternal sub-index which is composed of traits attributable to the calf, and the cow maternal sub-index which is composed of traits attributable to the beef cow (Dunne et al., 2020). The calf maternal sub-index includes all traits in the aforementioned terminal index, while the cow maternal sub-index includes calving interval, maternal calving difficulty age at first calving, milking ability, cow docility, survival, cow live-weight, and cull cow carcass weight. The relative emphasis and economic weights applied to each trait in both the terminal and maternal indexes are presented in Supplementary Table 1. While the weights on both the terminal and maternal indexes change over time, the economic weights on the traits in both indexes used in the present study were those from the year 2020. Total genetic merit for both the Irish beef terminal and maternal index, and individual trait PTAs from the February 2020 national genetic evaluation were extracted from the ICBF database for all cattle that were present in the eProfit Monitor herds in each year.

Data Edits

As the present study was focused on the relationship between beef cattle genetic merit and profitability, only data from herd-years where ≤ 5% of the nonbreeding cattle were born in a dairy herd were retained; the birth herd was classified as a dairy herd if the average dam breed composition of the herd was > 75% dairy breeds (Ring et al., 2018). To ensure data integrity, the average farm LUs for each herd-year were also calculated based on the data recorded in the ICBF database by summing the LUs of cattle present in each animal category at the end of each month and averaging across all 12 months for each year. This was possible because it is a legal requirement to record all cattle births, deaths, and inter-location movements in Ireland, all of which are stored on the ICBF database. A total of 571 herd-years were discarded where the differential between the self-declared eProfit Monitor LUs and those calculated from the ICBF database was >5%. Data from a further 40 herd-years with <10 LUs were also removed as profitability was not considered to be a primary motivation for farming in these herds. Only weanling/yearling to beef herd-years where the recorded breeding beef cow LUs constituted <5% of total herd-year's LUs were retained; beef cow LUs below this threshold were not deemed to contribute to farm profit. Similarly, only herd-years of either cow-calf to weanling/yearling or cow-calf to beef production systems where breeding beef cow LUs constituted >30% of total herd-year LUs were retained. Additionally, all data from 177 unique herds with multiple years of records that were recorded to have changed production system across any of the 4 years of study were removed. Only herd-years where PTAs were available on ≥75% of the nonbreeding animals were retained. Additionally, for herds classified as either cow-calf to weanling/yearling or cow-calf to beef, only herd-years where PTAs were also available on ≥75% of cows and service sires were retained. Subsequently, data from 2,308 herd-years representing 1,311 unique herds remained for further analysis. The numbers of herd-years belonging to each production system were 1,520, 633, and 155 for cow-calf to weanling/yearling, cow-calf to beef, and weanling/yearling to beef, respectively.

Statistical Analyses

Preliminary analyses revealed nonlinear relationships between several of the dependent variables of interest and prospective independent variables, such as the value of concentrates consumed per ha, stocking rate and herd size. Therefore, the value of concentrates consumed per ha was stratified into 11 classes (≤ 50 €/ha, nine classes each of 50 €/ha from 50 €/ha to 500 €/ha inclusive, and >500 €/ha), stocking rate was divided into five classes (≤1.0 LU/ha, three classes each of 0.5 LU/ha from 1.0 LU/ha to 2.5 LU/ha inclusive, and >2.5 LU/ha), and herd size was categorized into eight classes (≤20 LU, six classes each of 20 LU from 20 LU to 140 LU, inclusive, and >140 LU).

Associations between the financial performance metrics and herd average genetic merit were determined using a series of linear mixed models in PROC MIXED (SAS 9.4, SAS Institute Inc., Cary, NC). Variables included as fixed effects in all models were year (i.e., 2016, 2017, 2018, or 2019), production system (i.e., cow-calf to beef, cow-calf to weanling/yearling, or weanling/yearling to beef), herd size (class variable; $n = 8$), stocking rate (class variable; $n = 5$), and the value of concentrates consumed per ha (class variable; $n = 11$) which was assumed to represent farm concentrate input. The two-way interactions between production system and either herd size, stocking rate, or the value of concentrates consumed per ha were also tested for inclusion in all models. Herd ($n = 1{,}311$) nested within the county of Ireland ($n = 26$) was included as a repeated effect in all models; the covariance structure chosen was based on minimizing the Akaike Information Criterion for the given model. Following model development, herd-average genetic merit features of interest were included as independent variables in the model. For all three production systems, the herd-average genetic merit independent variable of terminal index of young animals (progeny) was considered. Additionally, for both the cow-calf to beef and the cow-calf to weanling/yearling systems, the herd-average genetic merit independent variables also considered were either the maternal index of dams itself or both the maternal cow sub-index and the maternal calf sub-index of dams; in both models the herd-average terminal index of service sires was always included. For all models, the two-way interactions between herd average genetic merit variable and production system were also tested. In total, 45 linear mixed models were run yielding 90 financial performance on genetic merit variable combinations. The approximate expected coefficient from the regression of gross profit per LU on terminal index was 2, while the approximate expected coefficient from the regression of gross profit per LU on sire terminal index was 1.

In a separate series of analyses for the weanling/yearling to beef and cow-calf to beef systems, the herd-average genetic merit features included in the model were either the terminal index, carcass weight PTA, carcass conformation PTA, or carcass fat PTA of the young animals; the dependent variables were either herd-average phenotypic carcass weight, conformation, or fat. Whether terminal index, carcass weight PTA, carcass conformation PTA, or carcass fat PTA associations differed between weanling/yearling to beef and cow-calf to beef herds was also examined. Similar analyses were undertaken for both the cow-calf to beef and the cow-calf to weanling/yearling systems, where herd-median phenotypic calving interval was the dependent variable and the herd-average genetic merit independent variables were either the dam maternal index, both dam maternal calf sub-index and dam maternal cow sub-index, the dam PTA for calving interval, or the dam PTA for age at first calving. The same set of models were fitted for age at first calving where the dependent variable of herd median phenotypic calving interval was replaced with herd median phenotypic age at first calving. The two-way interaction between herd average genetic merit and cow-calf production system (i.e., cow-calf to beef and cow-calf to weanling/yearling systems) was also tested for inclusion.

RESULTS

Summary statistics of the physical performance metrics in the current study is in Table 1. On average, cow-calf to beef herds had the most cattle LUs and cattle hectares. On the other hand, weanling/yearling to beef herds had both the greatest live-weight output per ha as well as per LU.

Relationships Between Nongenetic Factors and Profitability

How the associations between stocking rate, herd size, and value of concentrates consumed per ha with gross profit per ha differed by production systems is demonstrated in Fig 1; the significance of the two-way interactions between production system and stocking rate, herd size, or value of concentrates consumed per ha were $P < 0.001$, $P = 0.339$, and $P < 0.001$, respectively. Gross profit per ha was positively related to stocking rate and increased almost linearly in both the cow-calf to beef and the cow-calf to weanling/yearling herds; in contrast, gross profit per ha of weanling/yearling to beef herds increased sharply from the 2.0–2.5 LU/ha to the >2.5 LU/ha stocking rate category. Irrespective of production system, gross profit per ha tended to initially increase as herd size increased but plateaued for herds > 100 LUs. Gross profit per ha in both the cow-calf to beef and the weanling/yearling to beef herds remained stable as concentrate cost per ha increased but reduced in the cow-calf to weanling/yearling herds with a sharp reduction in profit at higher concentrates costs per ha.

Least squares means of gross profit per LU for the interaction between production system and each of stocking rate ($P = 0.072$), herd size ($P = 0.721$), and value of concentrates consumed per ha ($P < 0.001$) are in Fig 2. Similarly, least squares means of gross profit per kg live-weight for the interaction between production system by each of stocking rate ($P = 0.673$), herd size ($P = 0.772$), and value of concentrates consumed per ha ($P < 0.01$) are in Fig 3. Both gross profit per LU and per kg live-weight increased as stocking rate increased in all three production systems, but the relationships were not linear which suggests diminishing returns in profit at higher stocking rates (Figs 1 and 2). The relationship between gross profit per LU and kg live-weight with herd size followed a similar trend to the relationship between herd size and gross profit per ha. Gross profit per LU and per kg live-weight reduced as the value of concentrates fed increased, with a greater reduction in profit in cow-calf to weanling/yearling herds at relatively high concentrate cost levels.

Table 1. Number of herd-years (N) along with the mean (SD in parentheses) farm physical performance for each beef production system

Farm performance variable	Weanling/yearling to beef	Cow-calf to beef	Cow-calf to weanling/yearling
N	155	633	1,520
Area farmed, ha	43.38 (25.95)	58.67 (30.17)	36.96 (24.03)
Cattle area, ha	37.63 (21.01)	51.13 (26.13)	32.51 (19.38)
Livestock units, LU	74.24 (53.92)	96.83 (51.87)	47.85 (31.03)
Stocking rate, LU/ha	1.92 (0.66)	1.94 (0.56)	1.51 (0.52)
Live-weight output per hectare, kg/ha	789.49 (482.20)	648.76 (250.18)	434.65 (195.35)
Live-weight output per LU, kg/LU	404.17 (172.14)	330.56 (70.97)	284.8 (73.09)

[1]Livestock unit: beef cow = 0.9 LU, calf (0–11 months of age) = 0.3 LU, yearling (12–23 months of age) = 0.7 LU and other adult cattle (≥24 months of age) = 1.0 L.

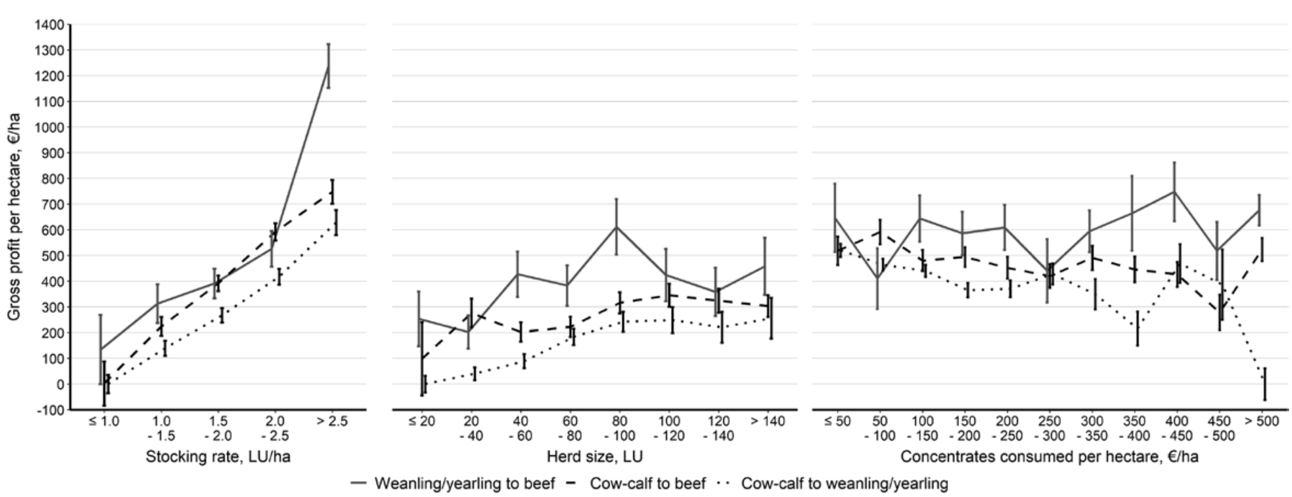

Figure 1. Least squares means (error bars represent one SE each side of the mean estimate) for gross profit per hectare for the interaction of beef production system (i.e., weanling/yearling to beef, cow-calf to beef, and cow-calf to weanling/yearling) with the class variables of either stocking rate, herd size, or value of concentrates consumed per hectare. The significance of the two-way interactions between production system and stocking rate, herd size, or value of concentrates consumed per hectare were $P < 0.001$, $P = 0.339$, and $P < 0.001$, respectively. Means are presented relative to the first category for stocking rate and herd size, and last category for value of concentrates consumed per hectare, within the cow-calf to weanling/yearling system.

Similar trends to gross profit per ha, per LU, and per kg live-weight were observed in the relationships between net profit per ha, per LU, and per kg live-weight, and the nongenetic factors of stocking rate, herd size, and concentrate input (Supplementary Figs 1–3).

Relationships Between Herd Average Genetic Merit and Financial Performance

An interaction between genetic merit and production system existed ($P < 0.05$) for nine of the 90 financial performance on genetic merit variable combinations investigated; these were for gross revenue output per ha on terminal index ($P < 0.05$); gross revenue output per ha ($P < 0.05$) and fixed costs per ha ($P < 0.05$) on dam maternal cow sub-index; variable costs per ha ($P < 0.01$) and gross revenue output per ha ($P < 0.05$) on dam maternal calf sub-index; and all of gross revenue output per ha ($P < 0.01$), gross revenue output per LU ($P < 0.05$), fixed costs per ha ($P < 0.05$), and variable costs per ha ($P < 0.05$) on dam maternal index. Only the main effects are discussed further as there was no interaction between genetic merit and production system when any of the profit variables were the dependent variable, and because some of

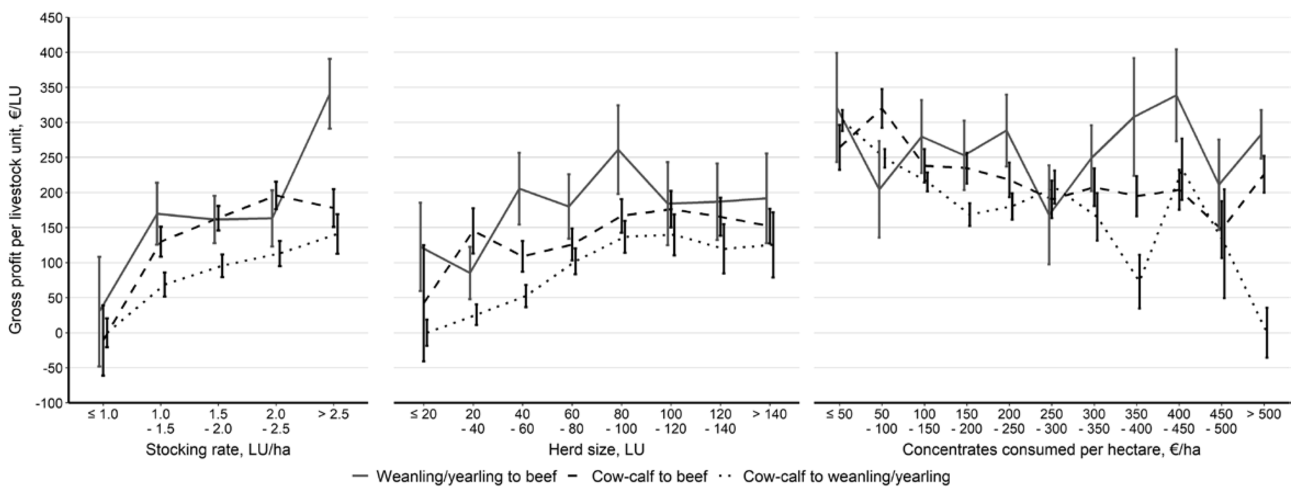

Figure 2. Least squares means (error bars represent one SE each side of the mean estimate) for gross profit per livestock unit (LU) for the interaction of beef production system (i.e., weanling/yearling to beef, cow-calf to beef, and cow-calf to weanling/yearling) with the class variables of either stocking rate, herd size, or value of concentrates consumed per hectare. The significance of the two-way interactions between production system and stocking rate, herd size, or value of concentrates consumed per hectare were $P = 0.072$, $P = 0.721$, and $P < 0.001$, respectively. Means are presented relative to the first category for stocking rate and herd size, and last category for value of concentrates consumed per hectare, within the cow-calf to weanling/yearling system.

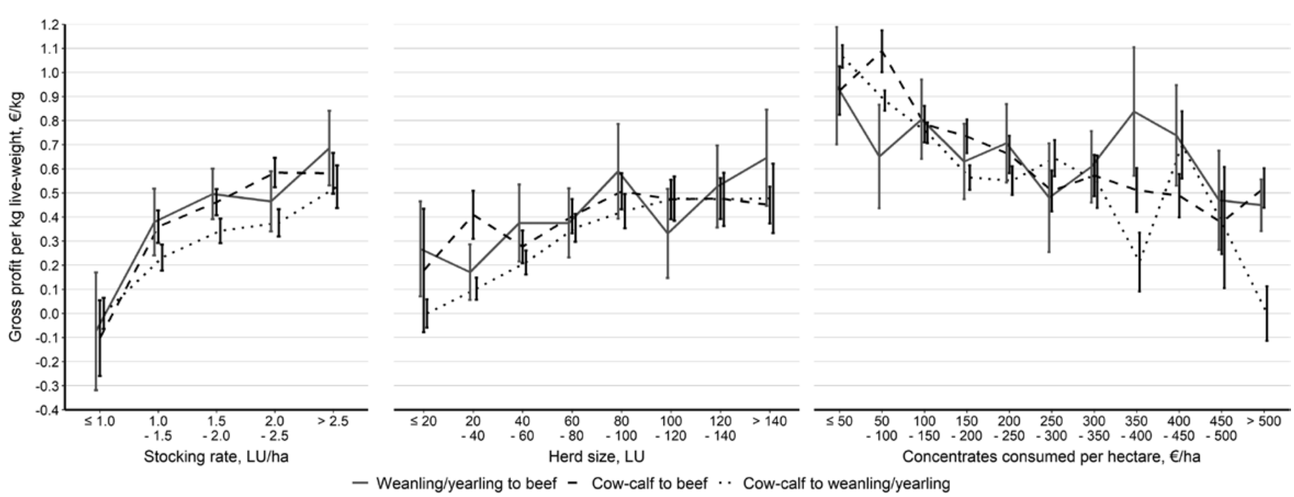

Figure 3. Least squares means (error bars represent one SE each side of the mean estimate) for gross profit per kg live-weight for the interaction of beef production system (i.e., weanling/yearling to beef, cow-calf to beef, and cow-calf to weanling/yearling) with the class variables of either stocking rate, herd size, or value of concentrates consumed per hectare. The significance of the two-way interactions between production system and stocking rate, herd size, or value of concentrates consumed per hectare were $P = 0.673$, $P = 0.772$, and $P < 0.01$, respectively. Means are presented relative to the first category for stocking rate and herd size, and last category for value of concentrates consumed per hectare, within the cow-calf to weanling/yearling system.

Table 2. Regression coefficients (*b*; SE in parentheses) estimated from a mixed model for a series of herd financial metrics on progeny terminal index

Financial variable	*b* (SE)[1]
Gross revenue output per hectare, €/ha	3.00 (0.42)***
Variable costs per hectare, €/ha	0.67 (0.26)*
Gross profit per hectare, €/ha	2.33 (0.39)***
Fixed costs per hectare, €/ha	0.19 (0.31)
Net profit per hectare, €/ha	2.23 (0.48)***
Gross revenue output per livestock unit, €/LU	1.95 (0.21)***
Variable costs per livestock unit, €/LU	0.53 (0.14)***
Gross profit per livestock unit, €/LU	1.41 (0.23)***
Fixed costs per livestock unit, €/LU	0.14 (0.20)
Net profit per livestock unit, €/LU	1.37 (0.30)***
Gross revenue output per kg live-weight, €/kg	0.0038 (0.0005)***
Variable costs per kg live-weight, €/kg	−0.0006 (0.0006)
Gross profit per kg live-weight, €/kg	0.0045 (0.0007)***
Fixed costs per kg live-weight, €/kg	−0.0016 (0.0008)*
Net profit per kg live-weight, €/kg	0.0063 (0.0011)***

[1]Significance of coefficient from zero: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

these interactions could simply be an artefact of multiple testing. For completeness, however, the regression coefficients for herd financial performance on each genetic merit feature in each production system are detailed in Supplementary Tables 2–4.

Although a greater terminal index value was associated higher variable costs per ha and per LU, superior terminal index was associated with both greater gross profit and net profit per ha, per LU, and per kg live-weight (Table 2). In fact, each standard deviation unit increase in the Irish terminal index (standard deviation of €37 on a PTA scale; Twomey et al., 2020) was associated with €86.13 (SE = €14.44), €52.20 (SE = €8.40), and €0.17 (SE = €0.026) more gross profit per ha, per LU and per kg live-weight, respectively; the respective values for net profit were €82.70 (SE = €17.76), €50.84 (SE = €11.13), and €0.23 (SE = €0.042).

The change in herd average financial performance per unit change in herd average genetic merit for both the dam maternal index and sire terminal index, when fitted in the same model, is in Table 3; the regression coefficients on both the dam maternal calf sub-index and dam maternal cow sub-index (whose sum is the overall dam maternal index) when fitted concurrently with the sire terminal index is also in Table 3. The regression coefficients on the sire terminal index were identical irrespective of whether the dam maternal index itself or its two sub-components simultaneously were fitted. The regression coefficients for gross revenue output, gross profit, and net profit on both the dam maternal and sire terminal indexes were generally positive although not always different from zero for the dam maternal index. Dam maternal index was not associated with either gross revenue output or gross profit per kg live-weight as well as not being associated with any of the net profit variables. Greater genetic merit for both dam maternal sub-indexes was associated with greater herd profitability, although not all the coefficients were different from zero for the dam maternal cow sub-index. This indicates an increase in gross revenue output and profitability per unit increase in each maternal sub-index, independent of both the other maternal sub-index of the dam and the terminal index of the service sires used. Every one standard deviation unit increase in the Irish maternal index (standard deviation of €38 on a PTA scale; Twomey et al., 2020) was associated, on average, with €53.26 (SE = €18.32) and €28.72 (SE = €11.11) more gross profit per ha and per LU, respectively.

Relationships Between Herd Average Genetic Merit and Phenotypic Performance

An interaction between genetic merit and production system existed for the regression of herd average carcass conformation on either terminal index ($P < 0.01$) or carcass conformation PTA ($P < 0.01$). Each one unit increase in terminal index was associated with a 0.069 (SE = 0.011) and 0.038 (SE = 0.002) unit increase in herd average carcass conformation in weanling/yearling to beef and cow-calf to beef herds, respectively. Similarly, every one unit increase in carcass conformation PTA was associated with a 4.35 (SE = 0.68) and 2.40 (SE = 0.13) unit increase in herd average carcass conformation in weanling/yearling to beef and cow-calf to beef herds, respectively. The expected coefficient was two as each unit increase in estimated breeding value (EBV) is expected to be associated with a one unit increase in phenotypic performance; therefore, as PTA = EBV/2 then each unit increase in PTA is expected to be associated with a two unit increase in phenotypic performance. Only the main effects are discussed further and, thus, the phenotypic change in carcass traits per unit change in terminal index or carcass trait PTA of young animals is presented in Table 4. The terminal index was positively associated with both phenotypic carcass weight and conformation, and negatively associated with carcass fat. The coefficients from the regression of each carcass trait PTA on its respective herd average phenotypic trait were

Table 3. Regression coefficients (b; SE in parentheses[1]) estimated from mixed models for each herd financial metric on both dam maternal index and sire terminal index value when fitted concurrently in the model, or on all of dam maternal calf sub-index, dam maternal cow sub-index and sire terminal index when fitted concurrently in the model

Financial variable	Dam maternal index	Dam maternal calf sub-index	Dam maternal cow sub-index	Sire terminal index
Gross revenue output per hectare, €/ha	2.34 (0.47)***	5.42 (0.70)***	2.23 (0.46)***	1.24 (0.29)***
Variable costs per hectare, €/ha	0.89 (0.31)**	2.35 (0.46)***	0.85 (0.30)**	−0.13 (0.19)
Gross profit per hectare, €/ha	1.40 (0.48)**	2.97 (0.73)***	1.34 (0.48)**	1.30 (0.29)***
Fixed costs per hectare, €/ha	0.70 (0.39)	0.95 (0.60)	0.70 (0.39)	0.07 (0.23)
Net profit per hectare, €/ha	0.75 (0.61)	2.13 (0.92)*	0.70 (0.61)	1.33 (0.37)***
Gross revenue output per livestock unit, €/LU	1.06 (0.26)***	3.01 (0.39)***	1.00 (0.26)***	0.82 (0.16)***
Variable costs per livestock unit, €/LU	0.22 (0.18)	1.23 (0.28)***	0.20 (0.18)	0.09 (0.11)
Gross profit per livestock unit, €/LU	0.76 (0.29)**	1.71 (0.44)***	0.72 (0.29)*	0.76 (0.18)***
Fixed costs per livestock unit, €/LU	0.28 (0.25)	0.21 (0.39)	0.28 (0.25)	0.13 (0.15)
Net profit per livestock unit, €/LU	0.50 (0.39)	1.55 (0.58)**	0.47 (0.39)	0.70 (0.23)**
Gross revenue output per kg live-weight, €/kg	−0.0005 (0.0006)	0.0024 (0.0010)*	−0.0006 (0.0006)	0.0016 (0.0004)***
Variable costs per kg live-weight, €/kg	−0.0017 (0.0008)*	−0.0017 (0.0012)	−0.0017 (0.0008)*	−0.0007 (0.0005)
Gross profit per kg live-weight, €/kg	0.0012 (0.0009)	0.0040 (0.0014)**	0.0011 (0.0009)	0.0023 (0.0006)*
Fixed costs per kg live-weight, €/kg	−0.0013 (0.001)	−0.0039 (0.0015)*	−0.0012 (0.0010)	−0.0004 (0.0006)
Net profit per kg live-weight, €/kg	0.0028 (0.0015)	0.0082 (0.0022)***	0.0026 (0.0015)	0.0028 (0.0009)**

[1]Significance of coefficient from zero: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 4. The phenotypic change (SE in parentheses[1]) in herd average carcass weight (kg), carcass conformation (scale 1–15), and carcass fat (scale 1–15) for a one unit change in terminal index, carcass weight PTA[2], carcass conformation PTA, and carcass fat PTA

Genetic merit variable	Carcass weight	Carcass conformation	Carcass fat
Terminal index, €	0.90 (0.08)	0.039 (0.0022)	−0.016 (0.0020)
Carcass weight PTA, kg	3.73 (0.30)	0.131 (0.0093)	−0.049 (0.0082)
Carcass conformation PTA, scale 1–15[3]	49.06 (4.86)	2.47 (0.13)	−1.02 (0.12)
Carcass fat PTA, scale 1–15[3]	−65.13 (8.69)	−3.13 (0.26)	2.52 (0.19)

[1]All coefficients were different from zero ($P < 0.001$).

[2]PTA = predicted transmitting ability.

[3]A score of 1 represents poor conformation or a lean carcass and a score of 15 represents a well conformed or fat carcass.

Table 5. The phenotypic change (SE in parentheses[1]) in herd median calving interval (*d*) and herd median age at first calving (*d*) for a one unit change in dam maternal index, dam maternal cow sub-index, dam maternal calf sub-index, dam calving interval PTA[2], and dam age at first calving PTA.

Genetic merit variable	Calving interval	Age at first calving
Dam maternal index, €	−0.12 (0.04)***	−0.73 (0.14)***
Dam maternal cow sub-index, €	−0.13 (0.04)**	−0.75 (0.14)***
Dam maternal calf sub-index, €	−0.06 (0.05)	−0.37 (0.22)
Dam calving interval PTA, d	1.63 (0.55)**	9.78 (2.12)***
Dam age at first calving PTA, d	0.07 (0.12)	4.03 (0.44)***

[1]Significance of coefficient from zero: $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

[2]PTA = predicted transmitting ability.

all not different from or greater than the expected coefficient of 2 ($P < 0.05$).

The only interactions between genetic merit and production system for the regression of herd median age at first calving was for dam maternal calf sub-index ($P < 0.05$) and dam age at first calving PTA ($P < 0.01$). The phenotypic change in herd median age at first calving was -1.17 d (SE = 0.42 d) and -0.10 d (SE = 0.25 d) for each unit increase in the dam maternal calf sub-index in cow-calf to beef herds and cow-calf to weanling/yearling herds, respectively. Likewise, every unit increase in dam age at first calving PTA was associated with a 6.12 d (SE = 0.85 d) and a 3.35 d (SE = 0.49 d) older herd median age at first calving in cow-calf to beef and cow-calf to weanling/yearling herds, respectively. The phenotypic change in herd median calving interval and herd median age at first calving per unit change in either the dam maternal index, the dam maternal sub-indexes, dam calving interval PTA, or dam age at first calving PTA are in Table 5. Each one unit increase in herd average dam maternal index was associated with a 0.12 d (SE = 0.04 d) shorter herd-median calving interval and 0.73 d (SE = 0.14 d) younger herd-median age at first calving. The respective coefficients for the dam maternal cow-sub-index were almost identical to the dam (total) maternal index coefficients. The regression coefficient from regressing herd-median calving interval on herd-average calving interval PTA was not different from 2 ($P > 0.05$).

DISCUSSION

While the contribution of nongenetic factors such as stocking rate, grazing season length, liveweight gain, and cow reproductive performance to beef herd profit has been well established (Ashfield et al., 2013; Clarke et al., 2013; Taylor et al., 2017a, 2017b), many of these management factors incur a reoccurring cost and, if not continued, performance may revert back to base line. The benefit of breeding is that it is cumulative and permanent, meaning that any gains made in performance are expected to persist for generations, assuming no further antagonistic selection takes place. Unequivocal evidence, however, that improved genetic merit translates to improved performance is paramount to instill confidence among producers as to this sustainable strategy to compound performance and profit year-on-year. Strategies to demonstrate the merit of genetic selection include controlled (selection) studies (Clarke et al., 2009; Coleman et al., 2009; McCabe et al., 2020), cross-sectional analysis of animal-level data (Connolly et al., 2016; Berry and Ring, 2020; Kelly et al., 2020; Twomey et al., 2020) or cross-sectional analysis of herd-level data (Ramsbottom et al., 2012). Each approach in itself has its own shortcomings but if a consensus is achieved across all three methods, then confidence in the results will be greater.

A number of controlled studies exist that have generally verified that cattle of different genetic merit perform differently (Clarke et al., 2009; Coleman et al., 2009); while the extent and depth of measurement on such studies is generally highly precise, and the environmental noise is strongly controlled, such studies can be hindered by a lack of statistical power, a reduced genetic diversity, and a danger of generalizing conclusions to production systems not directly represented in the controlled study (hence their inclusion as fixed effects in the statistical models). Cross-sectional analyses of large database of individual animal records (Connolly et al., 2016; Berry and Ring, 2020; Kelly et al., 2020; Twomey et al., 2020) do not generally suffer from a lack of statistical power (and, thus, the impact on Type II errors) or genetic diversity, but errors undoubtedly exist within the data; the hope is that the large number of experiment units will minimize the influence of such errors if occurring relatively randomly across genotypes. For example, Purfield et al. (2016) reported a sire parentage error of 13.28% in Irish cattle, and, because the assigned genetic merit of an animal is dictated, in part, by the sire, such errors undoubtedly influence confidence in the results. Similarly, assignment of cattle to the appropriate contemporary group for inclusion in the statistical model is problematic (Berry et al., 2021). Additionally, previous validation studies at the individual animal level (Connolly et al., 2016; Kelly et al., 2020; Twomey et al., 2020) applied a single economic value, common across all farms, to each trait within the selection indexes. This is not a true representation of reality, given that differences in the cost of production, and animal value, exist among herds and across time.

Cross-sectional analyses of large databases of herd-level data (Ramsbottom et al., 2012) suffer from similar issues to that of animal-level analyses, with the added problem of accounting for inter-herd differences in technical efficiencies. The statistical approach taken in the present study was similar to that applied by Ramsbottom et al. (2012) where an attempt was made to account for inter-herd differences in technical efficiency by adjusting financial performance metrics for stocking rate, herd size, and concentrate input. Genetic and non-genetic factors are usually confounding in beef herds as herds of superior genetic merit tend to also excel in animal husbandry and technical efficiency, relative to their contemporaries (P. Kelly, personal communication, 20 November 2020). Even so, the spearman correlations between total genetic merit and the variables of stocking rate, herd size, and value of concentrate consumed per ha in the current study were generally weak within each production system (Supplementary Table 5). For example, the spearman correlation between the terminal index of young animals and stocking rate in the present study was 0.22 in weanling/yearling to beef herds; similarly, there was a spearman correlation of 0.08 between dam maternal index and herd size. Nevertheless, each unit increase in terminal index was associated with a €0.91 increase in gross profit per LU when only year and system were included in the model, which is weaker than the coefficient of €1.41 when the class variables of stocking rate, herd size, and concentrate input, as well as their two-way interactions with production system, were all included in the mixed model. Therefore, the relationship between profit and genetic merit may not be fully realized without accounting for at least some metrics of the technical proficiency among herds.

The primary objective of the present study was to quantify the relationship between herd-average beef genetic merit and profitability using farm financial data from a large number of commercial Irish beef herds. Of particular interest was the association between profitability and both the maternal index of calving beef cows and the terminal index of young cattle (including the progeny of dams) in these herds. While cross-sectional analyses relating total genetic merit to financial metrics in dairy herds do exist (Ramsbottom et al., 2012), no such analysis has been undertaken in commercial beef herds. Nonetheless, results from the present study relating financial metrics to total merit indexes in beef cattle are consistent with conclusions based on similar herd-level analyses evaluating dairy cow total merit indexes (Ramsbottom et al., 2012). The results from the present study are also consistent with both controlled studies and cross-sectional analyses of animal-level data in beef cattle (Clarke et al., 2009; Connolly et al., 2016; Kelly et al., 2020; Twomey et al., 2020).

Within the Teagasc eProfit Monitor system, a standard value for each animal category is assumed when considering any inventory change across years; this approach does, therefore, not account for potential differences in animal value that differ in genetic merit despite Connolly et al. (2016) demonstrating that individual cattle excelling in the terminal index are expected to confer additional revenue output per animal through heavier carcass weights of greater quality and thus greater value. Additionally, the same dressing percentage is assumed within different animal categories within the Profit Monitor system, thus impacting financial metrics expressed on a per kg live-weight basis despite known genetic differences (Coyne et al., 2019). Superior terminal index cattle have also been documented to have a superior dressing percentage than their lower genetic merit counterparts (Kelly et al., 2020). The classification of costs as fixed or variable in the eProfit Monitor system may also differ slightly from similar financial benchmarking tools used in other jurisdictions, and thus used in other similar studies. Within the eProfit Monitor system, a variable cost is one that can be easily allocated or attributed to a particular enterprise on a mixed enterprise farm (e.g., both a cattle and sheep on the same farm), and/or is likely to also vary directly with the scale or efficiency of the enterprise. The eProfit Monitor definition of a fixed cost is on the basis that the cost may not necessarily be as easy to allocate to an individual enterprise and/or does not vary with the scale or efficiency of an enterprise. Therefore, costs, such as hired labor, which may be a variable cost in most farm systems, are treated as a fixed cost under the above definition within the eProfit Monitor, as the hours worked per enterprise on a mixed farm is often not known.

Nongenetic Factors and Financial Performance

Irish beef farms are primarily grass based where the majority of cattle feed is derived from in situ grazing; thus, many factors affecting profitability and overall financial performance on Irish beef farms are related to the pastoral-based nature of the beef enterprise (Ashfield et al., 2013). Such nongenetic factors included grazing season length and calving date (Crosson and McGee, 2015), stocking rate (Clarke et al., 2013), and the quantity of concentrates fed (Finneran and Crosson, 2013), in addition to other factors relating to farm structure such as beef production system (Taylor et al., 2017b) and herd size (Finneran and Crosson, 2013; Veysset et al., 2015). The relationship between profitability and stocking rate observed in the current study is largely in agreement with the scientific literature from Ireland (Clarke et al., 2013; Taylor et al., 2017b). Using a bio-economic modeling approach of a cow-calf to beef herd, Clarke et al. (2013) reported that net margin per ha increased from €389 per ha to €738 per ha as stocking rate increased from 1.8 LU per ha to 2.6 LU per ha. Similarly, in a study investigating the profit drivers on Irish beef farms using financial records from 38 herds participating in a knowledge transfer program, Taylor et al. (2017b) reported a correlation of 0.35 between stocking rate and gross profit per ha in cow-calf to beef herds. Both Taylor et al. (2017b) and Clarke et al. (2013) stressed, however, that any increases in stocking rate must be supported by greater grass growth and utilization rather than increased concentrate supplementation, the latter eroding herd profitability (Finneran and Crosson, 2013). This appears to be evident in the nonlinear relationship between gross profit per LU and per kg live-weight with stocking rate in cow-calf to beef herds in the current study. The current study also demonstrates that as the cost of concentrates increases, gross profitability reduces, suggesting that the expected greater herd gross revenue output associated with greater herd performance as a result of higher concentrate input is not sufficient to offset the greater cost associated with feeding more concentrates.

Several studies have also investigated the association between herd and farm size on herd financial performance. Using commercial French beef farm data, Veysset et al. (2015) reported that larger farms did not generate economies of scale as the fixed costs of extra infrastructure and mechanization also increased simultaneous with expanding farm area and herd size. Finneran and Crosson (2013) also reported that greater scale in intermediate to large-sized farms did not improve beef farm income efficiency or profitability as the costs per animal did not necessarily reduce; Finneran and Crosson (2013) did, however, argue that it may be possible for smaller beef farms to improve farm efficiency and take advantage of economies of scale by increasing in size up to an optimum. In agreement with the literature (Finneran and Crosson, 2013; Veysset et al., 2015), gross profitability per ha, per LU and per kg live-weight plateaued as herd size increased in the present study, perhaps again due to increasing costs of concentrate supplementation and diminishing economies of scale in relatively larger herds.

Genetic Merit and Financial Performance

At the individual animal level, Connolly et al. (2016) demonstrated that cattle excelling in genetic merit for the Irish beef terminal index were, on average, more profitable than their lower genetic merit contemporaries, corroborating the results at the herd level reported in the present study. As the terminal index is expressed on a PTA scale and not an estimated breeding value scale, a €1 difference in herd terminal index value of progeny is expected to translate to a €2 difference in herd profit per progeny slaughtered. The regression coefficient of €1.41 (SE = 0.23) of gross profit per LU on herd terminal index in the present study is, however, less than the expectation of €2. Nevertheless, the Irish terminal index only includes estimates of genetic merit for eight performance traits whereas gross profit in the present study is the accumulation of all costs and revenue output of the average animal in each beef herd; this could cause a deviation in the regression coefficient from expectation. Despite this, of the herds in systems that reared and/or finished cattle to slaughter, 54% of the heifers, steers, and young bulls slaughtered in those herds were between the ages of 12 and 23 months of age, inclusive. An increase in gross profit per LU of €1.41 per unit change in terminal index is reflective of adult cattle ≥ 24 months of age (i.e., 1.0 LU); assuming that an animal is slaughtered between 12 and 23 months of age (i.e., an animal of 0.7 LU), every €2 increase in herd terminal index would, in fact, be associated with a €2.02 increase in herd gross profit per progeny slaughtered between 12 and 23 months of age (i.e., €1.41 per LU/0.7 LU). The equivalent adjusted coefficient for net profit per progeny slaughtered at 12 and 23 months of age was €1.96 (i.e., €1.37 per LU/0.7 LU). Such adjusted coefficients are within expectation but may be considered only applicable to cattle within the 12 to 23 months of age group.

Positive relationships between dam maternal index and herd profit existed in the current study; however, the regression coefficients were smaller in magnitude than those reported for the regression of profit on terminal index. While the maternal index does include moderately heritable terminal traits such as the carcass traits and feed intake, lowly heritable traits such as survival, fertility, and calving difficulty (Berry and Evans, 2014) comprise 30% of the trait emphasis in the maternal index, and such traits may be not as strongly phenotypically expressed as the more heritable terminal traits. Also, the realization of genetic merit as profit depends on many on-farm management factors and so there may be underlying nongenetic factors, of which data were unavailable in the present study, having an impact on the associations between financial performance and genetic merit. Twomey et al. (2020) and McHugh et al. (2014) evaluated the phenotypic performance of cattle differing in genetic merit for fertility and calving traits. Following a similar trend to the relationship between profit and dam maternal index in the present study, Twomey et al. (2020) and McHugh et al. (2014) both reported that although phenotypic differences deviated from expectation, the direction of the association between the phenotype and its measure of genetic merit was consistent with expectation.

Interestingly, the regression coefficients for financial performance on dam maternal cow sub-index were almost identical to the respective coefficients for the dam (total) maternal index even though the coefficients for the calf component of the maternal index are of the same sign but greater in magnitude than the coefficients for the cow sub-index. This trend is most likely due to the negative relationship between the two maternal sub-indexes; there was a correlation of −0.66 between the two herd average dam maternal sub-indexes in the current study, which is in agreement with Twomey et al. (2020) who reported a correlation of −0.62 between the calf and cow contributions of the maternal index in 1,286 high reliability beef sires. Such a negative relationship is to be expected given a component of the calf sub-index is composed of several terminal traits which are known to be antagonistically correlated with several of the reproductive performance traits in the cow sub-index (Crowley et al., 2011; Berry and Evans, 2014). The intention of including such terminal traits within the maternal index is to avert any erosion in progeny carcass performance with selection on maternal characteristics. In fact, Twomey et al. (2020) demonstrated that cows excelling in the beef maternal index had less calving difficulty and better fertility, while their progeny were able to maintain satisfactory carcass performance.

CONCLUSION

Results from the present study at the herd level concur with previous validation studies at the individual animal level that superior genetic merit for profit-based total merit indexes (i.e., the terminal and maternal indexes described herein) translate into greater profit. While the present study was undertaken using Irish data and Irish breeding indexes, when taken in conjunction with results from other validation studies using different methodological techniques, there should indeed be strong confidence among relevant industry partners as to the sustainable gains achievable through breeding programs.

SUPPLEMENTARY DATA

Supplementary data are available at *Translational Animal Science* online.

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