agriculture

MDPI

Article

Deriving Economic Values for Female Reproductive Traits in Lifetime Carcass Production of Japanese Black Cows Using Deterministic Profit Function

Shinichiro Ogawa [1,*], Suguru Kitajima [2], Hayato Saito [3] and Masahiro Satoh [1]

[1] Graduate School of Agricultural Science, Tohoku University, Sendai 980-8572, Japan; masahiro.satoh.d5@tohoku.ac.jp
[2] Faculty of Agriculture, Tohoku University, Sendai 980-8572, Japan; suguru.kitajima.t8@alumni.tohoku.ac.jp
[3] Livestock Industry Division, Agriculture Department, Miyagi Prefectural Government, Sendai 980-8570, Japan; saito-ha812@pref.miyagi.lg.jp
* Correspondence: shinichiro.ogawa.d5@tohoku.ac.jp; Tel.: +81-22-757-4114

Abstract: Improving reproductive efficiency is required to strengthen the production base of high-quality Wagyu beef in Japan. We developed a deterministic profit function (P) for lifetime carcass production of Japanese Black cows to calculate economic values (EVs) for representative female reproductive and carcass traits. The total calving number per cow was expressed using the age at first calving (AFC) and calving interval (CI). Revenues and costs were calculated from calf market price (CaP) and carcass unit price (CUP). A cubic regression equation was developed with CaP as the response variable and calf market weight as the explanatory variable. A multiple linear regression equation was developed with CUP as the response variable and five carcass traits as explanatory variables. EVs were calculated using the first-order partial derivatives of P. The first-order partial derivative of CI was a function of CI with the quadratic term of CI in the denominator. Values of EVs for AFC and CI were negative, suggesting that earlier AFC and shorter CI increase the lifetime profit of Japanese Black cows through producing higher numbers of feeder cattle per cow. However, this might bring benefit to only calf-producing farmers. The results would contribute to achieving sustainable high-quality Wagyu beef production.

Keywords: breeding objective; calving interval; carcass weight; economic value; Japanese Black cattle; marbling score; deterministic profit equation

Citation: Ogawa, S.; Kitajima, S.; Saito, H.; Satoh, M. Deriving Economic Values for Female Reproductive Traits in Lifetime Carcass Production of Japanese Black Cows Using Deterministic Profit Function. *Agriculture* **2021**, *11*, 1055. https://doi.org/10.3390/agriculture11111055

Academic Editor: Sanzidur Rahman

Received: 7 September 2021
Accepted: 25 October 2021
Published: 27 October 2021

1. Introduction

Wagyu cattle comprise four modern native Japanese breeds: the Japanese Shorthorn, the Japanese Brown, the Japanese Polled, and the Japanese Black, which is the primary beef breed in Japan [1], and whose meat is well-known to excel in quality, especially in marbling, e.g., [2–4]. Japanese Black cattle farmers can be typically divided between calf-producing farmers and fattening farmers [4]. Calf-producing farmers market calves from 8 to 10 months of age as feeder cattle, which fattening farmers buy and fatten until 28 to 32 months of age, e.g., [4–6]. The current calf production system is based on a cow–calf operation with non-seasonal year-round mating by artificial insemination (AI) using frozen semen [4]. In recent years, a decline in the number of feeder cattle and a sharp rise in calf market price (CaP) have been observed, and a decline in the number of reproductive cows and a prolonged calving interval (CI) have been pointed out as contributing factors [4,7,8].

In response to the liberalization of beef imports into Japan in 1991 [9,10], each prefecture initiated routine genetic evaluation of carcass performance of Japanese Black cattle, and representative carcass traits, including the degree of marbling, have been genetically improved by selecting elite sires separately for each prefecture [11,12]. On the other hand, the number of calf-producing farmers has been decreasing and the number of cattle reared per farmer has been increasing in Japan. Owing to this fact, various efforts have been made to improve reproductive efficiency for stable Wagyu beef production. Among them, more attention has been paid recently to the possibility of genetically improving reproductive efficiency, although the heritability has been estimated to be low, e.g., [13–15]. For instance, genetic evaluation of age at first calving (AFC) and CI has been conducted nationally, and genetic correlations of AFC and CI with major carcass traits were estimated to be weak or negligible [16]. Earlier AFC and shorter CI are now desired for efficient production of high-quality Wagyu beef [7,8], so it is necessary to genetically improve both carcass and reproductive traits.

Economic values (EVs) for traits could be used to determine a breeding objective or an aggregate genotype [17], including multiple traits, each one with a different weight depending on its economic importance, e.g., [18–20]. Previous studies calculated EVs for carcass traits of Japanese Black cattle using multiple regression analysis and a bioeconomic model, and a larger EV for marbling has been repeatedly obtained, e.g., [21–23]. Morimoto and Morita [7] and Tarumoto et al. [8] assessed the economic impact of varying CI to change the number of feeder cattle on a calf-producing farm with 100 cows. Hirooka and Oishi [24] calculated EVs for marbling score (MS), cold carcass weight (CW), and CI using a bioeconomic model simulating a commercial integrated cow–calf-fattening system in Japan, in which days open was modeled using the function of conception rate proposed by Bailie [25]. Their bioeconomic model assumed AI at 51 days after calving, an estrus cycle of 21 days, and one AI for each estrus event. The reason for using the function of Bailie [25] might have been to enable them to calculate the EV for conception rate. However, a longer CI could be due not only to a decreased conception rate but also to a lower estrus detection rate, e.g., [7,8,26,27], so the assumption of one AI for every estrus might deviate from reality. On the other hand, no study has calculated the EV for AFC of Japanese Black cows.

EVs could also be calculated as the first-order partial derivative of a profit function, e.g., [28–30]. With this approach, the basis for calculating EVs can be explicit. Using this approach, Kahi and Nitter [31] calculated the EV for CI in dairy production systems in Kenya, and Forabosco et al. [19] calculated the EV for the length of productive life (LPL) in Chianina beef cow. On the other hand, no study has developed a profit function for lifetime carcass production of Japanese Black cows. Furthermore, previous studies for Japanese Black cattle targeted only calf-production farms [7,8] and commercial integrated cow–calf-fattening systems [24], although there are mainly two types of farmers for Wagyu beef production, namely calf-producing and fattening farmers [4]. Therefore, the objectives of this study were (1) to develop a deterministic profit function (P) for lifetime carcass production of Japanese Black cows in Japan, and (2) to calculate EVs for AFC, CI, and representative carcass traits, including MS. A simple deterministic selection simulation was conducted as an example.

2. Materials and Methods

2.1. Ethics Statement

Approval of the Animal Care and Use Committee was not required for this study because the data were acquired from an existing database.

2.2. Market Performance Data

We used calf market performance data, including CaP and calf market weight (CaW), for individuals transported to the calf market in Miyagi Prefecture, northeastern Japan, from 2001 to 2014, and their carcass performance at carcass markets, including CW, ribeye area (RA), rib thickness (RT), subcutaneous fat thickness (SF), MS, and carcass unit price (CUP). MS expresses the degree of marbling ranging from null (1) to very abundant (12), assessed on the ribeye of the carcass dissected at the sixth and the seventh rib sections, according to the Japanese carcass grading standards [32]. Carcass records for female cattle with too-old age at slaughter were regarded as those for culled reproductive cows and then removed. Phenotypic records of AFC and CI for dams were calculated according to the birth dates of calves in calf market performance data, and then, AFC of <18 or >37 months and CI with days open of <21 or >364 days or gestation length of <260 or >310 days were removed [15]. Table 1 summarizes phenotypic measurements of the traits.

Table 1. Descriptive statistics of traits studied [1].

Trait	Abbreviation	Unit	No. of Records	Mean	SD	Min	Max
Age at first calving	AFC	month	18,565	24.7	3.6	18.2	37.0
Calving interval	CI	day	103,649	403.5	66.9	295	661
Age at calf market	ACM	month	107,438	9.8	0.7	7.8	11.9
Calf market price	CaP	JPY	107,424	424,662	102,305	20,000	1,105,000
Calf market weight	CaW	kg	107,438	298.3	31.0	204	392
Carcass unit price	CUP	JPY/kg	38,192	1797.4	363.6	652	2944
Age at slaughter	AS	month	43,826	30.9	1.9	21.8	45.1
Cold carcass weight	CW	kg	43,826	471.1	65.7	257.5	653.0
Ribeye area	RA	cm^2	43,826	60.3	9.3	30.0	87.0
Rib thickness	RT	cm	43,826	8.1	0.9	5.0	10.8
Subcutaneous fat thickness	SF	cm	43,826	2.5	0.7	0.3	4.9
Marbling score	MS	score	43,826	7.0	2.1	2	12

[1] Abbreviations: JPY, Japanese yen; SD, standard deviation; Min, minimum value; Max, maximum value.

2.3. Values in the Literature

We acquired values of revenue from by-products and costs of AI, feeding, equipment, and labor per calf and per fattened animal from 2003 to 2014 from "e-stat" (https://www.e-stat.go.jp/ (accessed on 12 October 2020)), and calculated their average values over 11 years (values for 2001 and 2002 were not available). Table 2 lists the calculated income from by-products, including manures, during the calf growing period (IBP1) and the fattening period (IBP2), the total cost of single calf production (TCC), labor and equipment fees per fattened animal (LEF), the feeding cost per 1 kg weight gain during the fattening period (FC), the dressing percentage of a fattened animal at slaughter (DP), and mortalities of calves during the growing period (M1) and of fattened animals during the fattening period (M2) [5]. Length of productive life (LPL) was 9 years [15,33].

Table 2. Values of parameters used in calculating economic values [1].

Parameter	Abbreviation	Unit	Input Value
Length of productive life of cow	LPL	year	9
Dressing percentage of fattened animal	DP	%	60
Mortality of calf during growing period	M1	%	2
Mortality of fattened animal during fattening period	M2	%	2
Income from by-products during calf growing period	IBP1	JPY	33,706
Income from by-products during fattening period	IBP2	JPY	13,012
Total cost of single calf production	TCC	JPY	367,580
Labor and equipment fees per fattened animal	LEF	JPY	87,088
Feeding cost per 1 kg weight gain during fattening period	FC	JPY/kg	609

[1] See Table 1 for abbreviations.

2.4. Multiple Regression Analysis

Cubic regression analysis was performed with CaP as the response variable and CaW as explanatory variables:

$$CaP_i = \mu + \beta_1 CaW_i + \beta_2 CaW_i^2 + \beta_3 CaW_i^3 + \varepsilon_i,$$

where μ is the regression intercept, β is the partial regression coefficient, ε is the residual, and subscript i corresponds to individual. As a preliminary analysis, we compared linear, quadratic, cubic, and quartic regression equations using Akaike's and Bayesian information criteria [34,35], which both chose the cubic regression model as the best. Multiple linear regression analysis was performed with CUP as the response variable and five carcass traits as explanatory variables [21,23]:

$$CUP_i = \mu + \beta_{CW} CW_i + \beta_{RA} RA_i + \beta_{RT} RT_i + \beta_{SF} SF_i + \beta_{MS} MS_i + \varepsilon_i.$$

These equations were substituted for CaP and CUP in the deterministic profit function, P. The lm function in R software [36] was used for the regression analyses.

2.5. Deriving Deterministic Profit Function

The total calving number per cow (N) was expressed as:

$$N = 1 + \frac{LPL \times 12 - AFC}{ACI \times 12 \div 365.25},$$

where ACI is average CI. Kahi and Nitter [31] expressed the calving number per cow per year as the value of 365 divided by ACI, whereas Forabosco et al. [19] directly used information on the total lifetime number of calves born alive per cow. The first-order partial derivatives of N for AFC and ACI are:

$$\frac{\partial N}{\partial AFC} = -\frac{1}{ACI \times 12 \div 365.25},$$

$$\frac{\partial N}{\partial ACI} = \frac{AFC - LPL \times 12}{ACI^2 \times 12 \div 365.25}.$$

With these terms, the deterministic profit function, P, was expressed as:

$$P = P1 + P2 = (R1 - C1) + (R2 - C2),$$

where P1 and P2 represent the profits in calf-production and fattening production respectively, R1 and C1 denote the revenue and cost respectively, for feeder cattle production in calf-production, and R2 and C2 denote those for fattening production. They were calculated as:

$$R1 = N \times \left(1 - \frac{M1}{100}\right) \times (IBP1 + CaP),$$

$$C1 = N \times \left(1 - \frac{M1}{100}\right) \times TCC,$$

$$R2 = N \times \left(1 - \frac{M1}{100}\right) \times \left(1 - \frac{M2}{100}\right) \times (IBP2 + CW \times CUP),$$

$$C2 = N \times \left(1 - \frac{M1}{100}\right) \times \left[CaP + \left(1 - \frac{M2}{100}\right) \times \left\{LEF + FC \times \left(CW \div \frac{DP}{100} - CaW\right)\right\}\right].$$

Here, it should be noted that such a definition is for a deterministic profit equation because the estimated regression equations were used instead of various figures.

2.6. Calculating Economic Values

The EVs for traits were calculated by using the first-order partial derivatives of P and the mean and literature values of traits (Tables 1 and 2). For instance, the EV for CI was calculated as:

$$\frac{\partial P}{\partial ACI} = \frac{\partial P1}{\partial ACI} + \frac{\partial P2}{\partial ACI} = \frac{\partial R1}{\partial ACI} - \frac{\partial C1}{\partial ACI} + \frac{\partial R2}{\partial ACI} - \frac{\partial C2}{\partial ACI},$$

$$\frac{\partial R1}{\partial ACI} = \frac{AFC - LPL \times 12}{ACI^2 \times 12 \div 365.25} \times \left(1 - \frac{M1}{100}\right) \times (IBP1 + CaP),$$

$$\frac{\partial C1}{\partial ACI} = \frac{AFC - LPL \times 12}{ACI^2 \times 12 \div 365.25} \times \left(1 - \frac{M1}{100}\right) \times TCC,$$

$$\frac{\partial R2}{\partial ACI} = \frac{AFC - LPL \times 12}{ACI^2 \times 12 \div 365.25} \times \left(1 - \frac{M1}{100}\right) \times \left(1 - \frac{M2}{100}\right) \times (IBP2 + CW \times CUP),$$

$$\begin{aligned}\frac{\partial C2}{\partial ACI} = \; & \frac{AFC - LPL \times 12}{ACI^2 \times 12 \div 365.25} \times \left(1 - \frac{M1}{100}\right) \times \\ & \left[CaP + \left(1 - \frac{M2}{100}\right) \times \left\{LEF + FC \times \left(CW \div \frac{DP}{100} - CaW\right)\right\}\right]\end{aligned}$$

Calculated values of EVs were converted to standardized economic values (SEVs), e.g., [24,37,38]. Here, SEVs were based on phenotypic and genetic standard deviations (σ_p and σ_g), denoted as SEVp and SEVg, respectively. SEVp was calculated as $\sigma_p \times EV$, where σ_p is assumed to be equal to the sample standard deviation of phenotypic measurements in this study (Table 1). SEVg was calculated as $\sigma_g \times EV$, where $\sigma_g = \sigma_p \times \sqrt{h^2}$, and heritability ($h^2$) was set to 0.09 for AFC, 0.05 for CI, 0.30 for CaW, 0.48 for CW, 0.46 for RA, 0.38 for RT, 0.39 for SF, and 0.55 for MS [14].

2.7. Deterministic Simulation to Determine the Effects of Breeding Objectives

Aggregate genotypes (H) corresponding to different breeding objectives were defined [17] as:

$$\mathrm{H} = \mathbf{a}'\mathbf{g} = a_{AFC}g_{AFC} + a_{CI}g_{CI} + a_{CW}g_{CW} + a_{RA}g_{RA} + a_{MS}g_{MS},$$

where g is the breeding value of a trait, a is the (relative) weight, and $\mathbf{a'}$ is the transpose of column vector **a**. Values of trait heritability and genetic correlations among traits come from the literature and are listed in Table 3 [14,16]. The genetic variance-covariance matrix, **G**, was calculated based on the assumption that the phenotypic variance equals the sample variance of phenotypic measurements of the trait. The following seven definitions for H were examined:

$$\mathrm{H1} = 0g_{AFC} + 0g_{CI} + 0g_{CW} + 0g_{RA} + 1g_{MS},$$

$$\mathrm{H2} = 0g_{AFC} - 1g_{CI} + 0g_{CW} + 0g_{RA} + 0g_{MS}$$

$$\mathrm{H3} = 0g_{AFC} + 0g_{CI} + 0.03g_{CW} + 0.12g_{RA} + 1g_{MS},$$

$$\mathrm{H4} = 0g_{AFC} - 0.23g_{CI} + 0.02g_{CW} + 0.19g_{RA} + 1g_{MS},$$

$$\mathrm{H5} = 0g_{AFC} + 1.11g_{CI} - 0.1g_{CW} - 1.56g_{RA} + 1g_{MS},$$

$$\mathrm{H6} = 0g_{AFC} - 0.24g_{CI} + 0.01g_{CW} + 0g_{RA} + 1g_{MS},$$

$$\mathrm{H7} = -0.03g_{AFC} - 0.01g_{CI} + 0.02g_{CW} - 0.01g_{RA} + 1g_{MS}.$$

H1 and H2 correspond to the breeding objectives that aim to improve MS and CI respectively, as a top priority. H3 aims to obtain the intended genetic changes of +38.5 kg for CW, +5.5 cm^2 for RA, and +1.4 points for MS. H4 aims to obtain the intended genetic changes of +38.5 kg for CW, +5.5 cm^2 for RA, +1.4 points for MS, and −25 days for CI. The settings for H3 and H4 were according to the content of the breeding plan in Miyagi prefecture. H5 aims to obtain the intended genetic changes of +38.5 kg for CW, +5.5 cm^2 for RA, 0 points for MS, and −25 days for CI. The reason for setting H5 was that previous studies related higher MS to increased intramuscular fat percentage in ribeye, which is sometimes >50%, e.g., [23,39,40], so it is necessary to include the case of the reduced amount of genetic improvement in MS. H6 is based on the EVs for CW, MS, and CI by Hirooka and Oishi [24], and H7 is based the EVs for the five traits obtained in this study. Relative weights for traits with the intended genetic changes in H3, H4, and H5 were calculated as [41]:

$$\mathbf{a}_{sub} = \mathbf{G}_{sub}^{-1}\mathbf{d},$$

where **d** is the column vector of the intended genetic changes, $\mathbf{a}_{sub}$ is the column vector of the corresponding weights, and $\mathbf{G}_{sub}$ is the genetic variance-covariance matrix of the traits with the intended genetic changes.

With the aim of assessing the agreement of the breeding objectives, the correlation between H was calculated as:

$$Cor(\mathrm{H}i, \mathrm{H}j) = \frac{\mathbf{a}_i{}'\mathbf{G}\mathbf{a}_j}{\sqrt{\mathbf{a}_i{}'\mathbf{G}\mathbf{a}_i}\sqrt{\mathbf{a}_j{}'\mathbf{G}\mathbf{a}_j}}.$$

The correlation of H with breeding value for each of the five traits was also calculated as for the accuracy of selection for a given trait. Expected genetic and economic gains by truncated selection using H with a selection intensity of 1 were calculated based on the assumption that the selection index was the same as H and using P derived in this study. It should be noted that a higher value of H is preferable, and therefore, the preferable sign of the value of selection accuracy is negative for AFC and CI and vice versa for CW, RA, and MS in this study.

Table 3. Values of additive genetic variance (σ_g^2), heritability (h^2, diagonal), and genetic correlation (r_g, below diagonal), used for selection simulation [1].

Trait	σ_g^2	h^2 **and** r_g				
		AFC	**CI**	**CW**	**RA**	**MS**
AFC	1.15	0.09				
CI	223.96	0.25	0.05			
CW	2070.65	−0.27	0.05	0.48		
RA	39.55	−0.13	0.08	0.44	0.46	
MS	2.39	−0.24	0.01	0.15	0.43	0.55

[1] See Table 1 for abbreviations.

3. Results and Discussion

3.1. Multiple Regression Analysis

The following cubic regression equation was obtained for CaP:

$$CaP_i = 1.21 \times 10^6 - 1.42 \times 10^4 \times CaW_i + 62.15 \times CaW_i^2 - 0.08 \times CaW_i^3.$$

Pearson's correlation coefficient between CaP and CaW was 0.534. The coefficient of determination of the equation was 0.298. Figure 1 shows the expected values of CaP based on the derived prediction equation. Generally, CaP is higher when CaW is heavier. This is because a feeder cattle with CaW within the proper range seems to be healthy and is expected to have good carcass performance. Previous studies reported a positive genetic correlation between CaW and CW in Japanese Black cattle populations [42,43]. However, CaP for feeder cattle with too-heavy CaW is lower. This could be because a feeder cattle with too-heavy CaW may have a health problem such as obesity or be thought to have difficulties in group-raising at fattening. Adding information on body condition and body shape might afford an equation for predicting CaP with greater explanatory power.

The following multiple linear regression equation was obtained for CUP:

$$CUP_i = 877.72 + 0.22 \times CW_i - 0.97 \times RA_i + 1.41 \times RT_i + 15.14 \times SF_i + 117.53 \times MS_i.$$

The coefficient of determination was 0.447. The values of the standardized partial regression coefficients, in descending order, were 0.674 for MS, 0.040 for CW, 0.031 for SF, −0.025 for RA, and 0.004 for RT. Okamoto et al. [23] performed multiple regression analysis with the same five carcass traits, beef color standard score and beef fat standard score as explanatory variables, and calculated values of standard partial regression coefficients of 0.570 for MS, 0.118 for RT, 0.044 for RA, −0.042 for CW, and −0.031 for SF. We obtained a small but negative value for RA and a positive value for SF, but accurate interpretation of the results is difficult. First, the values of Pearson's correlation coefficient of MS were relatively high with CUP and RA, and those among CW, RA, and RT were also relatively high (Table 4), suggesting the effect of multicollinearity. Hirooka and Sasaki [21] performed regression analyses with RA, RT, SF, and MS using a total of 33 datasets divided by year and month, and reported that the signs of the regression coefficients were the same (positive) across all 33 analyses only for MS. On the other hand, Okamoto et al. [23] showed that the shapes of ribeye and marbling particles in ribeye affected CUP. Kato et al. [39] and Goto et al. [40] reported a relationship of RA with these shapes, so the partial regression coefficient for RA in this study might reflect the effect of change in these shapes due to larger RA. Furthermore, a positive correlation has been reported between MS and intramuscular fat percentage, e.g., [39,40,44], so the possibility of confounding with factors that were not addressed here should also be noted.

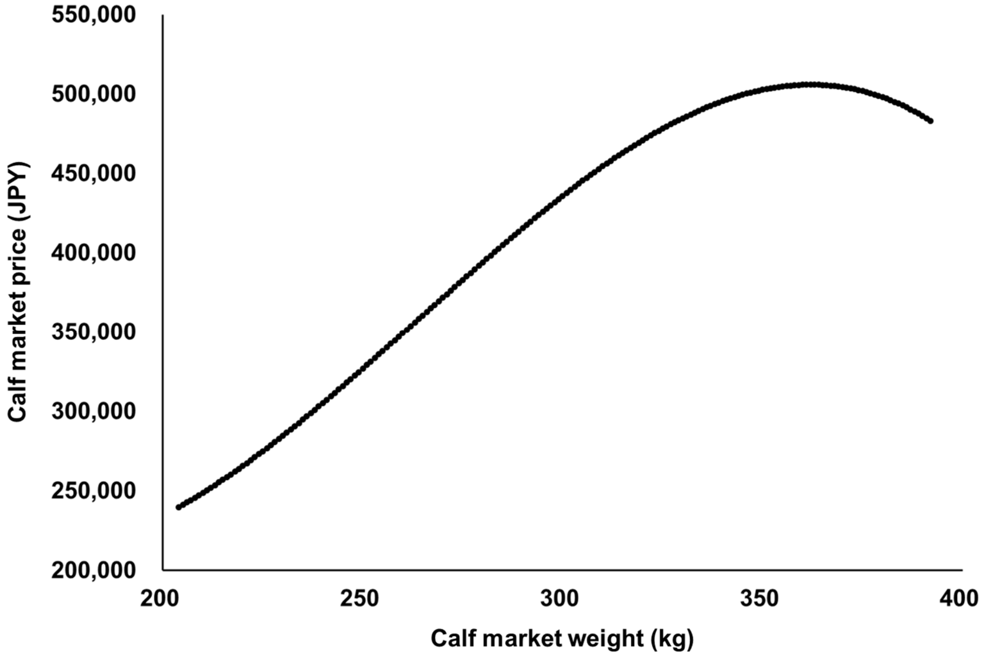

Figure 1. Values of calf market price (CaP) predicted from calf market weight (CaW) using the regression equation: $CaP = 1.21 \times 10^6 - 1.42 \times 10^4 \times CaW + 62.15 \times CaW^2 - 0.08 \times CaW^3$. Minimum and Maximum values for CaW are shown in Table 1.

Table 4. Pearson's correlation coefficients among carcass traits [1].

Trait	CUP	CW	RA	RT	SF
CW	0.196				
RA	0.334	0.503			
RT	0.251	0.641	0.501		
SF	0.057	0.192	0.023	0.221	
MS	0.667	0.241	0.504	0.341	0.028

[1] See Table 1 for abbreviations.

3.2. Calculating Economic Values

Substituting the prediction equations for CaP and CUP afforded the profit function, P, as:

$$
\begin{aligned}
P = {} & N \times \left(1 - \tfrac{M1}{100}\right) \\
& \times \left\{IBP1 + \left(1.21 \times 10^{6} - 1.42 \times 10^{4} \times CaW + 62.15 \times CaW^{2} - 0.08 \times CaW^{3}\right)\right\} \\
& - N \times \left(1 - \tfrac{M1}{100}\right) \times TCC \\
& + N \times \left(1 - \tfrac{M1}{100}\right) \times \left(1 - \tfrac{M2}{100}\right) \\
& \times \left\{ \begin{array}{l} IBP2 + CW \\ \times (877.72 + 0.22 \times CW - 0.97 \times RA + 1.41 \times RT + 15.14 \times SF + 117.53 \times MS) \end{array} \right\} \\
& - N \times \left(1 - \tfrac{M1}{100}\right) \\
& \times \left[\begin{array}{l} \left(1.21 \times 10^{6} - 1.42 \times 10^{4} \times CaW + 62.15 \times CaW^{2} - 0.08 \times CaW^{3}\right) + \\ \left(1 - \tfrac{M2}{100}\right) \times \left\{LEF + FC \times \left(CW \div \tfrac{DP}{100} - CaW\right)\right\} \end{array} \right]
\end{aligned}
$$

Results for calculating EVs using the first-order partial derivatives of P are summarized in Table 5. EVs of traits not included in the function were zero. As expected, values of EVs were positive for LPL and negative for AFC and CI, suggesting that longer LPL, earlier AFC, and shorter CI contribute to higher lifetime profit from a cow, although P1 provided large proportions of EVs. This is because both earlier AFC and shorter CI increase the number of feeder cattle by increasing N. Furthermore, the absolute value of the EV of CI became larger as the value of ACI became smaller (Figure 2), e.g., [18,45]. Values of EVs for M1 and M2 were negative, and the absolute value was larger for M2 than for M1. This was due to a higher carcass price, defined as CUP × CW, than CaP (Table 1). A positive EV was obtained for CaW in this study, as with the EV for body weight at 9 months by Hirooka and Oishi [24]. However, the EV for CaW was negative when using P2 because CaP was included in C2. The signs of EVs for carcass traits were the same as those of partial regression coefficients obtained from multiple linear regression analysis for CUP. Hirooka and Oishi [24] also reported positive EVs for CW and MS. It should be noted that the value of EV is population-dependent, since means are used for EV calculation.

Table 5. Economic values (EVs) for the traits included in the profit function [1].

Trait	**EV**							
	∂N	$\partial R1$	$\partial C1$	$\partial P1$	$\partial R2$	$\partial C2$	$\partial P2$	∂P
AFC	−0.08	−34,464.0	−27,170.1	−7293.9	−62,335.1	−59,759.3	−2575.8	−9869.7
CI	−0.02	−7113.1	−5607.7	−1505.4	−12,865.5	−12,333.9	−531.6	−2037.0
LPL	0.91	413,567.6	326,040.7	87,526.9	748,020.9	717,111.7	30,909.2	118,436.1
M1	0	−33,953.2	−26,767.4	−7185.8	−61,411.3	−58,873.7	−2537.6	−9723.4
M2	0	0	0	0	−61,411.3	−27,375.0	−34,036.3	−34,036.3
CaW	0	14,143.3	0	14,143.3	0	9884.1	−9884.1	4259.2
CW	0	0	0	0	13,302.9	7098.6	6204.3	6204.3
RA	0	0	0	0	−3187.4	0	−3187.4	−3187.4
RT	0	0	0	0	4647.3	0	4647.3	4647.3
SF	0	0	0	0	49,883.0	0	49,883.0	49,883.0
MS	0	0	0	0	387,236.5	0	387,236.5	387,236.5

[1] See Table 1 for abbreviations.

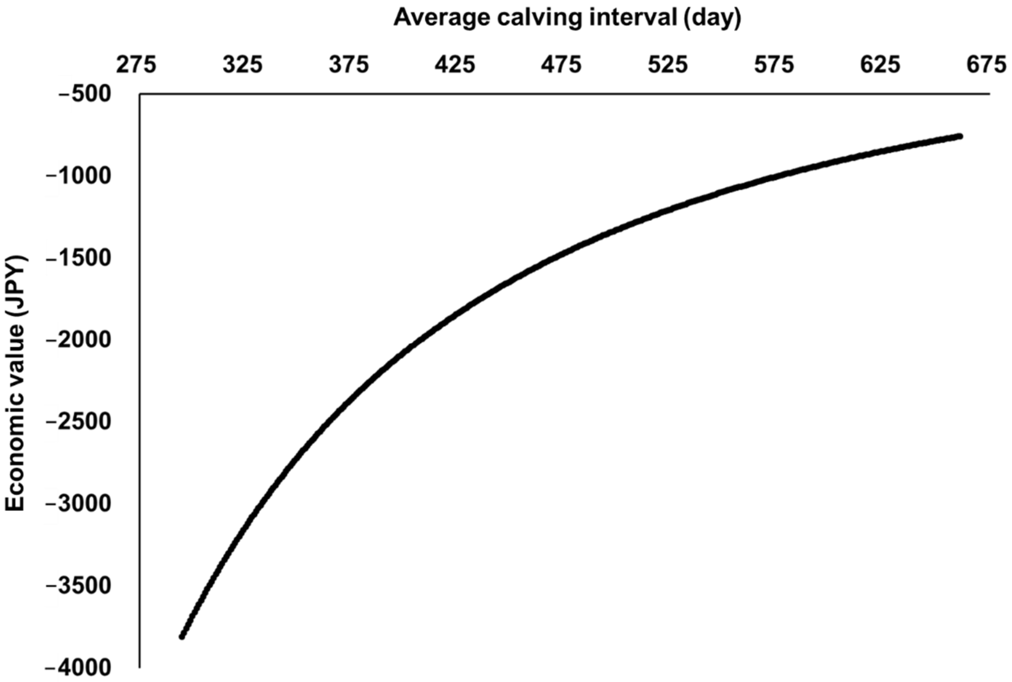

Figure 2. Relationship between calving interval (CI) and economic value for CI. Minimum and Maximum values for CI are shown in Table 1.

Using bioeconomic models directly considering CI, Albera et al. [46] calculated the EV for CI in the Italian Piemontese beef cattle population to be −2.60 EUR per cow per year, and Åby et al. [47] calculated the EV in Norwegian extensive (British) breed groups to be −1.47 EUR and that in Norwegian intensive (Continental) breed groups to be −0.97 EUR per cow per year. Hirooka and Oishi [24] reported their EV for CI in Japanese Black cattle to be −51.5 EUR per cow per year. Although the results should be compared with caution, the EV for CI obtained here was ~4% of that by Hirooka and Oishi [24], or −2.18 EUR per cow per year. On the other hand, EVs for CW and MS were greater here than those of Hirooka and Oishi [24]. However, the full extent of the settings in the bioeconomic model of Hirooka and Oishi [24] was not clear, making further discussion difficult. Using system dynamics, Tarumoto et al. [8] calculated the profit from the reduction of 1 day in CI to be 128,000 JPY on a calf-producing farm with 100 Japanese Black cows, corresponding to 1280 JPY per cow, and found the results to be similar to those of Morimoto and Morita [7], who evaluated the economic loss on a calf-producing farm with 100 Japanese Black cows caused by lengthening CI from 12.5 to 14 months. The EV for CI using P1 here was −1505.4 JPY, which seems not so different from the value of Tarumoto et al. [8].

Values of SEVp and SEVg are listed in Table 6. The absolute value of EV was larger for AFC than for CI, but those of SEVp and SEVg were both larger for CI than for AFC. This difference was due to the value of σ_p and suggests that shortening CI has greater potential to increase the profit than earlier AFC. On the other hand, the absolute values of SEVs for CW and MS were larger than those for AFC and CI. Hirooka and Oishi [24] reported that the absolute value of SEVg for CI was larger than those for MS and CW, depending mainly on the results of EV calculation.

Table 6. Standardized economic values of the traits on the basis of phenotypic standard deviation (σ_p) (SEVp) and additive genetic standard deviation (σ_g) (SEVg) [1].

Trait	σ_p	h^2	σ_g	Economic Value		SEVp		SEVg	
				Value	**Ratio**	**Value**	**Ratio**	**Value**	**Ratio**
AFC	3.6	0.09	1.1	−9869.7	−1.59	−35,530.9	−0.09	−10,659.3	−0.04
CI	66.9	0.05	15.0	−2037.0	−0.33	−136,275.3	−0.33	−30,472.1	−0.11
CaW	31.0	0.30	17.0	4259.2	0.69	132,035.2	0.32	72,318.7	0.26
CW	65.7	0.48	45.5	6204.3	1	407,622.5	1	282,409.2	1
RA	9.3	0.46	6.3	−3187.4	−0.51	−29,642.8	−0.07	−20,104.7	−0.07
RT	0.9	0.38	0.6	4647.3	0.75	4182.6	0.01	2578.3	0.01
SF	0.7	0.39	0.4	49,883.0	8.04	34,918.1	0.09	21,806.4	0.08
MS	2.1	0.55	1.6	387,236.5	62.41	813,196.7	1.99	603,082.8	2.14

textsuperscript1 See Table 1 for abbreviations. Ratio shows the proportion to the value for carcass weight.

3.3. Deterministic Simulation of Breeding Objectives

Calculated correlations among different values of H are shown in Table 7. Except for two pairs (H1 and H2; H2 and H3), correlations were positive. The correlation was >0.9 between H1 and H7, H2 and H6, H3 and H7, H4 and H5, and H4 and H6. The correlation between H1 and H2 corresponded to the genetic correlation (r_g) between MS and CI (Table 3). Among H3, H4, and H5, the order of the highest correlation with H6 was H4 (0.93), H5 (0.83), and H3 (0.33), whereas that with H7 was H3 (0.93), H4 (0.61), and H5 (0.33). The correlation between H6 and H7 was positive but not fully high (0.44), meaning that the direction of genetic improvement was partly but not completely consistent between them.

Table 7. Correlations among aggregate genotypes (H).

H	H1	H2	H3	H4	H5	H6
H2	−0.01					
H3	0.76	−0.05				
H4	0.50	0.76	0.61			
H5	0.16	0.79	0.43	0.92		
H6	0.40	0.90	0.33	0.93	0.83	
H7	0.92	0.02	0.93	0.61	0.33	0.44

Results of the accuracy of selection for and expected genetic gain in each trait are summarized in Table 8. Values of selection accuracy in the case of H1 corresponded to r_g of MS with other traits (Table 3), so CI was expected to become longer. Similarly, values of selection accuracy in the case of H2 corresponded to r_g of CI with other traits, so MS was expected to become lower. However, as Oyama et al. [16] stated, these undesirable changes in the case of H1 and H2 are not considered to have an immediate negative effect. Among H3 to H7, only H3, where the weight for CI was 0, was expected to change CI in an undesirable direction. This suggests that it is necessary to explicitly include CI in a breeding objective to shorten CI. Adding CI shortening into a breeding objective could lead to a different direction of genetic improvement (Table 7), and might be useful to ensure the genetic diversity of the Japanese Black cattle population, which has been reducing by extensive use of frozen semen beyond prefectural borders collected from fewer elite sires excelling in genetic ability for marbling [48]. The reason why AFC was expected to be genetically improved in the desired direction in cases other than H7 was due to r_g of AFC with carcass traits, especially MS. Selection accuracy in the case of H6 was −0.91 for CI and 0.40 for MS, while that in the case of H7 was −0.02 for CI and 0.92 for MS. This means that H6 was more focused on shortening CI and H7 was more focused on improving carcass traits, although the correlation between H6 and H7 was pretty high (0.44) (Table 7).

Table 8. Selection accuracies and expected genetic gains [1].

Trait	**H**													
	Selection Accuracy							**Expected Genetic Gain**						
	H1	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**
AFC	−0.24	−0.25	−0.31	−0.39	−0.32	−0.35	−0.34	−0.26	−0.27	−0.33	−0.41	−0.34	−0.38	−0.36
CI	0.01	−1	0.05	−0.76	−0.79	−0.90	−0.02	0.15	−14.97	0.79	−11.31	−11.87	−13.54	−0.32
CW	0.15	−0.05	0.71	0.38	0.40	0.12	0.53	6.83	−2.28	32.43	17.32	18.23	5.52	23.99
RA	0.43	−0.08	0.74	0.47	0.50	0.14	0.52	2.70	−0.50	4.67	2.95	3.15	0.91	3.28
MS	1	−0.01	0.76	0.50	0.16	0.40	0.92	1.55	−0.02	1.18	0.78	0.25	0.62	1.42

[1] See Tables 1 and 7 for abbreviations.

Results of the expected economic gain by selection calculated using P are summarized in Table 9. Profit was expected to increase in all cases, more so when the relative weight for MS in H was larger. Values of P1 and P2 were also expected to increase in all cases. The majority of the increase in P in the case of H1 was due to the increase in P2, while that in the case of H2 was due to the increase in P1. Among H3 to H7, the aggregate genotype with a relatively large weight for CI resulted in a larger increase in P1 but a smaller increase in P2. Therefore, it is suggested that genetically improving both carcass traits and female reproductive traits can improve total profit, P, in lifetime carcass production of cows, but with different contents. The profit function, P, developed here could offer results related to the profit function P1, focusing on calf-producing farmers, and P2, focusing on fattening farmers.

Table 9. Expected economic gains [1].

H	**Economic Gain (JPY)**						
	R1	**C1**	**P1**	**R2**	**C2**	**P2**	**P**
H1	7783.9	6136.5	1647.4	610,253.4	13,497.0	596,756.4	598,403.8
H2	120,123.5	94,700.7	25,422.8	211,028.1	208,289.9	2738.2	28,161.0
H3	5761.5	4542.1	1219.4	477,017.4	9990.2	467,027.2	468,246.6
H4	97,430.2	76,810.2	20,620.0	488,299.0	168,940.5	319,358.5	339,978.5
H5	99,161.9	78,175.4	20,986.5	282,665.5	171,943.2	110,722.3	131,708.8
H6	113,104.7	89,167.3	23,937.3	455,443.9	196,119.5	259,324.3	283,261.7
H7	14,817.5	11,681.6	3136.0	585,127.3	25,693.1	559,434.2	562,570.2

[1] See Table 7 for abbreviations.

3.4. General Discussion

The representative carcass characteristics such as the degree of marbling and carcass weight have been genetically improved in Japanese Black cattle in Japan, e.g., [1,9,11]. Now, simultaneously improving carcass and reproductive traits is required to achieve sustainable high-quality Wagyu beef production. It is important to develop a tool to objectively evaluate the importance of traits for determining the breeding objective, including carcass and reproductive traits. Therefore, we developed a deterministic profit function, P, representing lifetime carcass production of Japanese Black cows, and calculated EVs for representative carcass and female reproductive traits using the first-order partial derivatives of P. Substitution of a multiple linear regression equation for CUP in P made it possible to calculate EVs for carcass traits other than CW. Substitution of a cubic regression equation for CaP in P reflected the effect of overfertilization of feeder cattle on CaP. Therefore, the profit function, P, could be expressed using the traits to be already routinely genetically evaluated in the Japanese Black cattle population in Japan. As far as we know, this is the first study to develop a profit function for lifetime carcass production of Japanese Black cows and to calculate EVs for AFC. Furthermore, our approach targeted both calf-producing and fattening farmers, in contrast to the previous studies [7,8,24]. Negative EVs were calculated for AFC and CI, because earlier AFC and shorter CI increased the number of feeder cattle per cow. The results agreed with the efforts to shorten CI. However, it seems that only calf-producing farmers will benefit from earlier AFC and shorter CI [7,8].

We showed that ignoring shortening CI in breeding objectives might bring about a prolonged CI, although simple deterministic selection simulations were performed to demonstrate use cases of P and EVs for traits obtained in this study (Tables 7–9). The breeding objectives were just examples, but were based on the real scenario, and there might be other settings to be investigated. Furthermore, predicted breeding values, not true values, were used in the selection, so the accuracy of prediction of breeding values should be considered in the creation of a selection index. For instance, the lower h^2 of CI than of carcass traits [14] could reduce the accuracy of prediction of breeding values for CI [15]. Ignoring the difference in the accuracy of prediction of breeding values among traits might create a discrepancy between desired and actual genetic gains by selection. Furthermore, in cattle, it is better to calculate the results from selection in each selection path, e.g., [49–51]. Taking these factors into consideration, a more sophisticated investigation to define future breeding objectives of Japanese Black cattle needs to be conducted. On the other hand, CaW may change as carcass and female reproductive traits are improved. Studies have estimated r_g of CaW with carcass traits in Japanese Black cattle [42,43], but no study has estimated r_g of CaW with AFC and CI. If this information becomes available, it might be possible to examine the performance of selection while restricting the amount of genetic gain in CaW with the aim of controlling CaP [39,52]. The developed profit function in this study was a non-linear form for CI, CaW, and CW. Therefore, studies about constructing an optimal selection index including non-linear profit traits might be necessary [43,53].

There may be room for improving P. We implicitly assumed that age at calf market and age at slaughter were unchanged. To assess the effects of changes in these ages, P must be improved so that traits change according to age. For instance, Tokunaga et al. [6] modeled MS in fattened animals using a logistic function of age. Takeda et al. [54] and Inoue et al. [27] modeled body weights of fattened animals and of breeding females respectively, using a Gompertz function of age. The length of the fattening period to improve meat quality, including the degree of marbling, of Japanese Black cattle is relatively long among Wagyu breeds [7,8]. If a function of age developed by previous studies is used, e.g., [6,27,54], EVs for carcass traits might be calculated by changing the age at slaughter. Moreover, when taking feed utilization traits into account in terms of eco-friendly and sustainable Wagyu beef production in Japan, it might be possible to assess the performance of selection by focusing on reducing feeding costs in detail.

4. Conclusions

We developed a deterministic profit function, P, for lifetime carcass production of Japanese Black cows, which was expressed using the traits being routinely genetically evaluated: carcass and female reproductive traits. Calculated EVs for AFC and CI using P were negative values, suggesting that earlier AFC and shorter CI would increase the lifetime profit of Japanese Black cows through producing more feeder cattle. Including shortening CI into the breeding objective could achieve simultaneously improving carcass and female reproductive traits and bring about increased lifetime profit. The results would contribute to achieving future sustainable production of high-quality Wagyu beef in Japan.

Author Contributions: Conceptualization, S.O. and M.S.; Methodology, S.O. and S.K.; Formal analysis, S.O. and S.K.; Resources, H.S.; Data curation, S.O. and S.K.; Writing—original draft preparation, S.O. and S.K.; writing—review and editing, S.O. and M.S.; visualization, S.O.; supervision, M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by a grant from Miyagi Prefecture.

Institutional Review Board Statement: Ethical review and approval were waived for this study because the data were acquired from an existing database.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors thank Atsushi Zoda at the Research and Development Group, Zen-noh Embryo Transfer Center, for his useful comments.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Namikawa, K. *Wagyu: Japanese Beef Cattle—Historical Breeding Processes of Japanese Beef Cattle and Preservation of Genetic Resources as Economic Farm Animal*; Wagyu Registry Association: Kyoto, Japan, 1992.
2. Gotoh, T.; Takahashi, H.; Nishimura, T.; Kuchida, K.; Mannen, H. Meat produced by Japanese Black cattle and Wagyu. *Anim. Front.* **2014**, *4*, 46–54. [CrossRef]
3. Hirooka, H. Marbled Japanese Black cattle. *J. Anim. Breed. Genet.* **2014**, *131*, 1–2. [CrossRef] [PubMed]
4. Motoyama, M.; Sasaki, K.; Watanabe, A. Wagyu and the factors contributing to its beef quality: A Japanese industry overview. *Meat Sci.* **2016**, *120*, 10–18. [CrossRef] [PubMed]
5. Oishi, K.; Kato, Y.; Ogino, A.; Hirooka, H. Economic and environmental impacts of changes in culling parity of cows and diet composition in Japanese beef cow–calf production systems. *Agric. Syst.* **2013**, *115*, 95–103. [CrossRef]
6. Tokunaga, T.; Jomane, F.N.; Mandai, S.; Ishida, T.; Hirooka, H. Estimation of the marbling development pattern in Japanese Black cattle by using serial ultrasound measurement data. *Anim. Sci. J.* **2021**, *92*, e13533. [CrossRef] [PubMed]
7. Morimoto, M.; Morita, S. The economy balance of the breeding farm of Japanese Black cattle from the aspects of the reproduction performance and the growth result of calves. *Res. One Health* **2017**, 1–10. Available online: http://s3-ap-northeast-1.amazonaws.com/gra.rakuno.ac.jp/wp-content/uploads/2018/01/23062527/20170616.pdf (accessed on 20 December 2020). (In Japanese)
8. Tarumoto, Y.; Sakatani, M.; Kikkawa, Y. Use of system dynamics to evaluate shortening of the calving-to-conception interval in Japanese Black cattle. *Agric. Inf. Res.* **2018**, *27*, 75–82. (In Japanese) [CrossRef]
9. Ashida, I.; Iwaisaki, H. A numerical technique for REML estimation of variance components using average information algorithm and its computing property. *Anim. Sci. Technol.* **1998**, *69*, 631–636. [CrossRef]
10. Ashida, I.; Iwaisaki, H. An expression for average information matrix for a mixed linear multi-component of variance model and REML iteration equations. *Anim. Sci. Technol.* **1999**, *70*, 282–289. [CrossRef]
11. Sasaki, Y.; Miyake, T.; Gaillard, C.; Oguni, T.; Matsumoto, M.; Ito, M.; Kurahara, T.; Sasae, Y.; Fujinaka, K.; Ohtagaki, S.; et al. Comparison of genetic gains per year for carcass traits among breeding programs in the Japanese Brown and the Japanese Black cattle. *J. Anim. Sci.* **2006**, *84*, 317–323. [CrossRef]
12. Wagyu Registry Association. *Breeding and Improvement of Wagyu*, 2nd ed.; Wagyu Registry Association: Kyoto, Japan, 2007. (In Japanese)
13. Nishimura, K.; Honda, T.; Oyama, K. Genetic variability of semen characteristics in Japanese Black bulls. *J. Anim. Genet.* **2010**, *38*, 73–76. [CrossRef]
14. Oyama, K. Genetic variability of Wagyu cattle estimated by statistical approaches. *Anim. Sci. J.* **2011**, *82*, 367–373. [CrossRef]
15. Ogawa, S.; Satoh, M. Random regression analysis of calving interval of Japanese Black cows. *Animals* **2021**, *11*, 202. [CrossRef]
16. Oyama, K.; Katsuta, T.; Anada, K.; Mukai, F. Genetic parameters for reproductive performance of breeding cows and carcass traits of fattening animals in Japanese Black (Wagyu) cattle. *Anim. Sci.* **2004**, *78*, 195–201. [CrossRef]
17. Hazel, L.M. The genetic basis for constructing selection indexes. *Genetics* **1943**, *28*, 476–490. [CrossRef] [PubMed]
18. Wilton, J.W.; Goddard, M.E. Selection for carcass and feedlot traits considering alternative slaughter end points and optimized management. *J. Anim. Sci.* **1996**, *74*, 37–45. [CrossRef]
19. Forabosco, F.; Bozzi, R.; Boettcher, P.; Filippini, F.; Bijma, P.; van Arendonk, J.A.M. Relationship between profitability and type traits and derivation of economic values for reproduction and survival traits in Chianina beef cows. *J. Anim. Sci.* **2005**, *83*, 2043–2051. [CrossRef] [PubMed]
20. Hirooka, H. Economic selection index in the genomic era. *J. Anim. Breed. Genet.* **2019**, *136*, 151–152. [CrossRef]
21. Hirooka, H.; Sasaki, Y. Derivation of economic weights for carcass traits in Japanese Black cattle from field records. *J. Anim. Breed. Genet.* **1998**, *115*, 27–37. [CrossRef]
22. Hirooka, H.; Groen, A.F.; Hillers, J. Developing breeding objectives for beef cattle production 2. Biological and economic values of growth and carcass traits in Japan. *Anim. Sci.* **1998**, *66*, 623–633. [CrossRef]
23. Okamoto, K.; Kuchida, K.; Kato, T.; Suzuki, M.; Miyoshi, S. Influence of image analysis and carcass traits on beef carcass price. *Nihon Chikusan Gakkaiho* **2003**, *74*, 475–482. (In Japanese) [CrossRef]
24. Hirooka, H.; Oishi, K. Economic values for production and reproduction traits of Japanese Black (Wagyu) cattle from a bio-economic model. In Proceedings of the 11th World Congress on Genetics Applied to Livestock Production, Auckland, New Zealand, 11–16 February 2018.
25. Bailie, J.H. The influence of breeding management efficiency on dairy herd performance. *Anim. Sci.* **1982**, *34*, 315–323. [CrossRef]
26. Nabenishi, H. Practical approaches to improve reproductive performance in Japanese Black cows. *Jpn. J. Grassl. Sci.* **2015**, *61*, 39–42. (In Japanese)
27. Inoue, K.; Hosono, M.; Oyama, H.; Hirooka, H. Genetic associations between reproductive traits for first calving and growth curve characteristics of Japanese Black cattle. *Anim. Sci. J.* **2020**, *91*, e13467. [CrossRef]

28. Ponzoni, R.W.; Newton, S. Developing breeding objectives for Australian beef cattle production. *Anim. Prod.* **1989**, *49*, 35–47. [CrossRef]
29. Amer, P.R. Approaches to formulating breeding objectives. In Proceedings of the 8th World Congress on Genetics Applied to Livestock Production, Belo Horizonte, Brazil, 13–18 August 2006.
30. Krupová, Z.; Oravcová, M.; Krupa, E.; Peškovičová, D. Methods for calculating economic weights of important traits in sheep. *Slovak J. Anim. Sci.* **2008**, *41*, 24–29.
31. Kahi, A.K.; Nitter, G. Developing breeding schemes for pasture based dairy production systems in Kenya I. *Derivation of economic values using profit functions. Livest. Prod. Sci.* **2004**, *88*, 161–177. [CrossRef]
32. Japan Meat Grading Association (JMGA). *New Beef Carcass Grading Standards*; JMGA: Tokyo, Japan, 1988.
33. Okano, A.; Shimada, K.; Izaike, Y.; Oishi, T. Reproductive performance of Japanese Black cows in their lifetimes. *Jpn. J. Zootech. Sci.* **1983**, *55*, 458–464. (In Japanese) [CrossRef]
34. Akaike, H. A new look at the statistical model identification. *IEEE Trans. Automat. Contr.* **1974**, *19*, 716–723. [CrossRef]
35. Schwarz, G. Estimating the dimension of a model. *Ann. Statist.* **1978**, *6*, 461–464. [CrossRef]
36. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2020. Available online: https://www.R-project.org/ (accessed on 1 April 2020).
37. Jagannatha, S.; Keown, J.F.; Van Vleck, L.D. Estimation of relative economic value for herd life of dairy cattle from profile equations. *J. Dairy Sci.* **1998**, *81*, 1702–1708. [CrossRef]
38. Komlósi, I.; Wolfová, M.; Wolf, J.; Farkas, B.; Szendrei, Z.; Béri, B. Economic weights of production and functional traits for Holstein-Friesian cattle in Hungary. *J. Anim. Breed. Genet.* **2010**, *127*, 143–153. [CrossRef]
39. Kato, K.; Maeda, S.; Kuchida, K. Genetic parameters for fineness of marbling in M. longissimus thoracis of Japanese Black cattle. *Nihon Chikusan Gakkaiho* **2014**, *85*, 21–26. (In Japanese) [CrossRef]
40. Goto, Y.; Asa, R.; Hagiya, K.; Kuchida, K. A new evaluation method of marbling fineness in M. longissimus thoracic of Japanese Black cattle. *Nihon Chikusan Gakkaiho* **2020**, *91*, 103–110. (In Japanese) [CrossRef]
41. Yamada, Y.; Yokouchi, K.; Nishida, A. Selection index when genetic gains of individual traits are of primary concern. *Jpn. J. Genet.* **1975**, *50*, 33–41. [CrossRef]
42. Shojo, M.; Okanishi, T.; Anada, K.; Oyama, K.; Mukai, F. Genetic analysis of calf market weight and carcass traits in Japanese Black cattle. *J. Anim. Sci.* **2006**, *84*, 2617–2622. [CrossRef]
43. Osawa, T.; Hidaka, S.; Hokiyama, H.; Kato, T.; Kamidate, N.; Kuchida, K. Genetic relationships of calf market weight with carcass and image analysis traits in Japanese Black steer of Hokkaido. *Nihon Chikusan Gakkaiho* **2008**, *79*, 185–192. (In Japanese) [CrossRef]
44. Horii, M.; Sakurai, Y.; Kanbe, Y.; Kasai, K.; Ono, K.; Asada, T.; Mori, T.; Kobayashi, M.; Iguchi, A.; Yamada, M.; et al. Relationship between Japanese Beef Marbling Standard numbers and intramuscular lipid in M. longissimus thoracis of Japanese Black steers from 1996 to 2004. *Nihon Chikusan Gakkaiho* **2009**, *80*, 55–61. (In Japanese) [CrossRef]
45. Goddard, M.E. Selection indices for non-linear profit functions. *Theor. Appl. Genet.* **1983**, *64*, 339–344. [CrossRef]
46. Albera, A.; Carnier, P.; Groen, A.F. Definition of a breeding goal for the Piemontese breed: Economic and biological values and their sensitivity to production circumstances. *Livest. Prod. Sci.* **2004**, *89*, 67–78. [CrossRef]
47. Åby, B.A.; Aass, L.; Sehested, E.; Vangen, O. A bio-economic model for calculating economic values of traits for intensive and extensive beef cattle breeds. *Livest. Sci.* **2012**, *143*, 259–269. [CrossRef]
48. Nomura, T.; Honda, T.; Mukai, F. Inbreeding and effective population size of Japanese Black cattle. *J. Anim. Sci.* **2001**, *79*, 366–370. [CrossRef]
49. Schaeffer, L.R. Strategy for applying genome-wide selection in dairy cattle. *J. Anim. Breed. Genet.* **2006**, *123*, 218–223. [CrossRef] [PubMed]
50. Garcia-Ruiz, A.; Cole, J.B.; VanRaden, P.M.; Wiggans, G.R.; Ruiz-López, F.J.; Van Tassell, C.P. Changes in genetic selection differentials and generation intervals in US Holstein dairy cattle as a result of genomic selection. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, E3995–E4004. [CrossRef] [PubMed]
51. Yazaki, N.; Uemoto, Y.; Ogawa, S.; Satoh, M. Responses to selection for maximizing component characters with no change in proportion-defined character: An example of selection for milk fat percentage. *Nihon Chikusan Gakkaiho* **2021**, *92*, 35–39. (In Japanese) [CrossRef]
52. Kempthorne, O.; Nordskog, A.W. Restricted selection indices. *Biometrics* **1959**, *15*, 10–19. [CrossRef]
53. Martin-Collado, D.; Byrne, T.J.; Visser, B.; Amer, P.R. An evaluation of alternative selection indexes for a non-linear profit trait approaching its economic optimum. *J. Anim. Breed. Genet.* **2016**, *133*, 476–484. [CrossRef]
54. Takeda, M.; Uemoto, Y.; Inoue, K.; Ogino, A.; Nozaki, T.; Kurogi, K.; Yasumori, T.; Satoh, M. Evaluation of feed efficiency traits for genetic improvement in Japanese Black cattle. *J. Anim. Sci.* **2018**, *96*, 797–805. [CrossRef] [PubMed]