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Genetic Relationship between Carcass Traits and Carcass Price of Korean Cattle*

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ABSTRACT : The objectives of this study were to estimate genetic parameters for the carcass price and carcass traits contributing to carcass grading and to investigate the influence of each carcass trait on the carcass price using multiple regression and path analyses. Data for carcass traits and carcass prices were collected from March 2003 to January 2009 on steers of Korean cattle raised at private farms. The analytical mixed animal model, including slaughter house-year-month combination, linear and quadratic slaughter age as fixed effects and random animal and residual effects, was used to estimate genetic parameters. The effects of carcass traits on the carcass price were evaluated by applying multiple regression analyses. Heritability estimates of carcass traits were 0.20±0.08 for carcass weight (CWT), 0.33±0.10 for back fat thickness (BFT), 0.07±0.05 for eye-muscle area (EMA) and 0.25±0.10 for marbling score (MS), and those of carcass prices were 0.21±0.10 for auction price per 1 kg of carcass weight (AP) and 0.13±0.07 for total price (CP). Genetic correlation coefficients of AP with CWT and MS were -0.35±0.29 and 0.99±0.04, respectively, and those of CP with CWT and MS were 0.59±0.22 and 0.39±0.29 respectively. If an appropriate adjustment for temporal economic value is available, the moderate heritability estimates of AP and CP might suggest their potential use as the breeding objectives for improving the gross incomes of beef cattle farms. The large genetic correlation estimates of carcass price variables with CWT and MS implied that simultaneous selection for both CWT and MS would be also useful in enhancing income. (**Key Words :** Carcass Price, Carcass Trait, Heritability, Multiple Regression, Path Analyses)

INTRODUCTION

Korean cattle, also called Hanwoo, have been the major indigenous beef breed in South Korea, and there has been great concern regarding their meat production ability because of unsatisfactory production resulted from their use as draught animals and as organic fertilizers until the 1960s. Recent goals in the Korean cattle improvement plans established by the Korean government were to increase carcass weight (CWT), to enlarge eye muscle area (EMA), and to enhance marbling score (MS) under the current level of back fat thickness (BFT) (MFAFF, 2008). All carcasses of cattle should be officially graded before shipping in Korea. The carcass grading system is based on both quantity and quality of the meat. The quantity grade is determined by the amount of saleable meat estimated with the mathematical equation formed by CWT, BFT, and EMA. The quality grade is determined by the five categorical traits of marbling, fat color, meat color, firmness, and maturity, but greatly depends on the marbling. Most farmers, therefore, focus their efforts on increasing MS for their animals and thereby to sell the carcass at a higher price. Nevertheless, studies of the side effect on CWT, BFT, and EMA resulting from MS improvement in Korean cattle have been quite limited. Furthermore, the contribution of the quantity traits to determining carcass price has not been examined despite its importance in maximizing the gross income of beef cattle farms. The objectives of this study were to estimate genetic parameters for the carcass prices and carcass traits contributing to carcass grading and to investigate the influence of each carcass trait on carcass prices using multiple regression and path analyses.

MATERIALS AND METHODS

Animals and traits

Data for carcass traits and carcass prices were collected from March 2003 to January 2009 on the steers of Korean

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cattle raised at private farms in Kangwon province, South Korea. Animals were castrated at approximately six months of age and fed commercial concentrate feed with rice straw during the fattening period. Finished animals were transported from fattening farms to one of two slaughter houses at a distance within 3 hours by truck. Slaughtering and data collections were carried out according to the standard industrial procedures suggested by the Ministry for Food, Agriculture, Forestry and Fisheries (MIFAFF, 2007).

Animals were weighed on arrival, and held over-night with free access to drinking water. On the next morning, animals were stunned, bled by cutting the jugular vein, dressed using the standard procedures (removal of head, skin, viscera, and foot), and cut into halves. Two-sided carcasses were chilled for one night in a 0°C storage room, and then CWT, BFT, EMA, and MS were evaluated by official graders. The left side of the carcass was cross-sectioned at a position between the last thoracic vertebra and the first lumbar vertebra, and EMA (cm^2), BFT (mm), and MS were measured on the cross-section. MS was classified into 1 (poor) to 9 (best) according to the Korean Beef Marbling Standard. Both sides of carcass were weighed and summed as CWT. After the carcass traits were measured and graded, the carcasses were transferred to an auction hall where carcass unit auction price per 1 kg of CWT (AP, monetary unit; Korean won(KRW), 1 US$≒1,200 KRW) was decided by auctioneers, and total carcass price for each carcass (CP) was calculated by multiplying AP with CWT.

Data were collected on 1,892 animals produced from 62 sires and 1,638 dams. They were raised on 480 farms, and each farm raised an average of 4 animals. Some observations for BFT and AP were lost during data collection, and the final data set for statistical analyses included observations of 1,892 for CWT, EMA and MS, 1,856 for BFT, and 1,233 for AP and CP. Pedigree information was additionally included for 3,064 animals, and the total of 4,956 animals, of which 266 were sires and 2,798 were dams, were included in the genetic parameter estimation.

Genetic parameter estimation

The analytical model included slaughter house-year-month combination fixed effect with 62 levels for CWT, EMA, BFT, and MS and 55 levels for AP and CP, and age at slaughter (days) effects were fitted as linear and quadratic covariates. Direct additive genetic effects and residuals were fitted as random effects. Variance and covariance components were estimated using the WOMBAT package of Meyer (2006). Single trait analyses were conducted to estimate heritability and breeding values, and two-trait analyses were conducted to estimate genetic and phenotypic correlation coefficients between the traits.

Multiple regression and path analyses

The effects of CWT, EMA, BFT, and MS on AP and CP were evaluated by multiple regression analyses. Partial regression coefficient for an independent variable means response on a dependent variable (AP or CP) when all other fitted independent variables (CWT, EMA, BFT, and MS) were held constant. Use of the variables standardized by the respective mean and standard deviation led to standardized partial regression coefficients equal to the path coefficients. Path coefficients could explain the change of standard deviation in a dependent variable which occurred by the change of standard deviation in an independent variable when all other fitted independent variables were held constant.

Path coefficients from independent to dependent variables and correlation coefficients among independent variables were used to partition the variation in price, the dependent variable. The variance was proportionally partitioned by all of the direct and indirect paths of influence from independent variables. Direct contribution of one independent variable to the dependent variable was simply the square of the path coefficient, and indirect contribution was estimated by summing up the product of the correlation coefficients and path coefficients along the indirect path (Lynch and Walsh, 1998). The correlation coefficients between traits were calculated using the following standardized breeding values from single trait analyses.

$$SBV_i = \frac{BV_i - \overline{BV}}{SD(BV_i)}$$

where SBV_i is a standardized breeding value, BV_i is an individual breeding value, $\overline{BV}$ is the mean of the individual breeding values, and $SD(BV_i)$ is standard deviation of breeding value.

Partial- and standardized partial regression coefficients of CWT, EMA, BFT, and MS on AP or CP were estimated using the following multiple regression model.

$$SBVAP(or\ SBVCP) = b_1SBV1 + b_2SBV2 + b_3SBV3 + b_4SBV4 + e$$

where SBVAP (or SBVCP) is the standardized breeding value of AP (or CP), SBV1, SBV2, SBV3, and SBV4 are the standardized breeding values for CWT, BFT, EMA, and MS, respectively, b1, b2, b3, and b4 are their corresponding regression coefficients, and e is the residual.

Contribution of carcass trait to the variation in the dependent variable was calculated as follows;

$$C_i = D_i + \sum IND_{ij} = PC_i^2 + \sum PC_iCC_{ij}PC_j$$

Table 1. Simple statistics for variables used in the study

Traits[1]	N	Mean	SD	CV	Min.	Max.
SAGE (d)	1,892	889.84	89.09	10.01	535	1,373
CWT (kg)	1,892	420.89	52.29	12.42	245	644
BFT (kg)[a]	1,856	12.09	4.73	39.12	3	45
EMA(cm^2)[a]	1,892	88.15	9.98	11.32	60	130
MS[ab]	1,892	5.79	1.87	32.24	1	9
AP	1,233	15.61	2.10	13.43	5.6	27.71
CP	1,233	6.33	1.15	18.13	1.56	12.16

[1] SAGE = Age at slaughter; CWT = Cold carcass weight; BFT = Back fat thickness; EMA = Eye-muscle area; MS = Marbling score; AP = Carcass price per 1 kg of carcass (unit; Korean Won (KRW, 1 US$ ≒ 1,200 KRW); CP = Carcass total price per animal (unit; 1,000 KRW).

[a] Measured at the last rib to first lumbar vertebra cross-sectioned.

[b] Evaluated on the Korean Beef Marbling Standard with scores 1 (poor) to 9 (best).

where C_i is contribution of independent trait i, D_i is direct contribution of independent trait i, IND_{ij} is indirect contribution of trait i through trait j, $PC_{i(j)}$ is path coefficient of trait $i(j)$, and CC_{ij} is correlation coefficient between traits i and j.

RESULTS AND DISCUSSION

The averages of CWT, BFT, EMA and MS with the slaughtering age of 889.84 d were 420.89 kg, 12.09 mm, 88.15 cm^2, and 5.79, respectively (Table 1). All of these values were larger than those of the corresponding traits with a smaller slaughtering age. Moon et al. (2007) obtained 368.03 kg, 10.10 mm, 80.64 cm^2, and 4.19 from the data of 85,441 steers with unknown slaughter ages, and Hwang (2008) obtained 321.01 kg, 8.27 mm, 75.72 cm^2, and 2.91 with the slaughtering age of 726.33 d. The coefficients of variations (CV) for BFT and MS were larger than those for CWT and EMA in this study. This concurred with the results from other Korean cattle (Kim et al., 2006; Hwang et al., 2008) and from Japanese Brown cattle (Kahi et al., 2007). On the other hand, a small CV for MS was obtained in Brahman (15.80%, Smith, 2007) and in various US sires (15.69%, Van Vleck et al., 2007). This might be because the US sires are put out to pasture more frequently in management and that genetics differ among the breeds. Furthermore, this might be also due to a different measuring system, giving especially wide ranges of MS from 200 to 899 (Smith et al., 2007) and from 20 to 109 (Van Vleck et al., 2007). This was supported by the large CV estimate of 62.2% with the MS from 1 to 7 in Hereford cattle (Galli et al., 2008).

Heritability estimates for CWT, BFT, EMA, and MS in the current study (0.20, 0.33, 0.07, and 0.25, Table 2) were smaller than those in the study of Hwang et al. (2008) where the estimates were obtained from Hanwoo steers raised in a progeny test station (0.30, 0.44, 0.37, and 0.44). This implied that the smaller heritability estimates were caused mainly by various management systems in private farms. Nevertheless, the heritability estimate of 0.20 for CWT in this study concurred with the weighted average heritability (0.23) in the review study of Koots et al. (1994). Our low heritability estimate (0.07) for EMA agreed with the estimate (0.07) obtained in steer progeny from composite, Angus, and Simmental sires in the study of Hassen et al. (1999). However, many studies showed moderate to large estimates in Australian Angus and Hereford (0.26 and 0.38, Reverta et al., 2000), Angus (0.45, Kemp et al., 2002), in Simmental (0.26-0.27, Rumph et al., 2007), Japanese Black cattle (0.43, Osawa et al., 2006), and in Brahman (0.44, Riley et al., 2002; 0.50, Smith et al., 2007). The small estimate in the current study might be due

Table 2. Variance component and heritability estimated from single trait analysis for carcass and price traits

Traits	σ_G^2	σ_E^2	σ_P^2	h^2
CWT [1]	376.19	1,547.61	1,923.80	0.20±0.08
BFT	6.91	14.18	21.09	0.33±0.10
EMA	5.79	74.21	80.00	0.07±0.05
MAR	0.78	2.39	3.17	0.25±0.10
AP	0.58	2.18	2.76	0.21±0.10
CP	0.12	0.80	0.92	0.13±0.07

σ_G^2 = Additive genetic variance, σ_E^2 = Environmental variance, σ_P^2 = Total phenotypic variance, h^2 = Direct heritability.

[1] SAGE = Age at slaughter; CWT = Cold carcass weight; BFT = Back fat thickness; EMA = Eye-muscle area; MS = Marbling score; AP = Carcass price per 1 kg of carcass (unit; Korean Won (KRW), 1 US$ ≒ 1,200 KRW); CP = Carcass total price per animal (unit; 1,000 KRW).

Table 3. Genetic correlation (above the diagonal) and phenotypic correlation (below the diagonal) between traits from bi-variate analysis

Traits	CWT	BFT	EMA	MS	AP	CP
CWT [1]		0.16±0.26	0.07±0.36	-0.48±0.24	-0.35±0.29	0.59±0.22
BFT	0.31±0.03		-0.45±0.32	-0.01±0.27	-0.45±0.25	-0.21±0.33
EMA	0.48±0.02	-0.01±0.03		-0.40±0.36	-0.23±0.40	-0.11±0.42
MS	0.07±0.03	0.04±0.03	0.19±0.03		0.99±0.04	0.39±0.29
AP	0.01±0.03	-0.20±0.03	0.27±0.03	0.74±0.01		0.35±0.30
CP	0.70±0.0	0.10±0.03	0.56±0.02	0.56±0.02	0.70±0.02	

[1] SAGE = Age at slaughter; CWT = Cold carcass weight; BFT = Back fat thickness; EMA = Eye-muscle area; MS = Marbling score; AP = Carcass price per 1 kg of carcass (unit; Korean Won (KRW), 1 US$ ≒ 1,200 KRW); CP = Carcass total price per animal (unit; 1,000 KRW).

to the higher slaughter age of 889d as well as the genetic difference, considering another Korean cattle study in which 0.37 was obtained with the age of 726 d (Hwang et al., 2008).

Heritability estimates (0.21 and 0.19) of AP and CP in the current study were also small comparing to other studies. Kahi et al. (2007) reported heritability estimates of 0.41 for carcass price and 0.62 for net income per year in Japanese Brown cattle, and Ibi et al. (2006) reported the heritability ranges from 0.32 to 0.42 for AP and from 0.33 to 0.46 for CP in Japanese Black cattle. On the other hand, there were small heritability estimates for carcass market value of Gelbvieh bulls using different data sources (0.10 and 0.19 from slaughterhouse data and programmed field test data, Engellandt et al., 1999).

Most of the genetic correlation estimates were not significant (p>0.05) except for the correlation between CWT and CP and the correlation between MS and AP (Table 3). There was a lack of genetic correlation between MS and BFT in the current study (-0.01). In other Korean cattle studies, negative or negligible estimates were obtained (0.04, Kim et al., 2006; -0.11, Moon et al., 2007; 0.04, Hwang et al., 2008). This corresponded to other breeds such as Japanese Black cattle (-0.13, Mukai et al., 1995; 0.01, Kim et al., 2006; -0.20, Oikawa et al., 2006), Japanese Brown cattle (-0.12, Hirooka et al., 1995), Brahman (0.04, Smith et al., 2007), Angus (-0.13, Wilson et al., 1993), and American Shorthorn (-0.31, Pariacote et al., 1998). These results implied that single trait selection for high marbling might not be a reason for increased carcass BFT. There have been debates on the impact because many studies have revealed positive genetic correlations (Kemp et al., 2002; Riley et al., 2002; Rios-Utrera et al., 2005).

Genetic correlation between AP and MS was considerably high (0.99), which concurred with the results from Japanese cattle (0.96 to 0.98 for Japanese Black cattle, Ibi, 2006; 0.98 for Japanese Brown cattle, Kahi, 2007). These results reflected that the marbling degree was a critical trait for deciding carcass value both in Korean and Japanese carcass markets.

Our estimate of genetic correlation between CP and MS (0.39, p>0.05)) was smaller than the estimates (0.71 to 0.96) reported by Ibi et al. (2006). This could have resulted from the negative genetic relationship between CWT and MS.

Ultimately, either AP or CP would be used as a breeding objective because the final goal of beef producers is improving their farm profitability. A caution should be attached to the single trait selection for higher AP because it would lead to small carcass weight with the negative genetic correlation between AP and CWT. This is undesirable because increasing body weight was another important breeding goal in Korea (MAFF, 2008).

Multiple regression analyses revealed that the analytical model with the independent variables of CWT, BFT, EMA, and MS accounted for 72.6% and 73.7% of the variability of AP and CP, respectively (Table 4). Partial regression coefficients of MS and BFT on AP were 0.6233 and -0.0737. Partial regression coefficient would be an indicator of economic value for each independent trait, and 1 unit increase of breeding value for MS (BFT) raised the breeding value for AP by 0.6233 KRW (-0.0737 KRW). Standardized partial regression coefficients would be a relative economic weight of each individual trait, and larger standardized partial regression coefficients on AP for MS and BFT than those for CWT and EMA suggested that MS and BFT were more influential on the carcass value of Korean cattle. A negative value of the standardized partial multiple regression coefficient for CWT revealed that a heavy carcass was less preferable in the Korean market. This agreed with the study of Ibi et al. (2006) where a negative economic weight was estimated for CWT of Japanese Black cattle. The largest standardized partial regression coefficient on CP was estimated for CWT (743.1 KRW) with the greatest relative importance on CP, and the smallest was for EMA (-2.8 KRW). While the relative importance of MS on the total carcass value was smaller than that of CWT for the Korean cattle, the standardized economic weight of MS was larger than that of CWT for Japanese black cattle (Ibi et al., 2006). The negative values of BFT on AP and CP in the current study were also observed for Japanese black cattle (Ibi et al., 2006).

Table 4. Partial regression coefficients of carcass traits on carcass price (n = 4,956)

Price variable[1]	Carcass variable[2]	Partial regression[3]	Standardized partial regression[4]
AP	CWT	-0.0016±0.0003	-0.0439±0.0081
	BFT	-0.0737±0.0021	-0.2884±0.0081
	EMA	0.0100±0.0033	0.0250±0.0083
	MS	0.6233±0.0061	0.7696±0.0076
	$R^{2, 5}$	0.726	0.726
CP	CWT	0.0107±0.0001	0.7431±0.0079
	BFT	-0.0299±0.0008	-0.2924±0.0080
	EMA	-0.0005±0.0013	-0.0028±0.0081
	MS	0.1783±0.0024	0.5505±0.0074
	R^2	0.737	0.737

[1] Each price variable was fitted as a dependent variable. AP = Auction price; CP = Carcass price.
[2] The carcass variables were fitted as independent variables. CWT = Carcass weight; BFT = Back fat thickness; EMA = Eye-muscle area; MS = Marbling score.
[3] Breeding values estimated from uni-variate analysis were used for partial regression analyses.
[4] Breeding values were standardized with respective mean and standard deviation for each trait before regression analyses.
[5] R^2 = Coefficient of determination for the multiple regression model.

Path analyses partitioned the variability of AP and CP by each carcass trait, and path diagrams of relationships between carcass traits and AP (CP) are presented in Figure 1 and 2. The direct effect of MS on AP was estimated as 0.592 (= 0.770×0.770). Each independent variable had three indirect effects on the carcass price in the current study. For example, MS had an indirect effect on AP of 0.006 (= 0.770×-0.171×-0.044) through CWT, 0.016 (= 0.770×-0.073 ×-0.288) through BFT, and -0.002 (= 0.770×-0.129×0.025) through EMA. Then, the contribution of MS on the variability of AP was 0.612 (= 0.592+0.006+0.016-0.002). This means that MS accounted for 61.2% of the variability

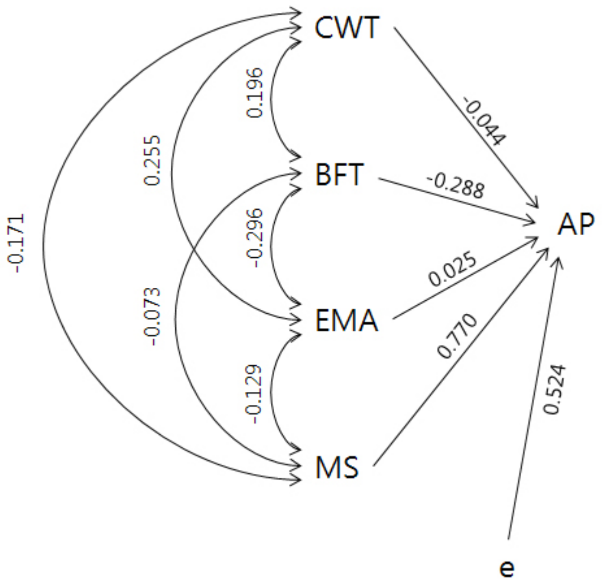

Figure 1. Path diagram illustrating cause and effect relationships between carcass traits and auction price (AP). Numbers along single-headed arrows are path coefficients. Numbers along double-headed arrows are path coefficients. Correlation coefficients among traits were calculated using the breeding values estimated by single trait analyses. Path coefficients were standardized partial regression coefficients of carcass traits on carcass value, AP, listed in Table 4. CWT = Carcass weight; BFT = Back fat thickness; EMA = Eye-muscle area; MS = Marbling score; e = Error in the statistical model.

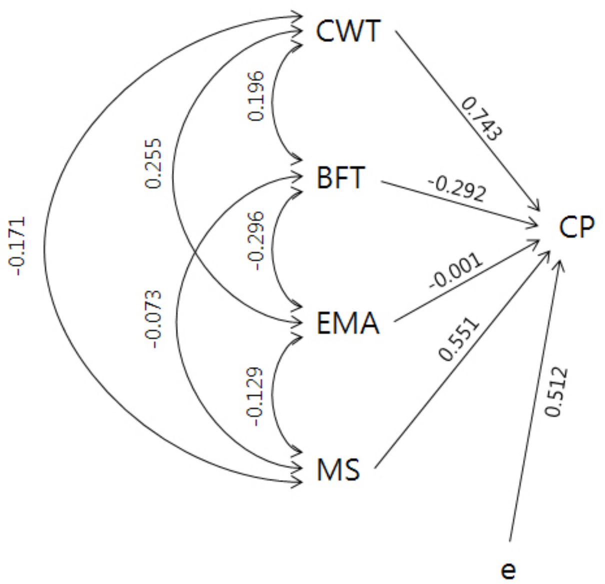

Figure 2. Path diagram illustrating cause and effect relationships between carcass traits and carcass price (CP). Numbers along single-headed arrows are path coefficients. Numbers along double-headed arrows are path coefficients. Correlation coefficients among traits were calculated using the breeding values estimated by single trait analyses. Path coefficients were standardized partial regression coefficients of carcass traits on carcass value, CP, listed in Table 4. CWT = Carcass weight; BFT = Back fat thickness; EMA = Eye-muscle area; MS = Marbling score; e = Error in the statistical model.

Table 5. Path contribution of carcass traits to carcass prices

		CWT	BFT	EMA	MS
AP	CWT	0.002	0.002	-0.000	0.006
	BFT	0.002	0.083	0.002	0.016
	EMA	-0.000	0.002	0.001	-0.002
	MC	0.006	0.016	-0.002	0.592
	TC	0.010	0.104	0.000	0.612
CP	CWT	0.552	-0.043	-0.001	-0.070
	BFT	-0.043	0.086	-0.000	0.012
	EMA	-0.001	-0.000	0.000	0.000
	MS	-0.070	0.012	0.000	0.303
	TC	0.439	0.054	-0.001	0.245

Diagonal element indicates direct contribution of the carcass variable on each price variable, and off-diagonal element indicates joint contribution resulting from correlations between carcass traits and path coefficients of carcass traits. AP = Auction price; CP = Carcass price; CWT = Carcass weight; BFT = Back fat thickness; EMA = Eye-muscle area; MS = Marbling score; TC = Total contribution of each carcass trait on the variation of dependent price variable. The TC was calculated by summing over all the direct and indirect contributions of each carcass trait.

of AP. All the contributions of the carcass traits on the variation of the price variables, AP and CP, were estimated in Table 5. The MS showed the largest effect on the variability of AP. On the other hand, CWT showed the greatest effect on the variability of CP, indicating that CWT was a more important factor than MS on deciding CP. The small contribution estimates of EMA on AP (0.000) and CP (-0.001) implied negligible effects of EMA on the variability of AP and CP. The contributions of CWT and MS on the variability of CP in the current study were similar to those obtained in the study of Pyatt et al. (2005) where CWT and MS accounted for 51 and 10% of the variability of carcass values for Simmental steers.

The final goal of beef cattle breeding would be to increase the gross income of beef cattle farms. The current study showed that AP and CP have the potential as a breeding objective due to their moderate heritability estimates. However, this should satisfy the assumption of a reasonable adjustment for temporal economic value. The moderate to high genetic correlation of carcass prices with CWT and MS implied that simultaneous selection for both CWT and MS would be also useful for raising income.

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