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Response to alternative genetic-economic indices for Holsteins across 2 generations

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ABSTRACT

Four US genetic-economic indices for dairy cattle were retrofitted to illustrate differences in phenotypic response observed for retrospective selection over 2 generations for currently evaluated traits, even though producers did not have evaluations available at the time for direct selection for those traits. Differences among cows were compared based on ranking of their sires and maternal grandsires (MGS) for the 4 retrofitted indices. Holstein artificial insemination bulls (106,471) were categorized by quintile for each index, and 25 cow groups were formed based on quintiles for sire and MGS (2 generations). Data included records from 1,756,805 cows in 26,106 herds for yield traits, productive life, pregnancy rate, and somatic cell score; 692,656 cows in 9,967 herds for calving difficulty; and 270,564 cows in 4,534 herds for stillbirths. For each index, least squares differences between the 25 cow groups were examined for 8 first-parity traits (milk, fat, and protein yields; productive life; somatic cell score; pregnancy rate; calving difficulty; and stillbirth) that had been standardized for age. Analysis removed effects of herd and cow birth year. Seven of 25 cow groups were consolidated into 3 groups based on index ranking for their male ancestors (low, medium, and high). The cow group with high sire and MGS rankings for the 2006 net merit index produced more milk (219 kg), fat (21 kg), and protein (11 kg) and had longer productive life (6.3 mo), lower somatic cell score (0.21), higher pregnancy rate (1.2 percentage units), fewer difficult births in heifers (3.8 percentage units), and lower stillbirth rate (4.6 percentage units) than did the group with low sire and MGS rankings. For cow groups based on sire and MGS rankings for 1971 (milk and fat) and 1977 (milk, fat, and protein) indices, advantages for the group with high sire and MGS rankings were much larger for yield traits but smaller (and sometimes even unfavorable) for other traits. Cow groups based on sire and MGS rankings for the 1994 net merit index generally had differences that were intermediate to groups based on sire and MGS rankings for the 1977 and 2006 indices. Phenotypic differences revealed retrospectively between genetic-economic indices indicate that genetic improvement should be made for all traits included in recent net merit indices.
Key words: genetic-economic index, ranking, yield, fitness

INTRODUCTION

For dairy cattle populations throughout much of the 20th century, considerable emphasis was directed toward yield traits (volume and component percentages). A consequence was some deterioration in other traits with an unfavorable genetic relationship with milk yield. A negative association between production and reproduction has been reported in several countries with different breeds of cattle (Hermas et al., 1987; Hoekstra et al., 1994; Lucy, 2001; Pryce and Veerkamp, 2001; Wall et al., 2003; González-Recio et al., 2004). A large decline in cow fertility and a small increase in SCS were particularly unfortunate consequences (Nieuwhof et al., 1989; Hare et al., 2006; Animal Improvement Programs Laboratory, 2009).

As more comprehensive data recording became available in the United States, national genetic evaluations for a few health and fitness traits were developed: dystocia (Berger and Freeman, 1978), SCS (Schutz, 1994), productive life (**PL**; VanRaden and Wiggans, 1995), daughter pregnancy rate (**DPR**; VanRaden et al., 2004), and stillbirth (Cole et al., 2007). Future genetic evaluations are likely to include health and disease traits that are being recorded through DHI (Animal Improvement Programs Laboratory, 2008).

To address the growing complexity of making breeding decisions for a multitude of traits, national genetic-economic indices were developed to combine estimates of genetic merit for several traits in addition to yield (VanRaden, 2004; VanRaden and Multi-State Project S-1008, 2006). Those indices permit breeders to focus selection on a single composite trait in the expectation that doing so will produce optimal improvement among multiple traits. Choosing parents of the next genera-

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Table 1. History of USDA genetic-economic indices for dairy cattle and relative emphasis (%) on traits included in the indices[1]

	USDA economic index (and year introduced)						
Traits included	PD$[2] (1971)	MFP$[3] (1977)	NM[4] (1994)	NM (2000)	NM (2003)	NM (2006)	NM (2010)
Milk	52	27	6	5	0	0	0
Fat	48	46	25	21	22	23	19
Protein	—	27	43	36	33	23	16
Productive life	—	—	20	14	11	17	22
SCS	—	—	−6	−9	−9	−9	−10
Udder composite	—	—	—	7	7	6	7
Feet/legs composite	—	—	—	4	4	3	4
Body size composite	—	—	—	−4	−3	−4	−6
Daughter pregnancy rate	—	—	—	—	7	9	11
Service sire calving difficulty	—	—	—	—	−2	—	—
Daughter calving difficulty	—	—	—	—	−2	—	—
Calving ability index[5]	—	—	—	—	—	6	5

[1]Source: Cole et al. (2009).

[2]Predicted difference dollars.

[3]Milk-fat-protein dollars.

[4]Net merit.

[5]Includes calving difficulty and stillbirth for both service sire and daughter.

tion based on such indices is expected to produce cows with fewer functional deficiencies and thus with greater capacity for efficient performance over a longer herd life. Most countries that evaluate several traits update their genetic-economic indices periodically when genetic evaluations for new traits become available or when economic values of the traits change so that the previous weights are no longer appropriate (International Bull Evaluation Service, 2009).

Since the "predicted difference dollars" index developed in 1971 that included milk and fat yields (**MF71**; Norman and Dickinson, 1971), USDA has introduced 6 additional genetic-economic indices to provide more effective selection for all traits as genetic evaluations for new traits became available (Table 1; Cole et al., 2009). When the basis for USDA genetic-economic indices was changed from largely annual gross value of milk to net profit in 1994 (VanRaden and Wiggans, 1995), weighting of traits was based on both published and unpublished information from academic and industry personnel. Although obtaining precise weights is nearly impossible, indices based on reasonable approximations for many traits are usually quite robust. The economic weights used in net merit 2006 (**NM06**; VanRaden and Multi-State Project S-1008, 2006), the USDA index from 2006 through 2009 for standard milk-fat-protein pricing, should bring genetic improvement in the 10 traits included if selection is directed exclusively to that index. Based on genetic correlations of Holstein breeding value with NM06, VanRaden and Multi-State Project S-1008 (2006) predicted an increase in breeding values per decade of 486 kg for milk yield, 34 kg for fat yield, 24 kg for protein yield, 6.0 mo for PL, 0.80 for udder composite, 0.60 for feet/legs composite, 1.4 percentage units for DPR, and $25 for calving ability and a decrease of 0.34 for SCS and 0.80 for body size composite. Parameters used in genetic predictions are often taken from the literature and may be based on different breeds or estimates from different countries. How well the parameters work in predictions for specific traits of a particular population depends on how closely they approximate true parameters for that population. Using the economic weights that were adopted for NM06 and genetic and phenotypic parameters for US Holsteins, Cunningham and Tauebert (2009) reported that an index with only yield traits overstated economic gain from selection by 4.4%, an index with yield and functional type traits had an improvement of 0.2% in economic gain, and an index with yield, functional type, health, and fertility traits improved gain by 3.4%.

Before genetic evaluations for SCS were introduced, concern had been expressed that lowering SCC through selection might produce a population unable to respond to mastitis challenges. Examination of selection outcomes across 2 generations can help to alleviate such concerns and indicate possible consequences of long-term decision making. One approach is to examine phenotypic response based on genetic merit of sires and maternal grandsires (**MGS**). The objective of this study was to compare phenotypic changes in currently evaluated traits of US Holsteins using a retrospective reranking of sire and MGS based on various genetic-economic indices that have been introduced by USDA during the last 38 yr. Although those traits were often not evaluated at the time of mating, selection both for and against various traits was occurring even if unknown to the breeder.

MATERIALS AND METHODS

Four selection indices were formulated based on economic values of traits in NM06 and relative weights of traits (Table 1) in MF71, the 1977 predicted difference dollars index for milk, fat, and protein (**MFP77**; Norman, 1986), the 1994 net merit index (**NM94**; VanRaden and Wiggans, 1995), and NM06 (VanRaden and Multi-State Project S-1008, 2006):

1) MF71 = 0.0745(PTA milk) + 1.50(PTA fat);
2) MFP77 = 0.016(PTA milk) + 1.50(PTA fat) + 1.95(PTA protein);
3) NM94 = 0.7[0.016(PTA milk) + 1.50(PTA fat) + 1.95(PTA protein)] + 11.67(PTA PL) − 29.13(PTA SCS − 3.00); and
4) NM06 = 2.70(PTA fat) + 3.55(PTA protein) + 29(PTA PL) − 150(PTA SCS − 3.00) + 28(PTA udder composite) + 13(PTA feet/legs composite) − 14(PTA body size composite) + 21(PTA DPR) − 4(PTA service sire calving ease − 8) − 3(PTA daughter calving ease − 8) − 4(PTA service sire stillbirth − 8) − 8(PTA daughter stillbirth − 8).

For the NM06 index, the udder, feet/legs, and body size composites were those calculated by Holstein Association USA (2009).

January 2008 official USDA-DHIA PTA were used to calculate MF71, MFP77, and NM94 index values for 106,471 Holstein AI bulls with ≥35 daughters. January 2008 official USDA-DHIA net merit values were used as NM06 index values.

For each index, bulls were categorized by quintile (1 = lowest, . . . , 5 = highest), and 25 cow groups were formed based on sire and MGS quintiles (2 generations). For example, $group_{11}$ included cows with both sire and MGS in the lowest quintile, where the first subscript refers to sire quintile and the second subscript to MGS quintile. Although dairy producers choose sires and dams of herd replacements, dam selection is represented by MGS in this study.

Phenotypic data were mature-equivalent first-parity records from the USDA national dairy database for 1,756,805 cows in 26,106 herds for yield traits, PL, pregnancy rate, and SCS; 692,656 cows in 9,967 herds for calving difficulty; and 270,564 cows in 4,534 herds for stillbirth. Only cows born from 1993 through 1999 and calving from 1995 through 2005 were included. Cows that changed herds or had missing lactation records between the first and last of their first 5 parities were excluded as were those in herds with <5 cows. Numbers of cows in each sire and MGS quintile are shown in Table 2 for the 4 selection indices.

For each index, differences among least squares means for the 25 cow groups were examined for 8 first-parity traits: milk, fat, and protein yields; PL; SCS; pregnancy rate; percentage of difficult births (calving ease score of 4 or 5; VanTassell et al., 2003) for primiparous heifers (**%DBH**); and stillbirth. Analysis was based on the following model:

$$\text{First-parity trait} = \text{herd effect} + \text{cow group} + \text{cow birth year} + \text{residual}.$$

Cow birth year was included to avoid bias in many of the traits that would have resulted from differences in opportunity (e.g., cow's actual herd life). Because 800 least squares means (25 cow groups × 4 indices × 8 traits) were generated, cow groups were combined according to sire-MGS quintile (Figure 1): low ($group_{11}$ and $group_{12}$), medium ($group_{32}$, $group_{33}$, and $group_{34}$), and high ($group_{54}$ and $group_{55}$). Least squares means for only the low, medium, and high cow groups are reported. Index differences in least squares means for the 8 traits were tested for significance.

RESULTS AND DISCUSSION

Differences among least squares means for the 25 cow groups were significant ($P < 0.0001$) for all traits and all indices. Table 3 shows least squares means for the high, medium, and low cow groups for each of the genetic-economic indices. Means for the group with medium sire-MGS ranking were intermediate to those for the groups with low and high sire-MGS rankings except for pregnancy rate under NM94 selection. Differences in means between the groups with low and high sire-MGS rankings suggest that progress would have been made for all traits regardless of the selection index except for SCS and pregnancy rate. The increase in SCS and decrease in pregnancy rate associated with high sire-MGS rankings for MF71 and MFP77 likely resulted from the unfavorable genetic correlation between milk yield and those traits (Schutz, 1994; VanRaden et al., 2004).

Milk yield superiority for the cow group with high sire-MGS rankings compared with the group with low sire-MGS rankings was greatest (1,366 kg) for MF71. As other traits were added to the index and emphasis on milk yield was reduced (Table 1), superiority in milk yield for high versus low groups for sire-MGS ranking decreased: 1,127 kg for MFP77, 755 kg for NM94, and 219 kg for NM06. Weighting on milk yield in the indices was eliminated by 2006, and superiority for first-parity milk yield for Holsteins with high versus low sire-MGS rankings was reduced by 84% from MF71 to NM06. However, the reduced relative index emphasis on milk yield was partially offset by an increased weight on protein yield, which is highly correlated with milk yield. Corresponding superiority for fat and protein yields was greatest for the 2 yield indices (44 kg for fat and 31 kg for protein for MF71 and 50 kg for fat and 37 kg for protein for MFP77) but declined for the net merit indices (36 kg for fat and 24 kg for protein for NM94 and 21 kg of fat and 11 kg of protein for NM06). The reason that the fat yield difference between the cow groups with high and low sire-MGS rankings was less for MF71 than for MFP77 was unclear considering that relative index emphasis for fat yield remained about the same for MF71 and MFP77. Relative emphasis on fat yield in the net merit indices was less than that in the yield indices. More emphasis was placed on protein yield in NM94 than in MFP77; the emphasis on protein in NM06 was less than that in NM94, and difference in protein yield between cow groups with high and low sire-MGS rankings decreased from 24 to 11 kg.

Differences between cow groups with high and low sire-MGS rankings for the yield indices (MF71 and MFP77) were moderate (around 2 mo) for PL. However, corresponding differences for the net merit indices (NM94 and NM06), which included PL directly in the indices, were considerably larger (around 6 mo).

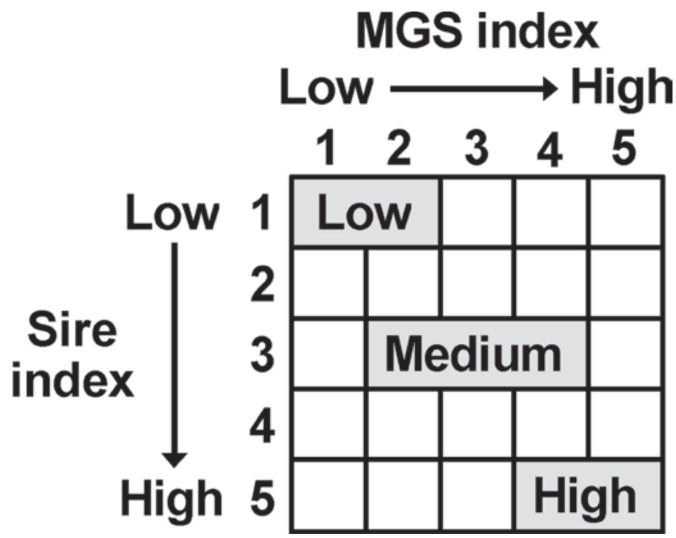

Figure 1. Cow groups based on sire and maternal grandsire (MGS) quintiles for a genetic-economic index: low = $group_{11}$ and $group_{12}$; medium = $group_{32}$, $group_{33}$, and $group_{34}$; and high = $group_{54}$ and $group_{55}$, where the first subscript refers to sire quintile and the second subscript refers to MGS quintile.

Mastitis resistance appeared to deteriorate slightly for cow groups with high versus low sire-MGS rank-

Table 2. Numbers of cows in 25 groups based on sire and maternal grandsire (MGS) quintile for 4 genetic-economic indices

Index[1]	Sire quintile[2]	MGS quintile[2] 1	2	3	4	5
MF71	1	9,291	14,095	11,682	5,107	762
	2	35,534	71,399	67,777	32,643	5,097
	3	63,930	155,460	172,687	99,733	19,260
	4	55,035	162,961	229,218	163,022	38,957
	5	19,262	69,051	115,782	104,592	34,468
MFP77	1	13,281	19,089	12,901	4,609	300
	2	55,917	97,172	80,885	32,025	2,315
	3	93,111	208,535	214,920	99,559	10,529
	4	60,412	164,871	213,686	119,664	18,368
	5	14,894	52,415	89,281	63,282	14,784
NM94	1	17,396	22,655	19,092	9,627	1,796
	2	62,172	98,065	91,286	54,298	12,184
	3	82,963	145,606	150,489	94,737	26,222
	4	66,080	139,464	156,295	111,608	39,623
	5	34,402	86,521	109,789	87,101	37,334
NM06	1	37,513	40,326	38,311	22,797	10,792
	2	73,937	87,493	82,387	51,702	27,580
	3	88,927	110,845	112,887	72,728	42,199
	4	77,894	105,114	111,991	76,838	49,551
	5	66,084	100,531	116,586	87,875	63,917

[1]MF71 = 0.0745(PTA milk) + 1.50(PTA fat); MFP77 = 0.016(PTA milk) + 1.50(PTA fat) + 1.95(PTA protein); NM94 = 0.7[0.016(PTA milk) + 1.50(PTA fat) + 1.95(PTA protein)] + 11.67(PTA productive life) − 29.13(PTA SCS − 3.00); and NM06 = 2.70(PTA fat) + 3.55(PTA protein) + 29(PTA productive life) − 150(PTA SCS − 3.00) + 28(PTA udder composite) + 13(PTA feet/legs composite) − 14(PTA body size composite) + 21(PTA daughter pregnancy rate) − 4(PTA service sire calving ease − 8) − 3(PTA daughter calving ease − 8) − 4(PTA service sire stillbirth − 8) − 8(PTA daughter stillbirth − 8).

[2]Lowest quintile is 1 and highest quintile is 5.

Table 3. Least squares means for first-parity traits standardized to mature equivalence for cows grouped by ranking of sire and maternal grandsire (MGS) for 4 genetic-economic indices

Trait	Index[1]	Cow group based on sire-MGS ranking[2]			Difference (high − low)
		Low	Medium	High	
Milk, kg	MF71	10,235	10,967	11,601	1,366
	MFP77	10,443	11,053	11,570	1,127
	NM94	10,620	11,047	11,375	755
	NM06	10,961	11,083	11,180	219
Fat, kg	MF71	375	399	419	44
	MFP77	374	400	424	50
	NM94	381	401	417	36
	NM06	391	401	411	21
Protein, kg	MF71	300	318	332	31
	MFP77	299	319	336	37
	NM94	305	319	329	24
	NM06	314	320	325	11
Productive life, mo	MF71	29.6	30.6	31.8	2.2
	MFP77	29.8	30.7	31.9	2.1
	NM94	28.1	30.4	33.9	5.8
	NM06	27.9	30.5	34.2	6.3
SCS	MF71	2.86	2.91	2.95	0.09
	MFP77	2.83	2.91	2.95	0.12
	NM94	2.98	2.90	2.86	−0.12
	NM06	3.03	2.91	2.82	−0.21
Pregnancy rate, %	MF71	29.7	28.6	28.0	−1.7
	MFP77	29.5	28.5	28.1	−1.4
	NM94	28.6	28.4	28.7	0.1
	NM06	27.9	28.3	29.1	1.2
Difficult births[3] in primiparous heifers, %	MF71	8.8	8.5	7.5	−1.3
	MFP77	8.9	8.3	7.4	−1.5
	NM94	9.6	8.3	7.2	−2.4
	NM06	10.5	8.0	6.7	−3.8
Stillbirths, %	MF71	12.5	12.0	10.6	−2.0
	MFP77	12.1	11.6	11.3	−0.9
	NM94	13.4	12.5	11.1	−2.3
	NM06	13.6	11.9	9.0	−4.6

[1]MF71 = 0.0745(PTA milk) + 1.50(PTA fat); MFP77 = 0.016(PTA milk) + 1.50(PTA fat) + 1.95(PTA protein); NM94 = 0.7[0.016(PTA milk) + 1.50(PTA fat) + 1.95(PTA protein)] + 11.67(PTA productive life) − 29.13(PTA SCS − 3.00); and NM06 = 2.70(PTA fat) + 3.55(PTA protein) + 29(PTA productive life) − 150(PTA SCS − 3.00) + 28(PTA udder composite) + 13(PTA feet/legs composite) − 14(PTA body size composite) + 21(PTA daughter pregnancy rate) − 4(PTA service sire calving ease − 8) − 3(PTA daughter calving ease − 8) − 4(PTA service sire stillbirth − 8) − 8(PTA daughter stillbirth − 8).

[2]Cow group based on sire and MGS quintiles for the genetic-economic index: low = $group_{11}$ and $group_{12}$; medium = $group_{32}$, $group_{33}$, and $group_{34}$; and high = $group_{54}$ and $group_{55}$, where the first subscript refers to sire quintile and the second subscript refers to maternal grandsire quintile.

[3]Calving ease score of 4 or 5.

ings for the yield indices as indicated by the increase (around 0.1) in SCS. In contrast, a decrease in SCS was observed for the net merit indices, which include SCS directly: around 0.1 for NM94 and around 0.2 for NM06. Index differences between cow groups with high and low sire-MGS rankings suggest that although mastitis resistance was on the decline before its direct inclusion in the indices, it started to increase after it was incorporated. Relative emphasis on SCS was −6% for NM94 and −9% for NM06.

Differences between cow groups with high and low sire-MGS rankings for NM94, which includes yield traits, PL, and SCS, were intermediate to those for MFP77 and NM06. Relative trait emphasis (Table 1) and assigned economic values (VanRaden and Multi-State Project S-1008, 2006) affected whether NM94 differences were closer to MFP77 or NM06 difference for individual traits. The NM94 differences for milk yield, %DBH, and stillbirth were closer to the MFP77 difference than to the NM06 difference. However, NM94 differences for PL, SCS, and pregnancy rate were closer to NM06 than to MFP77 differences. The NM94 differences for fat and protein yields were halfway between MFP77 and NM06 differences.

Changes in Holstein EBV for many traits appear to coincide with changes in USDA indices (Table 4; Animal Improvement Programs Laboratory, 2009). Trends were tested using linear and quadratic regressions of trait performance on year. All linear regressions were significant ($P < 0.001$). Quadratic effects were then tested in the presence of linear effects, and all were significant ($P < 0.01$ for milk yield; $P < 0.001$ for other

Table 4. Estimated breeding values and changes since preceding birth year for US Holsteins born since 1970 for traits included in USDA genetic-economic indices[1]

Birth year[2]	Milk, kg		Fat, kg		Protein, kg		Productive life, mo		SCS		Pregnancy rate, %	
	EBV	Change	EBV	Change	EBV	Change	EBV	Change	EBV	Change	EBV	Change
1971	−2,465	62	−81	2	−60	−1	−6.51	0.42	—	—	5.80	−0.12
1972	−2,394	71	−79	2	−59	1	−6.18	0.33	—	—	5.60	−0.20
1973	**−2,326**	**68**	**−77**	**2**	**−59**	**0**	**−5.72**	**0.46**	—	—	**5.48**	**−0.12**
1974	−2,256	70	−75	2	−58	1	−5.37	0.35	—	—	5.39	−0.09
1975	−2,195	61	−73	2	−58	0	−5.12	0.25	—	—	5.29	−0.10
1976	−2,110	85	−71	2	−58	0	−4.89	0.23	—	—	5.01	−0.28
1977	−2,019	91	−68	3	−56	2	−4.50	0.39	—	—	4.86	−0.15
1978	−1,942	77	−66	2	−54	2	−4.19	0.31	—	—	4.68	−0.18
1979	**−1,858**	**84**	**−63**	**3**	**−53**	**1**	**−3.81**	**0.38**	—	—	**4.43**	**−0.25**
1980	−1,777	81	−60	3	−51	2	−3.48	0.33	—	—	4.18	−0.25
1981	−1,691	86	−57	3	−50	1	−3.08	0.40	—	—	3.92	−0.26
1982	−1,607	84	−54	3	−49	1	−2.72	0.36	—	—	3.70	−0.22
1983	−1,519	88	−50	4	−47	2	−2.33	0.39	—	—	3.51	−0.19
1984	−1,441	78	−47	3	−45	2	−2.07	0.26	−0.23	—	3.24	−0.27
1985	−1,355	86	−44	3	−43	2	−1.81	0.26	−0.21	0.02	2.97	−0.27
1986	−1,271	84	−41	3	−40	3	−1.74	0.07	−0.19	0.02	2.72	−0.25
1987	−1,193	78	−38	3	−38	2	−1.59	0.15	−0.18	0.01	2.49	−0.23
1988	−1,100	93	−34	4	−35	3	−1.33	0.26	−0.17	0.01	2.22	−0.27
1989	−999	101	−29	5	−32	3	−1.24	0.09	−0.14	0.03	1.89	−0.33
1990	−915	84	−26	3	−29	3	−1.15	0.09	−0.11	0.03	1.63	−0.26
1991	−819	96	−24	2	−26	3	−0.92	0.23	−0.10	0.01	1.44	−0.19
1992	−720	99	−21	3	−23	3	−0.70	0.22	−0.11	−0.01	1.22	−0.22
1993	−628	92	−18	3	−20	3	−0.53	0.17	−0.12	−0.01	0.91	−0.31
1994	−535	93	−15	3	−17	3	−0.54	−0.01	−0.09	0.03	0.63	−0.28
1995	−442	93	−13	2	−15	2	−0.40	0.14	−0.08	0.01	0.50	−0.13
1996	**−346**	**96**	**−10**	**3**	**−12**	**3**	**−0.17**	**0.23**	**−0.07**	**0.01**	**0.41**	**−0.09**
1997	−252	94	−8	2	−9	3	0.04	0.21	−0.06	0.01	0.38	−0.03
1998	−163	89	−5	3	−5	4	0.01	−0.03	−0.03	0.03	0.24	−0.14
1999	−83	80	−2	3	−3	2	0.12	0.11	−0.02	0.01	0.17	−0.07
2000	0	83	0	2	0	3	0.00	−0.12	0.00	0.02	0.00	−0.17
2001	88	88	3	3	3	3	0.13	0.13	0.02	0.02	−0.15	−0.15
2002	**180**	**92**	**6**	**3**	**6**	**3**	**0.25**	**0.12**	**0.01**	**−0.01**	**−0.29**	**−0.14**
2003	250	70	8	2	8	2	0.52	0.27	0.02	0.01	−0.19	0.10
2004	317	67	11	3	10	2	0.79	**0.27**	0.00	−0.02	−0.07	0.12
2005	**378**	**61**	**13**	**2**	**12**	**2**	**1.09**	**0.30**	**−0.01**	**−0.01**	**−0.01**	**0.06**
2006	454	76	16	3	15	3	—	—	−0.03	−0.02	0.07	0.08

[1]Source: Animal Improvement Programs Laboratory, 2009.

[2]Birth years that are shown in boldface are 2 years after implementation of a USDA genetic-economic index or its revision: predicted difference dollars, 1971; milk-fat-protein dollars, 1977; and net merit, 1994, 2000, and 2003. Insufficient data were available to include EBV associated with the revision of net merit in 2006 (birth years 2007 and 2008).

traits) except for fat yield. Differences between consecutive years were not tested for significance for individual traits. Annual gains for cow EBV for milk yield were high for birth years between 1991 and 1997 (93 to 96 kg) but have declined since then, especially after 2002. The index revisions of 1994 and 2000 eliminated nearly all emphasis on milk yield. Genetic gains for fat yield remained similar, even after index emphasis was halved with the introduction of net merit indices. Genetic gains for protein yield increased slightly after the implementation of MFP77 and then lessened slightly as other traits were added with the implementation of the net merit indices and relative emphasis on protein yield decreased. Although EBV for PL (first introduced in 1994) has generally had a positive trend over time, annual increases decreased until after the inclusion of PL in the net merit indices. Cow EBV for SCS (also first introduced in 1994) has steadily deteriorated (become numerically larger) but has improved (negative change in EBV) for 4 of the last 5 yr, which coincides with an increase in emphasis on SCS in the net merit index in 2000. Cow EBV for pregnancy rate (first introduced in 2003) declined every year from 1971 through 2002. However, the rate of decline decreased after 1994, the year that PL evaluations were introduced; PL and pregnancy rate are highly correlated (VanRaden et al., 2004). Since the inclusion of DPR in the 2003 net merit index, cow EBV for pregnancy rate has improved for 4 consecutive years.

Genetic change in a herd is a function of many factors, including availability and accuracy of breeding value estimates for traits, selection intensity, and the

Table 5. Regression coefficients (linear and quadratic) for annual[1] trend in breeding value for US Holsteins born since 1970 for traits included in USDA genetic-economic indices

Trait	Intercept	Linear coefficient	Quadratic coefficient
Milk, kg	−2,589	81.42	0.137
Fat, kg	−88	3.00	−0.002
Protein, kg	−64	0.97	0.037
Productive life, mo	−6.91	0.3999	−0.0053
SCS	−0.59	0.0313	−0.0004
Pregnancy rate, %	6.61	−0.2988	0.0028

[1]Year defined as 1 = 1971, 2 = 1972, … 36 = 2006.

criteria that dairy producers emphasize when choosing bulls to sire herd replacements. Choices made by AI organizations in selecting sires of young bulls are also important contributors to genetic change. Although not all producers use available indices in making their sire choices, the historical trends in Holstein EBV (Table 4) indicate that genetic improvement in fitness traits tended to reflect the availability of genetic evaluations for those traits. Linear and quadratic regression coefficients for annual trend in breeding values are shown in Table 5.

The trend for reduced genetic gains for milk yield and increased genetic gains for fitness traits is expected to continue as animals that resulted from breeding decisions based on NM06 enter the milking population, especially because NM06 includes an improved PL definition and new genetic evaluations for service sire and daughter stillbirth (VanRaden and Multi-State Project S-1008, 2006). The 2010 update of the net merit index (Cole et al., 2009) has less emphasis on fat and protein yields and calving ability and more emphasis on PL, SCS, udder composite, feet/legs composite, body size (favoring smaller cows), and DPR compared with NM06 (Table 1).

CONCLUSIONS

Four US genetic-economic indices for dairy cattle were retrofitted to illustrate differences in phenotypic response observed for retrospective selection over 2 generations for currently evaluated traits. First-parity least squares differences between cow groups with high and low sire-MGS rankings for NM06 indicated that NM06 provided improvement for all traits included in the index. Selection on a comprehensive index such as NM06 should produce a dairy population that performs more satisfactorily for several health and fitness traits than in the past. Some improvements are great enough that they may be apparent in a single generation in large herds (e.g., increases in PL and pregnancy rate and declines in SCS and stillbirths). Concern about animal welfare issues sometimes raised by consumers that are related to animal health (mastitis resistance, cow longevity, calving difficulty, and stillbirth) or fitness (conformation and fertility) should be reduced through the use of comprehensive composite indices that include health and fitness traits even though progress for yield traits will be slowed.

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