The impact of reproduction, replacement, and stocking density on profitability in dairy cattle[1]

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Economic value of a change in pregnancy rate

The key reproductive performance indicator for dairy herds is pregnancy rate, measured as the number of conceptions per non pregnant eligible cow every 21 days. The average pregnancy rate of herds in the US is approximately 18%, but the variation is large. **Figure 1** shows the distribution of annual pregnancy rates for 14,000 herds that submit data to DRMS, Raleigh, NC.

Realistic economic benefits of improved reproductive performance are not simple to obtain. When reproductive performance improves, all changes in cash flows that result from the improvement must be accounted for. For a good analysis, at least realistic estimates of milk production curves, feed intake, the risk of culling, and prices such as for milk, feed, labor, semen, possibly reproductive hormones, calves, replacement heifers and cull cows are needed. Therefore, the DairyVIP simulation program (De Vries (2004, 2006) was used to evaluate the economic effects of a change in pregnancy rate. To do so, 21-day service rate and conception rate were simultaneously varied from -15 percentage points to +20 percentage points with increments of 5 percentage points. This resulted in pregnancy rates from 7% to 38%. **Table 1** shows some selected herd statistics for various pregnancy rates. Increasing pregnancy rates lead to fewer cows in parities 1 and 2 and a lower cull rate. This trend can be seen in reduced cow sales and reduced heifer purchase costs. A greater pregnancy rate resulted in shorter lactations as can be seen by more milk per lactating cow, and fewer cows lactating. Collectively, milk sales did not increase very much because the increase in milk per lactating cow was offset by fewer cows lactating because cows were more often dry. Feed costs did not vary much. Profit per slot per year increased from $255 to $658 with greater pregnancy rate, but the rate of increase declined. Average days not pregnant decreased from 172 to 111.

The value of a marginal increase in pregnancy rate i.e., from 15% to 16% is the change of profit per cow slot per year when pregnancy rate changes one percentage unit. **Figure 2** shows that the marginal

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value is more than $40 per cow per year in herds with low pregnancy rates to less than $5 per cow per year in herds with greater than 30% pregnancy rates. For a pregnancy rate of 18%, the marginal value under the default assumptions is approximately $15 when it is changed to 19%. When there is a cost associated with improving pregnancy rate, these marginal values will be smaller.

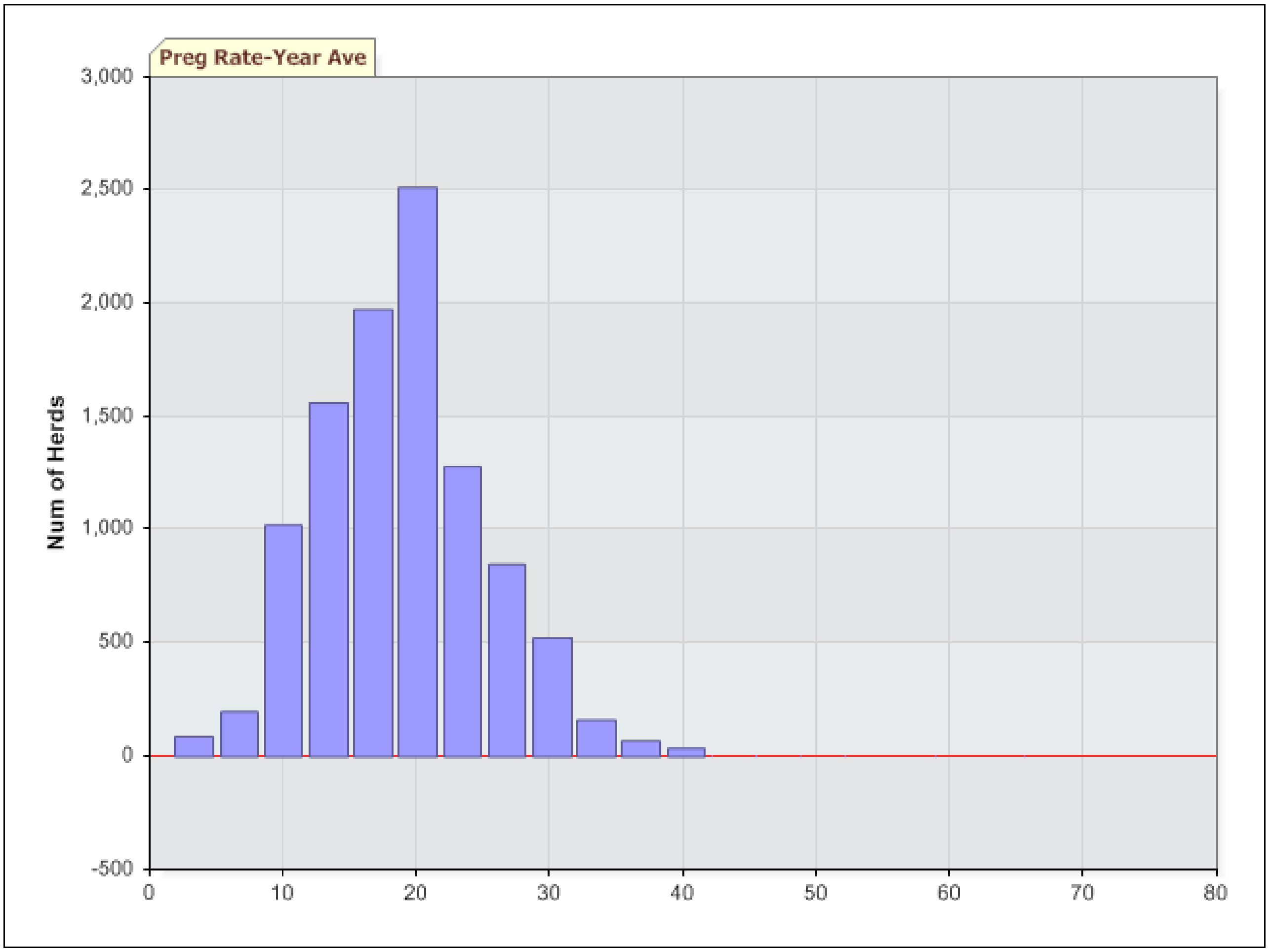

Figure 1. Distribution of year-average pregnancy rates reported by DRMS (2013) for 14,000 Holstein herds located primarily in the eastern USA. Data compiled on October 5, 2013.

The calculations assume that the total herd size is constant. In many herds, other constraints apply, such as parlor capacity, or the number of milking cows. When the number of milking cows is constant, then the marginal value of an increase in pregnancy rate is slightly greater. In other cases, the number of available heifers may be the constraint, or the herd may be closed without sales or purchases of heifers. It is actually not quite clear how the marginal value of an increase in pregnancy rate changes in closed herds.

Table 1. Effect of pregnancy rate on selected herd statistics under the default assumptions calculated with the DairyVIP computer program (De Vries, 2006).

Herd statistic	---- Pregnancy rate ----							
	7%	10%	14%	18%	22%	27%	32%	38%
21-day service rate	40%	45%	50%	55%	60%	65%	70%	75%
Conception rate	18%	23%	28%	32%	37%	41%	46%	50%
% cows in parity 1	52	44	39	36	34	33	32	31
% cows in parity 2	28	28	27	27	26	25	25	25
% cows lactating	92	90	89	88	88	87	87	86
Milk yield lactating cows (kg/day)	34.5	35.2	35.7	36.1	36.5	36.7	36.9	37.1
Milk yield all cows (kg/day)	31.6	31.7	31.8	31.8	31.9	32.0	32.0	32.1
Average days in milk	232	234	233	231	229	226	224	222
Annual cull rate (%)	48	41	37	34	32	31	31	30
Days to conception	172	162	152	143	136	130	124	120
Value of new pregnancy ($)	646	494	375	284	216	166	128	102
Breeding cost per pregnancy ($)	110	87	73	62	54	48	44	40
Milk sales ($/slot/year)	4614	4626	4635	4646	4656	4666	4673	4680
Cow sales ($/slot/year)	260	225	201	186	176	170	167	164
Calf sales ($/slot/year)	293	299	305	311	316	321	325	328
Feed cost ($/slot/year)	1957	1957	1955	1954	1953	1953	1952	1952
Heifer purchase cost ($/slot/year)	958	825	737	682	647	627	614	606
Profit ($/slot/year)	255	380	469	534	580	614	640	658

Variations in inputs lead to different values of a marginal change in pregnancy rate as is seen in **Table 2**. Especially, a marginal increase in pregnancy rate is worth more when the heifer price is high or cows are given fewer breeding opportunities. Both effects illustrate the importance of culling on the value of a marginal change in pregnancy rate. Increases in milk price and herd milk production have smaller effects.

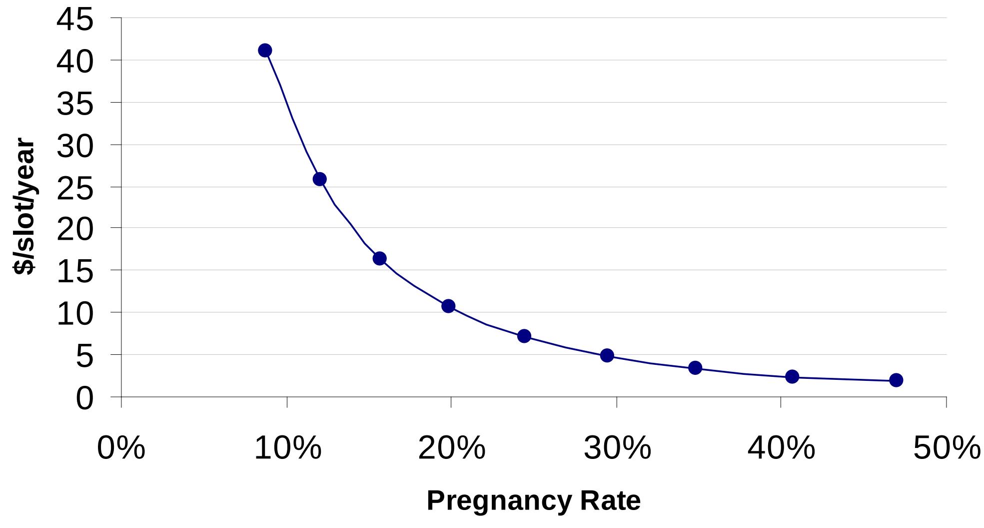

Figure 2. Effect of marginal, one percentage unit, change in pregnancy rate (for example, from 15% to 16%) on profit per slot per year calculated with DairyVIP (De Vries, 2006).

Table 2. Effects of variations in some inputs on the value of a marginal change in pregnancy rate.

Inputs	---- Pregnancy rate ----							
	9%	12%	16%	20%	24%	29%	35%	41%
Default	41.00	25.69	16.41	10.69	7.11	4.82	3.36	2.37
Heifer price $2400	49.59	30.44	19.00	12.13	7.93	5.28	3.55	2.53
Heifer price $1600	31.46	20.30	13.35	8.95	6.11	4.21	3.01	2.18
Milk price $34 / 100kg	40.39	25.20	15.91	10.28	6.84	4.61	3.15	2.27
Milk price $46 / 100kg	41.12	25.98	16.77	11.03	7.36	5.03	3.51	2.45
Max. 8 months breeding	45.39	33.48	23.48	16.02	10.55	7.03	4.85	3.38
Max. 12 months breeding	42.42	27.35	17.34	11.35	7.54	5.10	3.53	2.51
Milk yield +30%	41.00	26.18	16.95	11.31	7.49	5.11	3.58	2.55
Inv. cull rate –30%	44.03	27.62	17.72	11.62	7.77	5.30	3.67	2.66
Inv. cull rate +30%	38.36	24.25	15.40	9.98	6.63	4.47	3.09	2.17

Cost per day not pregnant

The average cost per day not pregnant per month after calving for some typical inputs is shown in **Figure 3**. The negative cost per day not pregnant on day 61 illustrates that on average the optimal day to conception is not yet reached: a day later pregnancy would actually increase profitability.

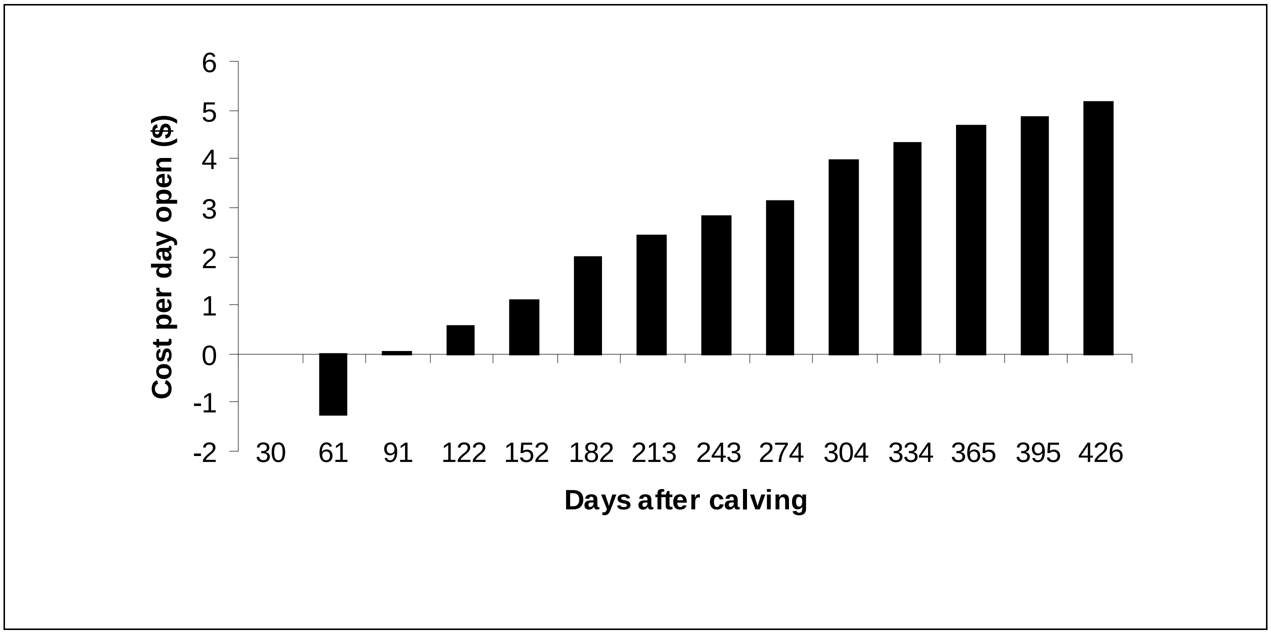

Figure 3. Herd average cost per day open by day after calving for the default situation

These analyses do not include an effect of later conception on the risk of death and live culling around subsequent calving. Pinedo and De Vries (2010) reported that the risk of death and live culling in the first 60 days around subsequent calving increased from 2.5% to 5.8% when days open increased from less than 90 to greater than 300 days. The risk of live culling increased from 5.0% to 8.1% for the same periods. The risk of culling for cows who failed to get pregnant increased sharply after 250 days after calving (De Vries et al., 2010).

Figure 4 shows the economic loss caused by conception earlier or later after calving compared to the optimal day of conception for first parity cows for a slightly different set of default assumptions as described above (De Vries, 2008). The optimal day of conception is reached when the economic loss is $0 (bottom of the curve). The optimal day of conception for average first lactation cows was 133 days. For second and third lactation cows was 112 and 105 days, respectively. For lower producing cows, fewer days to conception were optimal. Similarly, for higher producing cows, greater days to conception were optimal.

The economic loss from a later day of conception (conception was too late) was smaller in first parity cows than in second parity cows. This is primarily caused by the much flatter lactation curve of first parity cows. Historically, the optimal calving interval has been 12 to 13 months (Stevenson, 2004), which is 90 to 120 days to conception.

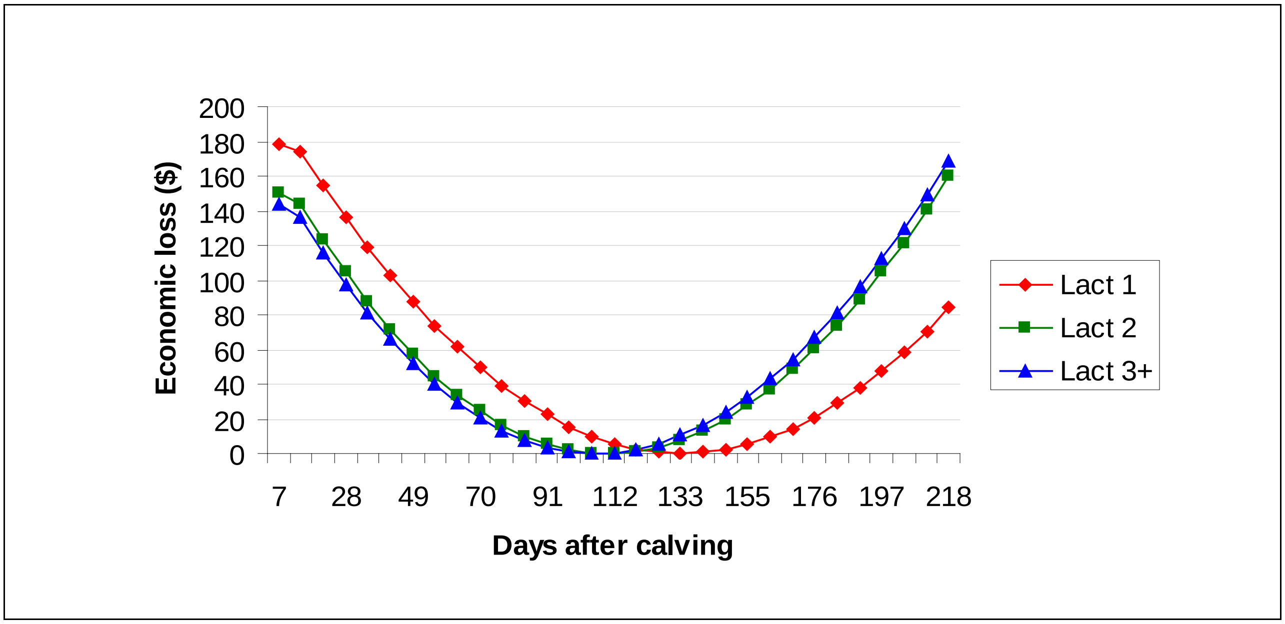

Figure 4. Economic loss ($/cow) caused by conception earlier or later after calving compared to the optimal day of conception. The optimum days of conception were 133, 112, and 105 for first, second, and third lactations, respectively.

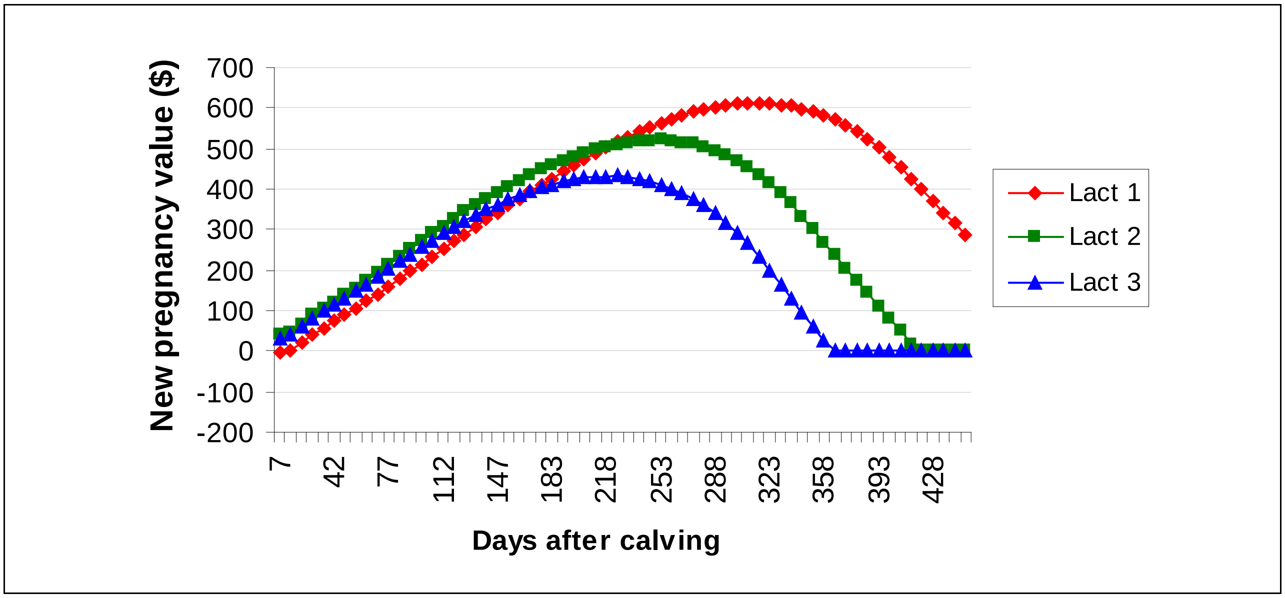

Figure 5. Value of a new pregnancy by days after calving and parity.

Value of a new pregnancy

Figure 5 shows values of a new pregnancy by days after calving for the first three lactations for the default assumptions. The value of a new pregnancy increases during the course of the lactation until late in lactation when it starts to decrease again. For cows that differ in individual milk production, the value of a new pregnancy is greater for low producing cows early in lactation, but their peak value is lower and earlier than higher producing cows.

Economic aspects of herd replacement

Looking at cows as assets, they get "used up" and need to be replaced by new assets. **Figure 6** shows that on average cost to 40% of cows get replaced every year. Because in the US almost all heifer calves are raised to replace culled cows, nationally the annual cow cull rate is equal to the number of heifers raised. This is more a reflection of the success in raising heifers and herd reproduction, than it is a signal of poor herd health. Nevertheless, statistics show that too many cows are culled due to poor health.

Replacement cost is intended to represent the cost of maintaining herd size and structure (Bethard and Nunes, 2011). The best measuring stick of successful herd replacement is replacement cost/cwt, calculated per herd as [(total value of cows sold – total cost of replacements) / cwt milk sold]. A reasonable goal in most areas of the country is <$1.50/cwt (Bethard and Nunes, 2011). Replacement costs are low when cull rates and low, and/or when the difference in price between raising or purchasing heifers and culled cows is small. On the other hand, low replacement cost could mean that the farm hangs on to some cows too long and also produces fewer cwt of milk. Thus, replacement cost/cwt could be too low.

Currently, USDA values one month longer productive life at $35 in their genetic selection indices lifetime Net Merit, (NM$) Cheese Merit and Fluid Merit (Cole et al., 2009). This economic value is largely determined as (calving heifer cost - salvage value) / productive life, although the exact inputs have not been published. For example, ($1800 - $600) / 36 months = $1200 / 36 = $33. The $35 used in the NM$ selection index is strictly the value of the long term replacement cost. It does not include the additional cost or revenue from keeping the animals longer. For example, a reduction of the incidence of metabolic diseases might increase milk yield and fertility, which have value on their own in addition to their effect on culling and replacement cost.

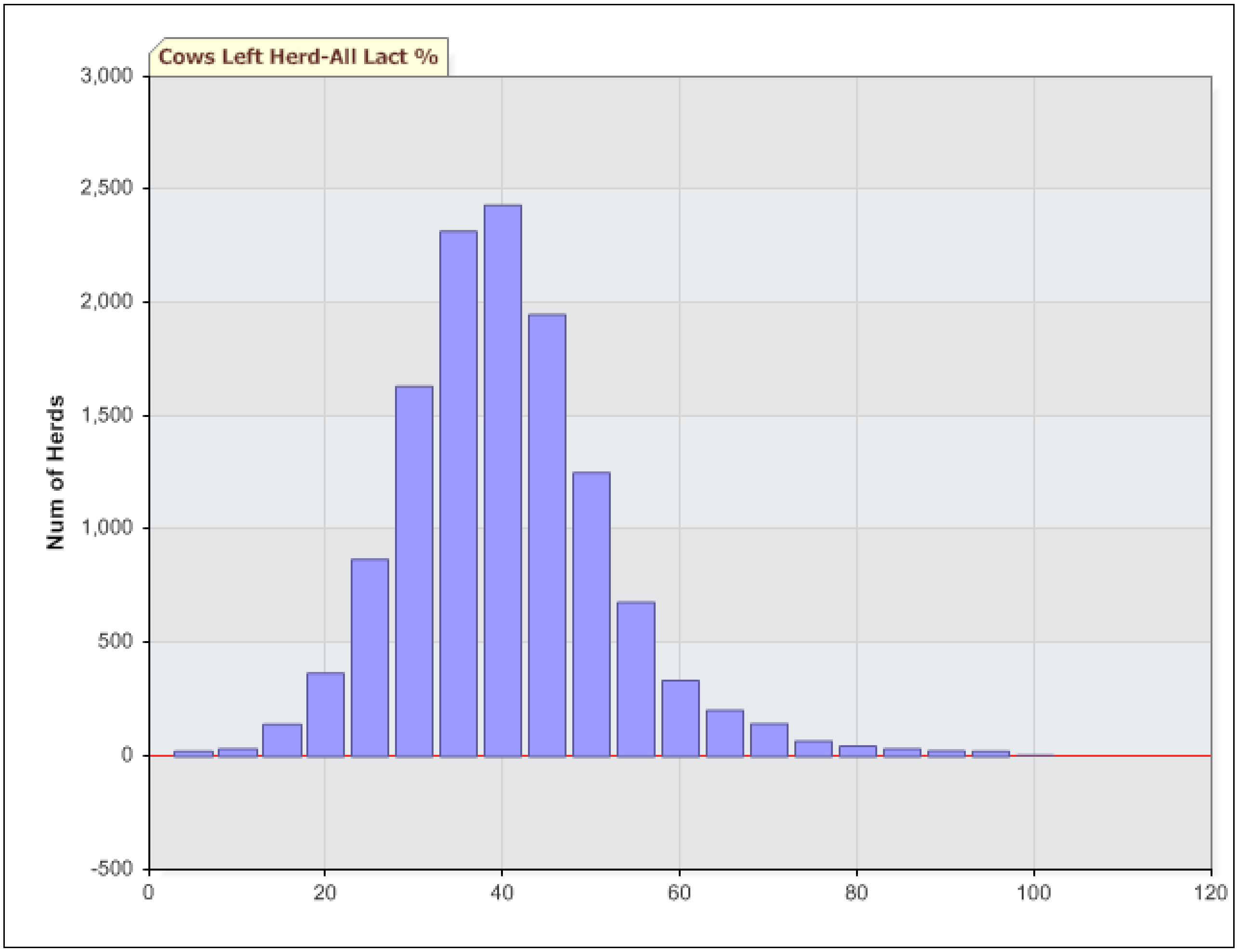

Figure 6. Distribution of annual cow cull rates reported by DRMS (2013) for 14,000 Holstein herds located primarily in the eastern USA. Data compiled on October 5, 2013.

Ranking cows for culling decisions

Ranking cows for replacement decisions, as well as determining the value of cow longevity, is not a trivial task. Assuming a constant herd size, the marginal future profit of a present cow has to be weighed against the average profit of a replacement young cow that could be obtained in that period (Zeddies, 1972). Thus, the economic criterion of the replacement decision in a herd with constant size is: a cow of a particular age should be kept in the herd as long as her expected marginal profit is higher than the expected average profit during a replacing young cow's life (Renkema and Stelwagen, 1979).

A large number of computer programs have been developed that optimize culling decisions as well as rank cows for future profitability, also known as retention pay-off (RPO). Optimized culling decisions are assumed to give better estimates of costs of for example diseases. These optimization programs commonly assume that profit per cow per time period is maximized in a herd of a fixed number of cows with an unlimited supply of replacement heifers. Often the optimal cull rate (and hence cow longevity) was not the main focus of these studies.

The referenced models calculate RPOs for individual cows that are used to rank cows for culling. The RPO is defined as the net present value of keeping the incumbent cow in the herd until the optimal time of replacement, compared with replacing her now with a replacement heifer. For both the incumbent cow and the challenging heifers and her replacements, future cash flow projections need to be made. An RPO of <$0 means that the incumbent cow should now be replaced. If the RPO is for example $500, then replacing the incumbent cow now with a calving heifer amounts to a loss of $500. **Figure 7** shows RPOs by days since calving for first parity cows with low (90% of average), average, and high (110% of average) milk production throughout the lactation. The RPOs for both open cows and cows that became pregnant on day 61 after calving are shown. The patterns in **figure 7** suggest that the RPOs of open cows decrease as they fail to become pregnant over time. This decrease is primarily a function of the shape of the lactation curve. The low producing cow reaches a negative RPO 6 months earlier than the high producing cow. Pregnant cows are more valuable than open cows (except for early gestation in the high producing cow which suggests delayed breeding is advantageous) and the difference increases with stage of lactation. The RPO is generally also lower for older cows and pregnant cows that conceive later in lactation.

When the RPO of open cows reaches $0, the milk sales minus the variable cost for that cow that day are typically still positive, in the order of $1 to $3 (De Vries, 2009). However, when milk prices are temporarily very low (resulting in negative profitability), the RPO can still be positive when milk income minus variable cost is $0. Such cows do not generate enough milk sales to cover their variable costs any longer. But there is still a chance that they get pregnant and reach the next lactation. Although these pregnant cows would have to go through an extended period of low milk production, at a very low milk price, this option is still less costly than culling the cow and replacing her with a heifer. The farm would have to decide if it wants to remain in business until the milk prices increase again.

This general RPO is an estimate of the value of keeping the incumbent cow in the herd, accounting for future risks of forced culling, and assuming that an average replacement heifer will take the place of the culled cow as soon as her RPO becomes negative. The RPO also represents the expenses that could be made to keep the cow in the herd if she faced a health problem. The economic loss of a dead cow is equal to her RPO at the time of death plus the missed beef income if the cow was culled alive.

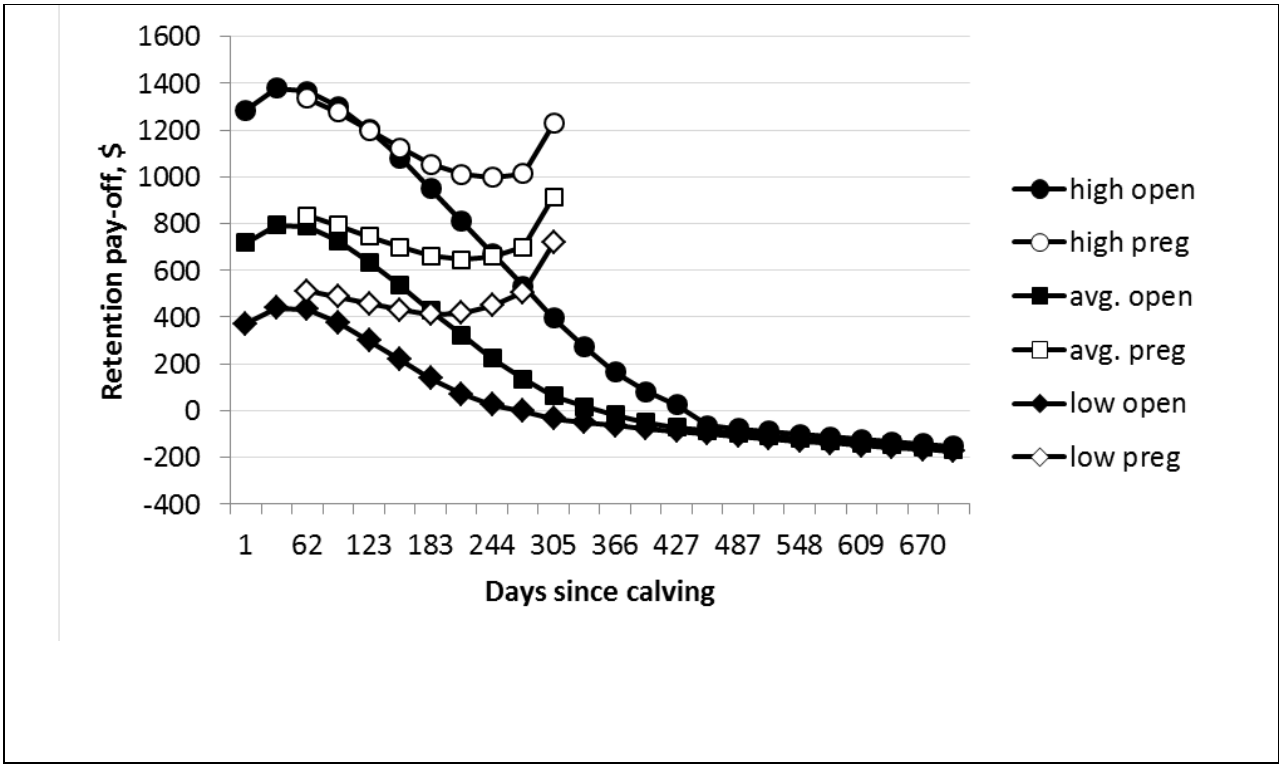

Figure 7. Retention pay-offs (RPO) by days since calving in monthly increments for first parity cows with low (90% of average), average, and high (110% of average) milk production throughout the lactation. The cow should be replaced when her RPO < $0. The RPOs for both open cows and cows that became pregnant on day 61 after calving are shown. Results were calculated with the model of De Vries (2008) with inputs for a typical dairy farm in the US in 2013.

The referenced optimization programs assume that there is no shortage or surplus of replacement heifers and optimize profit per stall. The assumption of fixed herd size is common. **Table 3** is an example of herd statistics calculated with the model of De Vries (2008) including updated prices under typical US conditions and an optimal, unrestricted, replacement policy. Sensitivity analyses were performed with cull prices ($1.20 to $2.00 per kg body weight) and 21-day service rates (45% to 75%) as a measure of reproductive performance. Key findings are the sharp increase in annual cull rate from 35% to 57% with higher cull prices, and a small decrease in cull rate (35% to 31%) with increased reproduction. Thus, higher beef prices reduced productive life and better reproduction increased productive life. However, in practice improved reproductive efficiency is generally not associated with lower cull rates (extended productive life).

Table 3. Herd statistics for an optimal cow replacement model under US conditions depending on cow cull price or 21-day service rate.

	Cull price ($/kg body weight)			21-Day service rate (%)		
Herd statistic	$1.20	$1.60	$2.00	45%	60%	75%
Profit ($/cow/year)	316	400	510	316	350	370
Milk yield (kg/cow/year)	11872	12019	12222	11872	11919	11946
21-Day pregnancy rate (%)	18%	18%	18%	18%	24%	30%
Cull value ($/head)	658	890	1124	658	647	639
Cow sales/cow/year	229	375	644	229	211	200
Replacement cost ($/cow/year)	327	299	273	327	311	301
Annual cull rate (%)	35%	42%	57%	35%	33%	31%
Calvings (#/cow/year)	1.05	1.11	1.21	1.05	1.07	1.08
Heifers raised (#/cow/year)	0.43	0.45	0.49	0.43	0.44	0.44
Heifers entered (#/cow/year)	0.35	0.42	0.57	0.35	0.33	0.31
Surplus heifers (#/cow/year)	0.08	0.03	-0.08	0.08	0.11	0.13
Productive life (months)	34.5	28.5	20.9	34.5	36.7	38.3

Source: model of De Vries, 2008 with updated prices for 2013

A few economic aspects of stocking density

Cows perform best when they are not overcrowded, for example by having access to one stall per animal. But economics show overall profitability is higher when pens are overstocked. Dechassa (2012) studied the effects of overstocking on cow performance such as milk production and reproduction, as well as welfare measures. Adding more cows to a pen with a fixed number of stalls reduces milk production and fertility, but the total profitability of that pen may still be greater due to the marginal value of the additional cows. These additional cows don't have to pay for the fixed cost that do not change when a few more cows are added to the pen. Examples of cost that may not change (much, if at all) are mixing and delivering the feed, barn depreciation, utilities, and some of the labor. Thus, the revenues minus additional costs of the added cows is typically high. However, the added cost will reduced performance of the cows already in the pen.

Using some typical prices and a considering the effect of stocking density on milk production and fertility, Dechassa's analysis showed that the baseline profit was about $173 per stall at the 90% stocking density. Additional profit per stall per year climbs from about $28 at 100% stocking density, to a peak of about $40 at 120% stocking density. It drops back to $32 per stall at 130% stocking density, $18 per stall at 140% and goes negative at 150% stocking density (**Figure 8**). Lower variable costs and high milk prices increase optimum stocking rate and profit per stall per year. Fixed costs impact overall farm profitability but not optimum stocking rate. Animal welfare is reduced at the economically optimum stocking rate when it exceeds one stall per cow. However, at 120%, there is not much loss in welfare.

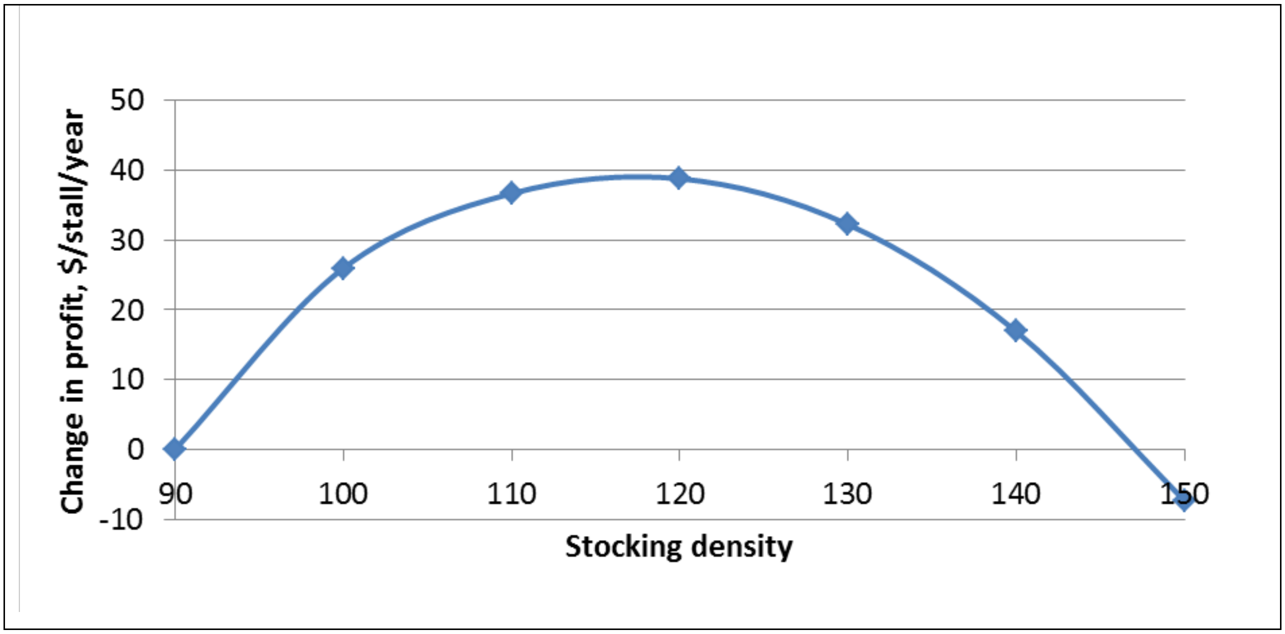

Figure 8. Change in profit per stall per year with varying stocking density. The maximum was 120%, which implies 120 cows per 100 stalls.

Used references are found in the following publications:

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