Sexed Semen: economics of a new technology

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Almost since the advent of AI breeding, producers and researchers alike have anticipated the development of the ability to sort or select semen in order to produce more female offspring. This technology is now a commercial reality thanks to technological developments in recent years that have improved cell sorting capabilities.

There have been various approaches developed that allow researchers to separate bovine semen into fractions containing higher than normal concentrations of X-bearing sperm. These technologies include the use of gender specific antibodies, centrifugation, free flow electrophoresis, and flow cytometry. Of these, the only proven method to date for separating X- and Y-bearing sperm in a manner that has commercial applications has been flow cytometry. This method was first used in the 1980's, but early results produced dead sperm. Johnson et al. helped refine the technique of using fluorescence-activated cell sorting (Johnson et al, 1987 and 1999). The current method of using flow cytometric techniques for sperm sorting was licensed to XY, Inc (www.xyinc.com) for commercial development. This approach uses technologies developed by U.S.D.A., Colorado State University and DakoCytomation, which is a company that develops advanced flow cytometers for commercial development.

Briefly, the process involves identification of differences in DNA content (Weigel 2004, DeJarnette 2005). X-bearing sperm contain 3.8% more DNA than the Y-bearing counterparts. Sperm is diluted to a very low concentration and then stained with a harmless DNA-specific fluorescent dye. This dilute and dyed sperm sample is then sent through the flow cytometer at speeds of approximately 60 mph under pressures of 40-60 psi. The sperm are aligned in a special manner, single-file and are passed through a laser beam. The stained DNA emits fluorescence and a difference in the amount of fluorescence is detected. In order for this process to work correctly, sperm heads must be precisely oriented during the cytometric evaluation by using a specially designed beveled nozzle. Without the proper orientation, differences in DNA content can not be accurately determined. The concept of sperm orientation is specifically protected under the Johnson patent, held by the USDA and licensed to XY Inc.

Depending upon the relative amount of florescence (based on relatively small differences in DNA content), positive or negative charges are applied to each droplet that contains a single sperm. Sperm then pass through charged deflector plates and positively charged particles go one direction, negatively charged in another, and uncharged droplets pass straight through. The uncharged particles may contain multiple sperm, uncharged sperm of either sex, or potentially damaged material. The result is a process that is able to repeatedly separate sperm with 85-90% purity. Commercialization of sexed semen using this sorting process in the U.S. was initiated with a 2003 license granted to Sexing

Technologies, Texas and this company is currently partnering with several semen companies in the U.S. and abroad (De Jarnette 2005 and Dr. Ray Nebel, personal communication).

As one might expect, running individual sperm through in single file, even at speeds of 3,000 to 5,000 sperm per second, takes some time and the process results in a reduced final sperm count of undamaged, progressively motile sperm of the desired sex as compared to the original starting sample. As a consequence of time, potential for sperm damage, and much less than 100% efficiency, only about 10-15% of the original sperm sample entering the machine are recovered as marketable, sexed product. Thus, commercially available straws contain only about 2 million sperm, as compared to traditional semen straws which contain closer to 20 million.

Due in large part to the reduced sperm count of sexed semen, fertility of the final product, as determined by conception risk in virgin heifers, is reduced by approximately 30%. The resulting semen generally has had a much lower conception rates than conventional AI semen. Conception rates in virgin heifers of 55% to 60% with conventional semen and 35% to 40% for sexed semen have been reported (Weigel, 2004). With the limited supply of GES, its higher cost, and its significantly lower conception rates, GES has thus far largely been applicable to only special niches in breeding in the dairy industry, such as embryo transfer, special matings for producing very high merit offspring, or limited use in virgin heifers.

With conventional semen, only about 35% – 38% of conceptions (at 40 days pregnant) result over the long term in a fertile female offspring that reaches her first lactation. Therefore, the availability of replacement heifers has been a production constraint for many dairy farms. If more heifers were readily available, farms could increase their herd replacement rate to some degree. This relative shortage of available heifers has played a key role in the unusually high market prices (prices in excess of the cost of production) of replacement heifers in the past several years in the U.S.

Since January 2001, the quarterly national price of replacement heifers has ranged from $1,300 to $1,870, with an average of $1,561. The lower end of the range probably represents the floor in price set by the cost of rearing a replacement heifer; the higher end reflected unmet demand driven by the value of filling empty slots on a dairy farm. (Midwest DairyBusiness 2005).

If sexed semen becomes more widely adopted, managers of dairy herds will be able to breed to produce more replacements, to source replacements from their best cows, or both. By using sexed semen on enough of the herd's cows, sufficient female heifers for replacements could be more easily achieved. With sexed semen that can produce approximately 85% female offspring (female sexed semen), roughly 65% of all calvings would produce a 2 year old pregnant replacement heifer. If roughly 60% of all cows were bred with sexed semen, those breedings could supply more replacements than the current national rate (0.60 * 0.65 = 39%). In this case, as many as 40% of all breedings would not be needed to produce replacement heifers (although they would still be necessary to return cows to another lactation).

Sexed semen will likely lead to a strategy where the top genetic merit cows (or nulliparous heifers) in a herd are bred with sexed semen, middle genetic merit cows (or heifers) are bred with conventional AI, and the bottom merit cows (heifers) are bred by some inexpensive means without intending to raise females born from those bottom end breedings.

For most dairy farms, there will be considerations that extend beyond simple biology of the technology and direct economic considerations. For many farms, the option of increasing the number of growing heifers is not just a question of long term profit, but also one of day-to-day operations. Many farms do not have the facilities, feed, labor, or capital needed to rear many more heifers. For those that contract heifer rearing off site, however, these may not be significant barriers. The payoff for the investment in sexed semen breedings happens further out into the future; cash flow constraints at the time of breeding may limit the amount of investment in sexed semen. For many dairy farms, environmental regulations and permitting restrictions would mean that more heifers on the site would require reducing the number of adult cows. In most circumstances, this would not be desirable. Finally, by investing in more sexed semen breedings that produce more heifers in a given year, the dairy farm might convert cash profit into long term assets, postponing taxes and converting ordinary income into capital gains in the long term.

Supply and price of replacement heifers

There are about 9 million adult dairy cows in the U.S. today. (USDA NASS 2006). That number is slowly declining as the dairy industry consolidates into fewer herds that produce more milk per cow, on average. Each year fewer than 4 million cows are replaced by new first lactation replacement heifers. Current prices for heifers are at a historical high because the demand for heifers, particularly by large herd expansions, has driven the price up far past the simple cost of rearing a replacement heifer. Currently, female heifer calves born in the U.S. are a limiting resource for the dairy industry, limited by the rate at which female calves are born from breedings with conventional semen and survive to calving. In the past, the shortfall in U.S. heifer production was partially buffered by heifers imported from Canada; however bovine spongiform encephalopathy (BSE) has ended that supply and has contributed to the very high current heifer prices. The loss of the Canadian market has removed about 75,000 heifers from the supply (DairyLine Archives 2005).

Once female sexed semen is adopted across a large enough portion of the industry, there will be an adequate supply of female dairy calves born to meet the demand for replacements. In all likelihood, only a small to moderate use of female sexed semen will increase the supply of replacement heifers enough to satisfy the demand, but the impact will not happen quickly. It will take a minimum of three years from the first significant introduction of the technology for sexed semen-derived heifers to arrive as replacements (about 1 year for breeding and gestation, plus 2 years for growth). In addition, adoption will inevitably be gradual, due to initial supply limits on female sexed semen and also because of all of the normal constraints to adoption of any new technology. Coupled with the fact that most dairy farms breed all year so no more than $1/12^{th}$ of a herd are available to be bred in any given month, the actual upturn in supply of replacement heifers will probably occur only gradually over a period from three to four years and longer after initial introduction of female sexed semen.

As the supply of replacement heifers rises and meets the demand, the price of heifers will drop to an equilibrium price driven by the cost of the newborn female dairy calf, the cost of rearing, and profit for the heifer raiser. We expect that in the long run the price of an average replacement in the market will drop to within a range of $1,300 to $1,500. This is consistent with published studies of the cost of rearing heifers, anecdotal reports from heifer raising operations, and the data on heifer prices in this decade that showed national average prices as low as $1,300 and prices below $1,500 for 40% of quarters since January, 2001. Once the price of replacements drops to nearly the cost of rearing, breeding for extra heifers beyond the herd's replacement needs would only make sense if the dairy farm can earn a premium above the general market price (e.g. for superior genetics or health) or could raise heifers for notably less than the average producer. Instead, it may be appropriate to breed poorer cows in the herd for other purposes, perhaps to produce crossbred beef calves.

As sexed semen first becomes available in a period when market prices are considerably higher than the cost of rearing, early adopters may reap a brief advantage as they sell excess heifers in a market where the price is still high from the temporary limitations in supply, but this opportunity will probably not be prolonged and has other limitations discussed below.

Herd replacement rates

As noted above, an increase in the supply of replacement heifers following the introduction of sexed semen will likely reduce the price of replacements. At a lower price, more cows will warrant replacement on many dairy farms. There will probably be an early phase where more cows are culled in response to the new, larger supply of heifers. With more available heifers, herds might be able to cull more cows that don't justify their presence in a "slot" on the dairy farm. This may mean that herd turnover rates would go up, to the economic advantage of the farm. The long term equilibrium culling rate will be driven by economics and preliminary modeled estimates run at $1,300 for a replacement heifer suggest that they will probably not be markedly different from the rates today, even if more heifers could be available because of female sexed semen. (Dr. Albert de Vries, personal communication). Given this, the overall current demand for heifers in North America will look much like it does today.

Over the long term, there will probably not be a significant overall increase in the nation's herd turnover rate beyond what has been observed in the industry several years ago when heifer prices were at a more moderate level. Optimum herd turnover rates will still be fundamentally driven by the complex mix of milk price, cost of replacement heifers, cull cow prices, and other factors specific to the particular herd at a given time. The need to properly care for cows and to preserve their value in the herd will not change.

Biosecurity

Sourcing replacements from within the herd helps the producer avoid the risk of introducing or increasing the prevalence of infectious diseases that could accompany outside replacements. In addition, heifers raised under the control of the home dairy farm will be adequately vaccinated according to the farm's protocols. Finally, home raised heifers will have been exposed to pathogens in the farm's environment and will therefore be more likely to have some degree of immunity at the time of their first calving. If the market for replacement heifers becomes more competitive, some of these biosecurity advantages may also be captured by dairy farms that purchase replacements, since competing heifer suppliers may differentiate themselves by supplying better quality heifers and paying added attention to heifer immune and disease status.

Fewer Dystocias

Dystocia in cattle has several negative impacts. Dematawewa (1997) reported an incidence of dystocia of 19% in first parity animals (dystocia score of 3 or higher in a 5 point scale) and 6.8% in later parities. Overall dystocia rates were 13.9%. Losses following dystocia included lost milk, fat, and protein yield in the lactation following, added days open, additional inseminations, and cow and calf deaths. Using data from that study, the average cost per case of dystocia was $147 per case with score 3 or greater. Van Tassel et al (2003) reported dystocia incidence rates of: parity 1: 10.9%, parity 2: 5.5% and parities >2: 5.15%, parities >1: 5.3%, overall: 7.7%. . In a two large studies on dystocia (19,793 and 31,367 calvings, Cady found a dystocia rate (calving score of 4 or 5 on a 5 point scale) of 7.4% for female calves and 17.4% for male calves in primiparous heifers and 2.4% for female calves and 5.3% for male calves for multiparous cows. Data from these studies are adapted for Table 1.

Since the use of sexed semen will produce proportionally more female calves and because female calves, being smaller on average, might lead to fewer dystocias, sexed semen use might reduce the rate and cost of dystocia on dairies. While possibly true, the overall impact of a change in dystocia rates is likely to be small. The effect, if any, will fall only on those cows bred with female sexed semen. If some of the herd were bred to beef sires (or perhaps male beef sexed semen to produce more beef bull calves) some of the effect may be counterbalanced by corresponding changes in risks in these other cows.

A simple model of the impact of dystocia with reasonable assumptions is shown in Table 1. The use of sexed semen for breeding nulliparous heifers reduces the dystocia rate by 3.7%. The value of that reduction per calving is $5.38. The savings per unit of semen is $2.34. For breedings in milking cows, the reduction in dystocia rate is only 1 % and the savings per calvings is $1.48. The savings per unit of semen is $0.45. Assuming a reasonable distribution of parities in the herd (37% first lactation, 63% older cows), the overall impact of 100% sexed semen use versus 100% conventional semen use would be a reduction in dystocias of 2%, a savings per calving of $2.93, and a savings per unit of sexed semen of $1.00.

It is unlikely that sexed semen will be used on every animal to be bred, so these effects will further reduced in a herd by limited use of sexed semen. If reasonable estimates of the rate of sexed semen use by parity in the herd are made (Table 1), the herd level impact of sexed semen use on dystocia is quite small: a reduction in dystocias of only 0.6% and a savings per calving of only about one dollar. Therefore while sexed semen use will have an impact on dystocia and its attendant consequences, the impact will be small enough that it should probably not be the principal driver for sexed semen use.

Genetic Selection for Other than Production Traits

Because genetic advance in traditionally selected traits will be accelerated by sexed semen, there will be an opportunity to add other traits to the selection criteria for AI bulls. Effort could be made to select for better performance in areas such as mastitis, stillbirths, feet and legs, udder conformation, and reproduction. Broadening the number of traits selected for will reduce the rate of gain in any particular trait, but the overall rate of genetic advancement will be accelerated.

Embryo Transfer

It seems very likely that once sexed semen is available at any reasonable price, the embryo transfer industry will shift entirely to sexed semen, at least presuming that the desired sires are available. In general, embryo transfer breedings have a clearly defined preferred gender outcome and sexed semen will make a significant contribution to those breedings. Sexed semen may also find some use for in-vitro fertilization of ova harvested from ovaries retrieved at slaughter from top genetic merit cows.

Culling Growing Heifers

With sexed semen, dairies might more readily cull poor performing growing heifers, avoiding the losses associated with bringing them into the herd only to have them perform inadequately as milking cows as well. This might include heifers with chronic pneumonia, heifers too slow to conceive, or heifers positive for specific diseases.

Extended Lactations

At least hypothetically, if a dairy were otherwise assured of enough pregnancies for replacements, they might delay re-breeding cows, extending their lactation, increasing the proportion of adult life spent milking (not dry), or even reducing a cow's total number of lactations and thereby avoiding the risks of the transition period. This is possible because with sexed semen fewer calvings per cow per year are needed to provide adequate replacements for the dairy. Given current lactation performance and the natural decline in production across the lactation, this seems unlikely to be a desirable strategy. If this were a profitable strategy for some cows, one would expect it to already be done across the industry to some degree, with the extra replacements purchased from other dairies. The fact that this is not a prevalent strategy on dairies suggests that the value of early lactation peak milk is simply too compelling and timely re-breeding and returning to early lactation after another calving is too valuable.

Specialized dairy sectors

For some specialized dairy sectors, the value of replacement heifers may remain significantly above the cost of rearing, making sexed semen more valuable. Organic dairies, for example, may have continuing demand for replacement dairies that qualify as organic animals for sale to other dairies wishing to convert to or expand their organic production. This type of situation may also apply to breeds with smaller base populations but growing popularity, for example some of the breeds being used in crossbreeding programs and for grazing dairies. These opportunities are likely to remain as relatively small sectors of the total U.S. dairy production market.

Economic evaluations

Table 2 shows a model of the economics of sexed semen; simple and wrong. This sort of evaluation is appealingly simple approach to the question of how much sexed semen is worth. It assumes that all cows (or in this case heifers) bred will get pregnant and deliver a live calf, that all calves are either sold at birth (bulls and freemartins) or grow to become replacements (heifer calves). This approach, particularly if applied to today's prices for replacement heifers, can show a respectable profit per unit of semen, in this case $22, given a price differential of $30 (conventional AI @ $10 and sexed semen @ $40). Unfortunately, the model leaves so much out that its conclusions are not useful. The model is included in this discussion only to serve as a warning against such a simple evaluation.

Table 3 shows a slightly more complex model that begins to account for losses of pregnancies, deaths of calves, etc. In essence, the model describes the economics as follows. This model follows the population to be bred through its breeding cycles, allowing sexed semen to be used for a specified number of initial breedings and then conventional semen for later breedings. Expenses include the cost of the semen, a charge for extending the age at first calving for using sexed semen (some heifers will calve at a later age in the sexed semen bred group), and adds the cost of culls of those few heifers that remain open at the end of the allowed breeding period. The model also more accurately accounts for the loss of heifer calves after birth up to their first calving. For the possible pool that could be bred with sexed semen, animals could be bred at only their first insemination or for more inseminations (this model allows up to 6 cycles to be bred with sexed semen, breeding any remaining open animals with conventional semen). Conventional semen will result in more pregnancies than sexed semen if a limit is set to how long heifers are eligible to be breed (set in the model at 8 cycles or a 168 day breeding window). This makes the differential in conception rates between the two types of semen a critical factor in determining their relative value. Some pregnancies are lost, some calves are stillborn, and some living calves die or fail to get bred; all factors that reduce the number of productive heifers that result from the breedings. Only these living, pregnant springing heifers bring significant value from the female embryos from a conception. On the other side of the gender divide, bull conceptions suffer similar losses up until a living bull calf is born and can be sold.

Springing heifers and bull calves sold constitute the principal revenues in the model. The expense side of the evaluation includes the costs of the semen (the differential cost is also a key factor), and the cost of raising those females that live to become springers.

Given this model and conditions that apply to breeding nulliparous heifers (60% conception with conventional semen; 45% with sexed semen) and a $30 price differential, using sexed semen loses $35 per heifer that enters the breeding pool even with a price of $1,800 for a springing heifer (Table 3). Figure 1 shows the two scenarios across a variety of price and conception rate differentials. As the graphs show, if heifers sell for $1,800 sexed semen using this simple model is only profitable at fairly low differentials in price (probably less than $15 added cost for sexed semen) and at low differentials in conception rate (less than 10% difference). This model assumes that heifers would be bred with sexed semen during as many as the first 6 cycles after the start of breeding. This was set based on sensitivity analyses that showed this to be the best level of potential utilization given the other input constraints and when the potential for genetic gain is included (described later in the paper). Using only this model that depends primarily on returns for extra heifers (as shown in Table 3), the optimal use of sexed semen would be to use it only on the first breedable cycle. In that case, the loss per heifer in the breeding pool is only $9, not $35.

This second model serves to frame the outside borders of possible value of sexed semen, but there are still important aspects not considered. The results displayed in Table 3 is based on a value of a springing heifer of $1,800; i.e. conditions as they now exist where there is an intense demand for replacements. Even under these positive market conditions, sexed semen can only be profitable if there are very small differentials in the price of sexed semen and small impacts on conception (Figure 1). If there were an adequate supply of heifers and the value of a springing heifer were to drop to $1,400, the value of sexed semen would drop further to a loss of $114 per unit of semen (given the modeled assumption). At this latter, likely steady state, situation the use of sexed semen never achieves profitability based solely on the value of the extra heifers produced.

All of the foregoing is been based on breeding nulliparous heifers that have relatively high conception rates. This tends to minimize the negative impact of reduced conception rates with sexed semen. If the same models are run but the conception rates in adult cows are used (e.g. 35% with conventional semen and 25% with sexed semen, and with some other input adjustments to reflect conditions for cows), the economics of sexed semen becomes even more difficult. The loss per cow bred based only on the value of extra replacements is now $88. If replacements are only worth $1,400, the loss per cow is $141. If sexed semen is only used for the first breeding in cows, these numbers can be reduced to losses of $21 and $33, respectively, but losses none the less.

The deterministic outcomes of these models that seek to justify the value of sexed semen on the basis of increased female offspring are obviously dependent on the input assumptions shown in Tables 2 and 3. Sets of assumptions can be contrived that generate a positive profit from sexed semen based primarily on the value of the extra heifer calves born, but to do so one has to select an array of fairly unlikely input conditions, given current dairy management and sexed semen technology. None of these models factor in the value of sexed semen to a dairy in terms of biosecurity.

Incorporating genetic gain

If sexed semen seems so hard to justify based on the extra heifer calves it produces or by reducing dystocia, are there other aspects to the value that justify its use on dairies? The answer is yes, although the arithmetic becomes more complex and will require more sophisticated management than a simple rule like “breed virgin heifers on their first service with sexed semen”. The key to the value of sexed semen lies not in the opportunity to simply have more heifers; it lies in the opportunity to have better heifers.

If a dairy uses sexed semen to breed cows without attention to genetic merit (as assumed in the models considered above), then there is no genetic gain from the “cow side” of the breeding, but only from the “bull side” (i.e. the relative genetic merit of the bull used compared to the average cow in the breeding pool). If, however, the dairy could source more of its heifer replacements from the better cows in the herd by using sexed semen to breed those cows, then the dairy would gain genetic merit from those female offspring from both sides of the breeding.

Since the genetic merit of cows on a dairy are normally distributed, one can calculate the average genetic merit of any subpopulation of cows. Figure 2 illustrates such a distribution. Population of cows to be bred can be segmented into three parts. The “top end” of the distribution of dams could be targeted for breeding using sexed semen producing more replacement females of higher genetic merit. Below a certain level, dams could be bred with conventional (and less expensive) conventional semen. If properly managed, these two upper populations of better cows could produce enough replacements to meet the needs of the dairy, or at least to match the number of replacements produced if the entire breeding population were bred using conventional semen. Given that the needs for replacements has been matched, the remaining “bottom end” of dams could be bred in a variety of ways. If also bred with conventional semen, any resulting female offspring could be sold as calves or raised and sold as marketable replacements, depending on market and farm conditions.

This next level adds considerable complexity to the issue. It is no longer an issue of “use sexed semen” versus “use conventional semen” on the breeding pool. First, the dairy must be able to reliably rank its breeding pool based on genetic merit. Many dairies cannot do this or can do so only with a large degree of error. For those who can rank genetic merit with some degree of reliability, the question now becomes one of degree, not absolute. For most dairies, it would be profitable to use sexed semen for the first insemination on the best dam in the breeding pool. It would not make sense to use sexed semen for the eighth breeding of the worst female in the population. The important question is: where is the cutoff between these two extremes? The answer is not simple, and as always in matters of economics, it depends on a host of factors that impinge on the decision.

Table 4 shows part of a complex deterministic economic model that considers this question. It builds off the model shown in Table 3, but includes the economic impact of accounting for the value of genetic gain in the replacements sourced by the partial use of sexed semen, compared against the baseline of all conventional semen use. In the example shown, the top 30% of virgin heifers are bred using sexed semen (in this case for up to as many as 6 cycles), the bottom 70% are bred with conventional semen. That top 30% suffers the loss of $35 per animal in the sexed semen breeding pool discussed above, resulting in a net loss of $11 (0.30 * $35) per animal in the total pool. As a result of the improved genetics of the selected population producing replacements, however, there is also a gain of $32 per heifer in the total pool. The net gain per heifer in the pool is $32 - $11 = $22 profit per heifer (the numbers suffer from the appearance of error due to rounding in display). Thus under these conditions (including a heifer price still or $1,800), it would be profitable to use sexed semen on the top 30% of the virgin heifers in the breeding pool. But is this the optimal proportion to breed with sexed semen?

Figure 3 attempts to answer this question. The bars in the top panel chart show the average profit per heifer in the breeding pool; this is highest if the top 40% of the pool were bred with sexed semen. At that level, the average profit per heifer in the breeding pool is $23. The line in Figure 3 shows the profit per heifer actually bred with sexed semen. Note that the profit can be quite substantial for the very best heifers. Breeding the top 5% has a profit of $145 per heifer thus bred. The foregoing numbers were based on a replacement heifer value of $1,800; if the value drops to $1,400 the situation is quite different. The second panel in Figure 3 shows this scenario; the best average profit is at only 10% utilization of sexed semen and is only $4. Breeding the top 5% of heifers now results in only $65 profit per heifer bred. Thus there are still some top end heifers that are worth breeding with sexed semen, but not nearly as many as at $1,800.

The most profitable use of sexed semen varies depending on how many top end heifers are bred, but also depending on other factors as well. Figure 4 illustrates the impact of the proportion bred with sexed semen and the absolute value of reduction in conception rate from sexed semen. As the figure show, if the impact on conception is small (5%), substantially more heifers should be bred with sexed semen than at higher reductions in conception. If conception rate were reduced by 25% (from 60% to 35%), essentially no scenario of use of sexed semen is profitable.

As noted earlier, sexed semen does not need to be used for every breeding on a heifer. It could be used in the first breedable cycle, the first and second, etc. for up to as many breedable cycles exist. Figure 5 illustrates this relationship, again with heifers valued at $1,800. In this scenario, it pays to breed an eligible heifer more than just on her first cycle (actually 5 to 6 cycles) with sexed semen. If the same evaluation is done with heifers at $1,400, the most profitable use is only during the first breeding. This latter finding tends to be the same for cows; multiple breedings with sexed semen tend to be less profitable than using it only once and then switching to conventional semen. All of this is highly dependent on the genetic merit of the cow and the actual impact of sexed semen on conception. Better conception tends toward more sexed semen breedings.

Broadly speaking, in heifers there are two opposing economic forces at play: genetic gain by breeding top merit animals for replacements versus the costs of delayed calvings, extra heifers culled as open and the cost of sexed semen itself. These costs can be mitigated if extra heifers are worth substantially more than the cost of raising them. Knowing that these are the major influencing factors, one can predict the general direction of the economic outcome, even if one cannot calculate the actual numbers on the back of an envelope. There is a place for using sexed semen in virgin heifers, but that place will depend on farm and market conditions, the price, the conception rate difference, and the ability of the dairy to accurately rank its heifers by genetic merit.

Moving from virgin heifers to milking cows makes everything harder for using sexed semen. In cows, the impact of reduced conception is much larger. The conception rate in cows is lower to start with, and any reduction increases average days open in cows bred with sexed semen and increases the risk that a cow may not get pregnant and be culled. Table 5 shows a scenario with replacement heifers at $1,800, top 30% of cows eligible to be bred with sexed semen, a 10% reduction in conception rate (35% versus 25%), and sexed semen used only on the first breeding cycle. Profits are much thinner than with heifers, on $1 per cow in the breeding pool and $3 per animal bred with sexed semen.

Figure 6 shows the graph for profit by percent of animals eligible for breeding with sexed semen. The "optimal" level is to use sexed semen in the top 20% of cows, but the profits, when there are profits, all hover around $1 per cow. The dairy can find better places to invest its money and energy. Even breeding the top 5% of cows with sexed semen only produces a profit of $19 per cow on an investment of $16 per cow bred with sexed semen. Clearly, the impact of reduced conception in cows is very hard to overcome. In fact, if the impact is larger than a 5% reduction in the absolute conception rate, it is hard to create a scenario that justifies use of sexed semen on any but the very best cows (Figure 7).

It must also be kept in mind that the above values for the use of sexed semen have all depended on the bull being the same for both options, sexed semen or conventional. If the genetic merit of the bull used for sexed semen is less than the genetic merit of the bull used for conventional breedings, then any genetic gain on the cow side is quickly wiped away. In the scenario shown in Table 4, if the bull used for sexed semen were 400 pounds of PTA Milk poorer than the bull used for conventional AI, then the profit from use of sexed semen would drop from $22 per heifer in the breeding pool to only $3.

Summary

Sexed semen is a new and potentially important new technology in dairy reproduction. It offers the promise of a more abundant supply of better replacement heifers, particularly if it can be made more widely available and if reductions in conception rates can be minimized.

Herds with better genetic information for their breeding populations will have an opportunity to capture more value from sexed semen. They will use sexed semen to breed their better dams and make more rapid genetic progress than before. Herds that want to assure a more reliable and better quality of internally grown heifers will use sexed semen to source more replacements and improve biosecurity. Genetic selection can potentially place some emphasis on characteristics not routinely selected for today.

Because of its impact on conception, sexed semen is currently more applicable in virgin heifers than in cows. Its use without consideration of genetic merit is not likely to be cost effective; the gain in value for more heifers does not offset the various costs involved. Significant biosecurity concerns (not considered in any of the models presented in this paper) might tip the balance in favor of more use of sexed semen to produce replacements internally.

The optimal use of sexed semen depends on many economic and biological factors. There is no reliable “rule of thumb” that can dictate proper use across the variety of herds and economic scenarios possible. Proper use of sexed semen will require good genetic information on females in the breeding pool and thoughtful calculation of the best targeted use in top genetic merit candidates.

Table 1. Impact of using sexed semen on dystocia and its costs

Estimating the value of decreased dystocia with gender enhanced semen		
loss per case of dystocia (Dematawewa et al, 1997)	**$147**	
number of calvings	100	
Gender distribution of calvings		
GES breedings		
percent female births from semen	**85%**	
	parity 1	**parity >=2**
single births	99%	94%
twins	1%	6%
single female births	84%	80%
single male births	15%	14%
conventional breedings		
percent female births from semen	**48%**	
	parity 1	**parity >=2**
single births	99%	94%
twins	1%	6%
single female births	48%	45%
single male births	51%	49%
Dystocia rate by gender of calf and parity		
rates developed from Cady, 1977 and 1980	**parity 1**	**parity >=2**
females	7.4%	2.4%
males	17.4%	5.3%
twins	17.5%	6.4%
Dystocias comparing 100% use of each breeding option with a given parity group		
parity 1	**GES**	**conventional**
single females	6.2	3.5
males	2.6	9.0
twins	0.2	0.2
dystocias: parity 1	9.0	12.6
dystocia rate if all breedings used a particular type of semen	9.0%	12.6%
reduction in dystocia rate from using GES: percent of births	3.7%	
parity 2 or greater		
single females	1.9	1.1
males	0.7	2.6
twins	0.4	0.4
dystocias: parity >=2	3.0	4.1
dystocia rate if all breedings used a particular type of semen	3.0%	4.1%
reduction in dystocia rate from using GES: percent of births	1.0%	
reduction in herd dystocia rate given the herd's mix of parities	**parity 1**	**parity >=2**
proportion of calvings	37%	63%
	GES	**conventional**
dystocias in first parity	3.3	4.7
dystocias in parity >= 2	1.9	2.6
total dystocias	5.2	7.2
total dystocia rate	5.2%	7.2%
total reduction in dystocia rate per birth with GES	**2.0%**	
Impact of the use of GES comparing 100% use of each breeding option and herd's parities		
	parity 1	**parity >=2**
savings per calvings from reduced dystocia	$ 5.38	$ 1.48
savings per unit of semen	**$ 2.34**	**$ 0.45**
overall herd savings per calving from possible reduction in dystocias	$2.93	
overall added value per unit of GES semen from reduction in dystocias	**$1.00**	
Impact of GES given a particular breeding mix of GES and conventional semen	**parity 1**	**parity >=2**
percent of calvings bred with GES	**36%**	**24%**
reduction in dystocia rate with actual breeding mix	1.3%	0.2%
savings per calving	$1.94	$ 0.36
savings per unit of semen	$ 0.84	$ 0.11
overall reduction in dystocia across all parities given the breeding mix	**0.6%**	
overall savings per calving in the herd	**$ 0.94**	
Semen use by parity group	**parity 1**	**parity >=2**
units of semen per calving	2.3	3.3
average units of semen per calving in the herd given parity distribution	2.9	

Table 2: Simple and flawed model of the economics of sexed semen

Simplistic and flawed model of the value of sexed semen

100 cows bred

conventional semen		sexed semen	
60%	conception rate	45%	conception rate
167	units of semen used	222	units of semen used
$ 10.00	semen price	$ 40.00	semen price
$ 1,667	cost of semen	$ 8,889	cost of semen
44%	percent fertile heifers	84%	percent fertile heifers
44	number of heifers produced	84	number of heifers produced
56%	percent bulls and freemartins	16%	percent bulls and freemartins
56	number of bulls and freemartins	16	number of bulls and freemartins
$ 1,800	price of a springing heifer	$ 1,800	price of a springing heifer
$ 1,300	cost to rear a heifer	$ 1,300	cost to rear a heifer
$ 500	profit per heifer	$ 500	profit per heifer
$ 200	sale price of a bull calf or freemartin	$ 200	sale price of a bull calf or freemartin
$ 22,000	income from heifers	$ 42,000	income from heifers
$ 11,200	income from bulls and freemartins	$ 3,200	income from bulls and freemartins
$ 33,200	total income	$ 45,200	total income
$ 31,533	income minus semen costs	$ 36,311	income minus semen costs

$ 4,778	**advantage (disadvantage) of sexed semen**
$ 22	**advantage per unit of sexed semen used**

Table 3: Model of the value of sexed semen by following a breeding cohort: heifers

Using sexed semen — 100 cows to breed

$ 30.00	**semen price differential**
15%	**conception rate differential**

Conventional semen

estrus detection	conception rate	
50%	**60%**	1st breeding cycle
50%	60%	even cycles
50%	60%	later odd cycles

45%	percent fertile females per pregnancy		
395	days old at breeding start	13.0	start age in months
8	cycles until DNB	17.8	months maximum breeding age
9%	abortions and stillbirths: heifer calves		
11%	abortions and stillbirths: bull calves		
4%	loss of heifer calves from birth to weaning		
2%	loss of heifers from weaning to first calving		

Sexed Semen

estrus detection	conception rate	
50%	45%	1st cycle
50%	45%	even cycles
50%	45%	later odd cycles

85%	percent fertile females per pregnancy		
395	age at breeding start		
8	cycles until DNB	17.8	max bred age
9%	abortions and stillbirths: heifer calves		
11%	abortions and stillbirths: bull calves		
6	# of cycles using sexed semen		

$ 10.00	conventional semen price
$ 40.00	sexed semen price
$ 2.50	cost of an extended day to calving
$ 1,800	value of a springing heifer
$ 1,300	cost to rear a heifer to calving
$ 125	value of a live newborn bull calf
$ 500	cost of a culled, open heifer
$ 800	money spent: culled heifer
$ 300	value of culled heifer
$ 100	cost of lost heifer calf

Costs

Conventional semen				Sexed Semen				difference	NPV
$ 1,571	conventional semen costs	157	units of conventional semen	$ 184	conventional semen costs	18	units of conventional semen	$ (1,386)	$ (1,386)
$ -	sexed semen costs	-	units of sexed semen	$ 6,963	sexed semen costs	174	units of sexed semen	$ 6,963	$ 6,963
$ 9,123	cost of average days to preg past breeding start	434	ave days	$ 11,060	cost of average days to preg past breeding start	444	ave days	$ 1,937	$ 1,794
$ 2,882	cost of culled heifers in brd. pool	5.8	# culled; **$ 19 diff in age cost**	$ 5,309	cost of culled heifers in brd. pool	10.6	# culled	$ 2,426	$ 2,246
$ 13,576	total costs (meaningless; the difference between the programs is all that matters)			$ 23,515	total costs (meaningless; the difference between the programs is all that matters)			$ 9,940	$ 9,616

$ 9,940 additional costs of sexed semen breeding program

Income

Conventional semen				Sexed Semen				difference	
$ 17,628	net income from heifer replacements	36	# of heifer calves raised to calving	$ 29,745	net income from heifer replacements	61	# of heifer calves raised to calving	$ 12,117	$ 9,619
$ 5,766	income from bull calves	46	# of bull calves sold	$ 1,983	income from bull calves	16	# of bull calves sold	$ (3,783)	$ (3,502)
$ 23,394	total income	82	total calves with value	$ 31,728	total income	77	total calves with value	$ 8,334	$ 6,116

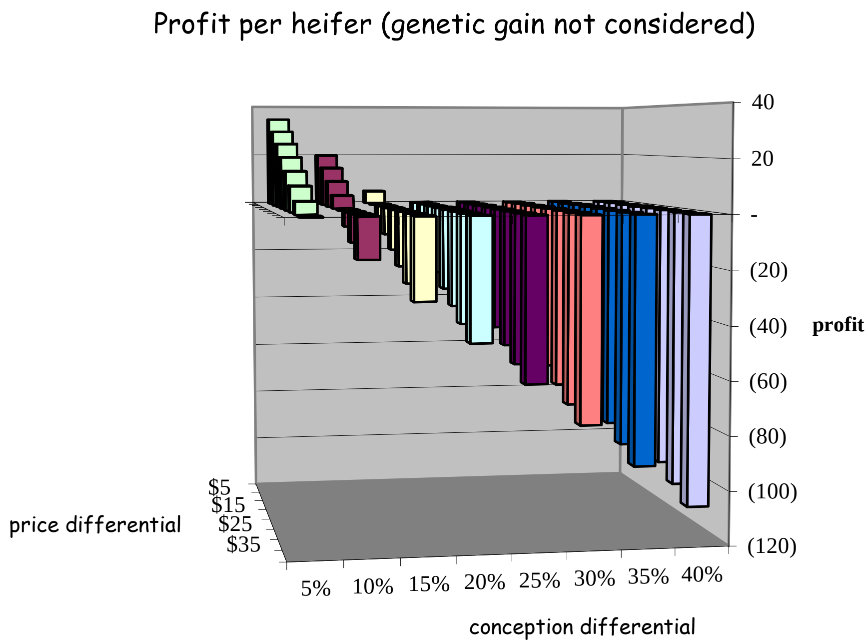
$ 8,334 additional income from sexed semen breeding program

NPV ot total advantage (disadvantage) $ (3,500)

$ (3,500)	**advantage of breeding with sexed semen for the whole breeding program**
$ (35)	**advantage (disadvantage) with sexed semen per heifer entering the breeding program**
-35%	*percent return on additional expenses for sexed semen program*
$ (20)	advantage (disadvantage) per unit of sexed semen used
$ 56	extra semen cost per heifer in the sexed semen program

Figure 1: Model of the value of sexed semen by following a breeding cohort showing the impact of differential in conception rates and price differentials

Heifers



Cows

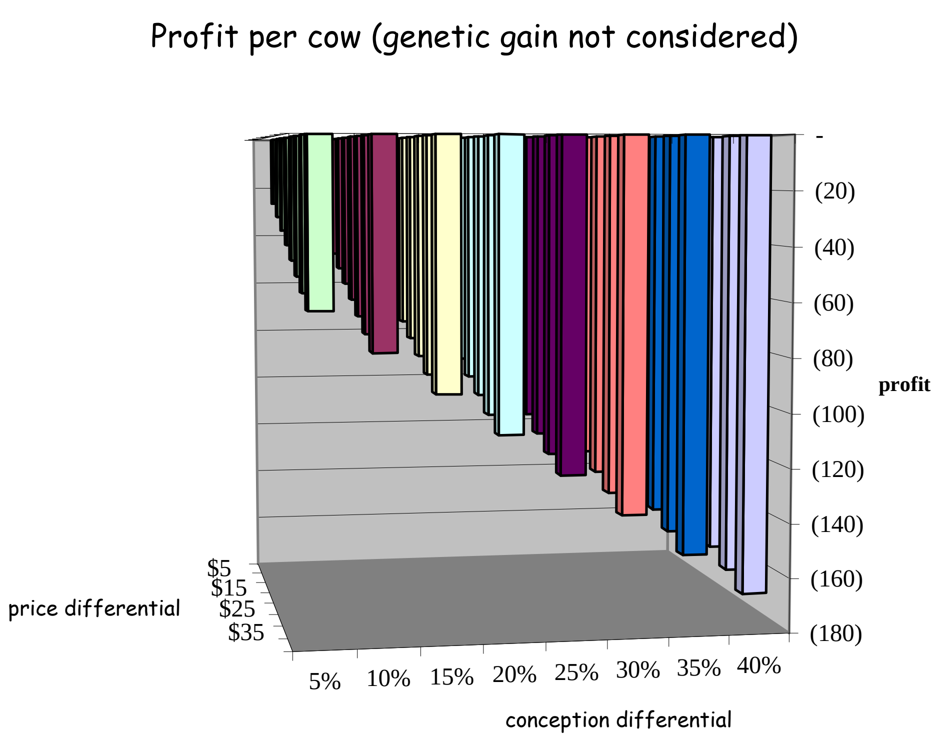


Figure 2: Segmentation of the breeding pool with sexed semen breeding programs

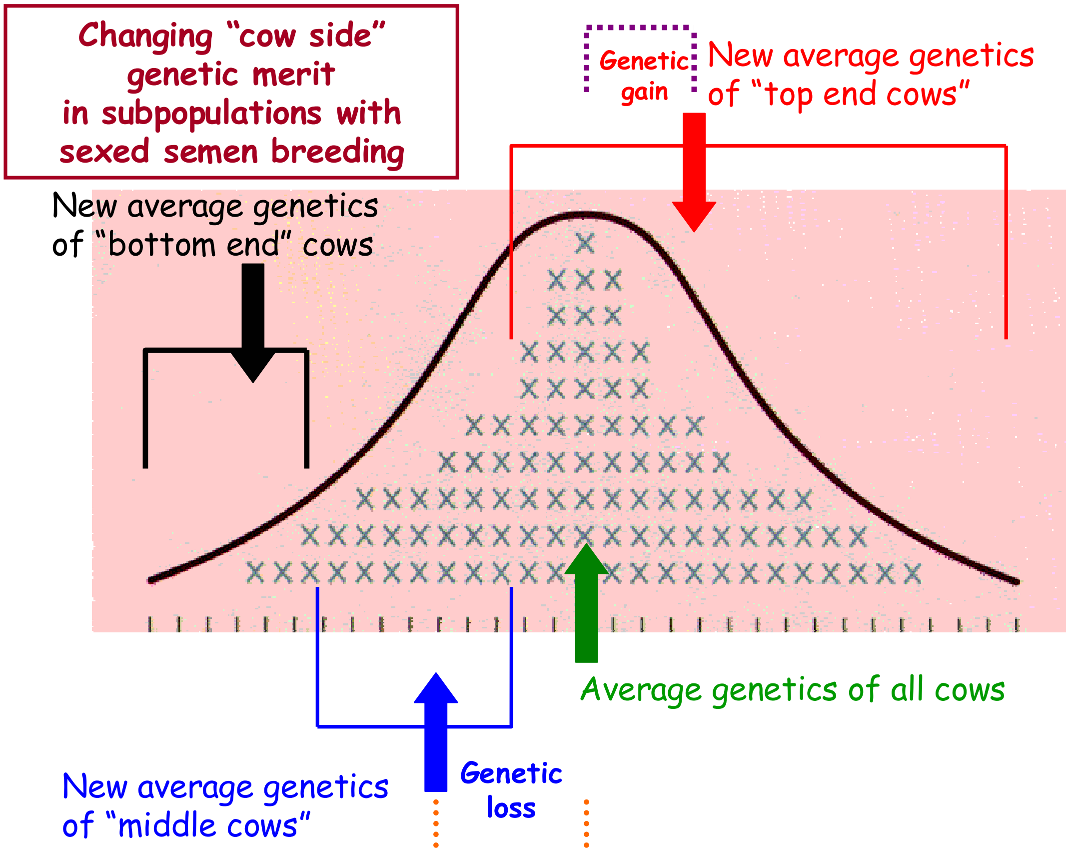
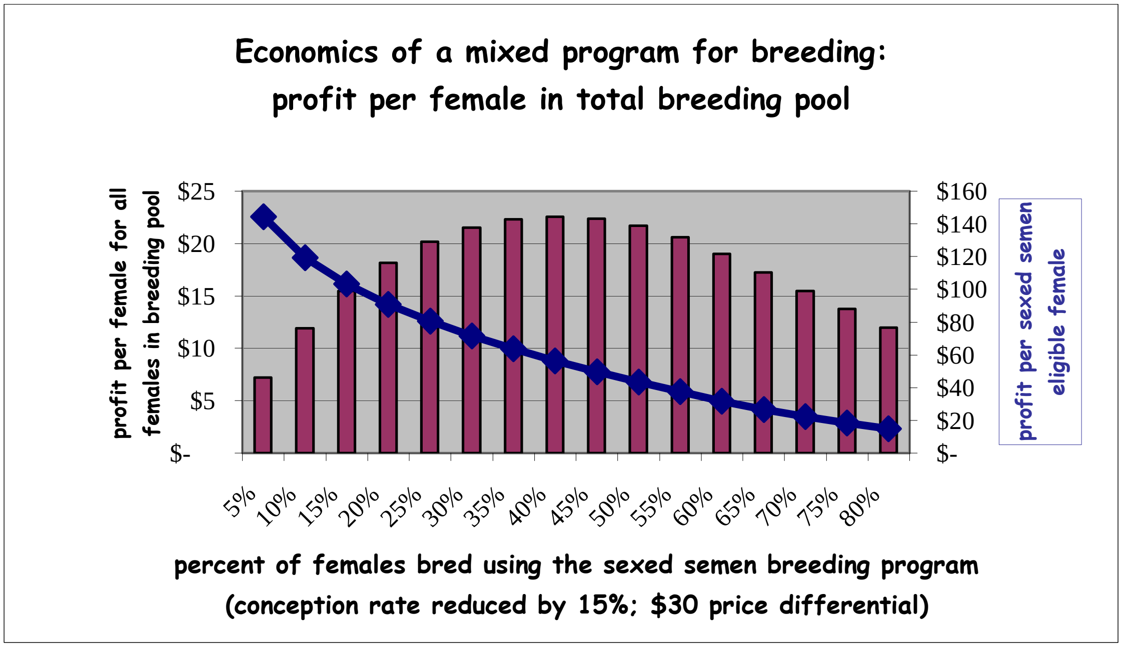


Table 4: model including the value of genetic gain: heifers

Sexed semen economics: including for the value of genetic gain nulliparous heifers

$	**10.00**	milk price minus marginal feed cost	
$	**30**	semen cost differential: if not the same bull, enter the sexed semen bulls PTA Milk differential below	
	15%	percent reduction in the absolute value of the conception rate (not proportion of conceptions)	
	1,800	value of a springing heifer	
	8%	discount rate	- sexed semen bull PTA Milk differential compared to conventional AI bull used
	30%	**percent of the sexed semen breeding pool at least initially bred with sexed semen: top end heifers**	
	61%	% of female **replacements** per animal exposed to the sexed semen program	
	36%	% of female **replacements** per animal exposed to conventional semen program	2.7 number of lactations
	69%	percent additional replacements from pool of animal bred with sexed semen compared to conventional AI	
	21%	% of all replacements that are extra sexed semen program heifers from the top end animals	
	51%	% of all replacements that are from the sexed semen program	
	79%	percent of the total population needed to produce replacements (including conventional semen if used)	
	665	standard deviation of PTA Milk of maternal (breeding pool) population (ME Milk)	
	771	average PTA Milk of the sexed semen heifers from the top end breedings (cow side gain)	
	239	average PTA Milk of the rest of the population produced with bottom tail discarded (cow side gain)	
	349	**average gain in PTA Milk of all the replacements, derived from both sexed semen and conventional breedings**	
		$ 195 NPV gain at time of breeding for the sexed semen program derived heifers: milk and offspring	
$	**88**	**average value of genetic gain discounted to the time of breeding for all replacements: milk and offspring**	
	36%	proportion of the breeding pool that produces a replacement female	
$	**32**	**genetic gain per animal entering the sexed semen program breeding pool**	
$	(11)	weighted gain or (loss) per animal entering the sexed semen program breeding pool: extra females, extended days to calving, etc.	
$	**22**	**total gain (loss) per animal entering the sexed semen program breeding pool**	
$	72	profit per heifer that is bred using sexed semen	
$	56	extra semen cost per heifer that enters the sexed semen program	
	129%	return on the investment in sexed semen program semen costs	

Figure 3: Impact of the proportion of the population bred with sexed semen on profit of the average animal in the breeding pool and those bred using sexed semen: heifers at $1,800



Heifers at $1,400

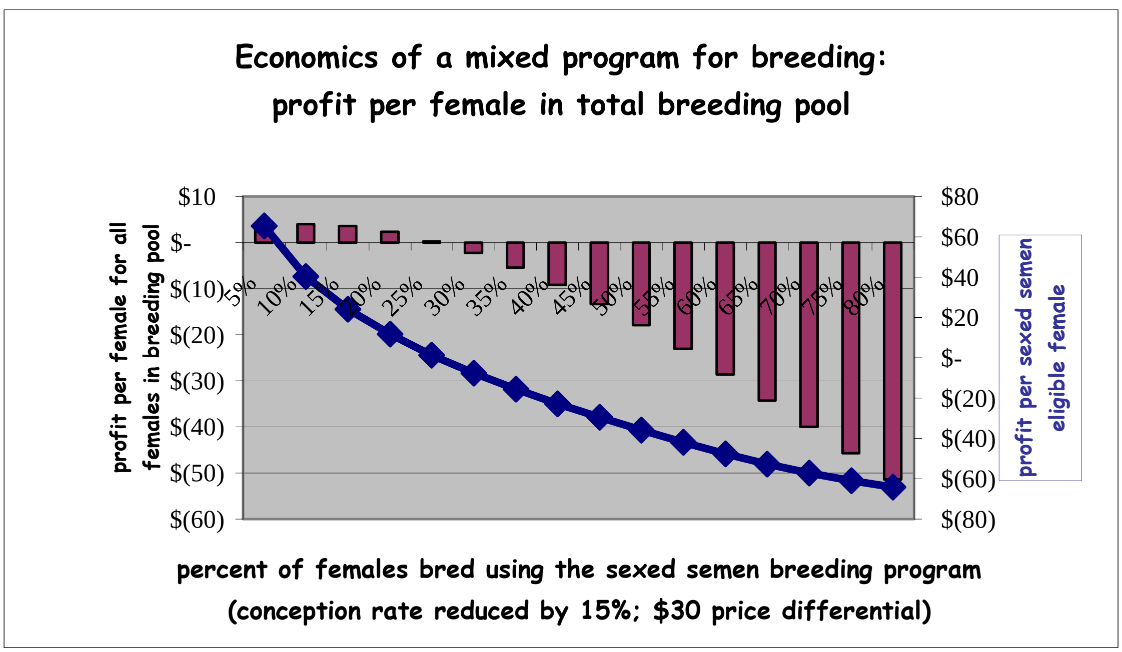


Figure 4: Impact of the level of use of sexed semen and the impact on conception on the profit per female in the breeding pool: heifers at $1,800

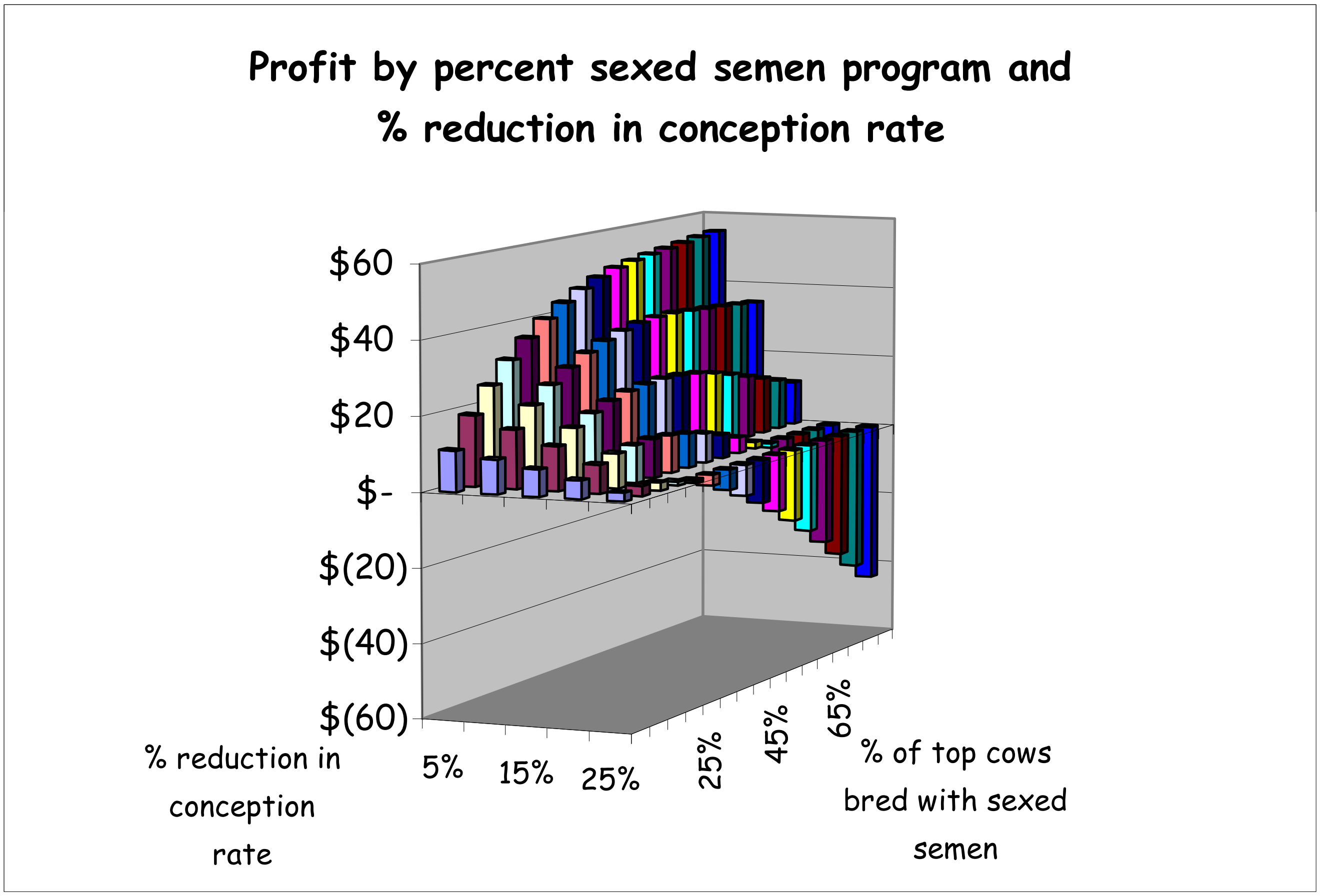


Figure 5: Impact of number of breedings using sexed semen by level of use: heifers

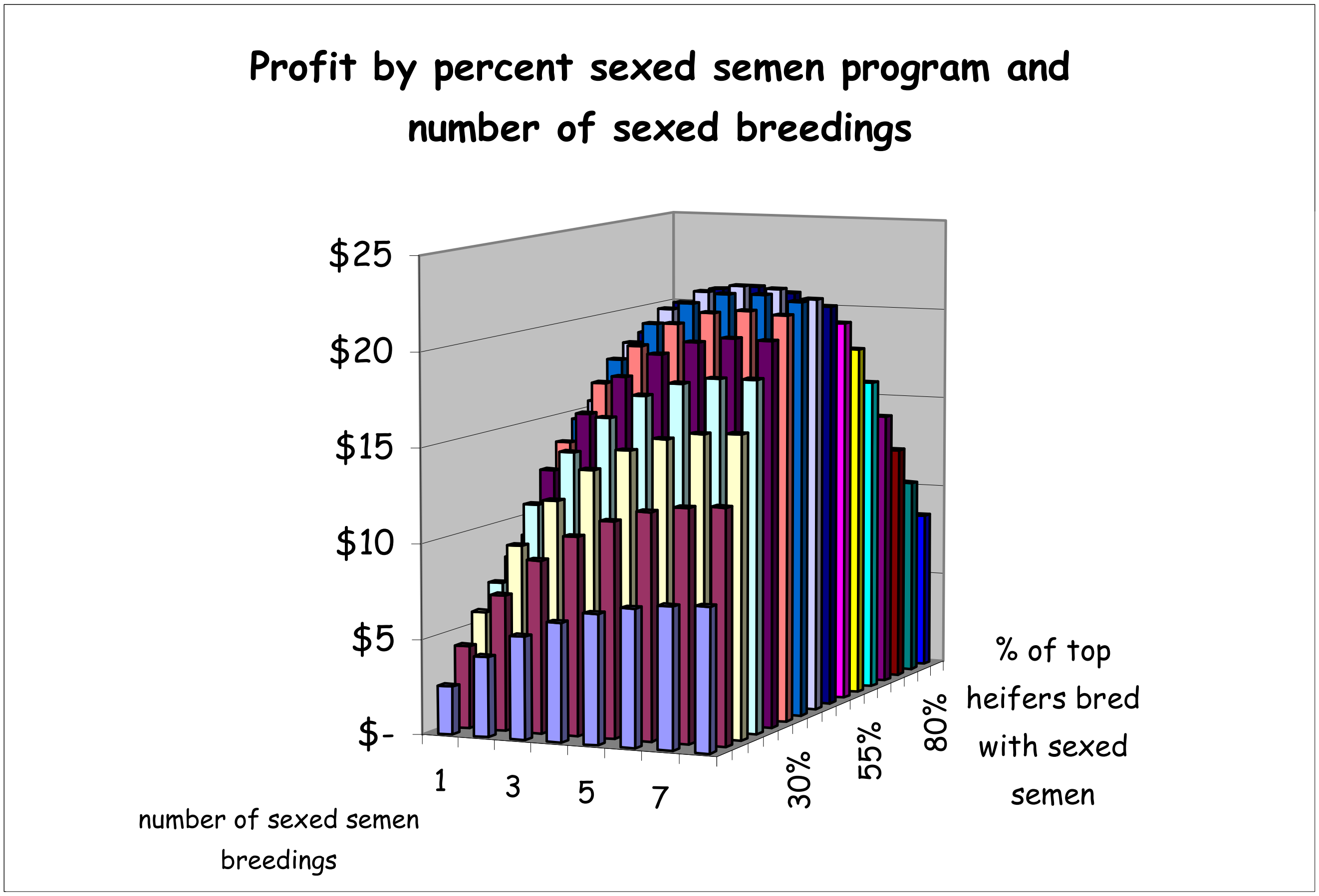


Table 5: model including the value of genetic gain: cows

Sexed semen economics: including for the value of genetic gain milking cows

$	**10.00**	milk price minus marginal feed cost
$	**30**	semen cost differential: if not the same bull, enter the sexed semen bulls PTA Milk differential below
	10%	percent reduction in the absolute value of the conception rate (not proportion of conceptions)
	1,800	value of a springing heifer
	8%	discount rate - sexed semen bull PTA Milk differential compared to conventional AI bull used
	30%	**percent of the sexed semen breeding pool at least initially bred with sexed semen: top end heifers**
	39%	% of female **replacements** per animal exposed to the sexed semen program
	35%	% of female **replacements** per animal exposed to conventional semen program 2.7 number of lactations
	12%	percent additional replacements from pool of animal bred with sexed semen compared to conventional AI
	4%	% of all replacements that are extra sexed semen program heifers from the top end animals
	34%	% of all replacements that are from the sexed semen program
	96%	percent of the total population needed to produce replacements (including conventional semen if used)
	665	standard deviation of PTA Milk of maternal (breeding pool) population (ME Milk)
	771	average PTA Milk of the sexed semen heifers from the top end breedings (cow side gain)
	54	average PTA Milk of the rest of the population produced with bottom tail discarded (cow side gain)
	80	**average gain in PTA Milk of all the replacements, derived from both sexed semen and conventional breedings**
		$ 193 NPV gain at time of breeding for the sexed semen program derived heifers: milk and offspring
$	**20**	**average value of genetic gain discounted to the time of breeding for all replacements: milk and offspring**
	35%	proportion of the breeding pool that produces a replacement female
$	**7**	**genetic gain per animal entering the sexed semen program breeding pool**
$	(6)	weighted gain or (loss) per animal entering the sexed semen program breeding pool: extra females, extended days to calving, etc.
$	**1**	**total gain (loss) per animal entering the sexed semen program breeding pool**
$	3	profit per cow that is bred using sexed semen
$	16	extra semen cost per heifer that enters the sexed semen program
	20%	return on the investment in sexed semen program semen costs

Figure 6: impact of proportion of cows bred with sexed semen on profit

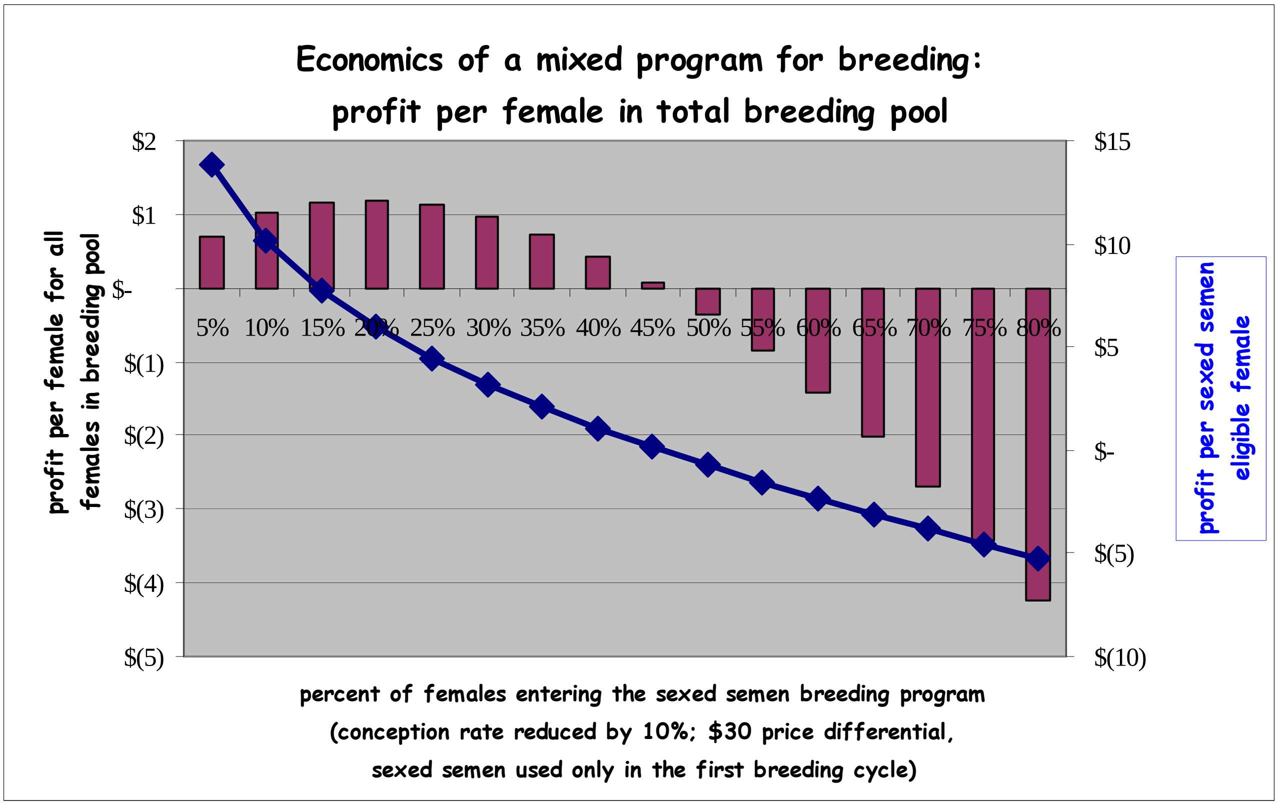
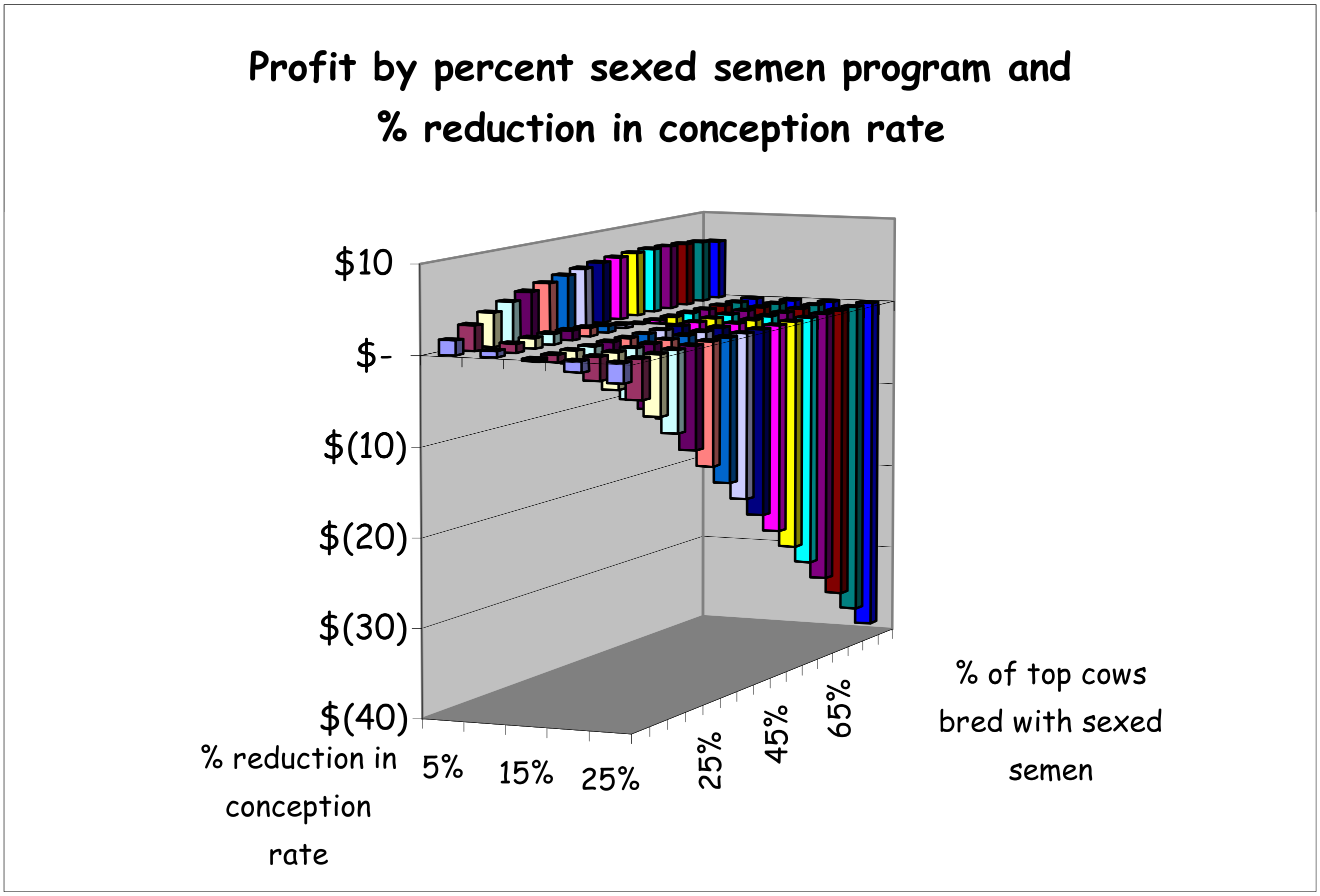


Figure 7: Impact of the level of use of sexed semen and the impact on conception on the profit per female in the breeding pool: cows



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