PART B

CALCULATING THE ECONOMIC BENEFIT OF USING SEX-SORTED SEMEN

Abstract

This paper builds on an earlier paper that developed a method to calculate the economic value of genetic gain using an investment analysis approach. This method has the capacity to factor the difference in fertility that is associated with new reproductive products. The method also has the capacity to factor gender selection. The method utilizes a part analysis model together with an investment analysis framework. This main aim of the paper is to focus on method rather than results and use the model to highlight the way in which the factors associated with different products affect the overall calculation. Three scenarios involving sex-sorted semen are evaluated. These are compared to the use of conventional semen. The comparison focuses on three major aspects. One is genetic gain, the other is cost of production and the third is additional sales. Sex-sorted semen is shown to be the most profitable strategy, however there are risks associated with the lower fertility, particularly in cows. The 'best bet' strategy would seem to utilize sex-sorted semen in heifers only. This paper takes a simplistic approach and a further refinement of this breeding strategy is undertaken in a subsequent paper that calculates the economic benefit of utilizing embryos derived from MOET, JIVET and other IVP techniques. In essence this paper takes a whole of herd approach whereas the subsequent paper takes a part herd approach. A final paper entitled 'The modern breeding decision - New dilemmas for the Australian dairy farmer' takes an individual mating approach.

CONTENTS

Introduction

Sex-sorted semen enables dairy farmers to generate more replacement females from his better cows or heifers. Fewer cows are therefore required to breed the herd replacements and this increases the selection pressure on the selected dams. To some extent this is eroded by the lower genetic merit of the bulls involved and a greater number of replacements required due to the inherently lower fertility associated with sex-sorted semen. Furthermore, sex-sorted semen is generally more expensive and this adds significantly to breeding costs. This is exacerbated by the higher number of returns to service due to lower conception rates. However, since most of the progeny will now be female, the cost of production is marginally reduced.

Consequently, the benefits of using sexed semen hinge largely on the ability to achieve additional sales and to take advantage of a strong demand for dairy replacements. For this to be profitable, the market price must sit well above the cost of production.

This paper also addresses the other suggested benefits of using sexed semen (lower rates of dystocia, better biosecurity and greater opportunity for voluntary culling) and where possible, determines the economic value involved.

Despite this, a consistent theme exists throughout. This is best described by De Vries (De Vries et al. 2008) who states, "the use of sex-sorted semen allows for a decoupling of the breeding decision". When using conventional semen the major constraint is simply to breed sufficient herd replacements. When using sex-sorted semen, the purpose of pregnancy is used to initiate a new lactation and/or generate surplus heifers to generate more profit. In practise this creates two breeding enterprises within the herd. One is the breeding of heifers for use as herd replacements and the other is the breeding of replacement heifers for sale. This is a central theme in this and subsequent papers.

Background

The use of sex-sorted semen is now wide spread in commercial dairy farms in the United State of America. The adoption rate has been quite dramatic after a relatively slow start. De Vries notes that sales of sex-sorted semen have increased from 18,000 units a month in 2006 to 300,000 units per month in 2008. This represents a total of over 3.7 million doses per year (De Vries et al. 2008). De Vries also notes that the majority of this semen is used in heifers, and most cases in the first service of a timed oestrus program. He estimates that 37% of heifers are served with sex-sorted semen in this way. This compares to cows where only 2.5% are served with sex-sorted semen.

De Vries estimate that the widespread use of sex-sorted semen may increase the supply of heifers at a national herd level by up to 17%. This may have implications for the price received for replacements and/or the price of milk if this leads to an overall increase in the size of the national herd. Similar herd dynamics are discussed by both Norman and De Jarnette (DeJarnette et al. 2007; Norman, Hutchison and Miller 2010).

This adoption rate, however, suggests that the economic benefits of the use of sex-sorted semen at the farm level are recognized (Madalena and Junqueira 2004; Fetrow 2007; De Vries ; Cabrera 2009b, a; eXtension 2010). It could be anticipated that this same rate of adoption will be seen in Australia, after a similar introductory period (Sexing Technologies 2009c, b). There is some indication that this is occurring although there is some resistance due to concerns about lowered fertility, particularly in cows.

The use of sex-sorted semen incurs major adjustments to management and herd structure and is inherently risky (Rath et al. 2009; Seidel et al. 1999; Seidel Jr 2007, 2009), however, Australia is well positioned to use sex-sorted semen due to the buoyant global demand for surplus replacements. This underpins the potential to use sex-sorted semen at the farm level.

The stated benefits of sex-sorted semen include:

1. Accelerated genetic advancement
2. Lower rates of dystocia
3. Better biosecurity
4. Greater opportunity for voluntary culling
5. More profit from additional sales

**Source (Bos sexed semen…www.bostrading.com.au)*

The potential for greater genetic gain is achieved through additional selection intensity amongst the dams selected to breed the replacement heifers. As mentioned, this is largely offset by the lesser genetic merit of many of the sires used in current sex-sorted semen. This paper determines the extent to which sex-sorted semen is able to accelerate genetic advancement.

The lower rates of dystocia are well documented (Norman, Hutchison and Miller 2010), particularly in heifers and the benefits are real and tangible, however, they would be unlikely to provide the only incentive to use sexed semen. Biosecurity is an underrated benefit and the ability to supply all the replacement heifers from within the herd is a major advantage. The ability to cull more non-performing cows is often offset (in cash flow terms) by the lower milk yields in the heifer's first lactation.

Without completely disregarding the above, the two major considerations when evaluating the economic benefits of sex-sorted semen are additional sales and the effects on genetic gain. The main source of additional profit stems from additional sales, however this is dependant on the both market and production factors. If the market value exceeds the cost of production then there is scope to use sex-sorted semen to generate additional profit. If there is no difference, or if the cost of production exceeds the market value, then the use of sex-sorted semen is probably not an attractive proposition.

The only proven technique that is commercially available (to this date) is the use of the Beltsville Sperm Sexing Technology. This technique uses a flow cytometer that is capable of detecting the small differences in DNA content that exist between X and Y bearing sperm. The X chromosome is marginally larger and possesses between 3.6 – 4.1% more DNA (De Vries et al. 2008). Sperm are separated using a procedure that recognizes these differences. The technique is, however, inherently slow.

Approximately 5,000 sperm can be sorted in a second using the method described above. This translates to approximately 1 hour and 7 minutes to process enough sperm for a standard semen straw of 20 million sperm. Consequently, commercialization is only possible if much lower sperm numbers per dose are used (approximately 2 million per straw). Although this affects the subsequent fertility using sexed semen, it represents a sensible trade off between logistics and cost. At the lower number of sperm per straw, each machine can process approximately 12 units (straws) per hour. This translates to approximately 215 units (straws) per day (assuming an 18 hour day) (De Vries).

With the existing technology (and assuming some down time), each machine has the capacity to produce approximately 63,000 units (straws) per year. Sorting technology continues to improve this capacity. Each machine costs approximately $USD 400,000, and the amortization of this cost adds greatly to the cost of each straw (De Vries).

The other critical factor in the use of sexed semen is its adverse effect on cryopreservation and subsequent semen quality after thawing (Seidel Jr and Schenk 2008). The detrimental effects have been documented (Rath et al. 2009) and relate to each of steps involved in the sorting procedure. Physical (mechanical) damage caused by pressure and sheer force as sperm pass through the sorter are thought to compromise the integrity of the cell membranes and is considered to be the main cause of sperm damage. However, there are also concerns about possible effects of the use of the fluorescent dye, the use of ultra violet lasers, high temperatures, initial dilutions and subsequent centrifugation (de Graaf et al. 2009). Perhaps the most underrated concern, however, relates to the time involved in the sorting process and possible "mitochondrial exhaustion". This may explain the known loss of fertilizing lifespan of sexed semen post thawing (Rath et al. 2009).

The lower fertility of sex-sorted semen is well documented (Schenk et al. 2009; Seidel Jr and Schenk 2008; Kurykin et al. 2007; Cerchiaro et al. 2007; DeJarnette et al. 2008; Norman, Hutchison and Miller 2010). Because of the slow processing time, the economics dictate that the sperm numbers used in sex-sorted semen straws is much lower than that used in conventional semen (Parati et al. 2006). This is assumed to be a major cause of the lowered fertility, however, it is also accepted that the procedure is hard on sperm and the lowered fertility is, in part due to sperm damage (Sharpe and Evans 2009). This conclusion is challenged slightly by de Graaf (de Graaf et al. 2009), who suggests that in sheep, sperm viability can be actually improved by the sorting process (i.e. non viable sperm have been removed). A balanced view is put forward by Frijters (Frijters et al. 2009) who attributes a value to both possible causes.

The two major limitations relating to the use of sex-sorted semen are therefore (Weigel 2004):

1. The speed of sorting and…
2. In vivo conception rates.

There has been a concerted bid to improve both of these limitations. Improvements in sorting speed have been incremental with no major breakthrough at this point of time (Sharpe and Evans 2009) although alternative technologies are being developed (e.g. Lumisort and/or Dairy Futures CRC sexed semen project). Similarly, efforts to improve conception rates by exploring the timing of insemination (Hohenboken 1999), the point of deposition (Kurykin et al. 2007) and alternative dose rates (DeJarnette et al. 2008) have delivered only marginal improvements.

The economics of using sex-sorted semen is discussed at length in the literature, however in the main, this discussion is general and only a few papers actually quantify the economic benefits involved (De Vries et al. 2008; De Vries ; eXtension 2010; Madalena and Junqueira 2004; Sexing Technologies 2009a; Weigel 2004; Hohenboken 1999). All the papers, however point to the complexity of the calculations and the need to combine a partial analysis model with an investment analysis approach (Cabrera 2009a; Fetrow 2007; Olynk and Wolf 2007). Unfortunately, much of the analysis has a focus on results rather than method.

All the papers mentioned acknowledge conception rate as a key determinant in the profit calculations. Actual conception rates achieved within the U.S. dairy herd are described. These form the basis for the anticipated conception rate utilized within the partial analysis model used in this paper (Cerchiaro et al. 2007; DeJarnette et al. 2007; Weigel 2004; Norman, Hutchison and Miller 2010).

The literature also describes how sex-sorted semen (and the ability to select gender) can "value add' more advanced reproductive techniques such MOET, JIVET and other In Vitro production techniques. This is explored in this paper in a subsequent paper entitled 'Calculating the economic benefit of using embryos derived from MOET, JIVET and other IVP production techniques".

Method

The method developed in this paper extends the logic of the previous paper to include the use of sex-sorted semen. The partial analysis model initially determines the amount and value of genetic gain attributable to both the dam and sire effect. It then adjusts for the cost of producing the herd replacements. The model then examines the cost of producing surplus replacements for sale. This is compared to the market value and a margin is determined. In this way the model determines both the economic value of genetic gain and the income stream derived from the sales of replacement females.

The partial analysis model used in this paper splits the herd into two compartments (cows and heifers) to better reflect the commercial application of sexed semen. Accordingly two further scenarios are compared, one being the use of sex-sorted semen in heifers only, the other being the use of sex-sorted semen across the whole herd. These scenarios are compared to the default and conventional scenarios described in the earlier paper. It is unusual, however, for farmers to use the same semen strategy across the entire herd situation since most farmers practice some form of mate selection particularly for cows that have the greatest chance of producing replacement heifers for the herd. To accommodate this, a 'part herd' approach is developed in a subsequent paper. Only the 'whole herd" and 'heifers only' strategies are evaluated in this paper. This provides a better sense of how sex-sorted semen affects the herd size and structure, how it affects the potential for genetic gain and how it affects the potential for sales.

The potential for genetic gain is the combination of the sire and dam effect. The sire effect is essentially half the difference between the genetic merit of the sire and the average genetic merit of the herd. The dam effect is half the difference between the average genetic merit of the dams used to breed the replacement heifers and the average genetic merit of the herd. This combined effect determines the genetic gain afforded to each of the heifers retained as herd replacements. The overall genetic gain is determined by multiplying the combined effect by the number of heifers involved (as described in the previous paper).

The genetic merit of sires used to produce sex-sorted semen is generally lower than those available for conventional semen. However, since sex-sorted semen requires fewer cows to generate the same number of replacements, the average genetic merit of the cows used to breed replacements is usually higher than in the 'conventional scenario. ***Sex-sorted semen provides the opportunity to breed more heifers from the dairy farmer's better cows***. The extent to which it is higher is dependant on the genetic standard deviation of the breeding herd and the number selected.

The lower fertility achieved when using sex-sorted semen is well documented in the literature. It is generally agreed that farmers should expect a conception reduction of 15-20% of that which they achieve with the use of conventional semen. However, since the progeny are predominantly female, the overall number of dams needed to breed the required number of herd replacements is less. The way in which fertility affects herd dynamics when using conventional semen is outlined in Table 2. The way in which fertility affects herd dynamics when using sex-sorted semen is outlined in Table 3.

Table 2. Showing the effect of conception rate on the number of breeders needed to breed the required number of herd replacements using conventional semen (within a herd of 100 milking cows).

Conception Rate*	Required number of herd replacements	Number of dams needed to breed the required number of herd replacements	Herd size
25%	39	128	130
30%	35	107	133
35%	30	85	135
40%	**26**	**71**	**137**
45%	23	61	138
50%	21	55	139
55%	20	51	139
60%	19	48	140
65%	18	47	140

** Conception rate refers to the 1st service conception rate in both cows and heifers.*

The number of dams needed to breed the required number of herd replacements dictates the proportion of breeders selected to breed the herd replacements. This in turn dictates the selection intensity and ultimately the anticipated average ABV of these dams. This is shown in Figure 1, 2 and 3. The selection intensity is higher if sex-sorted semen is utilized in heifers and higher again if used over the whole herd. The selection intensity contributes to the dam effect and subsequently the average ABV's of the replacement heifers. The partial analysis model assumes a conception rate of 40% in cows and a 60% in heifers in the 'conventional' scenario depicted in Figure 1. Note that 50% of the breeding herd is required to breed the required number of heifers.

Table 3. Showing the effect of conception rate on the number of dams needed to breed the required number of herd replacements using sex-sorted semen (within a herd of 100 milking cows).

Conception Rate*	Required number of herd replacements	Number of dams needed to breed the required number of herd replacements	Herd size
25%	42	79	155
30%	**35**	**60**	**160**
35%	30	48	164
40%	26	40	166
45%	23	34	168
50%	21	31	170
55%	20	28	171
60%	19	27	171
65%	18	26	172

** Conception rate refers to the 1st service conception rate in both cows and heifers.*

In the scenario depicted in Figure 2 sex-sorted semen is used in heifers only. In this scenario the same conception rate of 40% is assumed in cows but the conception rate in heifers is reduced from 60% to 40% to reflect the use of sex-sorted semen. In this scenario only 43% of the herd is required to breed replacements. The selection intensity increases from 0.7957 to 0.9164.

Figure 3 shows the proportion of dams required when using sex-sorted semen across the whole herd. The conception rate in cows falls to 30% to reflect the use of sex-sorted semen with the conception rate in heifers remaining at 40%. The proportion selected in this scenario is only 36% and the selection intensity increases to 1.0459.

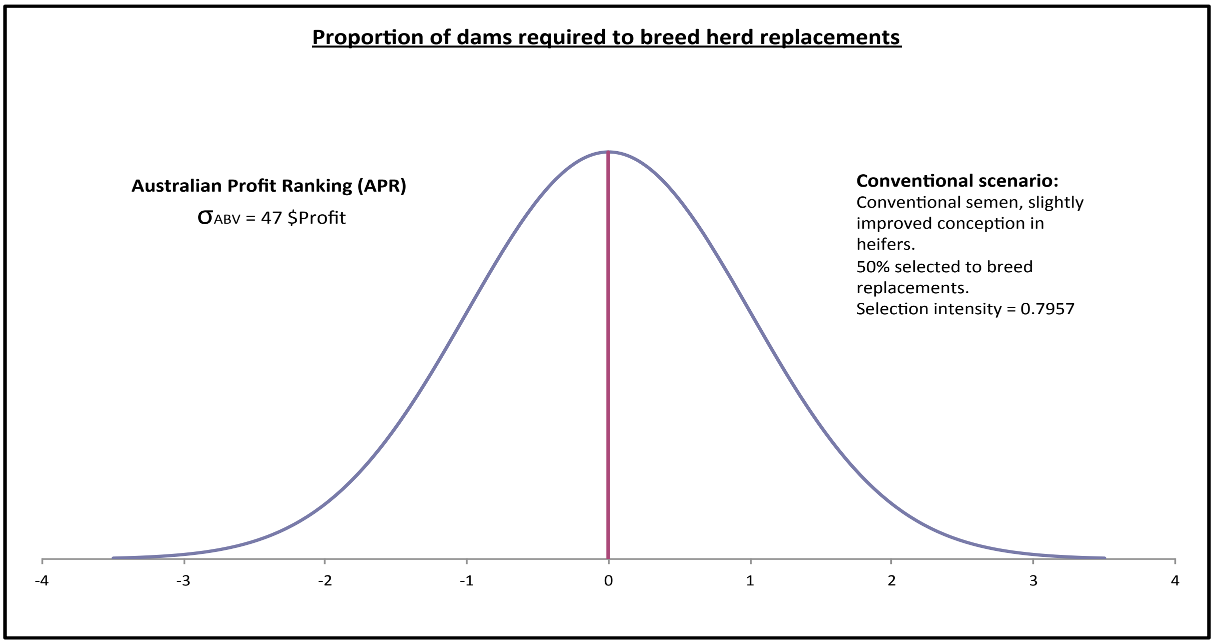

Figure 1. Showing the proportion of dams need to breed the required number of herd replacements using conventional semen in the 'conventional' scenario.

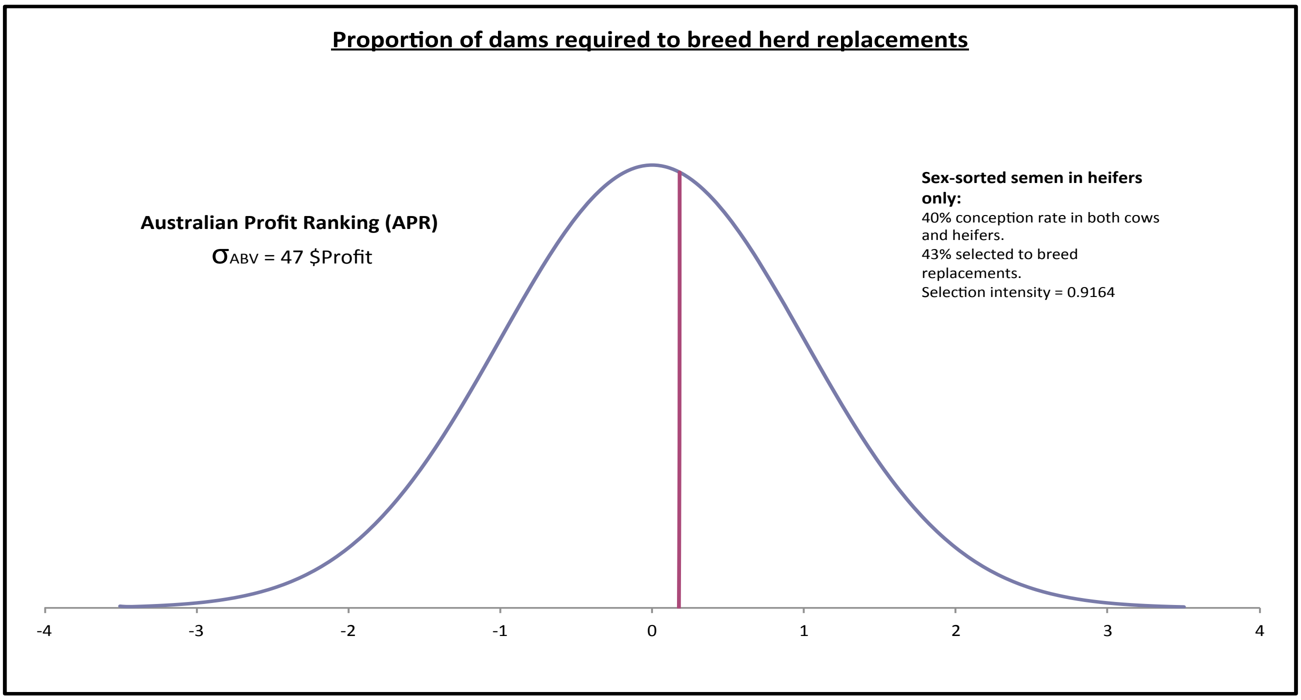

Figure 2. Showing the proportion of dams need to breed the required number of herd replacements using sex-sorted semen in heifers only.

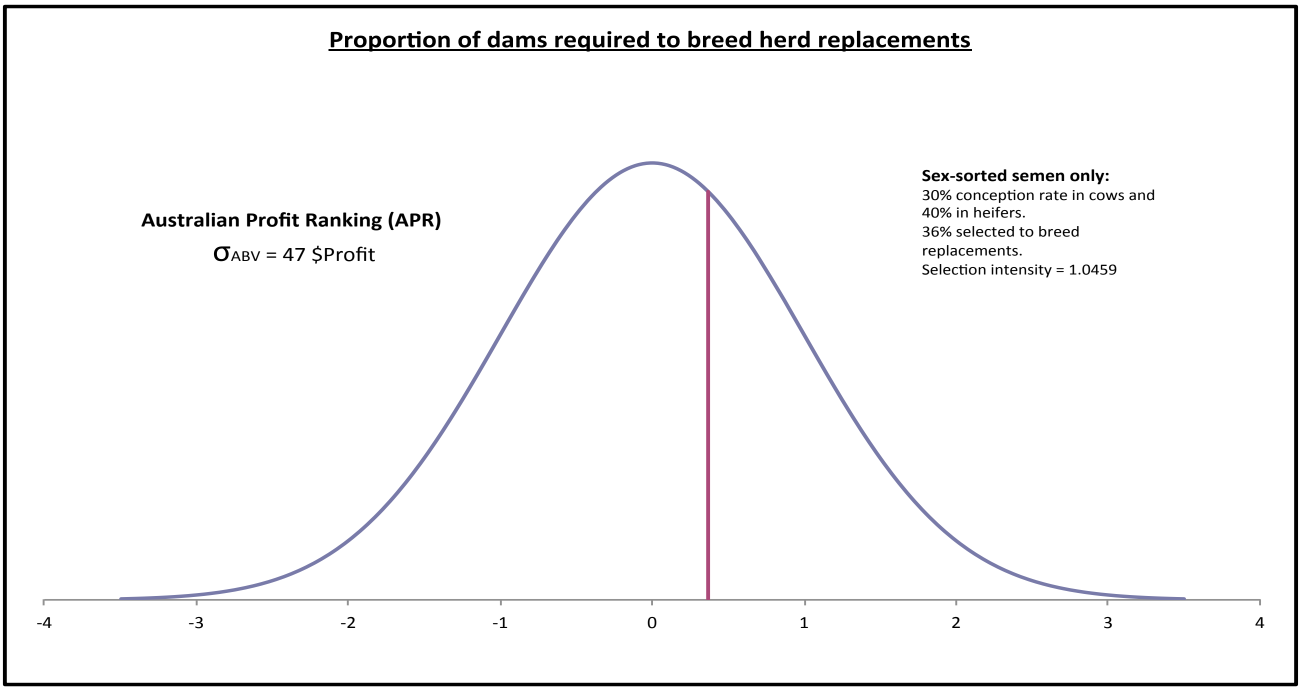

Figure 3. Showing the proportion of dams need to breed the required number of herd replacements using sex-sorted semen in both cows and heifers.

The partial analysis model uses these figures to calculate the contribution of the dam effect toward genetic gain. The sire effect is also evaluated using the method described in the previous paper. The overall genetic gain is the combination of both the dam and sire effect. By using the $Profit equation, the economic value of the genetic gain can be derived for each of the breeding strategies described. At the herd level, the genetic gain is the product of the overall effect multiplied by the number of replacements retained.

The next task is to assess the investment. This revolves around the number of inseminations required to produce of replacement female. This is exemplified by reference to the series of factors described in the previous paper. Lower conception increases the number of inseminations and the number of inseminations per pregnancy (I_1 & I_2), however the ability to select for female progeny substantially reduces the number of inseminations required per female replacement generated and/or per female replacement reared (I_3 & I_4) (see Table 4).

Table 4. Showing the effect of using sex-sorted semen on the investment factors determined by the partial analysis model.

	Conventional semen	Sex-sorted semen in heifers only	Sex-sorted semen over the whole herd
$I_{2conversion}$ factor	1.10	1.10	1.18
$I_{2cumulative}$ factor	2.5	2.5	3.01
$I_{3cumulative}$ factor	5.0	4.14	3.35
$I_{4cumulative}$ factor	6.25	5.18	4.18

Where: I_2 conversion factor converts the number of inseminations per cow to the number of inseminations per pregnancy. The I_2 cumulative factor is the number of inseminations per pregnancy. The I_3 cumulative factor is the number of inseminations per female calf generated and the I_4 cumulative factors is the number of inseminations per female replacement reared.

Note that although these factors relate only to the investment in semen (i.e. number of inseminations) each insemination has an associated breeding cost that contributes to the overall cost of production. The breeding cost is determined by the number of inseminations and includes the cost of semen, the insemination cost and the cost of pregnancy diagnosis. Each strategy will therefore have a slightly different cost of production. The partial analysis model calculates these as a difference to the default scenario described in the initial paper. This appears as a cost adjustment in the investment analysis cash flow.

In the case of the 'heifers only' scenario, the cost of production is averaged across the two part herds. The cost of growth is determined by a fixed cost of gain. A target weight of 280kg is assumed. This essentially completes the investment analysis.

There is one consideration that should be noted. Since cows used to breed replacement females are likely to be the better cows, losses due to repeated returns to service could affect the average genetic merit of the cows that are removed from the herd. If this is the case, it may no longer be valid to assume that the average genetic merit of the cows removed from the herd, is the same as the herd average. In this case the benefit of using sex-sorted semen may be over-stated. It is important to keep this issue in perspective, bearing in mind that most of the cows are removed due to their age, and that a significant number of cows are culled based on fitness criteria. Nevertheless it is important to recognise that farmers are reluctant to 'give up' their better cows to a sex-sorted breeding strategy.

Results

In this study, the ABV of the sire used to produce the sex-sorted semen is assumed to be 177 $Profit (ABS 2010b, a). This is significantly lower than the 210 $Profit assumed for the good quality conventional semen (ADHIS publication 2012). Note that it is also significantly more expensive (see Table 7). The sire effect, when expressed as an NPV, is significantly higher than the default in all three of the other breeding strategies, but the magnitude of the difference between the three other strategies is not great.

Table 6. Comparing the components of the dam effect within each of the scenarios.

	Conception rate		Proportion of dams selected to breed herd replacements	Selection intensity (i)	Anticipated change in average ABV of dams selected to breed replacements*	Dam effect ($Profit)	NPV of dam effect
	(cows)	(hfrs)					
Default	40%	40%	52%	0.7712	36.46	18.23	$2,788
Conventional	40%	60%	50%	0.7957	37.62	18.81	$2,877
SS in hfrs	40%	40%	43%	0.9163	43.32	21.66	$3,313
Sex-sorted	30%	40%	36%	1.0459	49.45	24.72	$5,110

** This assumes a standard deviation within the herd of 47 $Profit where the change in average ABV =* σ_{ABV} ** selection intensity*

Table 7. Comparing the components of the sire effect within each of the scenarios.

	Conception rate		ABV sire $Profit	$ per straw	Total number of inseminations	Total expenditure on semen	Sire effect ($Profit)	NPV of sire effect
	(cows)	(hfrs)						
Default	40%	40%	0	$16	311	$4,976	0	0
Conventional	40%	60%	210	$32	290	$9,280	105	$16,058
SS in hfrs	40%	40%	210/177	32/45	311	$10,992	101	$15,406
Sex-sorted	30%	40%	177	$45	408	$18,360	88	$18,291

** The investment (I_1) value for semen is the $ per straw value less the default value ($16).*

Note also that the total expenditure on semen when using sex-sorted semen across the whole herd is almost double that required when using conventional semen. This becomes a cash flow consideration.

The semen prices and ABV values were assumed after studying the catalogues provided by several artificial breeding companies. Better value for money in either conventional or sex-sorted semen may change the NPV of the sire effect significantly. Better than expected conception rate could be achieved the sex-sorted semen and this would also change the NPV of the sire effect.

Table 8. Comparing the cost of production within each of the scenarios

	Conception rate (cows)	(hfrs)	Number of inseminations	$ per straw	(I_2)	(I_3)	(I_4)	Cost of Growth	Breeding cost	Ave. cost of production
Default	40%	40%	311	$16	2.50	5.00	6.25	$840	$684	$1,524
Conventional	40%	60%	291	$32	2.27	4.53	5.67	$840	$722	$1,562
SS in hfrs	40%	40%	311	32/45	2.50	4.14	5.18	$840	$697	$1,537
Sex-sorted	30%	40%	408	$45	3.01	3.35	4.18	$840	$660	$1,500

** The investment (I_1) value for semen is the $ per straw value less the default value ($16).*

It can be seen from the above calculations that the key driver when using sex-sorted semen is not related to genetic gain, although sex-sorted semen fares much better than many would think. The main driver when using sex-sorted semen is the additional sales of replacement heifers. Apart from the actual number of replacements for sale, there are two key aspects to additional sales. The first is the anticipated market value and the second is cost of production. The assumed market value of a replacement female used in the partial analysis model is $2,300. This value sits well above the cost of production and is buoyed by a strong global demand for Australian heifers due to both their performance and their disease status. A minimum specification is required to obtain this market value, which is mostly based on performance, but type and other factors are also involved. For demonstration purposes it is assumed that all the surplus heifers meet this minimum requirement.

The cost of production associated with each of the described breeding strategies is shown in Tables 8. The lowest cost of production is achieved by using sex-sorted semen on the whole herd. This generates a healthy margin of $800. Because this strategy also generates the largest number of replacement females for sale the income from sales in significantly higher than any of the other strategies.

Note the discounted value of these sales. This is considerably less than the profit from sales displayed. The reason for this is that the costs involved are incurred at the outset of cash flow, whereas the sales occur much later and are appropriately discounted. Nevertheless, the income derived from heifer sales when using sex-sorted semen across the whole herd is significant and confirms this to be the main driver when considering sex-sorted semen. This is shown in Table 9.

Table 9. Comparing the sales of surplus females within each of the scenarios

	Market Value	Ave. cost of production	Margin	Number of sales	Profit from sales	NPV of sales	Difference
Default	$2,300	$1,524	$776	24	$18,653	$8,152	
Conventional	$2,300	$1,562	$738	26	$18,860	$7,688	-464
SS in hfrs	$2,300	$1,537	$763	34	$26,177	$11,186	3,034
Sex-sorted	$2,300	$1,500	$800	63	$50,129	$22,729	14,577

Having calculated the various components of the profit equation we can now combine them to determine the overall affect of adopting each of the described breeding strategies.

Adopting a breeding strategy that utilizes sex-sorted semen (in heifers only) adds $4,000 to the total NPV derived from the herd of 100 milking cows. Extending the strategy to include the whole herd adds a further $3,600. All of these figures are based on the assumptions described in this and the previous paper.

Although the use of sex-sorted semen across the whole herd is shown to be the most profitable scenario, it is also recognized as being the most risky. Parametric analysis shows that if the anticipated conception rate has been only slightly over-estimated; the overall advantage in profitability is quickly eroded. This applies also to the scenario that uses sex-sorted semen in heifers only. The breakeven points are shown in Table 10.

Table 10. Showing the conception rates at which the Total NPV breaks even for each of the three breeding strategies described.

Strategy	Conception rate (cows)	(hfrs)	Total NPV
Conventional Semen	40%	60%	$17,481
Sex-sorted in hfrs only	38%	38%	$17,478
Sex-sorted	28%	37%	$17,480

All three strategies deliver significantly more profit that the default scenario described in the earlier paper (see Table 11).

Table 11. Comparing the total NPV within each of the scenarios

	NPV Dam effect	NPV Sire effect	Total NPV of genetic gain	Cost of production adjustment	NPV of sales	Total NPV	Difference
Default	$2,788	0	$2,788	0	0	$2,788	
Conventional	$2,877	$16,058	$18,935	-$990	-$464	$17,481	$14,692
SS in hfrs	$3,313	$15,406	$18,719	-$338	$3,034	$21,415	$18,627
Sex-sorted	$5,110	$18,291	$23,401	-$12,957	$14,577	$25,022	$22,233

Discussion

The adoption of sex-sorted semen has been limited to heifers only within the dairy industries of both the United States and Australia. Risks associated with lowered fertility are more easily managed in heifers. Adoption rates in the United States have been quite dramatic after a slow start. The same pattern would appear to be developing in Australia.

The attraction of using sex-sorted semen exists due to Australia being uniquely positioned to meet the global demand for dairy heifers. To this end, dairy farmers are increasingly seeing themselves as producers of both milk and dairy replacements. Should market barriers, or shifts in the demand and supply dampen the market value of replacements, the competitiveness of sex-sorted semen would be adversely affected.

Conversely, small improvements in the fertility of sex-sorted semen and equally small increments of price reduction would dramatically improve the competitiveness of sex-sorted semen and it is most likely that improvements in breeding technology will result in sex-sorted semen being available from sires with better genetics.

The findings within this paper provide a useful basis to understand the effects of using sex-sorted semen and describe a method that is capable of factoring both the lower fertility as well as the gender selection. The analysis however, is restricted to the whole herd. A subsequent paper develops a part herd approach that is closer to the real commercial situation and a final paper develops a method to evaluate an individual mating using the same principles and logic described above. These papers address the issues from a more practical perspective.

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