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Economic Analysis of the Impact of Cloning on Improving Dairy Herd Composition

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While the potential for cloning animals has been realized for at least the last 25 years, it is only recently that sufficient advances have been made to allow the technology to advance to a stage where it is possible that widespread commercial applications of cloning may become a reality in the next few years. But much has yet to be accomplished before the farming of cloned animals and their offspring become as familiar as genetically modified plants are today. From a practical point of view, cloning could be used to increase the number, distribution, and availability of cows and bulls with superior genetics for increased milk yield, increased availability of stock with resistance to common diseases like mastitis, and increased availability of stock with desirable genetic traits associated with milk quality. Using a spreadsheet model of a "typical" dairy operation and simulation techniques, this study shows that the revenues generated by increased growth in milk production per cow were substantial and that producers may be willing to invest in such a technology. It was also found that the net present value (NPV) generated by the stream of increased net revenues created by the increased milk yields varied widely and depended on the genetic gains achieved relative to the price of the genetically superior animals. The increase in NPV from break-even is relatively rapid and indicates that there may be conditions under which dairy producers find it justifiable and profitable to invest in advanced breeding technologies like cloning in order to improve the genetic superiority of the herd.

Key words: cloning, genetic superiority, dairy, net present value, simulation.

Introduction[1]

While the potential for cloning animals has been realized for at least the last 25 years (Nicholas & Smith, 1983; Seidel, 1983; Van Vleck, 1981), it is only recently that sufficient advances have been made to allow the technology to advance to a stage where it is possible that widespread commercial applications of cloning may become a reality in the next few years. But much has yet to be accomplished before the farming of cloned animals and their offspring become as familiar as genetically modified plants are today. While there are still a large number of technological difficulties and problems to overcome, the most important determinants of advances in the use of cloning technologies are current success rates, variability of results, costs, government regulation, and public perception and acceptance.

The potential introduction of the products of cloned animals into the US food market is a natural extension of the introduction of the products of other genetically modified agricultural products into markets in the last 10 years, and also is a natural progression of the use of improved animal breeding technologies such as *in vitro* fertilization and embryo transfer. Cloned animals have become increasingly available in the last 5 years, but the products of these animals and/or their offspring have been withheld pending approval of the safety aspects of the food. In January 2008, the US Food and Drug Administration released a comprehensive study that concluded that meat and milk from cloned animals is safe for consumers. Nevertheless, there is still widespread uncertainty and significant debate about the feasibility and acceptability of animal cloning as a technology and its potential to enhance animal industry efficiencies and consumer welfare.

This article attempts to outline some of the economic impacts that cloning can—and probably will—have on the dairy industry in the future. The reader is duly warned that such an exercise at this early stage of development in cloning technologies is truly an exercise in speculation. Many of the elements of cloning technol-

1. *Some of the findings of this paper were first published in Butler (2006).*

ogy are currently incomplete or inconsistent and some aspects of the economic impacts defy objective measurement. In any study of this type, the conclusions reached are based in part on what little data there is to collect, in part on the insights and judgments that researchers and knowledgeable people have imparted, and in part on the review of the sparse relevant literature that has been generated by this topic.

Experience with previous biotechnologies shows that the potential for adoption and diffusion of cloning at the farm/production level is heavily influenced by the potential market/demand for those products, even when the new technology has the potential to increase efficiencies and reduce the costs of food production. Therefore, any analysis of the potential impacts of cloning to improve dairy herd compositions must take into account the demand for and marketing potential for the resulting products.

On the other hand, the market structure that would incorporate the products of genetically modified foods has already been established over the last 10-15 years. Significant changes in market structure over the past two decades have resulted in the establishment of highly differentiated markets that allows food products of all types—ranging from organic to natural to conventional to genetically modified—to co-exist in US food markets, and allows the consumer the widest possible choice of products regardless of philosophy and attitude toward the food they are offered.

Current Perspectives of Reproductive Technologies in the Dairy Industry

As mentioned previously, one perspective of cloning is that it is a natural progression in the continuing development of animal-breeding technologies. Over the last 100 years, a number of techniques have been developed and refined that have assisted dairy producers and dairy practitioners in obtaining large numbers of offspring from genetically superior animals (or obtaining offspring from infertile or sub-fertile animals). These technologies are referred to as assisted reproductive technologies (ART). The following is a brief discussion of the various techniques that have been developed and are currently used and how they fit into the overall picture in relation to cloning.

Artificial Insemination and Cryopreservation

Artificial insemination (AI) has been used to obtain offspring from genetically superior males for more than 200 years (see US Department of Agriculture, National Institute of Food and Agriculture's Animal Reproduction website for more information: http://www.csrees.usda.gov/nea/animals/in_focus/reproduction_if_assisted.html#insemination). The technique is simply to collect semen from male animals and use it to fertilize female animals. The actual placement of the semen into the female obviously needs to be timed to coincide with oestral ovulation to optimize the chances of fertilization.

Probably the largest improvements that have occurred in this technology are the ability to cryopreserve—or freeze and store—both semen and embryos and to make it available and accessible to increased numbers of livestock producers. Semen from beef and dairy bulls is especially amenable to freezing and long-term storage, and this technique has been widely adopted in the US dairy industry, where more than 60% of dairy cows are bred by AI each year. However, AI accounts for only about 5% of inseminations in the beef industry.

Multiple (Super) Ovulation and Embryo Transfer (MOET)

Multiple (or super-) ovulation can be induced in cows with the use of hormones. These ova are then fertilized, usually by AI. Embryo transfer is a technique whereby embryos produced in vivo (in the cow) are then flushed on day 7 after breeding and transferred individually (and non-surgically) to recipients. The development and refinement of this technology has allowed producers to obtain multiple progeny from genetically superior females. It is believed that less than about 20% of dairy producers have adopted this technology.

The introduction of MOET technology has also offered new opportunities for selection programs. It has helped increase female prolificacy of the selected donor cows. From one calf per year, the average number has increased to more than 10 with MOET. Generation level was also reduced since with MOET a cow can produce three calves by the time she is two years old instead of six years old without MOET.

In Vitro Fertilization

As an alternative to collecting embryos from donor animals, methods have been developed recently to produce embryos *in vitro* (in the laboratory). This technique includes *in vitro* maturation (IVM), *in vitro* fertilization (IVF), and ovum pick-up (OPU). *In vitro* fertilization involves harvesting immature oocytes (female eggs) from the ovary of the donor cow using ovum pick or

OPU techniques (a non-surgical technique that uses ultrasound and a guided needle to aspirate immature oocytes from the ovary), which are then matured *in vitro* (about 24 hours in culture), fertilized in a culture dish and allowed to develop for seven days in an incubator, then transferred individually to recipients, or they may be frozen for future use.

IVF has the potential, under appropriate conditions, to increase the annual rate of genetic progress by 10-30% when compared to using MOET alone because IVF offers greater flexibility in the mating of sires to the same cow, thus reducing inbreeding. However, because this is a much more complex operation, it is believed that less than 5% of dairy producers have adopted this method of ART.

Sex Determination of Sperm and Embryos

Methods have been developed in recent years that allow technicians to determine the sex of sperm and/or embryos so that producers can control the gender of the offspring of their livestock. Beef producers prefer male calves because they tend to have higher body weights and higher feed efficiencies compared to female offspring. In contrast, dairy producers prefer heifer calves that will ultimately be used to produce milk and further offspring. The procedures used are now able to determine the sex of sperm with 95% accuracy.

Cloning (Also Called Nuclear Transfer)

Since the mid 1980s, technological advances have allowed technicians to develop and transfer embryos that are identical genetic copies of the animals from which the somatic cells used to enucleate an oocyte have been derived. This nuclear transfer or cloning allows the production of single or multiple copies of the animals from which the somatic cells were derived.

Transgenics

A natural course to follow cloning is to introduce new genetic material into the enucleated oocyte of a clone, thus enhancing the genetic material to express superior or specialty traits. Transgenics is thought to have much more potential than cloning in the long run.

Cloning in the Dairy Industry

The actual word "cloning" means the production of a (usually exact) copy or copies of an individual, and occurs in animals either naturally or artificially when an embryo is split to produce identical twins. The word "clone" has thus been adopted to describe the process of "nuclear transfer," which is used for the production of an unlimited number of genetically identical offspring. Thus, cloning is simply the production of a genetic exact copy of the donor.

The Process of Cloning for Dairying

The process of cloning first involves a technique called enucleation, which entails removing the chromosomal genetic material or DNA from a mature oocyte (unfertilized female egg collected from abattoir-derived ovaries, frozen and stored, then matured in vitro), and then replacing that with the genetic material of a donor animal to be cloned. Enucleation involves manipulation of the eggs with microsurgical instruments under a microscope—to physically remove the chromosomes or genetic material—resulting in a cytoplast (a cell containing only cytoplasm). The donor cell (which may be obtained from either embryos, fetuses, or adults, and grown in the laboratory, and which may also be frozen and stored in liquid nitrogen and thawed for use) is then fused with the enucleated oocyte and activated either chemically or with electrical impulse to induce activation and reprogramming of the somatic cell genome to that of the embryonic genome. Reconstructed cloned embryos are then cultured for 6 to 9 days and then transferred to the uterus of a cow. Approximately 40-50% of these reconstructed embryos develop to a stage suitable for transfer to the uterus' of synchronized recipient cows and carried to term to produce live cloned offspring. Only about 10% result in the birth of a live cloned calf. Thus currently only about 4-5% of cloned embryos originally constructed actually make it to become calves (Kunkel, n.d.).

Applications and Uses of Cloning

The usefulness of cloning technology was discussed as early as 1981 by Van Vleck who concluded that it is based essentially on finding outstanding cows and mass producing them. A large number of other studies have considered the use of cloning in dairy cattle breeding and estimated its potential impact on the rate of genetic progress (see Bousquet & Blondin, 2004, p. 191 for a large number of citations).

It is generally agreed that nuclear transfer or cloning will have three main applications for agriculture, including (Hansen & Block, 2004)

1. the rapid spread of animals with better genetic characteristics,

2. the use of cloning for phenotypic evaluation and selection of superior animals, and

3. the production of genetically modified (or transgenic) animals.

From a practical point of view then, cloning could be used to increase the number, distribution, and availability of cows and bulls with superior genetics for increased milk yield, increased availability of stock with resistance to common diseases like mastitis, and increased availability of stock with desirable genetic traits associated with milk quality. The further development of transgenics will enhance each of these functions (Keefer, 2004).

Problems Associated with Cloning

Although cloning is commercially available, the technology still is considered to be quite inefficient and very costly. Inefficiencies stem from the micromanipulation of oocytes and culture of donor cells and cloned embryos. This is due to the large number of abortions that occur throughout gestation. In addition, when pregnancies actually progress to term, gestation is usually extended and calves are born much larger than average due to large offspring syndrome (LOS) that leads to dystocia, and most animals require cesarean section. These large offspring usually have postnatal weakness, hypoxia, hypoglycemia, metabolic acidosis, and hypothermia, all requiring immediate intensive care. Other problems that are sometimes associated with the technique include incomplete reprogrammation, shortening of telomeres (the physical ends of linear eukaryotic chromosomes), hypertension, kidney abnormalities, liver problems, and limb and body defects (Van Arendock, & Bijma, 2003).

Another problem that needs to be considered carefully is the possibility that many of these postnatal problems could be compounded from one generation to the next. Clearly, any problem that would affect the ability of a cloned animal to produce progeny that themselves can be cloned could become a serious impediment in the establishment of any selection programs. These problems are the largest hindrance to current widespread use by the dairy industry.

Another potential problem with cloning is the possibility of loss of genetic diversity. A number of authors have expressed concern with the possibility that cloning will reduce genetic diversity and result in problems of fertility and disease susceptibility. Since unlimited numbers of identical animals could be produced with cloning, an overpopulation of the same genetic makeup could result in inbreeding and loss of genetic variation, which is not desirable. Apparently, this same concern was expressed when AI was implemented commercially, but with careful management and planning of breeding schemes, these problems should not occur, if only because we are aware of the potential for the problem before it occurs. A number of authors have posited that, when used correctly, cloning of selected livestock potentially offers many advantages in animal breeding and production, one of which is to *preserve* biodiversity.

Cloning exceptional (male or bull) individuals, if it is done without limitations, also has the potential to reduce genetic variability. However, even in large dairy cattle populations without cloning, a substantial reduction in genetic variability is already occurring because of the massive use of relatively small numbers of sires which are quite often genetically related. Therefore, the issue of genetic variability should be addressed as a whole, not specifically for cloning. Because of the potential for loss of genetic variation from cloning, many animal scientists recommend that gene banks should be established as soon as possible.

Technologies to Overcome Problems Associated with Cloning

While many of the problems associated with cloning raise significant barriers to its success, a number of other technologies that are currently under development could be extremely useful in helping to overcome such problems.

Preimplementation Genetic Diagnosis. Preimplementation genetic diagnosis (PGD) is a newer technology that may provide much needed assistance toward reducing the costs of some of the problems associated with cloning and other advanced breeding technologies. PGD can be used to screen embryos for genetic defects post-development but preimplementation. A single cell is removed from the developing embryo and screened for an unlimited number of single gene traits or chromosomal abnormalities using a number of modern techniques. In this way, embryos can be pre-screened, thus allowing the elimination of genetically abnormal embryos. The same technique could also be used to select embryos with economically beneficial traits. PGD is still evolving as a tool for the livestock industry, and there are currently few commercially available tests for the dairy industry.

Gamete Storage. While the cryopreservation of animal semen and embryos has allowed great advances in artificial insemination and embryo transfer, a number of new techniques are now being developed that could make the storage and transportation of semen and embryos much more efficient than it has been in the past. Apparently, cryopreservation of in vitro matured, fertilized, and cultured embryos or cloned embryos is still quite problematic, but research is currently underway to improve the efficiency of this technology and make it more useful to the industry.

Genomics. The ability to sequence the nucleic acids of a genome has come a long way in the last 20 years. Science has learned much from the Human Genome Sequencing project during the 1990s. Sequencing the bovine genome and further advances in functional genomics promises great benefits for the dairy industry. As genes for production traits are identified, genetic selection strategies can be improved for traits such as milk yields, milk fat and protein composition, herd health, and food safety. Unfortunately, most traits are complex and involve several genes and environmental factors. Sequencing of the bovine genome was completed in 2009 (see, for example, http://www.hgsc.bcm.tmc.edu/projects/bovine).

Proteomics. Proteomics is the analysis of the full complement of proteins within an organism and is now gaining more attention as the technologies advance. It is much more complicated than genomics because proteins can be modified post-translation within the cell, among other complications that can occur. Understanding how proteins function together, however, will help in the development of new therapeutic agents and provide new ways to diagnose and treat reproductive disorders (Moore & Thatcher, 2006).

Bioinformatics. Bioinformatics is simply the compiling of large mountains of data on genomics and proteomics on computers. Simply put, as computer technologies advance, so too can our abilities to compile and search large databases of information and perform the complex operations of analyzing the data on genomics and proteomics.

Implications of Cloning for Breeding Improvement Strategies

There is little doubt that cloning could become an extremely valuable tool for the enhancement of genetic traits useful for the dairy industry. However, there are also many problems to overcome before it becomes a technology that can be widely adopted and used in commercial dairy operations. In a 1999 paper published in the *Journal of Animal Science*, L.D. Van Vleck, a pioneer in throwing light on the potential benefits of cloning (Van Vleck, 1999), goes to great lengths to dispel some of the myths that have arisen over the last 25 years about the virtues of cloning. The following is a synopsis of his findings.

Are clones identical? Van Vleck shows that only when traits are 100% heritable is complete uniformity likely to occur. And even that is no guarantee. In other words, while clones may be phenotypically similar in simply inherited characteristics (identical in color, shape, size, etc.), there is little likelihood that their genetic performance will be exactly the same as the clonal parents. Thus, the thought that one could find the "perfect" animal to clone and do away with uncertainty about breeding is unrealistic.

Are clones superior? Again, Van Vleck demonstrates that the answer to the question is yes, maybe, or no. Van Vleck shows that clones may be superior under some circumstances depending on the heritability of the characteristics that were being used to compare performance, but that in most cases there is no certainty that a clone will be superior, and in many cases, the clone may actually be inferior.

Can we find the "perfect" animal to clone? Van Vleck shows that finding an animal that meets high standards for several traits is unlikely, and that although the perfect animal may exist, finding such an animal and verifying that it is the perfect animal is highly unlikely.

Can cloning be a useful reproductive tool? Van Vleck concludes that cloning could provide faster dissemination of superior genetic material to the population than previous breeding schemes have achieved but cautions that the costs are currently extremely high, and that legal, ethical, and economic questions remain.

The Economic Impacts of Cloning in the Dairy Industry

The previous section laid out the current status of cloning and its applications in the dairy industry. The perspective that emerges is that despite the technical difficulties facing it, cloning has the potential to become an effective tool to enhance the genetic superiority of dairy cattle. Cloning could become a reality in the near future, not only to solve some of the problems that the dairy industry currently faces in the form of decreased fertility, but also to rapidly increase the number, distribution, and availability of cows and bulls with superior genetics that could allow increases in milk yield, increases in the availability of stock with resistance to common diseases such as mastitis, and/or with desirable traits associated with milk quality.

Despite the problems outlined in the previous section, it is assumed, for the sake of this analysis, that at some stage in the future cloning will become a reality. Exactly when this will occur is a subject of debate and speculation. In this section we review some of the potential economic impacts of cloning on the dairy industry *assuming that the technical difficulties are overcome*.

By far the largest economic impact of cloning, or at least the most immediate impact, will be the ability of dairy producers to increase milk yields, since this has an immediate economic return to producers, even more so than enhancing cows for disease resistance and other quality traits. Transgenics is further away because of the technological difficulties associated with the introduction of foreign DNA—although it too will eventually have an impact on the dairy industry. For the immediate future then, the analysis that follows focuses mainly on the impacts of potential adoption of genetically enhanced cows that produce more milk.

Cost of Cloning in Genetic Improvement of Dairy Cattle

The costs associated with cloning are considered to be a major obstacle in the widespread use of cloning in the dairy industry, yet we know very little about them. McClintock (1998) for example posits that

> "*if cloned embryos cost $30 and had a 50% pregnancy rate, they would be very attractive to most dairy producers. At $300 per cloned embryo, producers would be inclined to use cloned females to breed replacement cows, but there would be little advantage to producing F_1 clones. At $3,000 per cloned embryo there would be limited scope for cloning, except for a number of niche markets for either male or female clones (i.e., show-winners).*"

It is thought by some (Lewis, n.d.) that cloned embryos should sell for the same price as a straw of semen, and give—after implantation in recipients—similar outcomes to those achieved following AI (http://www.genaust.com.ca/cloning.pdf).

Perhaps the most extensive analysis to date on the costs of cloning is the widely quoted 1998 study by Dematawewa and Berger as published in the *Journal of Dairy Science*. Dematawewa and Berger (1998) enumerate the genetic and economic gains from 12 different models of alternative progeny testing schemes. The idea of the study was to compare the genetic and economic gains of the 12 progeny testing schemes using the rates of gain in milk yield and the discounted economic gain or break-even cost as criteria for efficiency. Among the many interesting results this study generated, Dematawewa and Berger (1998) conclude the following.

1. Current AI and progeny testing schemes have the potential to double their rate of genetic gain by performing selection for milk yield at optimal levels.
2. The production of 10 embryos per dam with sexed semen and using few bulls as sires under optimal selection could triple the annual genetic gain currently realized under modern progeny testing schemes.
3. Production of clones on both dams of sires and dams of dams' models produced higher genetic progress than did limiting the cloning process to only dams of dams.
4. While the use of single records of clones for dam selection further increased the rate of genetic gain, the use of three records of clones led to increased generation intervals that offset the gain from increased accuracy and resulted in lower genetic gains than from the use of single records.
5. The potential gains in accuracy and intensity of selection with cloning (relative to no cloning) appeared to be higher under modern progeny testing schemes than under optimal AI progeny testing.
6. The cost of producing a clone (a single copy of a dam) should be below $84 for cloning technology to be an economically viable alternative under commercial-testing schemes.

Table 1. Summary of variables, initial values, functions, and ranges of dairy simulation model.

Model input[1]	Initial values	Functions	Ranges
Number of cows	650		300-1,000
Milk production per cow (MPPC)	19,537 lbs		16-24,000
Percentage growth in MPPC	1.5%		1.5-2%
Total milk production	126,991 cwt	= (MPPC × # cows) / 100	
Replacement (cull) percent	30%		
Calving percentage	95%		
Milk price	$12 per cwt		$10-14
Calf price	$100 per calf		
Cull price	$300 per cow		
Interest rate	7%		
Replacement cow price	$1,500		
Depreciation	$70 per cow		
Fixed cost per cow	$285	= 350 − (0.1 × # cows)	
Investment per cow	$1,838	= 2000 − (0.25 × # cows)	
Revenues			
Milk	$1,523,886	= Total milk prod × milk price	
Calves	$61,750	= # cows × calf % × calf price	
Cull cows	$58,500	= # cows × cull % × cull price	
Total revenue	$1,644,136		
Costs			
Feed costs	$817,683	$= 9 \times (MPPC)^{0.5}$	
Labor costs	$128,495	= 100 + (0.005 × MPPC)	
Replacements	$292,500	= # cows × cull % × replace price	
Fixed costs	$185,250	= # cows × fixed cost per cow	
Depreciation	$45,500	= # cows × depreciation per cow	
Interest on investment	$83,606	= # cows × invest/cow × interest rate	
Total costs	$1,553,034		
Net revenues	$91,102		
Net revenue/cwt	$0.72		
Net revenue/cow	$140.16		
Loan interest rate[2]	7%		6-10%
Discount rate[2]	3%		2-4%
Net present value	$14,324.91	$NPV = \sum_{t=1}^{n} [C_t / (1 + r)^t] - C_0$	

[1]*Variables in **bold** indicate those used in the simulations over the indicated ranges.*
[2]*Bank loan rates and discount rates used here reflect average loan rates and inflation rates in the United States over the last 10 years. Preliminary analysis also indicates that these rates are positively correlated, so they are also correlated in the simulations at 0.7 (70%).*
Note: cwt = hundredweight

Revenue Generation Associated with an Investment in Cloning

As mentioned previously, many commentators on cloning in the animal industries have postulated that unless—and until—the cost of acquiring a clone has decreased to much lower levels, most dairy producers would not be interested in adopting such a technology (McClintock, 1998; Van Vleck, 1999; Wells, n.d.). Currently, the cost of acquiring a 3-month-old cloned heifer is quoted by some sources at around $10,000. At this price, most commentators have assumed that cloning will have little impact on the dairy industry. But this assumes that dairy producers would actually acquire a cloned heifer for their own purposes. An alternative method of making superior genetics available to dairy producers would be to do what is already currently being done under conventional methods: inseminating cows with semen from superior (in this case, cloned) sires, as suggested above by Dematawewa and Berger (1998).

Since there are no accurate estimates of the cost of a clone, the only way to measure the feasibility of investing in advanced animal breeding technologies such as cloning is to evaluate the returns associated with the increased milk production that results from the investment. In other words, if a producer were to invest in advanced animal breeding technologies that increased milk production, would the net revenues generated by the increase in milk production be sufficient to cover the costs of the investment?

To analyze this question, a spreadsheet model of a "typical" dairy was developed (see Table 1).[2] The entire model represents two dairy enterprises producing milk over a 10-year period. Both enterprises are exactly the same in every respect with the exception of growth in milk production per cow. The size of both operations (number of cows) remains constant over the 10-year period, however the second enterprise is assumed to adopt advanced animal-breeding technologies that result in increased milk production per cow. Therefore, the only differences in revenues between the two enterprises are increased milk production as a result of increases in milk production per cow. Preliminary analysis of cost of production survey data[3] reveals that feed costs and labor costs can also vary by the level of milk production per cow. We capture these differences in costs using simple linear equations for feed costs per cow and labor costs per cow.[4] Their inclusion, however, means that the resulting net revenue calculations are non-linear. Changes in farm size (number of cows) are also assumed to result in changes in economies of size, and these are captured by varying fixed costs per cow and investments per cow with cow numbers.[5] Both enterprises are assumed to have an initial compound growth in milk production per cow of 1.5% per year, which is the US average increase in milk production per cow for the last 10 years, but the second enterprise is assumed to achieve higher levels of increased growth in milk production per cow by investing in advanced breeding techniques such as cloning.[6]

The difference in milk production revenues and costs between the two dairies generates a stream of additional net revenues over the 10-year period. Access to advanced breeding techniques is assumed to be purchased in Year 0 through a bank loan, which is then paid off by the additional profits generated by the increased milk production. In this case, the magnitude of the bank loan is exactly equal to the sum of the additional net revenues generated over the 10-year period, discounted by the interest rate of the loan over the same period. In other words, the bank loan is the present value of the net revenues of the additional milk generated by the increased milk production. The assumption is that the investment will be covered *only* by the net revenues from *increased* milk production. To measure the stream of increased net revenues generated by the use of the advanced breeding techniques, we use the net present value (NPV) of the stream of increased revenues generated by the increased milk production.[7]

While an increase in the rate of growth in milk production will obviously be a major reason why we would expect NPV to increase, there are a number of other factors that may also cause differences in the magnitude or sign of these measures. These include variations in the size of operation (as measured by number of cows), milk prices, and base milk production per cow as well as the bank loan rate and assumed discount factor.[8] In order to measure the impact of these additional factors, a Monte Carlo simulation is used to generate changes in the NPV. This is achieved by generating 10,000 obser-

2. *The spreadsheet is a fairly simple model expressing revenues from milk, calves, and cull cows, and costs in broad categories of feed costs, labor costs, replacement costs, fixed costs, depreciation, and interest on investment.*
3. *http://www.cdfa.ca.gov/dairy/dairycop_annual.html*
4. *Feed costs (FC) per cow are estimated as FC/cow = 9 × (milk production per cow)$^{0.5}$. Labor costs (LC) per cow are estimated as LC/cow = 100 + (0.005 × milk production per cow).*
5. *Fixed costs per cow = 350 − (0.1 × # of cows). Investment per cow = 2000 − (0.25 × # of cows).*
6. *The growth in milk yields is assumed to be compounded annually following the usual formula $A(t) = A_0 (1 + r)^t$, where A(t) is the average milk yield of cows in year t, currently yielding A_0 lbs per cow growing at a rate r per year.*
7. *Net present value is given by $NPV = \sum_{t=1}^{n} [C_t / (1 + r)^t] - C_0$, where C_t = net cash flow at time t, C_0 = initial capital outlay at time t = 0, r = the discount rate, t = time in years, and n = total time in years.*
8. *Bank loan rates and discount rates used here reflect average loan rates and inflation rates in the United States over the last 10 years.*

Table 2. Simulation and regression results for NPV (1).

	Range	Mean (from simulation)	Coefficient[1]	Marginal effect[2]	Sensitivity (from simulation)[3]
NPV		$24,529			
Constant			-250,097		
# of cows	300-1,000	650	37.65	0.998	17.1%
Milk price ($/cwt)	$10-14	$12	2,935.3	1.436	2.4%
MPPC (lbs)	16-24,000	20,000	1.47	1.198	2.4%
% growth	1.5-2%	1.75%	9,824,360	7.011	76.7%
Interest rate	6-10%	8.15%	513,944	1.708	0.6%
Discount factor	2-4%	3%	-944,193	-1.155	-0.7%
Adj. R square			88.32%		

Table 3. Simulation and regression results for NPV per cow (1).

	Range	Mean (from simulation)	Coefficient[1]	Marginal effect[2]	Sensitivity (from simulation)[3]
NPV		$37.63			
Constant			-348.164		
Milk price ($/cwt)	$10-14	$12	4.512	1.439	3.5%
MPPC (lbs)	16-24,000	20,000	0.0023	1.204	3.1%
% growth	1.5-2%	1.75%	15,162.2	7.053	91.7%
Interest rate	6-10%	8.15%	789.302	1.709	0.8%
Discount factor	2-4%	3%	-1,446.18	-1.153	-0.9%
Adj. R square			94.40%		

[1] All coefficients were significant at the 99.9% level.
[2] Marginal effects measured at the mean of their respective variables.
[3] Sensitivity is measured as the contribution to total variance.

vations of changes in the independent variables and performance measures using a simulation program (Crystal Ball Premium Edition Software, Version 7, Decisioneering Inc, 2004), and then using OLS regression techniques to summarize the results of the simulation.

The simulation and regression exercise involves the following steps. Ranges for the selected variables are chosen (as shown in Table 1). All distributions used in the simulation are uniform because we want to measure the effects over the entire ranges indicated without bias. The data generated by the 10,000 iterations are then used to estimate regression equations for NPV and NPV per cow. We tried several different regression-model specifications, but found that simple linear equations provided the most satisfactory explanations of the variation in NPV and NPV per cow. The variable ranges, means, and sensitivity from the simulation, and the resulting coefficients and marginal effects from the regression analysis, are reported in Tables 2 (NPV) and 3 (NPV per cow), and some results are graphed in Figures 1 and 2.

The results of this fairly basic exercise show a number of interesting aspects of investing in advanced breeding techniques associated with increasing the rate of growth of milk production per cow. However it would appear that there are some significant scale effects. From the simulations, NPV ranged from $56 to $121,084 with a coefficient of variation of 75.09%, demonstrating a wide range of possibilities. NPV per cow showed slightly less variability, ranging from $0.14 to $148.54 with a coefficient of variation of 65.16%. In both cases, NPV and NPV per cow were most sensitive to changes in percentage growth rate of milk production per cow (76.7% and 91.7%, respectively) as might be expected, with some sensitivity to changes in farm scale (cow numbers) for NPV. For example, a 10% increase in percentage growth rates results in a more than 70% increase in NPV and a 90% increase in NPV per cow. Changes are less dramatic at lower levels and much more dramatic at higher levels of growth. Changes due to milk price and base milk production per cow (MPPC) were relatively small, and changes due to interest and

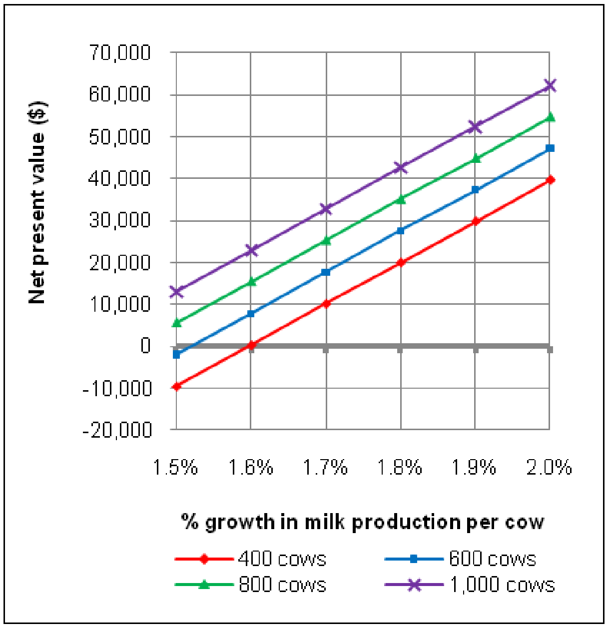

Figure 1. Net present value by percentage growth rate, for various sizes of operation (number of cows).

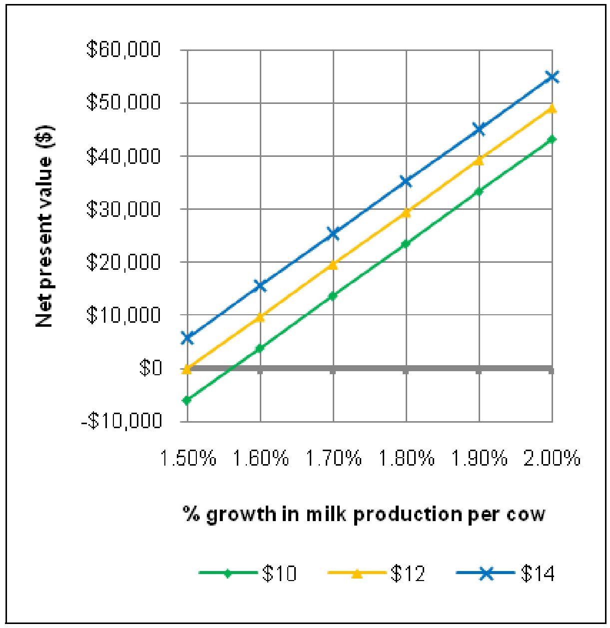

Figure 2. Net present value by percentage growth rates, for various milk prices ($ per cwt).

discount rates were negligible. These sensitivities for NPV are shown quite clearly in Figures 1 and 2, which are estimated from regressions.

The assumption that producers would be prepared to invest the entire amount of the stream of revenues generated by an increase in milk production per cow in advanced breeding techniques demonstrates that the increased revenues generated by small increases in the rate of growth in milk production per cow are much larger than one might expect. As expected, there are some economies of size and scale associated with the ability to invest, and milk prices and base milk production per cow are also important determinants of the level and success of the investment. More importantly, it would appear that the increases in milk production due to an investment in advanced breeding techniques are able to generate sufficient revenues to justify an investment at all but the lowest levels of growth, or when milk prices (and other variables) are very low. This in turn would indicate that dairy producers are likely to invest in advanced breeding technologies as soon as it can be shown that these increases in milk yields are possible.

Costs and Revenues Associated with a Genetically Enhanced Replacement

Suppose that a producer decided to invest in cloned animals by replacing 10% of the milking herd with cloned cows (that had demonstrated higher genetic gains) each year over a period of 10 years so that after 10 years the entire herd is made up of the improved dairy cattle. The improved genetic gains are expressed by increased levels of milk production. Obviously, as the producer replaces the old herd with the new herd, average milk production per cow will increase, thus generating increased revenues. The increased revenues are used to pay for the replacements. The question is: what price would the producer be willing to pay for the genetically improved cows?

Genetic gains in this exercise are measured in pounds of milk and are derived from the potential increases in genetic gain reported by Dematawewa and Berger (1998). They showed that genetic gains from 100 clones in a progeny testing program could boost yields to as much as 930 kgs (2,064 lbs). With a single clone, genetic gains could be boosted to as much as 300 kgs per year (660 lbs per year). If genetic gains of 150 kgs (330 lbs) per year can be reached by current traditional breeding techniques, then cloning could add another 330 lbs (obtained from 660 − 330) to 1,734 lbs (obtained from 2,064 − 330) per year. That is equivalent to an increase in the rate of growth in milk per cow from 1.5% to 1.65% per year (or 10%) for an average cow currently milking 19,537 pounds, with potential beyond that. Therefore, we use ranges from 200 to 900 lbs in the simulations.

The cost of the replacements is measured as the difference between the cost of conventional replacements

Table 4. Simulation and regression results for NPV (2).

	Range	Mean (from simulation)	Coefficient[1]	Marginal effect[2]	Sensitivity (from simulation)[3]
NPV		$3,025			
Constant			-152,912		
# of cows	300-1,000	650	4.45	0.957	1.0%
Milk price ($/cwt)	$10-14	$12	1,822	7.228	7.1%
MPPC (lbs)	16-24,000	20,000	0.9412	6.223	0.2%
% growth	1.5-2%	1.76%	7,014,180	40.743	60.0%
Interest rate	6-10%	8.00%	82,005.60	2.209	0.1%
Discount factor	2-4%	3%	-165,292	-1.639	-0.1%
Cost of clone	$50-200	$125	-100.88	-4.169	-31.6%
Adj. R square			84.63%		

Table 5. Simulation and regression results for NPV per cow (2).

	Range	Mean (from simulation)	Coefficient[1]	Marginal effect[2]	Sensitivity (from simulation)[3]
NPV		$4.63			
Constant			-229.832		
Milk price ($/cwt)	$10-14	$12	2.824	7.313	7.4%
MPPC (lbs)	16-24,000	20,000	0.0014	6.166	0.2%
% growth	1.5-2%	1.76%	10,756.7	40.787	60.0%
Interest rate	6-10%	8.00%	124.192	2.183	0.1%
Discount factor	2-4%	3%	-257.397	-1.666	-0.1%
Cost of clone	$50-200	$125	-0.1551	-4.184	-32.2%
Adj. R square			94.4%		

[1] All coefficients were significant at the 99.9% level.
[2] Marginal effects measured at the mean of their respective variables.
[3] Sensitivity is measured as the contribution to total variance.

and the cost of the genetically improved replacements. NPV is again measured by using the present value of the stream of increased revenues over a 10-year period as a bank loan, which is then invested in the replacements with superior genetics (which in turn produce higher levels of milk per cow). The variable ranges (which are the same as the previous exercise), means, and sensitivity from the simulation, as well as the resulting coefficients and marginal effects from the regression analysis, are reported in Tables 4 (NPV) and 5 (NPV per cow).

As would be expected, the NPVs are mostly determined by the genetic gains of the replacement cows (percentage growth) and the cost of the cloned animals, which together account for more than 90% of the total variance, and, in turn, offset each other. To maintain consistency with the previous exercise (and because they are easier to interpret), we used actual genetic gain (in pounds per cow as explained above) in the simulations but recorded the resulting percentage growth in milk production per cow, and we used that as an explanatory variable in the regressions. The relationship between genetic gain and percentage growth rates is reported in Table 6 for various base levels of milk production per cow. The additional variable in the results reported in Tables 4 and 5 is the cost of the cloned replacements, which, the reader is reminded, is the difference between the cost of a conventional replacement and the cost of the new (cloned) replacement, and

Table 6. Genetic gain (lbs of milk per cow) by percentage growth rates for various base levels of milk production per cow.

	1.6%	1.7%	1.8%	1.9%	2.0%
16,000	54	300	547	793	1,039
18,000	109	355	601	847	1,094
20,000	163	410	656	902	1,148
22,000	218	464	710	957	1,203
24,000	273	519	765	1,011	1,257

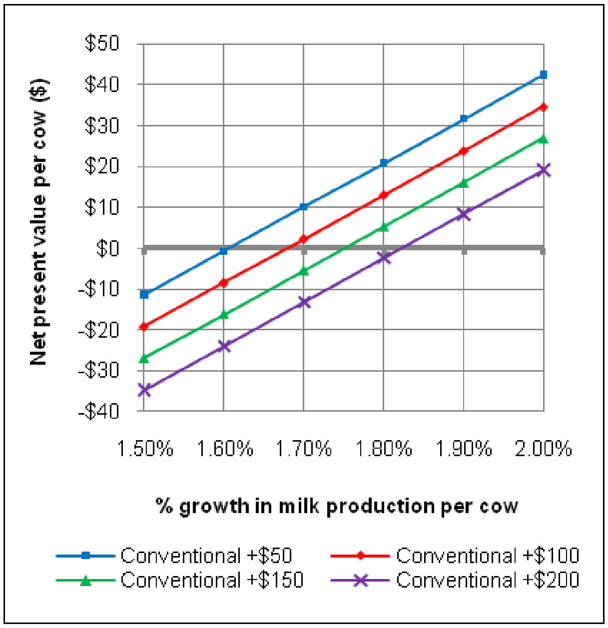

Figure 3. Net present value per cow by percentage growth rate, for various costs of clones.

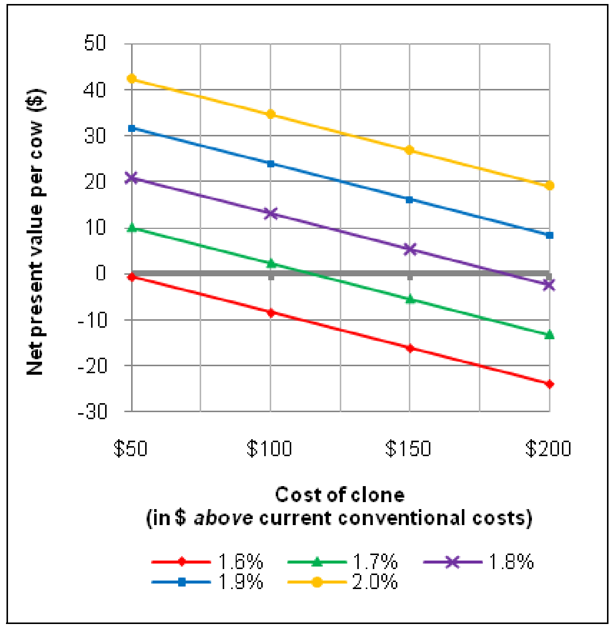

Figure 4. Net present value per cow by cost of clone, for various levels of percentage growth rate in milk production per cow.

ranges from $50 to $200 (above the cost of a conventional replacement).

An important difference in these simulations is that NPV varied from -$30,000 to +$50,000, and NPV per cow varied from -$32 to +$64. Negative NPVs are the result of forcing the model to evaluate low genetic gains in milk production per cow against the high cost of clones. In both cases, negative NPVs occurred 36.5% of the time or alternatively resulted in a 63.5% certainty level.

As mentioned previously, genetic gains (or percentage growth rates in milk production per cow) are offset by the cost of cloned replacements. NPV increases as the genetic gain (or percentage growth) increases (Figure 3), but decreases as the cost of the cloned replacements increases (Figure 4). The bottom line is that break-even NPVs will depend crucially on the level of genetic gain or percentage growth in milk production per cow achieved by the genetically improved cows and will be offset by the relative price of the cloned replacements. In contrast to the findings of Dematawewa and Berger (1998), the feasibility of adopting genetically superior cows that produce higher levels of milk can vary quite widely depending on the level of genetic gain achieved. Average levels of milk price may also influence the decision to adopt to a modest degree, but in comparison to the previous findings, base levels of milk production and size and scale of operation have little to no effect on the decision to adopt.

Factors Associated with the Feasibility of Investing in Cloning

From the above analyses there are a number of things we can conclude about the factors associated with the feasibility of investing in cloning. The results reported here are only indicators of the potential feasibility. Each individual producer will need to evaluate the investment for their particular case.

The factors that will influence the feasibility of investing in cloning are dependent on a number of interacting variables.

1. Size of operation: As would be expected, the size of the dairy operation as measured by the number of cows is an important determinant of feasibility. In general, as the size of the operation increases, the ability to capture economies of size and scale appear to make an investment in cloning more feasible for a large operation than for a small one.

2. Milk prices: As would be expected, milk prices play an important role in determining the feasibility of any investment on a dairy operation, including investments in advanced breeding tech-

nologies. US dairy producers have been plagued in recent years by some very low prices and by the same token have been blessed with some incredibly high prices. The range of prices used here (from $10-14 per cwt) is a purposeful limitation imposed on the variable to demonstrate simply that the feasibility of investing in cloning is strongly influenced by the returns dairy producers get for their milk, which in turn is determined by milk prices.

3. Base milk production per cow: A variable that is often overlooked by analysts is the base milk production per cow. Common sense dictates that any form of growth in milk production per cow will be influenced by its starting point. In general, the higher the base average milk production per cow the more feasible such investments tend to be.

4. Interest rates and discount factors: The use of bank loans, present values, net present values, and internal rates of return as measures of performance necessitates the use of interest rates and discount factors. In general, the higher the discount rate, the higher the interest rate, and the lower the NPV and internal rate of return. For a large investment in advanced breeding technologies, a period of high rates of inflation and high bank interest loan rates could have a serious impact on a producer's ability to justify the investment. This is another source of uncertainty that could have been built more effectively into the simulations and which may have created differences in the end results.

5. Other factors: There are invariably many other factors that would influence the feasibility of investing in advanced breeding technologies. Calving rates, culling percentages, replacement rates, prices received for calves and culls, depreciation rates, feed costs, labor costs, herd health, and many more are just some examples of the variables that were held constant in this exercise.

Conclusions

This study attempted to outline and analyze some of the potential economic impacts of cloning for the purpose of increasing dairy productivity by improving dairy herd composition. The study has three basic limitations. First, since cloning is not yet a reality, and in fact faces a number of technological difficulties, an analysis of the economic impact is necessarily limited. Second, the question of when these new breeding technologies will be available for widespread adoption by dairy producers or the firms that supply them with cloned animals or embryos is unknown. Finally, very little data has been generated with which to analyze the actual impact of cloning in comparison to other advanced breeding techniques.

Cloning is considered to be one of a number of assisted reproductive technologies, many of which are at various stages of development and have not necessarily been widely adopted, but which are considered to be technological solutions to problems associated with the declining reproductive efficiency of dairy cattle as a result of advances made in increasing milk production. In addition, the advances that have been made in selecting traits associated with increasing milk production have also caused a substantial reduction in genetic diversity. Thus, advances made in the ARTs are viewed as potential solutions to maintain and improve the genetic superiority of dairy animals.

From a practical point of view, cloning could be used to increase the number, distribution, and availability of cows and bulls with superior genetics for increased milk yield, increased availability of stock with resistance to common diseases like mastitis, and increased availability of stock with desirable genetic traits associated with milk quality. The further development of transgenics could enhance each of these functions and also increase the ability to produce specialized bioproducts for use in medicine, pharmaceuticals, and many other industries.

However, cloning technologies currently face a number of technological problems associated with the success of the development of cloned embryos, survival in being carried to term, health problems at birth, and shortcomings in the physical and genetic makeup of the postnatal cloned animal. By the same token, there are also a number of new technologies that are currently under development that could assist in overcoming many of the problems associated with cloning.

Overall then, it is extremely difficult to predict with any confidence the actual nature of the technology that will eventually emerge. Provided most of the technological problems are eventually overcome, the question remains as to whether it could or will become an economically feasible technology.

Assuming that cloning will become a reality in the near future, and that the technological difficulties that currently limit cloning will be overcome, it is also necessary to limit the economic analysis to the only use of cloning for which there exists some data on its economic effects—that of increasing milk yields. Fortunately, this is also probably the one use of cloning that is likely to have an immediate and fairly significant economic impact on the dairy industry. Other predicted uses of cloning will also have significant impacts in the longer term, but are more difficult to quantify and measure at this early stage of development.

The costs of cloning are considered to be a major obstacle in the successful application of cloning to increase dairy productivity, yet very little is known about them. In the absence of any reliable cost data, the first step in analyzing the potential economic feasibility of cloning is to analyze the increased revenues associated with an increase in milk production per cow and to see if those revenues could justify an investment in advanced breeding techniques such as cloning.

Using a spreadsheet model of a "typical" dairy operation and simulation techniques, this study showed that the revenues generated by increased growth in milk production per cow were substantial and that producers may be willing to invest in such a technology.

A similar simulation exercise was carried out using data reported by Dematawewa and Berger (1998). It was found that the net present value generated by the stream of increased net revenues generated by the increased milk yields varied widely and depended on the genetic gains achieved relative to the price of the genetically superior animals. The increase in NPV from break-even is relatively rapid and indicates that there may be conditions under which dairy producers find it justifiable and profitable to invest in advanced breeding technologies such as cloning in order to improve the genetic superiority of the herd.

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