

# A Stochastic Simulation Model for Dairy Business Investment Decisions

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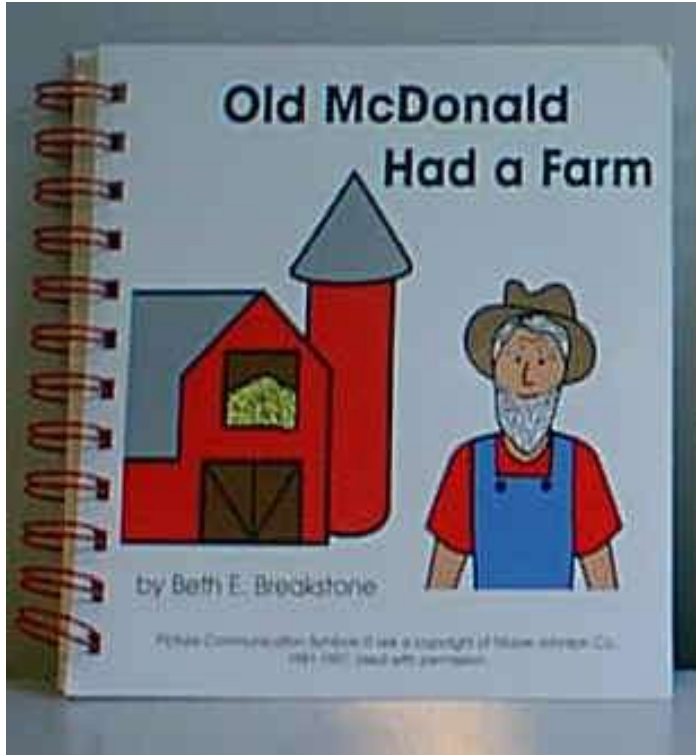


# Where Are We Going?

- Today's Dairy Industry
- Intro to Precision Dairy Farming
- Model Development
- Model Application
- Future Implications



# Dairy Industry-Technical Landscape



# Dairy Industry-Technical Landscape







# Dairy Industry Today

- Increasing herd sizes
- More volatile milk prices forcing dairy producers to improve management skills
- Managers improving computer skills
- Increased innovation in automated solutions
- Renewed focus on animal welfare issues
- Large quantities of underutilized information





# Projections for Number of Farms

Year	Farm Size (Number of Cows)					All Farms
	1 - 49	50 - 99	100 - 199	200 - 499	500 and over	
	Number of farms					
1982	240,747	53,341	14,608	n.a.	n.a.	202,068
1992	93,118	41,813	14,062	n.a.	n.a.	157,150
2000	52,920	31,360	12,865	5,350	2,675	105,170
	Continuation of increased per capita consumption					
2010 <sup>a</sup>	18,604	13,134	7,343	4,331	3,324	46,736
2020 <sup>a</sup>	3,245	4,093	2,971	2,592	3,416	16,316
	Constant per capita consumption					
2010 <sup>a</sup>	18,235	12,751	7,204	4,292	3,294	45,777
2020 <sup>a</sup>	2,821	3,549	2,655	2,335	3,361	14,721

<sup>a</sup> Estimated.

Source: 1982, 1992 data from U.S. Census of Agriculture.

2000 data from USDA NASS, Agricultural Statistical Data Base July, 2002.



# Current Barriers/Limits

- Decisions driven by “what the neighbor is doing”
- Producers accustomed to receiving information and tools for free
- “Way of life” mentality
- Lack of field data for innovative technologies





# Opportunities

- Dairy managers more versed in:
  - Data management
  - Computers
  - Financial decision making
- Producers see need to combine “cow skills” with business skills
- Rapid decision-making and intervention is necessitated by:
  - Food safety concerns
  - Animal welfare awareness
  - Tighter margins



# Dairy Uncertainty

- Yields
- Prices
- Conception
- Gender determination
- Disease occurrence
- Injury
- Death
- Economic conditions (e.g. inflation, interest)



# **Increased Decision Complexity**

- **Increased knowledge of animal science**
- **Quality demands of consumers**
- **Governmental regulations**
- **Emergence of a new social ethic (Rollin, 2004) with regard to animal care**
- **Increased concern of zoonotic disease transmission**
- **Waste management**
- **Odor control**
- **Agroterrorism**

# Dairy Decisions



- **Now**

- Standard recommendations
- Thumb rules
- Consultant advice
- “What my dad did”
- What the neighbor is doing
- “Back of the napkin” calculations

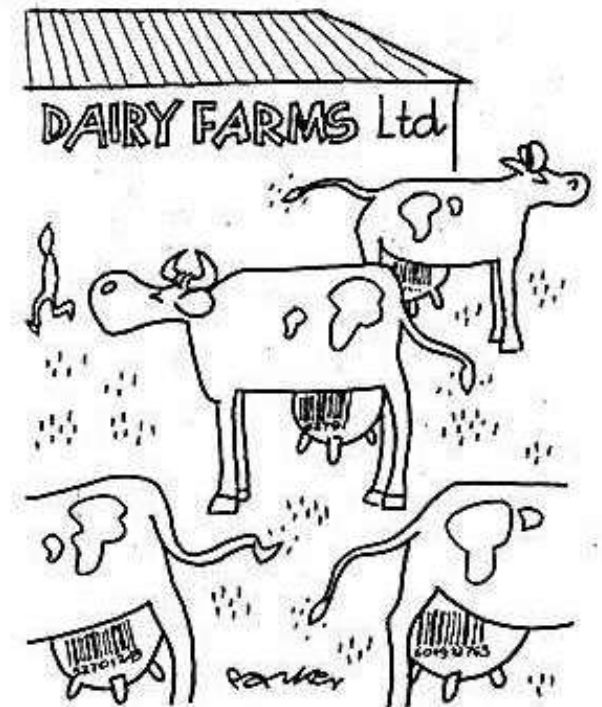
- **Future**

- Formal investment analysis
- Consider uncertainty
  - Price
  - Biological
  - Weather
- Better decisions=competitive advantage



# Precision Dairy Farming

“The use of information technologies for assessment of fine scale animal and physical resource variability aimed at improved management strategies for optimizing economic, social, and environmental farm performance  
--Eastwood et al. (2004)





# Objectives of PDF

- Reversing the trend toward group management with focus on individual animals through technology use
- Protection of consumers and animals
- Early detection of disease
- Minimization of medication through preventive health
- Maximization of individual animal potential





# Background

- **Numerous PDF technologies marketed to dairy producers**
- **Empirical “before and after” or adopter vs. non-adopter studies are expensive and complex**
- **Need to evaluate investments when little data is available**



# Model Basics

- **Investment decisions for PDF technologies**
- **Flexible, partial-budget, farm-specific**
- **Stochastically simulates dairy for 10 years**
- **Measures benefits from improvements in productivity, animal health, and reproduction**
- **Models both biology and economics**



# Simulation with @Risk

- **@Risk 5.0 Excel add-in (Palisade Corp.)**
- **Monte Carlo simulation**
- **Random drawings from distributions for stochastic variables**
- **Represent impact of different combinations on financial or production metrics**
- **Latin Hypercube sampling with a fixed seed of 31517**



## Inputs

Farm Specific or Industry Averages

Underlying System Behavior

Historical Prices

Technology Costs and Impact

## Intermediate Calculations (Modules)

Herd Behavior

Stochastic Variables

Improvements from Technology Adoption

## Technology Impact

Revenues

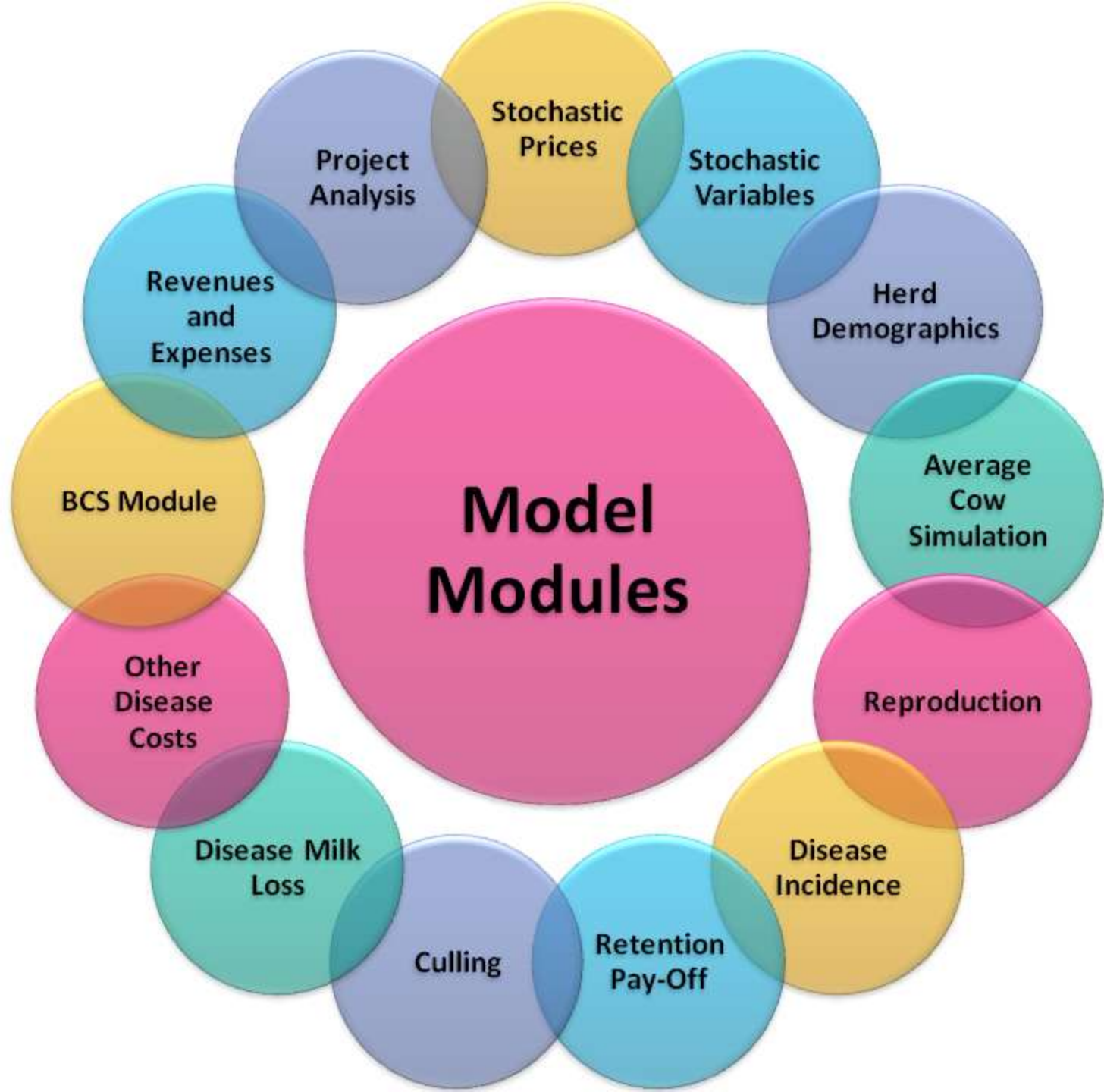
Expenses

## Project Analysis

Net Present Value

Financial Feasibility

Sensitivity Analysis

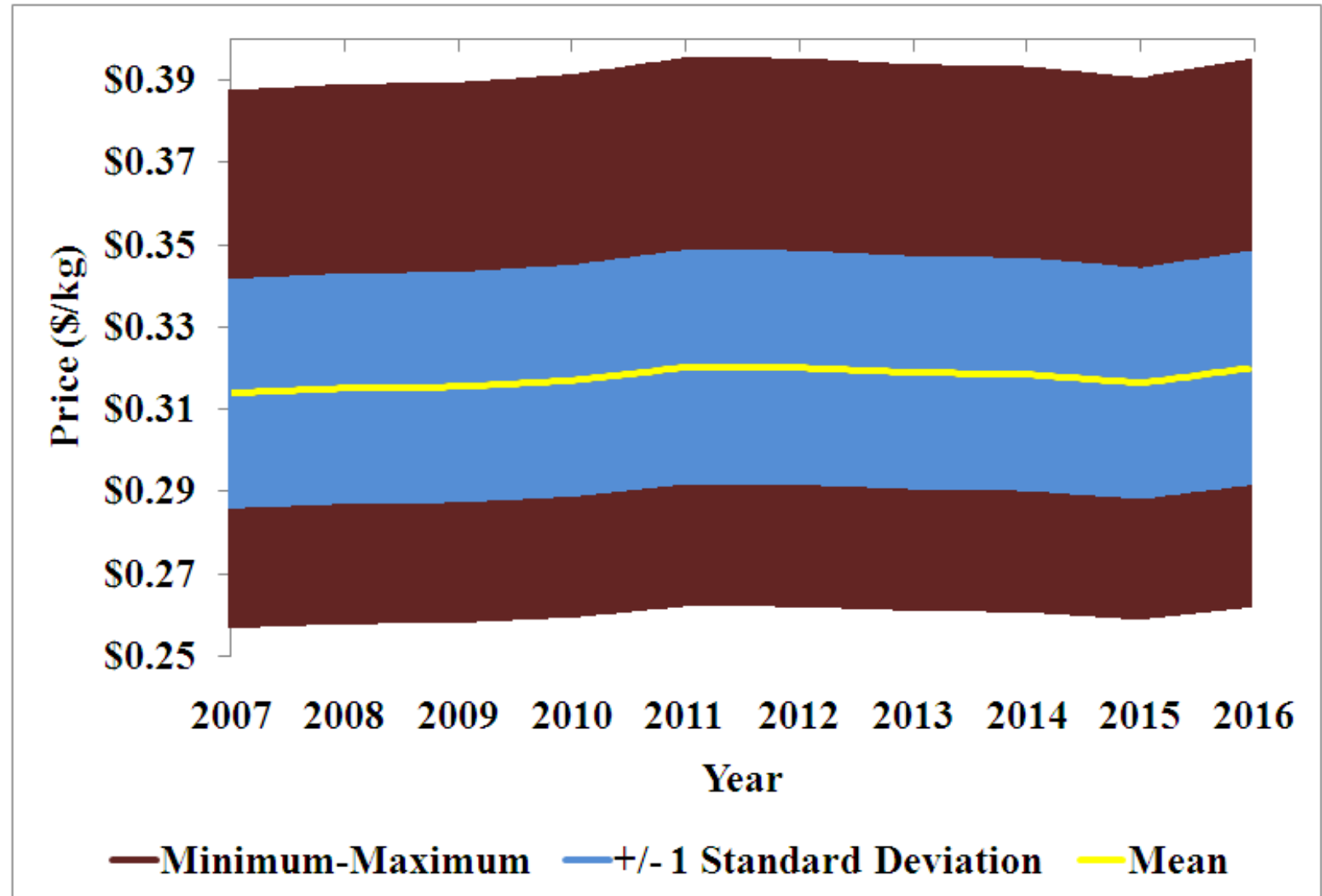




# Stochastic Prices Module

- **Key prices considered: milk, corn, soybeans, alfalfa, cull cow, replacement cow**
- **FAPRI (2007) forecasts for 2007-2016 set deterministic base prices**
- **Historical prices (1971-2006, USDA) used to predict variation in future prices**
- **Stochastic prices-variation from deterministic price within empirical distributions**
- **Correlations among 6 prices considered**

# Example of Simulated Prices-Milk





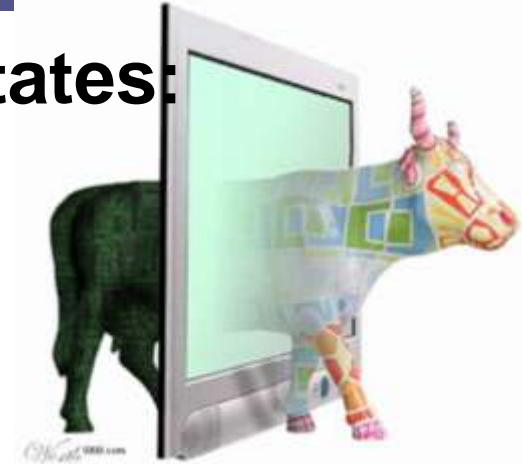
# Herd Demographics Module

- **Industry average or farm-specific**
- **1000 cow US Holstein herd**
- **St-Pierre (1999) herd dynamics methodology for herd movement through time**
- **Cows divided into 6 parity categories (1,2,3,4,5,≥6)**
- **Herd size controlled by purchase or sale of heifers**
- **Calvings evenly distributed throughout year**



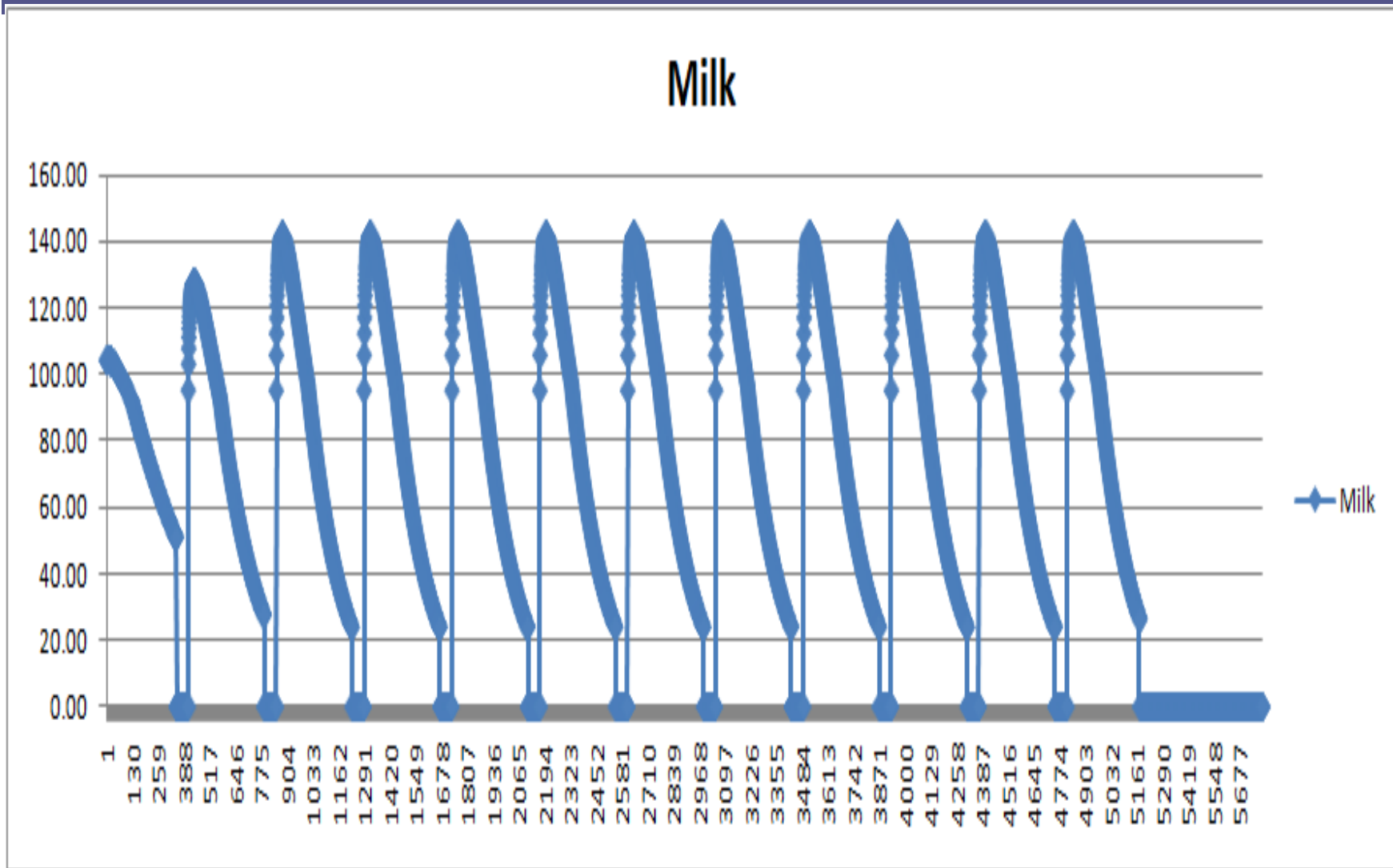
# Average Cow Simulation Module

- **Transitions between biological states:**
  - Age at first calving
  - Calving interval
  - Length of dry period
  - DIM at conception
- **Daily calculations for average cow in each parity:**
  - Milk production and milk revenue
  - DMI and feed costs
  - Body weight
  - BCS
  - Breeding costs and calf revenues





# Simulated Lifetime Milk





# Reproduction Module

- **French and Nebel (2003) regression equation used for cost of days open (DO)**
- **Cost per DO varied by lactation stage**
- **Considered multiple stochastic variables (e.g. milk price, replacement price, feed price, and pregnancy rate)**
- **DO beyond 100 days were a cost**



# Reproduction Module

- **DO costs calculated for 2 scenarios:**
  - **Status quo (no new PDF technology)**
  - **With PDF technology (impact on heat detection or conception rate)**
- **For each disease, reduced incidence impact on DO:**
  - **Modeled stochastically with PERT distributions from Fourichon et al. (2000)**

# Disease Incidence Module

- **Disease incidence from recent published estimates**
- **Separated by parity groups (1,2,≥3)**
- **Diseases considered:**
  - **Displaced abomasum**
  - **Dystocia**
  - **Ketosis**
  - **Mastitis**
  - **Metritis**
  - **Milk fever**
  - **Retained placenta**
- **Different disease incidence rates with and without PDF technology**



# Retention Pay-Off Module

- **Economic costs of culling**
- **Marginal net revenue approach**
- **Total profits from keeping cow until her optimum age compared with replacement**
- **Maximum amount of money to be spent to keep the cow**
- **When RPO is negative, cow should be culled**
- **Optimal replacement changes throughout life**



# Retention Pay-Off Module

- **Methodology of Huirne et al. (1997) and Groenendaal et al. (2004)**
- **Monthly marginal net revenues and costs**
- **Considered monthly probabilities of mortality and culling**
- **Assumption-replacing average cow with average cow**
- **Optimal replacement time calculated monthly**
- **Monthly RPO summarized for each parity**



# Culling Module

- **Base culling rate**
  - **Reproduction, production, conformation and “other” diseases**
  - **First parity-13%, increased with increasing parity**
- **Risk ratios from Rajala-Schultz and Gröhn (1999) estimated disease impact on culling**
- **Considered timing of disease and subsequent effects on culling (0-30, 31-60, 61-150, 151-240, and > 240 DIM)**



# Culling Module

- **Disease timing using Exponential and LogNormal distributions from Kinsel (1998)**
- **RPO used to estimate cost of culling**
  - **Only costs from additional culling risk from disease**
- **Additional costs from death (lost slaughter value) using Guard (1998) estimates**
- **Changes in culling costs**
  - **Reduced disease incidence**
  - **Reduced disease impact on culling risk ratios (e.g. earlier detection minimizes disease effects)**



# Disease Milk Loss Module

- **Losses from unrealized milk production**
- **Considered separately for parity 1 and  $\geq 2$  (Bar et al. 2007)**
- **Weekly losses modeled stochastically with PERT distribution**
- **Revenues from additional milk produced with disease reduction**
- **Adjusted for increased DMI**



# Other Disease Costs Module

- **Labor**
- **Veterinary and drug**
- **Discarded milk**
- **Guard (1998) estimates adjusted for inflation**
- **Modeled stochastically using a SD calculated at 10% coefficient of variation from base value**





# Revenues and Expenses Module

- **Revenues and expenses affected by PDF technology adoption**
- **Revenues:**
  - **culling, death, veterinary and drug, labor discarded milk, unrealized milk gain, reproduction, and energy efficiency**
- **Expenses:**
  - **maintenance fees, replacement parts, labor costs, and utility costs**



# Management Adjustment

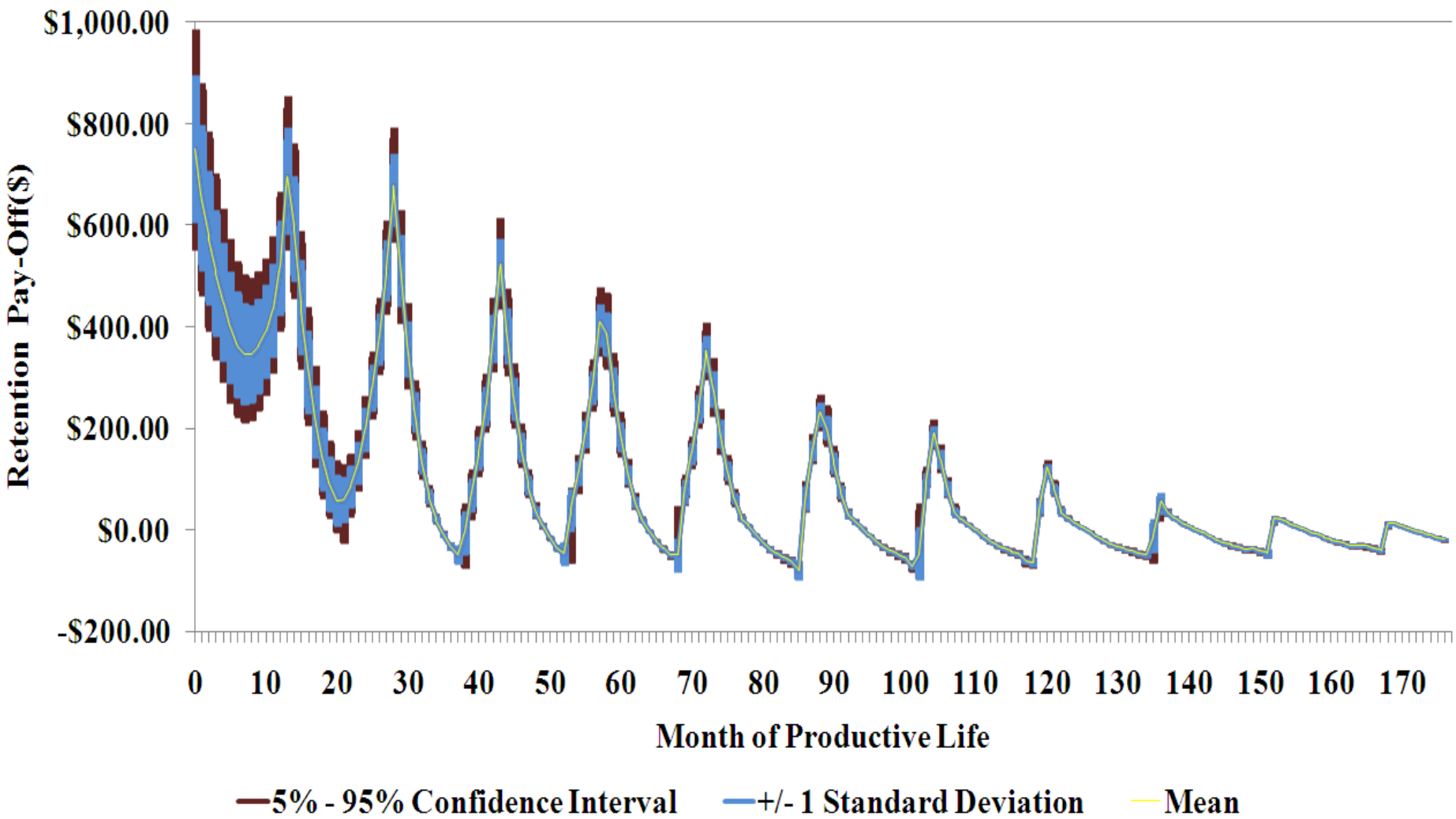
- **Best Management Practice Adherence Factor (BMPAF)**
- **Proxy for potential of observing maximum benefits**
- **Range from 0% (no management changes) to 100% (best management)**
- **Default of 77% (DairyMetrics RHA-Mean/Mean + 2 SD)**
- **Multiplied BMPAF by revenues**



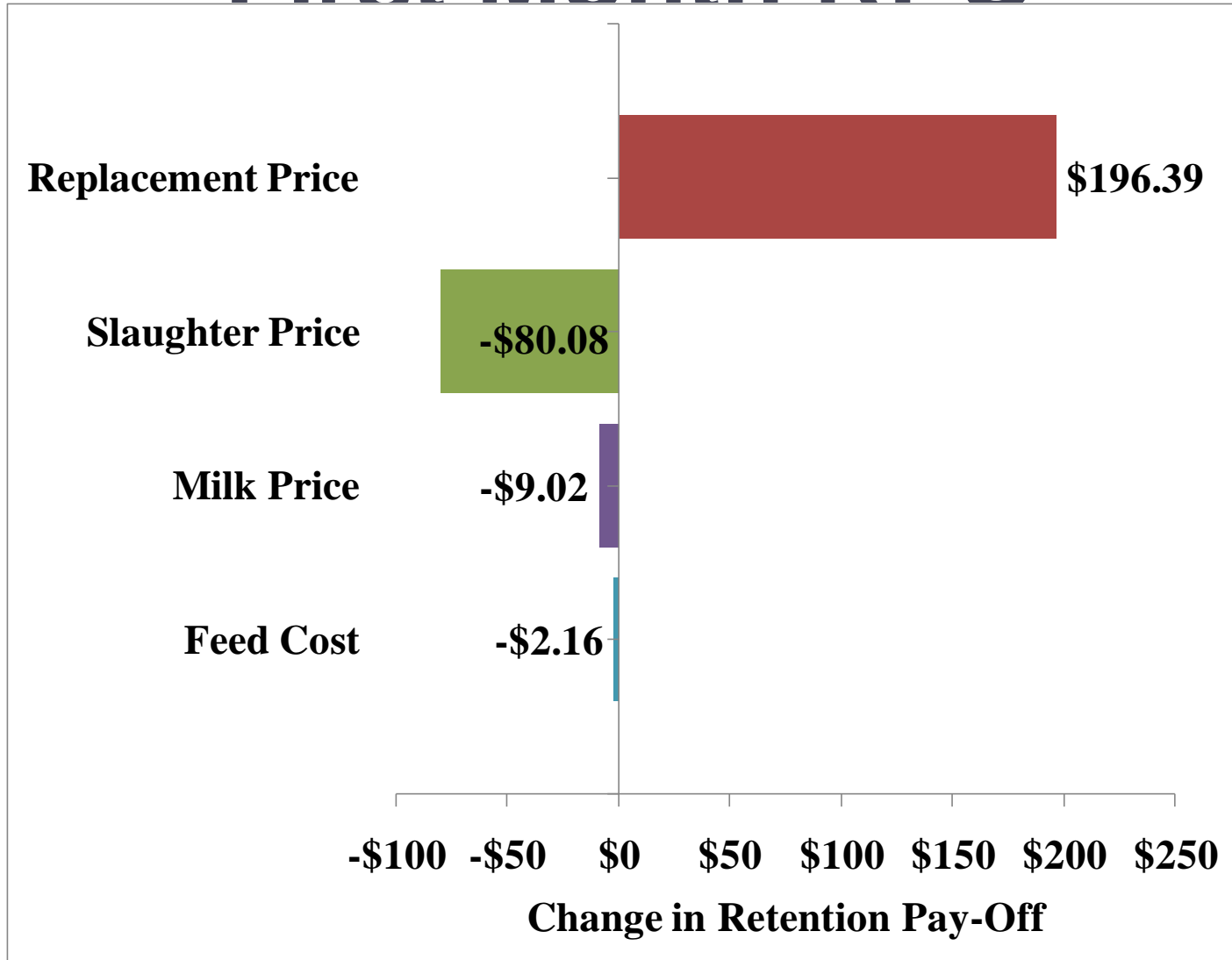
# Project Analysis Module

- **Net Present Value (NPV) assesses profitability**
- **Time value of money (8% discount rate)**
  - **Returns from alternative uses of capital**
  - **Newer technologies higher-more risk**
- **10 year investment horizon, no salvage value, 5 year depreciation**
- **Cash Flows determine financial feasibility**
- **Positive NPV-“go” decision**
- **Percent chance of positive NPV**

# Sample Retention Pay-Off

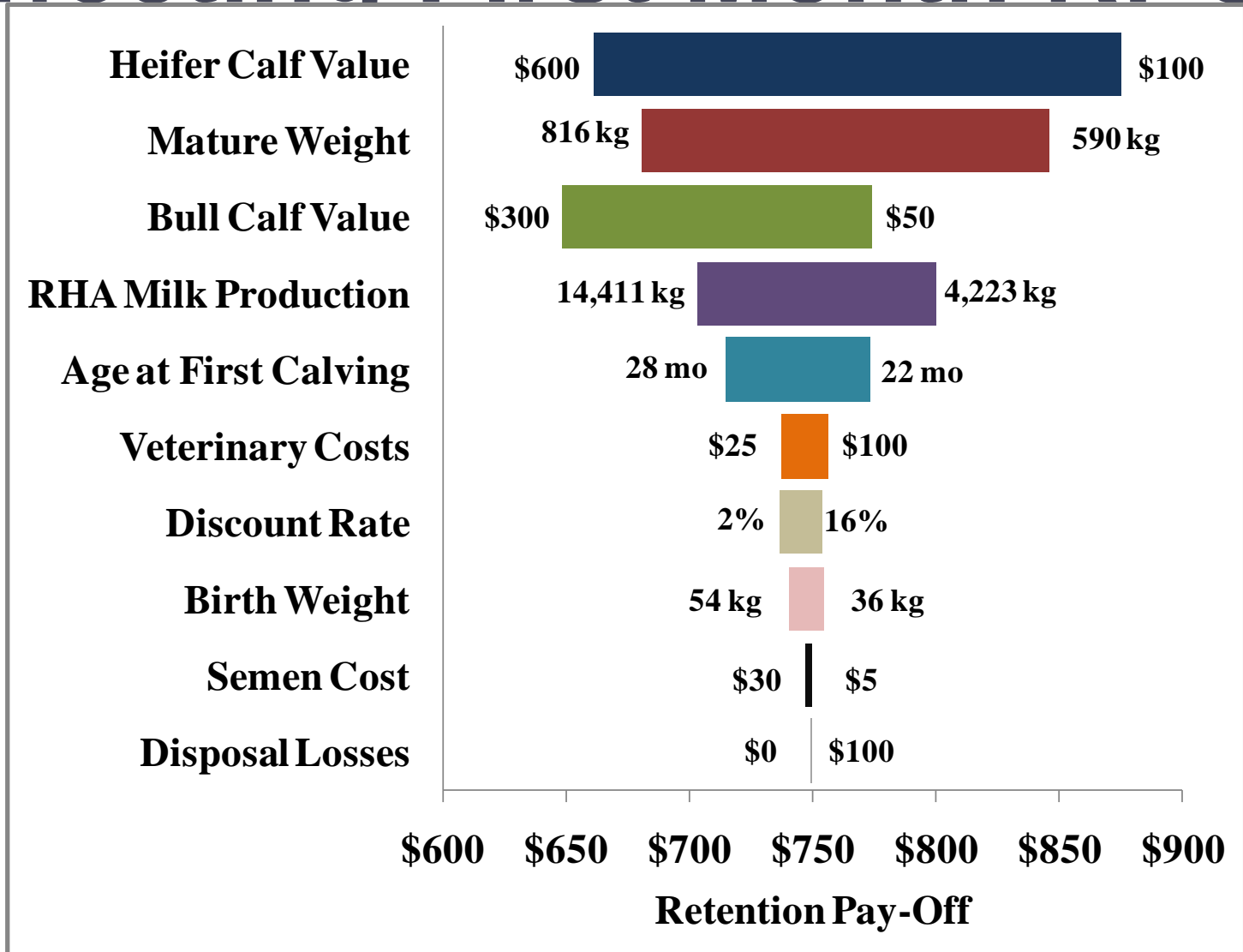


# Tornado Diagram for Stochastic Factors Affecting First Month RPO

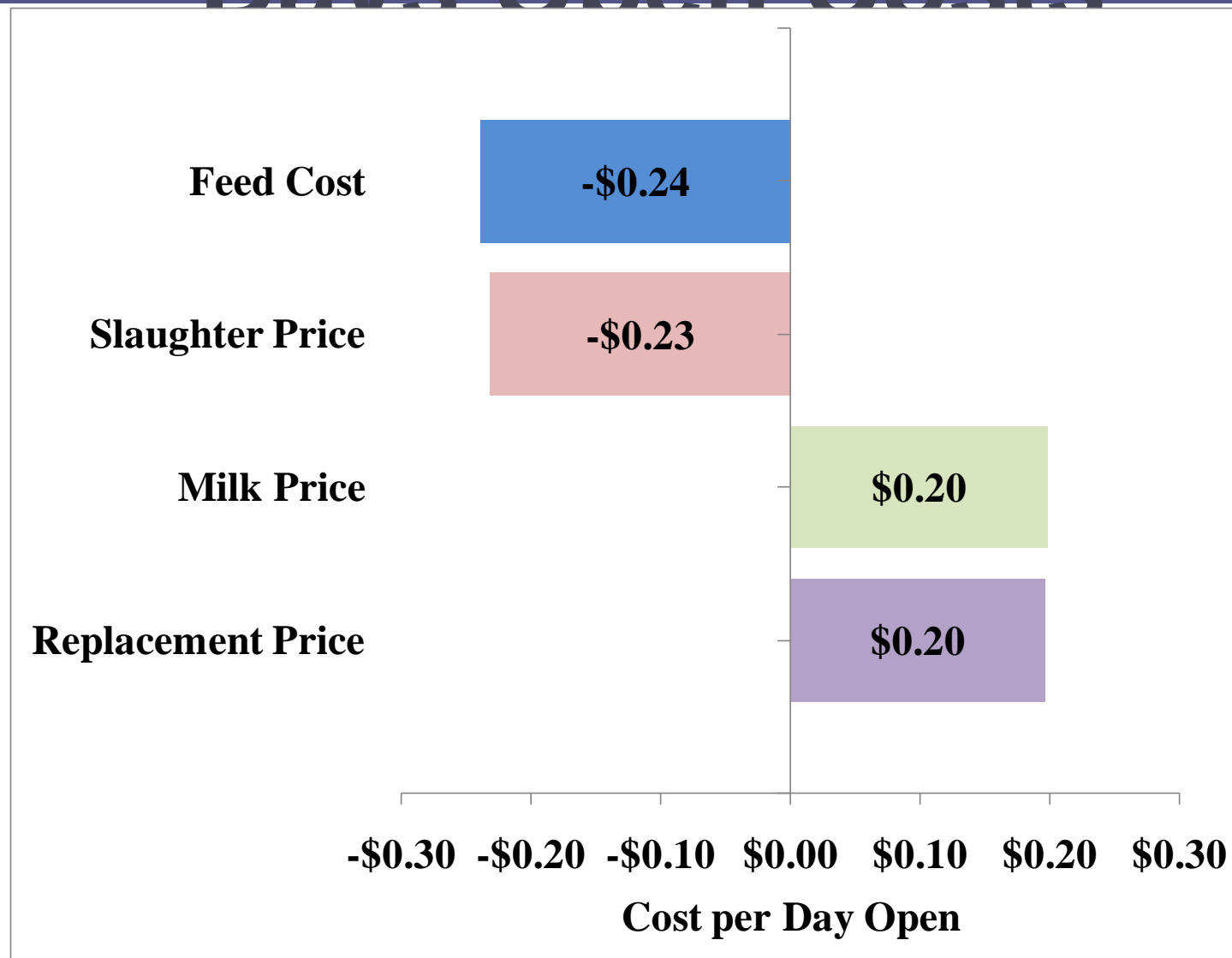


# Deterministic Factors

## Affecting First Month RPO

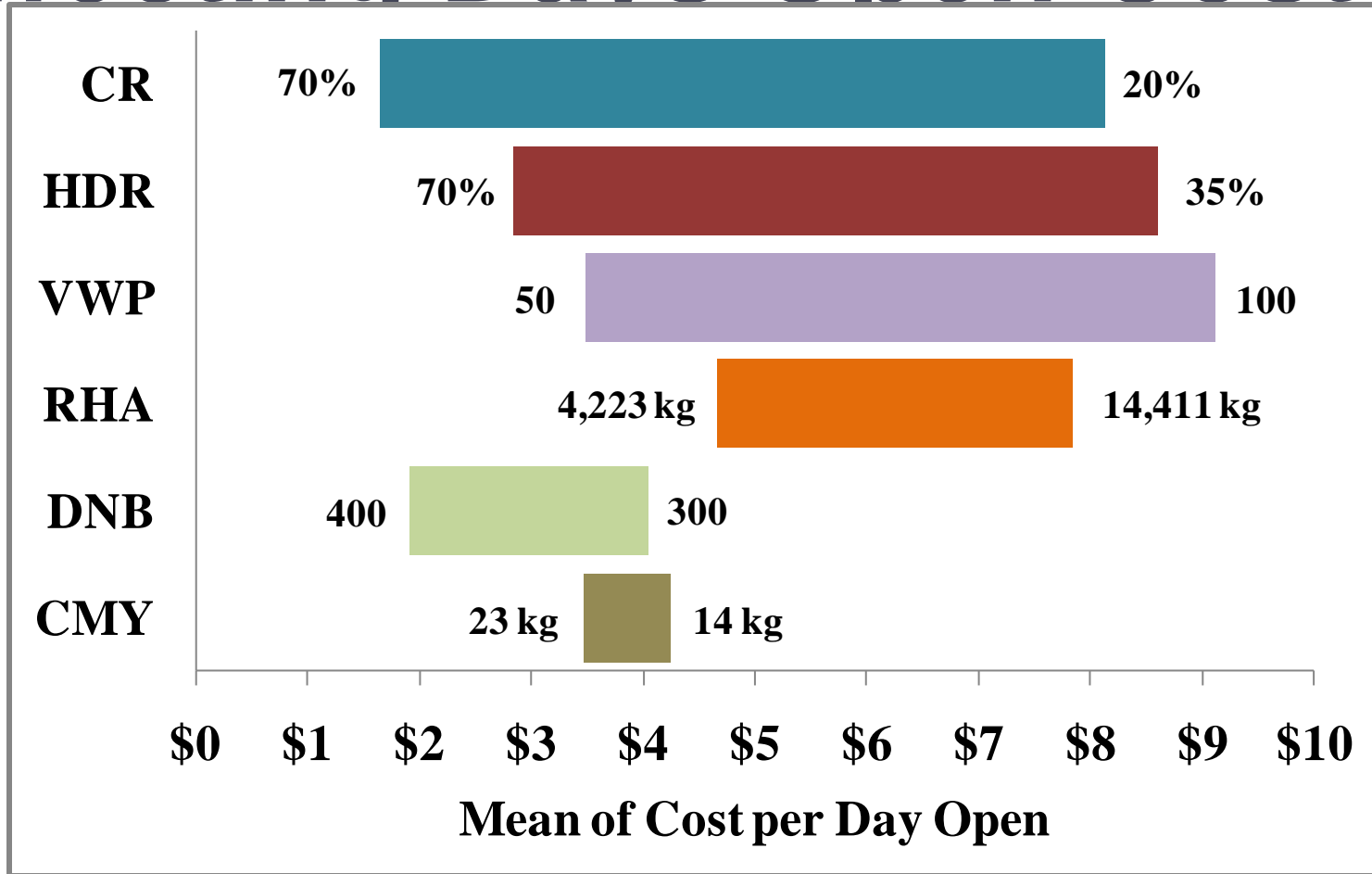


# Funnel Diagram for Stochastic Factors Affecting Days Open Costs



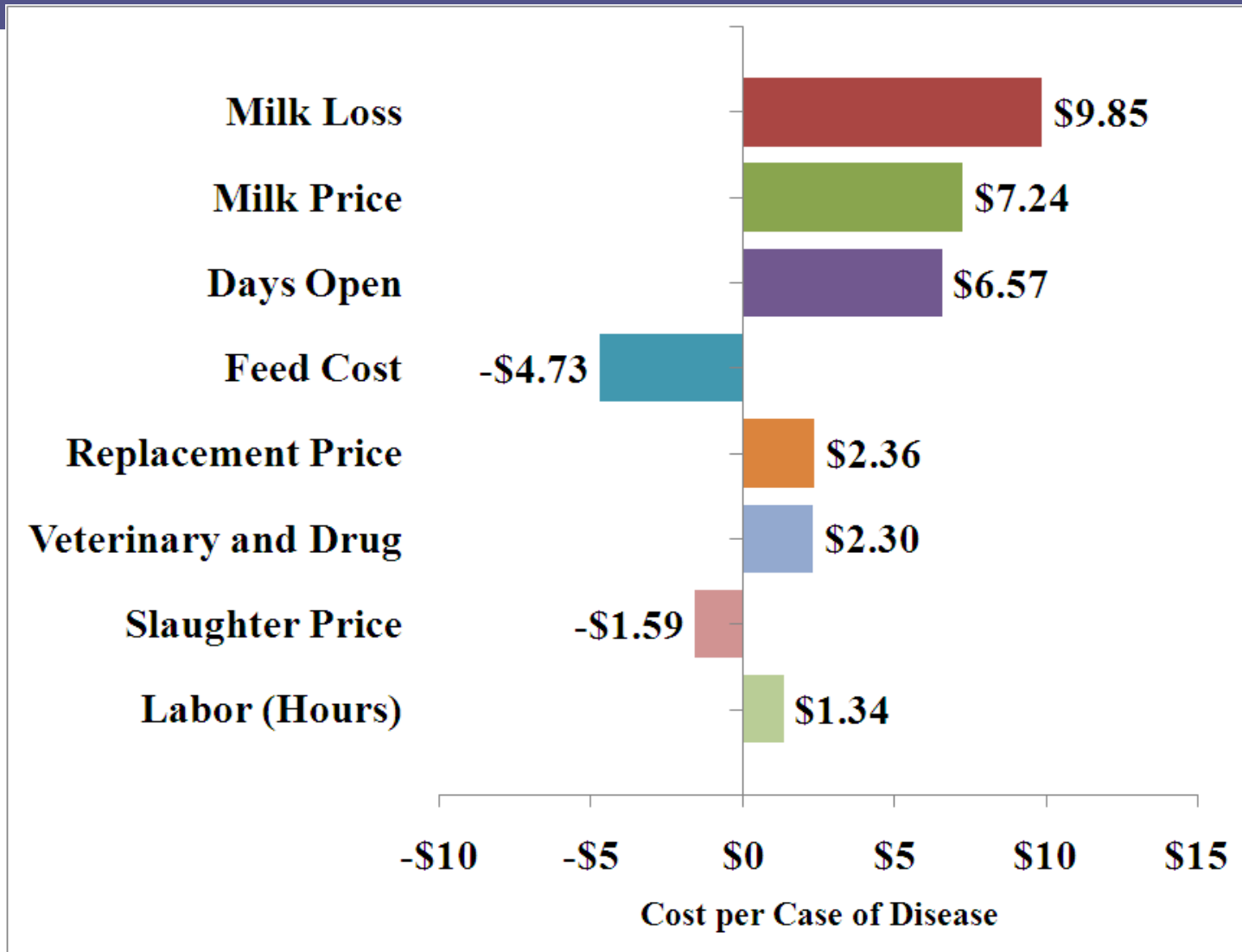
# Deterministic Factors

## Affecting Days Open Costs

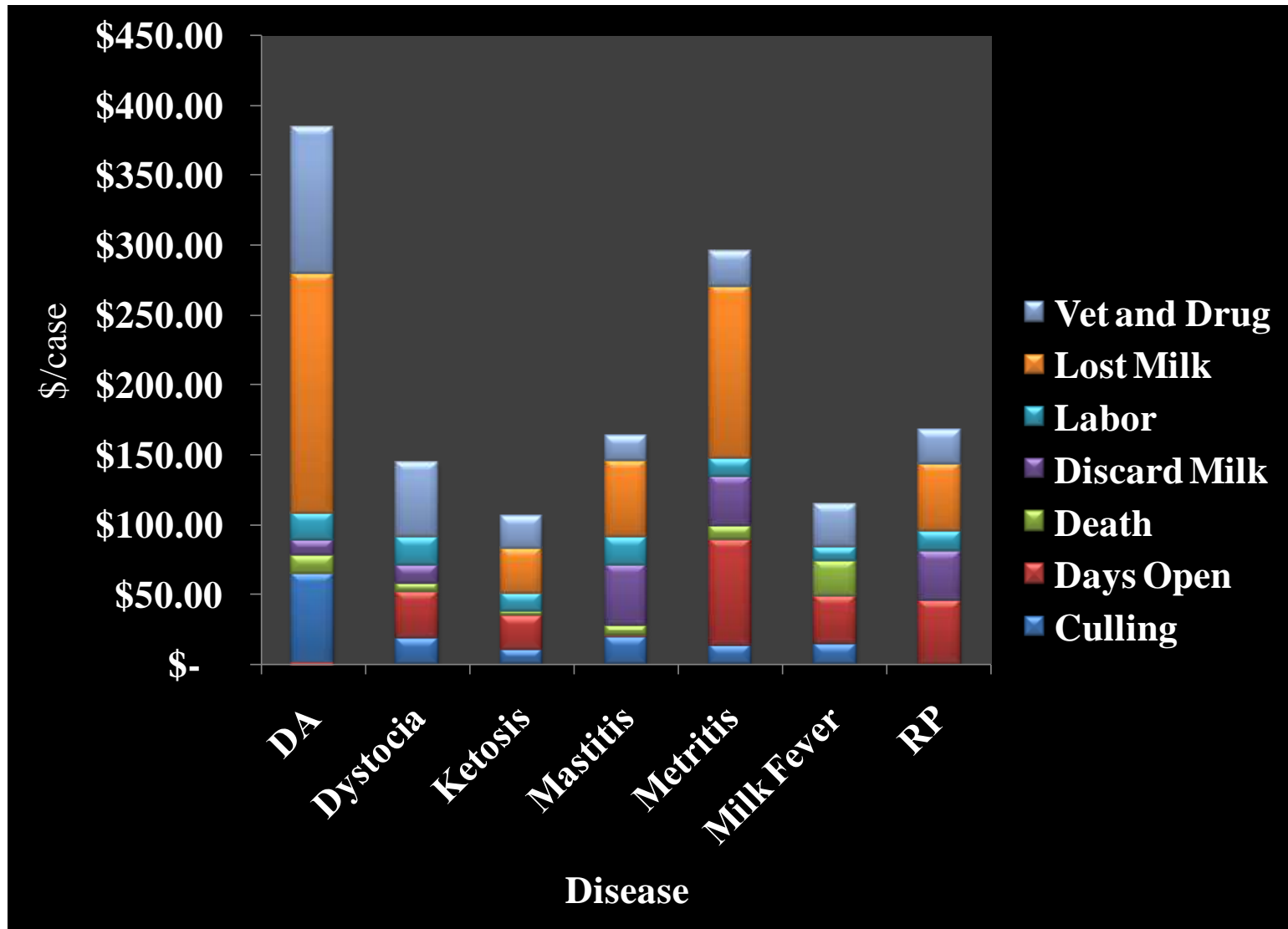


CR is conception rate, HDR is heat detection rate, VWP is voluntary waiting period, RHA is rolling herd average milk production in kg, DNB is DIM designated do not breed, and CMY is daily milk yield designated to cull a cow.

# Tornado Diagram for Stochastic Factors Affecting Ketosis Costs for Parity $\geq 2$ Cows



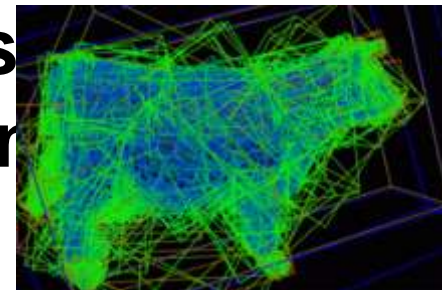
# Distribution of Sources of Disease Costs for Parity $\geq 2$





# Conclusions

- **Stochastic models account for risk and uncertainty in PDF investment decisions**
- **Modeling the dairy system is complex**
- **Costs of culling, days open, and disease are highly dependent on deterministic and stochastic inputs**
- **Farm-specific models should be used in decision making to supplement general recommendations**



# How Can We Use This?

Examples,  
please!



# Assessing The Potential Value Of Automated Body Condition Scoring Using Stochastic Simulation

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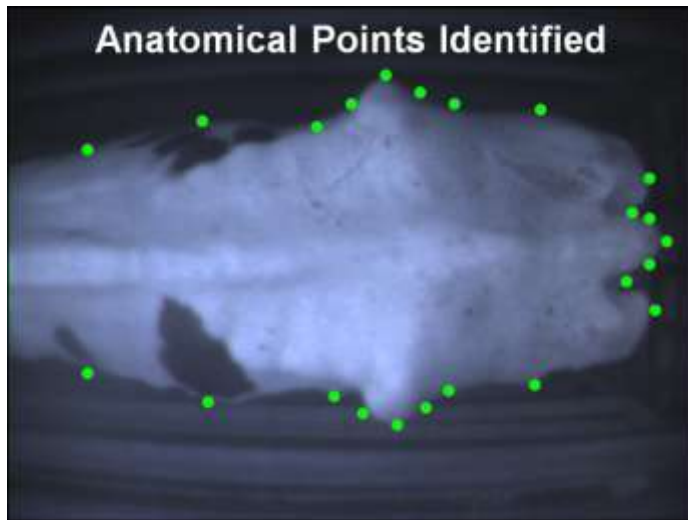
Camera

Weigh Station

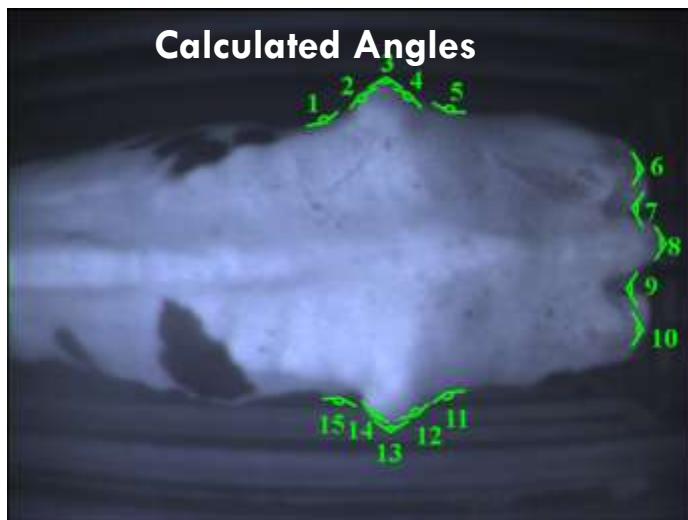


IceRobotics

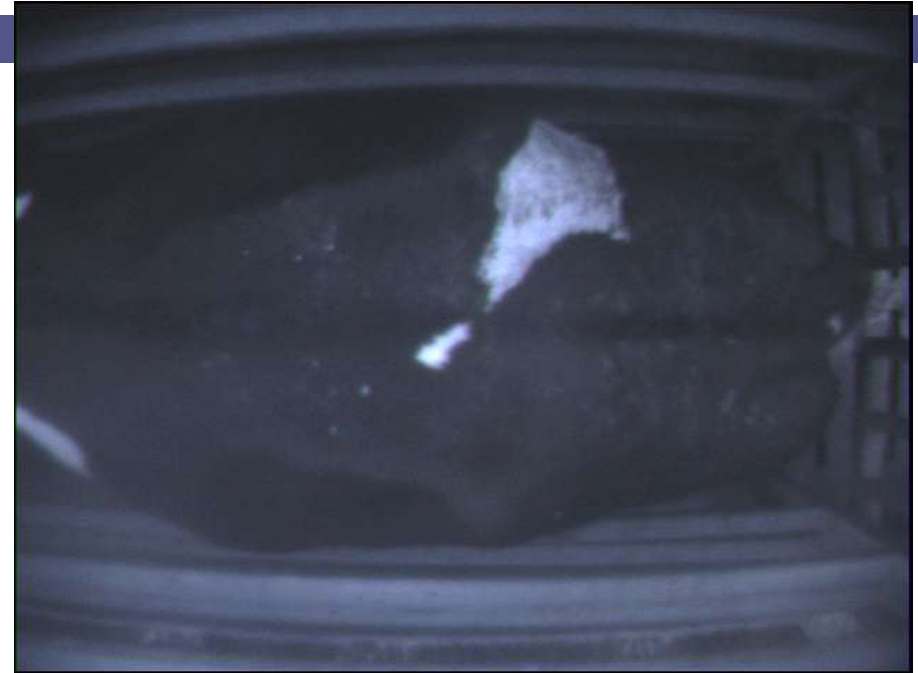
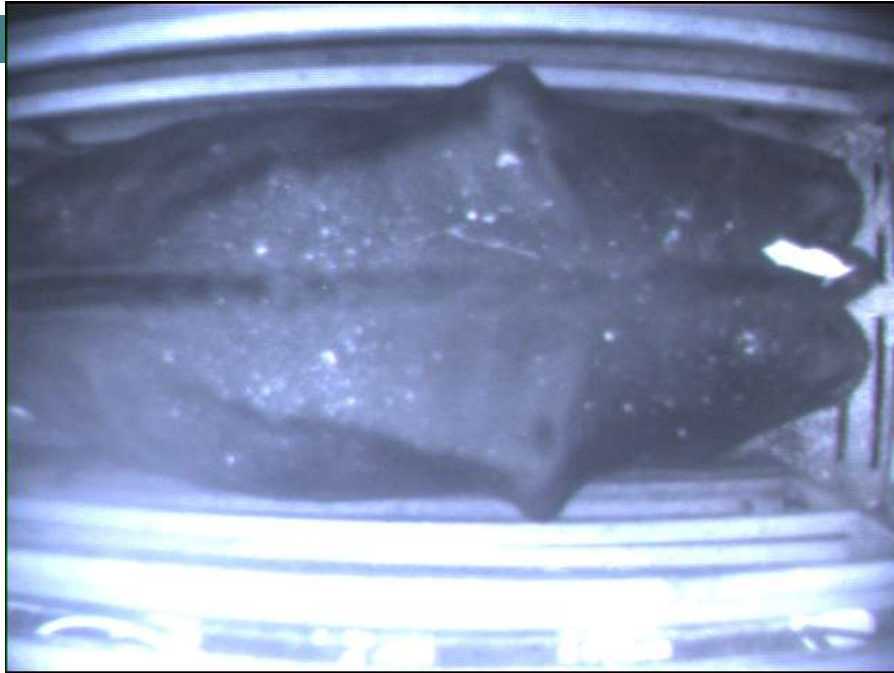
Anatomical Points Identified



Calculated Angles



# Predicting BCS Using Images



USBCS	2.50
Predicted BCS	2.63
Posterior Hook Angle	150.0°
Hook Angle	116.6°

USBCS	3.50
Predicted BCS	3.32
Posterior Hook Angle	172.1°
Hook Angle	153.5°



# Economic Evaluation

- Commercial technologies being developed
- Objective
  - Identify factors that influence potential profitability of investment
- Stochastic simulation model
- Potential impact from literature and expert opinion survey





# Materials and Methods

- Expert opinion useful when no data is available or expensive to collect (Vose, 2000)
- 45 experts polled
- 24 respondents
- 8 questions
  - Distributions of BCS
    - Current situation
    - Under optimal nutritional management
  - Ranking of benefits of automated BCS





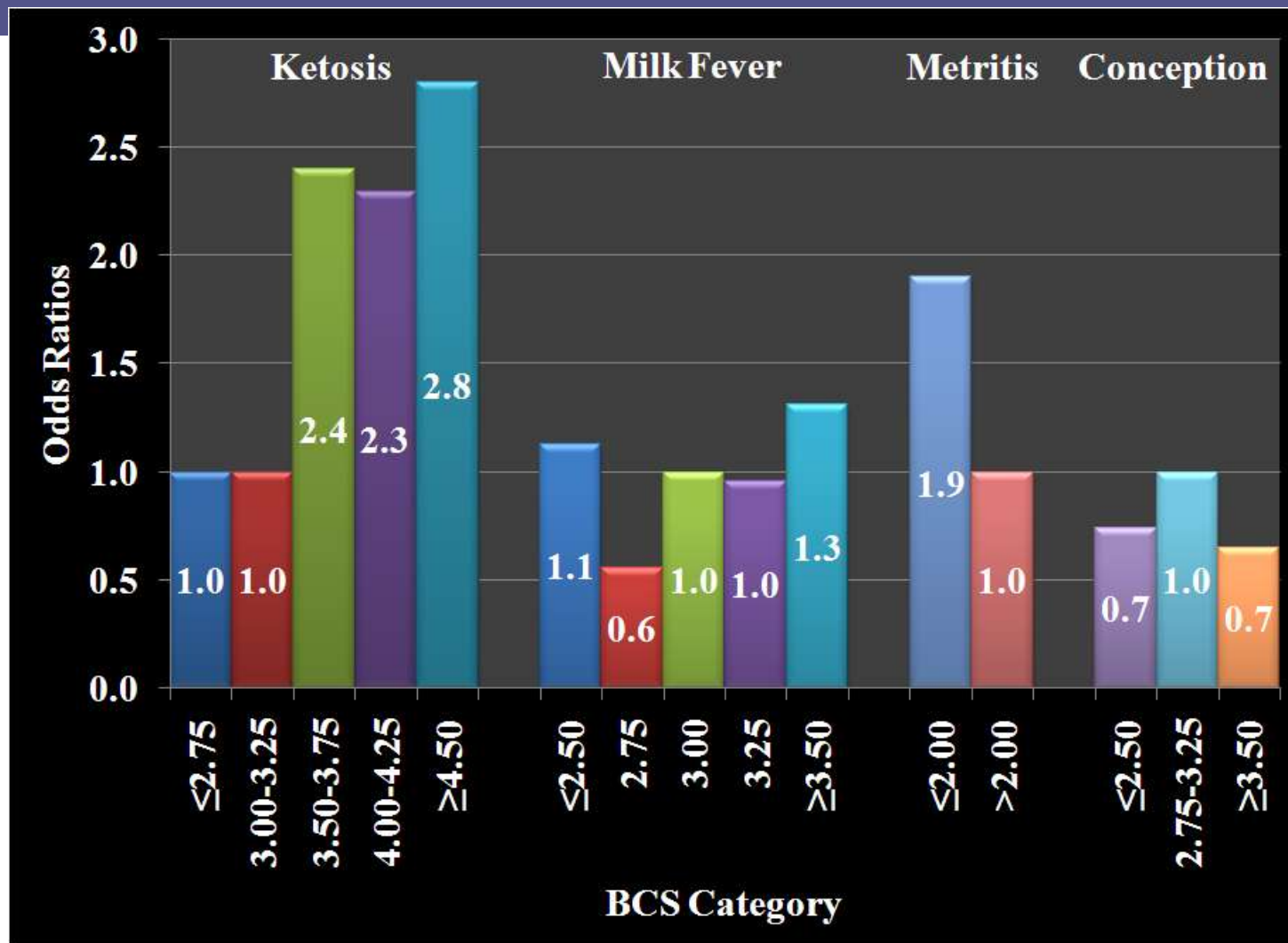
# Materials and Methods

- BCS at calving estimated from expert opinion with PERT distributions
- Odds ratios from literature modeled stochastically with PERT distributions
- Disease incidence and first service conception rate changed as BCS distribution varied
- Affects disease costs and days open costs





# Disease Odds Ratios



\*BCS at calving for Ketosis from Gillund et al. (2001), Milk fever from Roche and Berry (2006), Metritis from Heuer et al. (1999)

\*\*BCS at 1st service for first service conception from Loeffler et al. (1999)

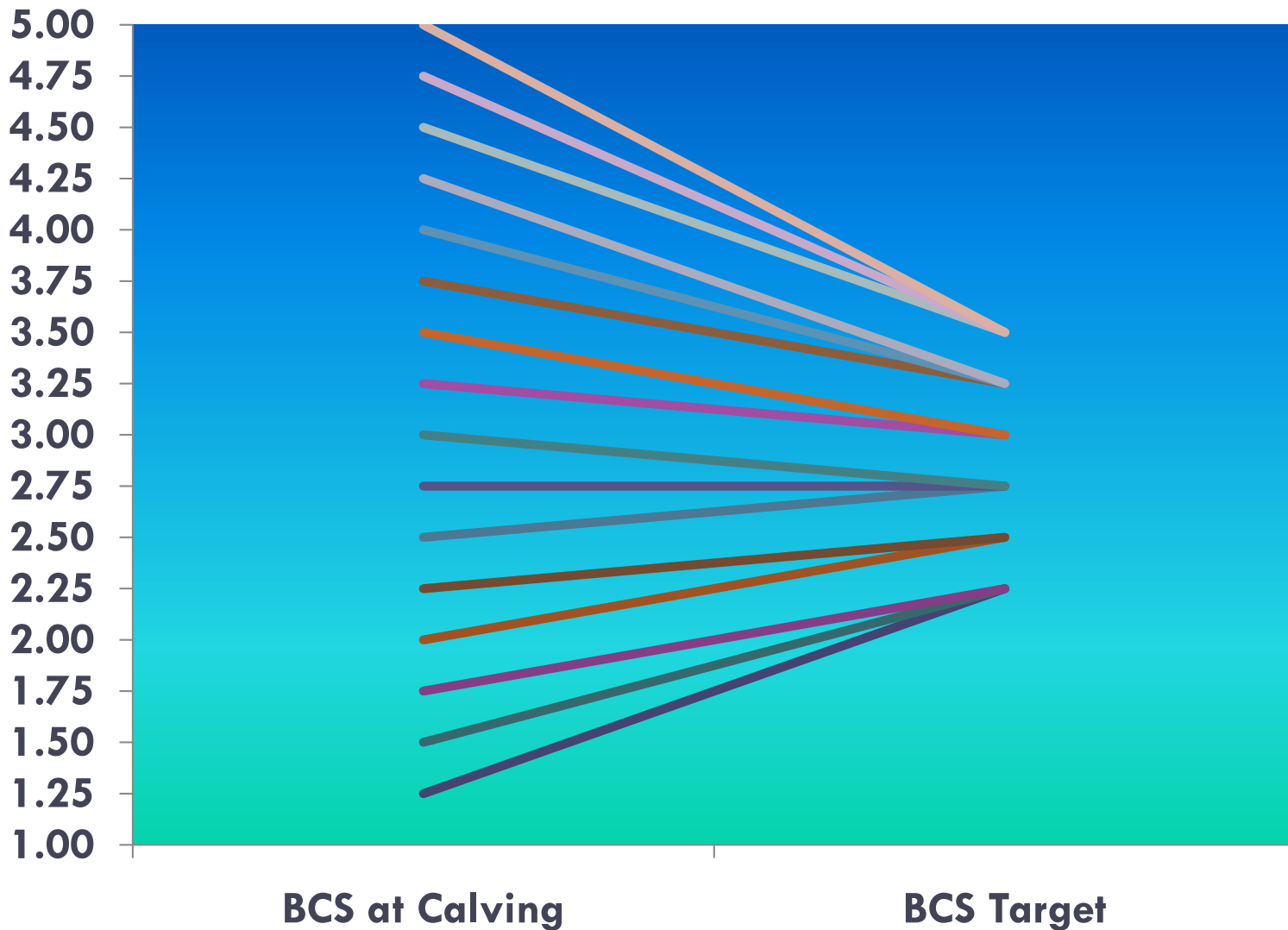


# BCS Module

- BCS at calving was primary input
- % of cows calving in ranges:  
1.00-1.75    2.00-2.25    2.50-2.75    3.00-3.25  
3.50-3.75    4.00-4.25    4.50-5.00
- Weighted average BCS at calving
- Daily BCS changes calculated with Friggens et al. (2004) methodology
- Predicted average target BCS from Garnsworthy (2007) equation



# BCS Change





# Energy Efficiency

- Using energy from feed is more efficient than using energy from body reserves
- Cows that use less reserves are more efficient
- Accounted for
  - Energy savings for losing BCS
  - Energy costs for gaining BCS
- Used distributions of BCS at calving for “average” cow calculations



# Energy Efficiency

- Daily change in empty body fat and protein from NRC equations
- Energy used when fat and protein change from Emmans (1994)
- Stochastic corn price per Mcal energy for costs
- Net energy exchange cost per lactation
- Multiplied by number of cows for herd level



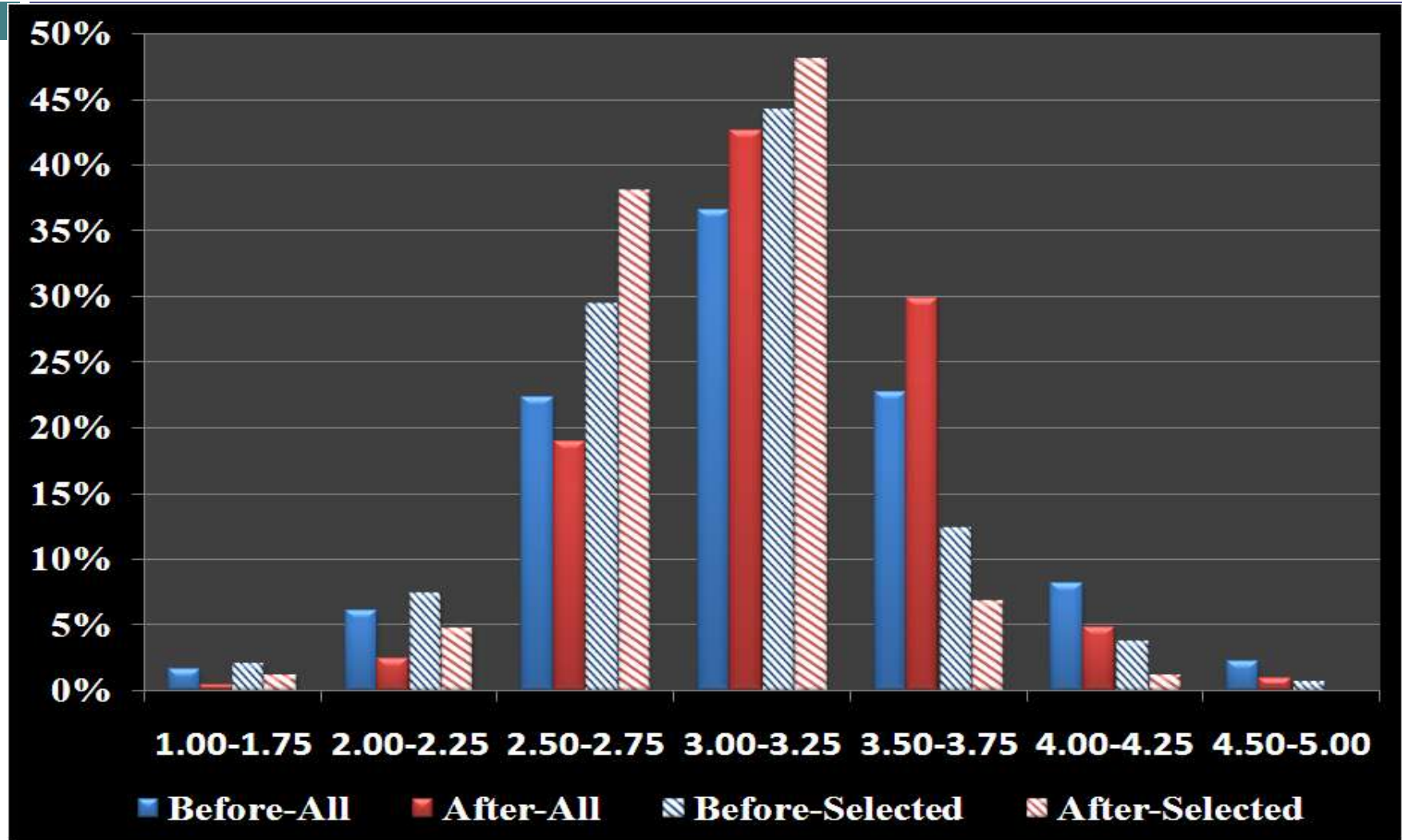
# Investment Considerations

- \$12,000 purchase, \$1,200 annual maintenance fee
- $\frac{1}{2}$  hour per week spent analyzing data
- Assumes multiple TMR's fed
- Incremental annual variable costs, per cow (\$0, \$2.5, \$5.0) in a PERT distribution





# Expert Predicted BCS Distributions



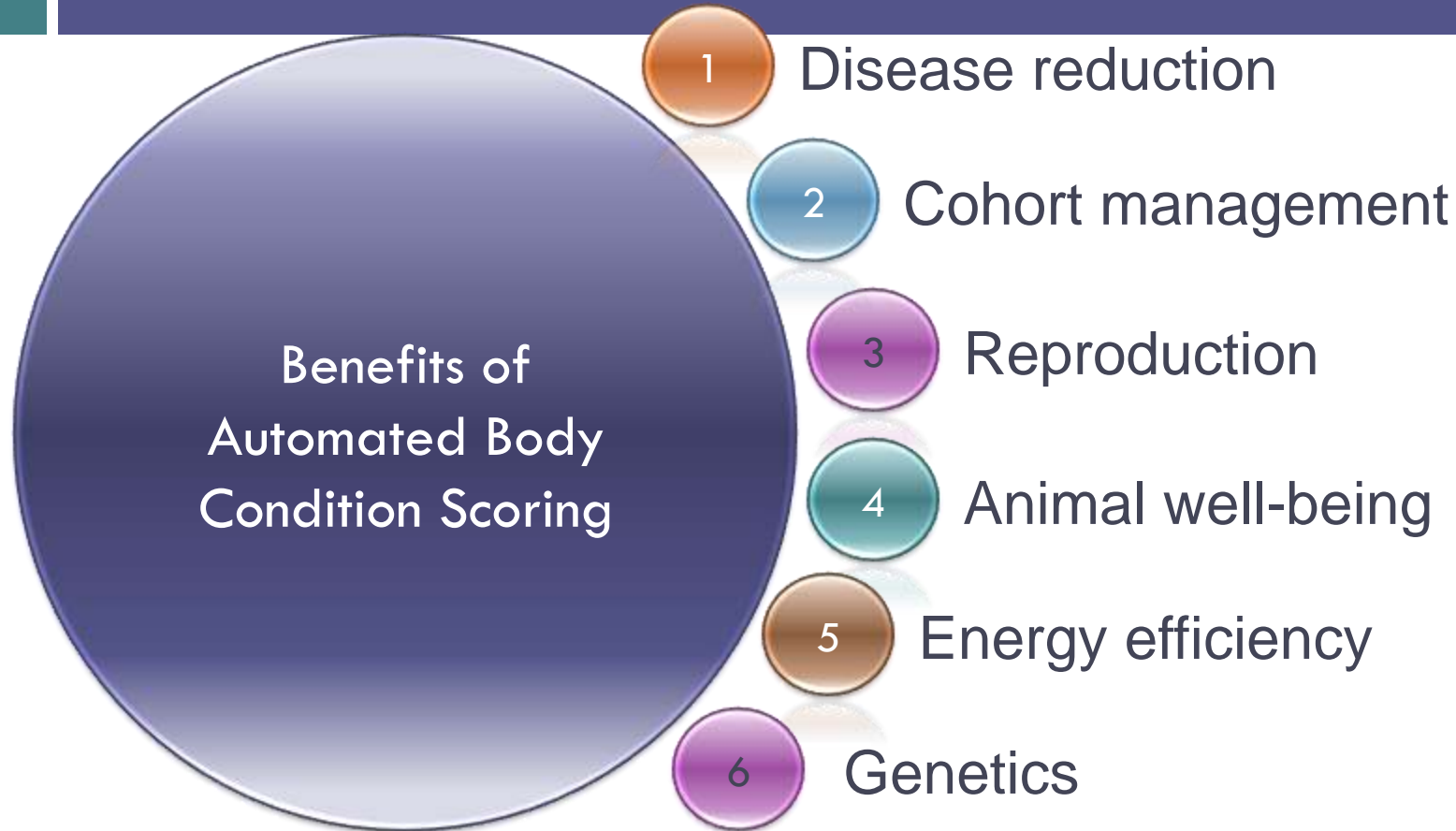
\* All survey respondents or selected respondents (N=5) who indicated a lower % of cows with BCS at calving >3.25 after technology adoption.



# Simulations

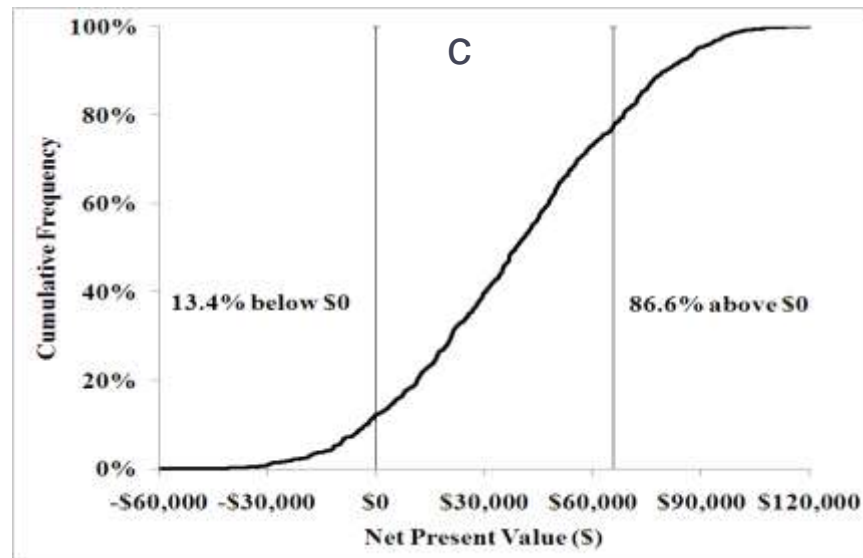
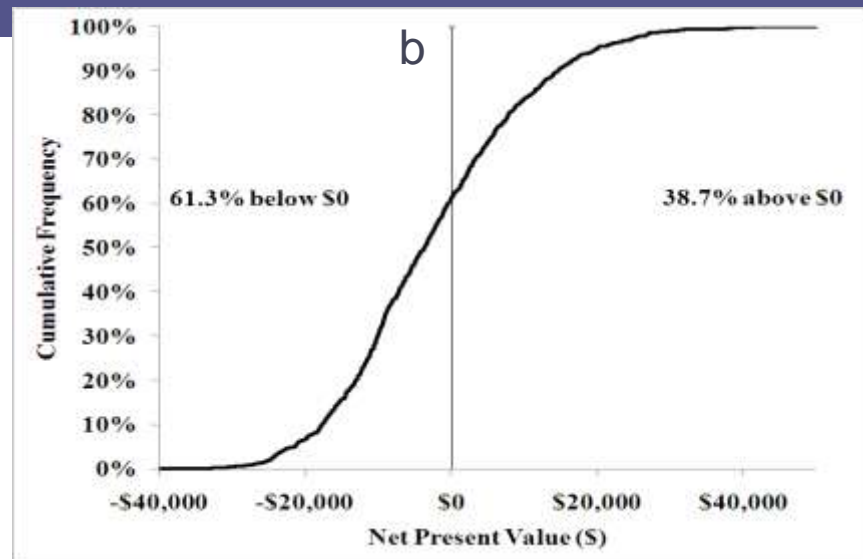
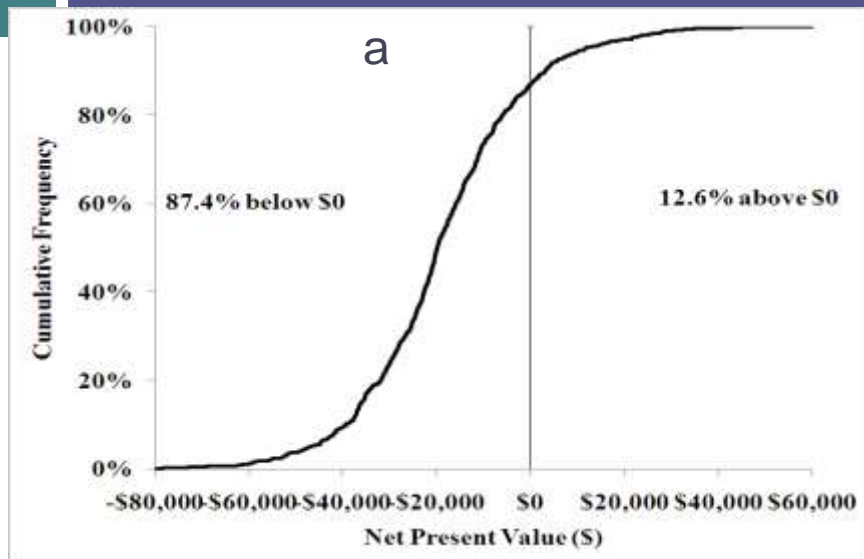
- 3 simulations
  - All 24 experts
  - Respondents in the 80<sup>th</sup> percentile for % of cows with BCS at calving  $\leq 3.25$
  - Deterministic mean BCS for all experts before; mean BCS for 80<sup>th</sup> percentile respondents after
- 1000 iterations for main simulations
- Deterministic sensitivity-100 iterations at minimum and maximum values

# Survey Says



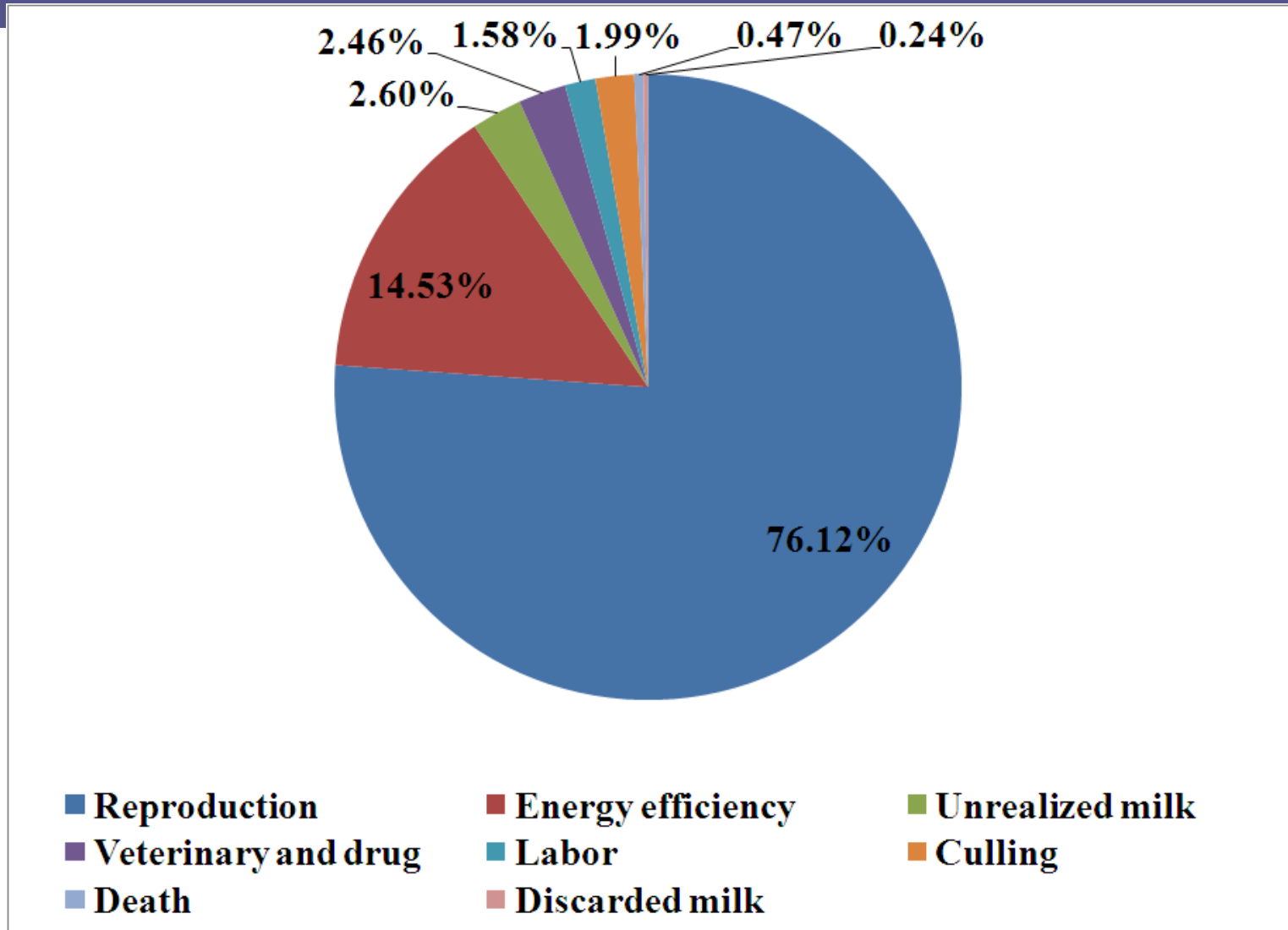


# NPV Cumulative Distribution Functions



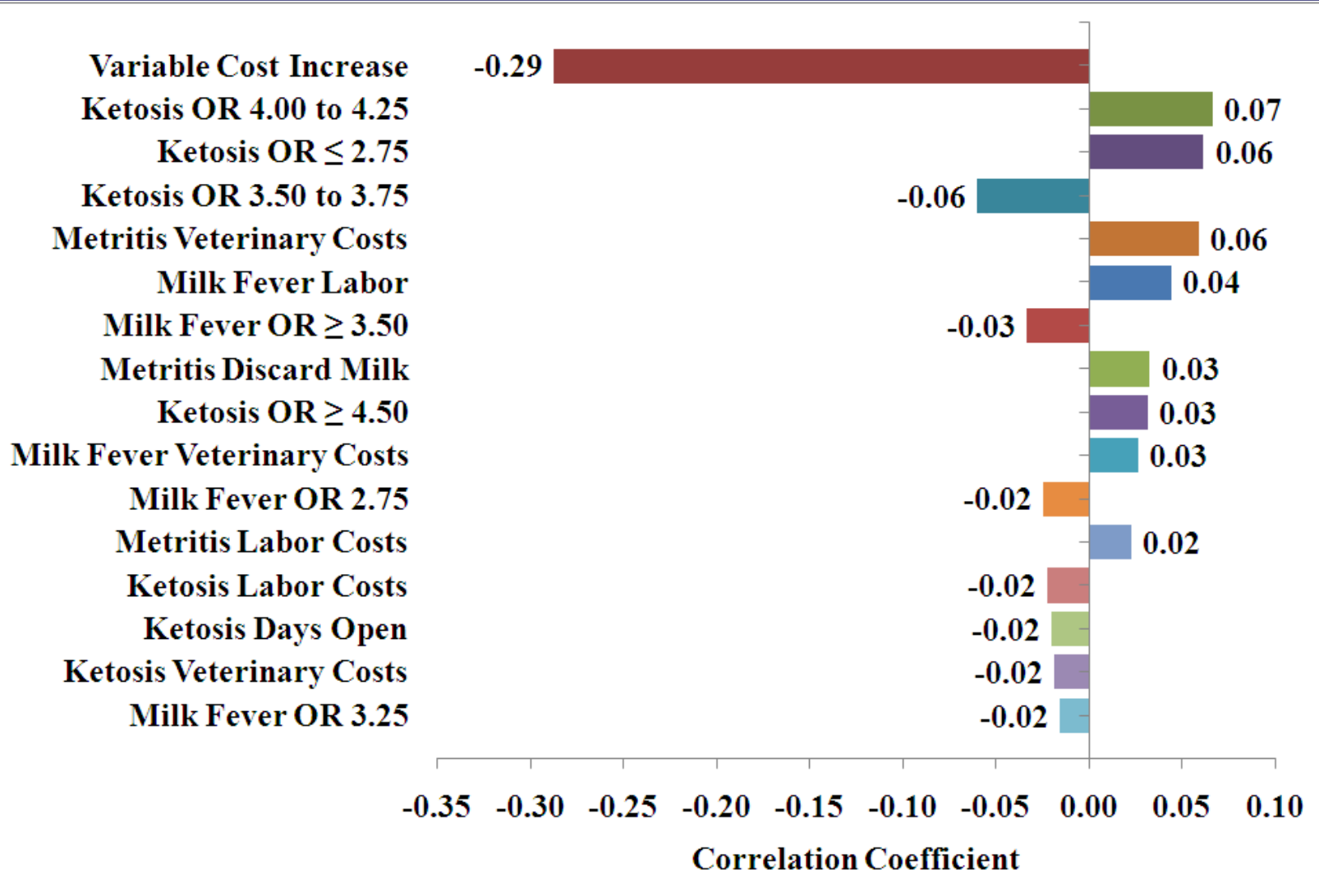
- a. Simulation using estimates from all respondents
- b. Simulation from selected respondents
- c. Simulation with deterministic improvement in BCS

# Distribution of Revenues for Simulation with Selected Respondents



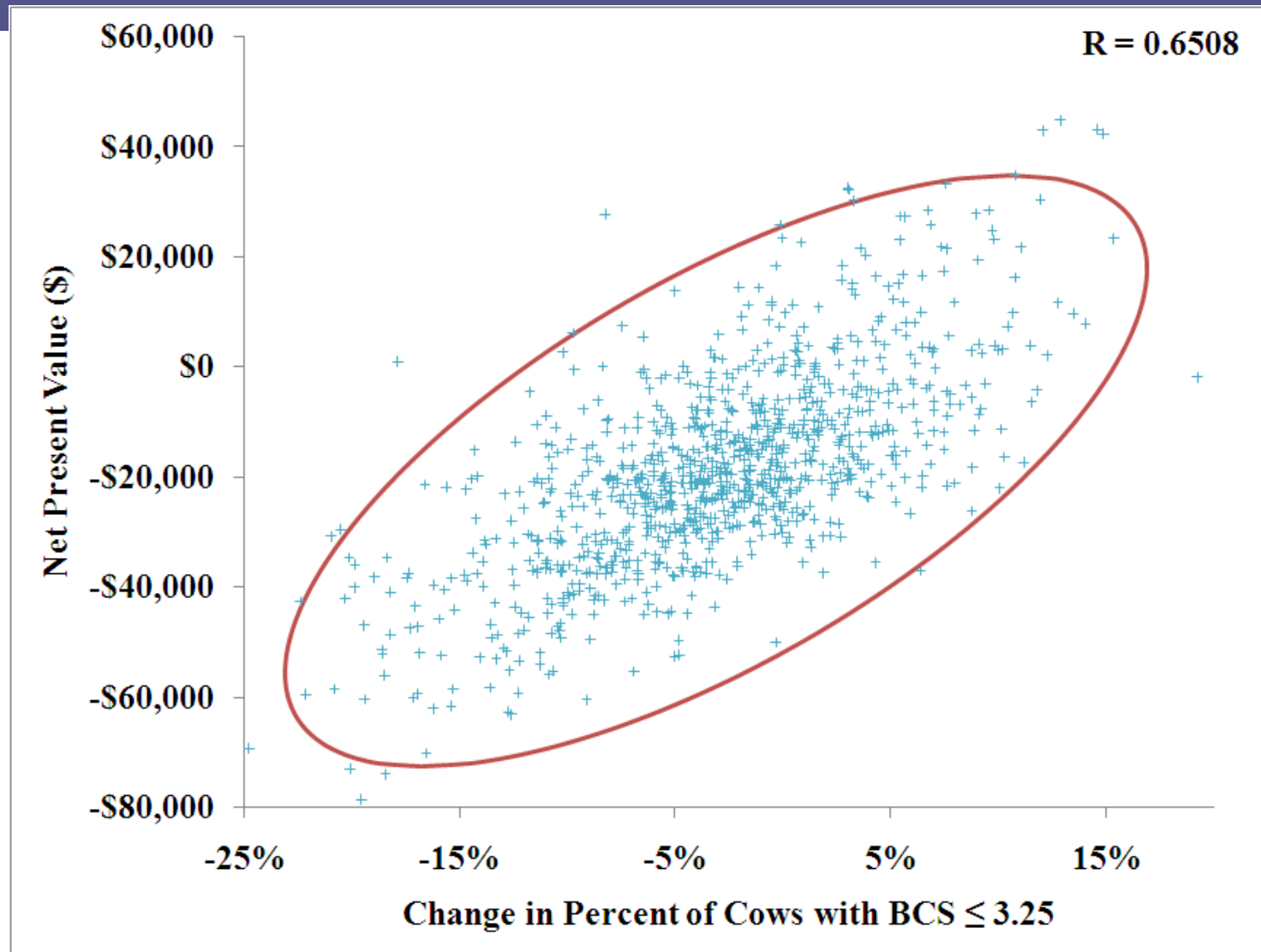


# Tornado Diagram for Stochastic Factors Affecting NPV



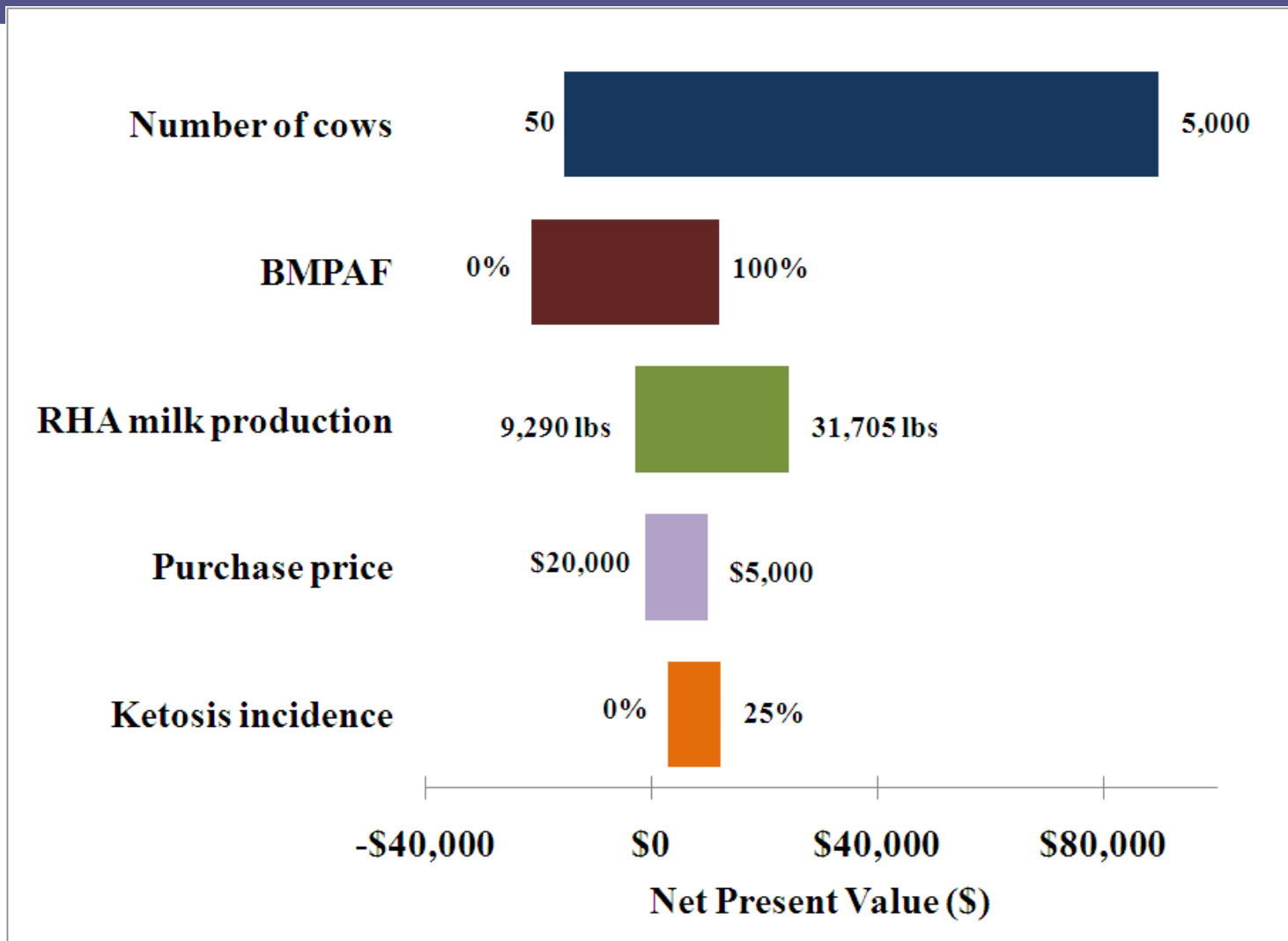
\* For simulation using estimates from all survey respondents

# NPV vs. Change in % of Cows with BCS $\leq 3.25$





# Tornado Diagram for Deterministic Factors Affecting NPV



\*95<sup>th</sup> percentile of NPV for simulations using estimates from all survey respondents



# Conclusions

- Recommendations for “ideal BCS” need to be re-examined
- Profitability of investment depends on:
  - Current BCS distribution of the herd
  - Magnitude of negative effects of low or high BCS
  - Ability of management to make changes
- Herds with problems managing BCS will benefit most
- Model can be used by individual producers



# Acknowledgements

## Committee

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and David Bell



# Vision for the Future

- Improved computing power increases usefulness of simulation models.
- Future models should incorporate more robust utility functions.
  - Economics is not the **ONLY** driver of decisions.
- Potential exists for applications beyond economics.
- Collaborative efforts are essential.
- User-friendly simulation models should be developed *with* producer input.

# Questions

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