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COMMERCIAL BEEF HERD REPLACEMENT STRATEGIES

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Introduction

In this paper we investigate optimal management decisions cow-calf producers cope with in acquiring replacement heifers for commercial beef operations. Optimal management of this problem is studied best in a capital theoretic framework, recognizing that cattle stocks are durable and costly to adjust (Clark 1990). This article follows Rosen (1987), Rosen, Murphy and Scheinkman (1994), and Hamilton and Kastens (2000) by formalizing the problem in a discrete time control framework. This facilitates solving the problem in a nonlinear programming framework (Canon, Cullum, and Polak), which allows the incorporation of complex biological processes in a dynamic optimization context (Standiford and Howitt).

Previous research has suggested that counter cyclical inventory management may be optimal. Trapp illustrates the optimal management strategy expands inventory in advance of the peak of the price cycle. Trapp considers an economic agent with no influence on aggregate levels or price and perfect foresight of future prices. Hughes also suggests that counter cyclical management by adjusting both replacement levels and cull rates throughout the cattle cycle results in higher profits than constant-inventory management. Hughes focuses on the net present value (NPV) of heifers retained at various stages of the cattle cycle, showing that heifers retained at the bottom of the price cycle typically have the highest NPV. Furthermore, Hamilton and Kastens report that a counter-cyclical manager outperforms both a constant-inventory and a representative (procyclical) manager. Lawrence developed a retention strategy using a dollar-cost-average replacement heifer investment strategy. Lawrence reported that a producer who retained the same dollar value of replacements each year outperformed a producer that retained the same number of heifers each year.

The paper proceeds in the following manner. First, we digress briefly on the cattle cycle and heifer prices. Second, we implement a dynamically optimal framework to estimate an efficient level and timing of input resources (i.e., replacement heifers) for cow-calf producers for an average Kansas' producer. Third, we compare results from the optimization model with alternative strategies that include constant-inventory, dollar-cost-averaging, and counter-cyclical strategies.¹ Importantly, we demonstrate that these strategies do not maximize profits and do not follow an optimal trajectory. In other words, the constant-inventory, dollar-cost-averaging, and counter-cyclical strategies have specific limitations and do not allocate resources efficiently. Fourth, conclusions of the study are presented.

Cattle Cycles and Heifer Prices

Cattle cycles are caused, in part, by the biological lag in beef production.² Once a producer decides to increase beef production in anticipation of an up swing or expansion of the cattle cycle there is a substantial lag effect before production actually increases. It takes almost three years from the time a replacement heifer is acquired until return on its first calf is realized. Expansion of the beef herd requires more females to be retained as replacements for the breeding herd and fewer slaughtered, driving up heifer prices.

The lag effect associated with the down swing or contraction of the cycle is slightly different. Production typically peaks three years after the last expansion decision, resulting in an oversupply of beef. The liquidation of the U.S. cow inventory corresponds to the downward segment of the cattle cycle. Liquidation of the herd

¹ See Hughes (1999) and Lawrence (2001) for additional insight into heifer retention issues.

requires more females to be fed for slaughter and fewer kept as replacements with typically the same if not a higher number of culls being marketed. This temporarily increases or at least maintains beef supply at higher levels, resulting in prices falling relatively quickly. In all, the biological lag of beef production and the cattle cycle play a vital role in replacement decisions by cow-calf producers.

Bred heifer and cow markets are influenced by both i) short-run effects within a year and ii) long-run effects across years. The shorter run effects tend to be demand and supply changes as a result of seasonality or external factors such as weather, disease, geographical location, and other environmental conditions. The longer run effects are tied to the cyclical nature inherent in the cattle cycle. For example, as the national beef herd is liquidated, producers retain fewer replacement heifers. The decrease in replacement heifers demanded then coincides with lower prices (Figure 1).

The present value of a bred heifer today is the value placed on all of its future net income and future cull or salvage value both adjusted for the time value of money. Thus, the questions of “What to Pay?” and “When to Buy?” are inextricably linked. In other words, where one is at in terms of the cattle cycle (and hence the price cycle) is a key factor in determining the value of a replacement heifer. For example, a heifer that has its first two or three calves in the bottom of the price cycle will have a different value than a heifer that has its first calves over the top of the price cycle.

Methods/ Model

² Other factors that impact the cattle cycle are exogenous shocks [Rosen, Murphy and Scheinkman. (1994)] and market timing [Hamilton and Kastens (2000)].

To evaluate replacement strategies we consider an average Kansas producer over the period 1975-1999. A dynamic optimization model is specified based on previous work by Rosen (1987), Rosen, Murphy and Scheinkman (1994), and Hamilton and Kastens (2000), among others. It extends the previous literature by considering the age structure of the breeding stock and allowing for control decisions to raise or purchase replacement heifers or bred heifers. The dynamic optimization model is formulated consistent with profit maximization criteria and then constrained to reflect constant-inventory, dollar-cost-averaging, and counter-cyclical management strategies. In this manner, we can directly compare net returns and resource allocation of inputs. Net returns are dependent on output and input prices at the market level and input allocation, which is the number of replacements and timing of replacement purchases by the cow-calf producer. The models are simulated based on historical weaning and cull cow weights, commodity prices, and production costs faced by Kansas producers. Fixed costs are based on an initial herd size of 100 cows. Bred heifer and cow prices are calculated using price relationships from Kansas livestock markets. See Marsh, Terry, and Jones (1999) for specific details regarding data, price relationships, and budget information.

Herd Dynamics

Female replacement decisions impact the age dynamics of the breeding herd for about a decade, as cows are assumed to produce a maximum of 10 calves. To capture age dynamics the cow herd is segregated into four age levels, replacement heifers retained, r_t , bred heifers, b_t , young cows, y_t , and mature cows, o_t .

Let y_t denote the number of young cows in the breeding herd at time t . Young cows are assumed to wean a calf 40 pounds lighter than a mature cow. Thus, changes in

the age dynamics of a breeding herd reduce (increase) the average weaning weight as the average age of the cow herd decreases (increases). Young cows are less efficient due to increased calving difficulty and are assumed to wean 96% of calves, opposed to 97% for mature cows. Young cow inventory is determined by the number of bred heifers placed in the herd during the three previous years and by the cull rate of young cows, γ^y ,

$$(1) \quad y_t = b_{t-1} + b_{t-2}(1 - \gamma^y) + b_{t-3}(1 - \gamma^y)^2.$$

Mature cow inventory in time t is thus determined by mature cow inventory in $t-1$, the number of bred heifers placed in the herd at $t-4$, and the cull rates of young cows and mature cows, γ^o .

$$(2) \quad o_t = o_{t-1}(1 - \gamma^o) + b_{t-4}(1 - \gamma^y)^3.$$

Thus, total breeding herd inventory, x_t , is the sum of young and mature cow inventory.

$$(3) \quad x_t = y_t + o_t.$$

Bred heifers, b_t , can be brought into the herd from two sources, from heifer calves raised and bred, r_t , or from bred heifer purchases, p_t ,

$$(4) \quad b_t = r_{t-1}(1 - \lambda) + p_t,$$

where replacement heifers are culled at the rate of λ .

The number of culls, c_t , is determined by cow inventory levels, death rate, ϕ , and the cull rate, where

$$(5) \quad c_t = y_t(\gamma^y - \phi) + o_t(\gamma^o - \phi),$$

as $c_{t,o} = o_t(\gamma^o - \phi)$ and $c_{t,y} = y_t(\gamma^y - \phi)$.

Objective Function

Revenue R_t , is the sum of receipts generated from heifer sales, h_t , steer sales, s_t , and cull sales, c_t ,

$$(6) \quad R_t = P_{t,o}^H h_{t,o} + P_{t,o}^S s_{t,o} + P_{t,o}^C c_{t,o} + P_{t,y}^H h_{t,y} + P_{t,y}^S s_{t,y} + P_{t,y}^C c_{t,y}.$$

where $P_{t,y}^H$, $P_{t,y}^S$, and $P_{t,y}^C$ denote the market price of heifer calves and steer calves raised by young cows and young cull cows respectively and $P_{t,o}^H$, $P_{t,o}^S$, and $P_{t,o}^C$ denote the market price of heifer calves and steer calves raised by mature cows and mature cull cows respectively. The value of each subset is multiplied by the number of animals in that subset. In the case of heifer calves, h_t , represents the heifer calves sold and not kept as replacements. The subscripts “y” and “o” on animal subset variables represent animals belonging to or produced by the young cow and mature cow subsets of the breeding herd population. It is assumed that 90% of exposed cows and 85% of exposed replacement heifers are bred and that half of live calves born are heifers.

Expenses, E_t , include feed costs, ω_t , operating costs, σ , and fixed costs, ψ_t .

Interest is incurred on feed and operating costs for six months at a rate of ρ .

$$(7) \quad E_t = (1 + .5\rho)(\omega_t + \sigma)_t + \psi_t.$$

Operating costs include items incurred on a per head basis such as veterinary expenses, fuel, and marketing expenses. Fixed costs include items such as depreciation on facilities, machinery, and equipment, property taxes, insurance, and repairs.

The present value of annual returns to labor and management and the ending breeding herd value, PV , is calculated with a discount rate of α , where the ending value of the breeding herd is denoted as V .

$$(8) \quad PV = \sum_t [(R_t - E_t)(1 + \alpha)^{-t}] + V(1 + \alpha)^{-24}.$$

The optimization model optimizes PV , by choosing replacement levels and between raising and purchasing bred heifers for given input and output prices.

Scenario 1: Optimization

The cow-calf producers optimization problem is specified to maximize the present value of a stream of net returns (equation 8) subject to breeding herd dynamics and economic constraints from 1975 to 1999. The terminal value of the control problem reflects the discounted cull or salvage value of breeding stock in 1999. The profit maximizing solution selects the optimal time and rate of input resources, which are restricted to heifer and bred heifer replacements for this study. The algorithm also selects the total stock of breeding animals with the requirement that herd inventory remain between 80% and 120% of initial herd inventory. Here, the culling rate of the breeding herd is fixed, along with some inputs, in order to focus only on the replacement decision. It is assumed the forage base can be increased or decreased by rental agreements.

The objective function is the sum of net present value of pretax net returns to labor and management discounted at 8%. Throughout the paper net returns are expressed on a per head basis. In the model the initial herd inventory is set equal to 1, resulting in inventory levels expressed as a percentage of the initial herd size. For example, 1 is equivalent to a herd size of 100 head of cow-calf pairs and .75 is equivalent to 75 head.

Scenario 2: Constant-Inventory

The constant-inventory producer behaves differently from the profit-maximizing producer. In decision making the constant-inventory producer does not take into account the cattle cycle, but rather maintains a fixed herd inventory year-in and year-out. To

model the constant-inventory producer herd inventory is constrained to be equal to initial herd inventory or $y_t + o_t = 1$. In this strategy, it is assumed the same number of heifers are acquired each year to replace females culled at a constant rate. Since constant culling and replacement rates are used, the breeding herd size remains constant. Cows are culled at a rate of 15%, while 21% of heifers retained as replacements are culled before entering the breeding herd. In all, constant-inventory management simplifies the planning required to allocate resources over time.

Scenario 3: Counter-Cyclical

The counter-cyclical herd inventory management strategy adjusts an individual producer's breeding herd in a manner inversely related to changes in the U.S. cow herd inventory. The counter-cyclical producer increases (decreases) the breeding herd inventory one percent for every one percent decrease (increase) in January U.S. cow herd inventory. The U.S. cow inventory and its counter cyclical dual are depicted in Figure 2. Under this approach the producer attempts to increase profits by maintaining a larger herd when the U.S. breeding herd is smaller, which typically corresponds with the high price segment of the price cycle. Like the constant-inventory producer, the counter-cyclical producer also makes decisions differently from the profit maximizing producer.

For the analysis presented in this paper, the U.S. cow herd inventory is detrended to delineate between shorter and longer run effects (Hamilton and Kastens). The linear trend of U.S. cow herd inventory was estimated over the period from 1975 to 1999. Dividing U.S. cow herd inventory by the trend estimate of U.S. inventory isolates the change in U.S. cow herd inventory caused by cyclical forces from the change in

inventory caused by long-run trends in inventory. Constraining herd inventory to change opposite of detrended U.S. herd inventory in the optimization model resulted in the raise or buy replacements decision being the only choice variable in the maximization framework.

Scenario 4: Dollar-Cost-Averaging

The dollar-cost-averaging replacement strategy utilizes a diversified stock market investment strategy. The strategy simply invests the same dollar amount in each period. In the case of replacement heifer investment, the same dollar value of replacement females is retained or purchased each year. The dollar value invested in replacement females each year for this study is the average value of bred heifers retained by the constant inventory manager during the 1975-1999 period, or \$112.55 per bred cow. The investment for the constant-inventory manager is the value of replacement heifers retained at weaning plus the cost of servicing and feeding the heifer until calving. Thus, the dollar-cost-average strategy required the manager to invest \$112.55 in replacement females each year, per cow unit based on the average herd size.

Results

In this section model outcomes for each of the above management strategies are presented for the average Kansas producer.

Scenario 1: Optimization

Figure 3 shows net income and cow inventory for the optimal solution. Net income is positive from 1978 to 1982, 1986 to 1994, and in 1997. Breeding cow inventory starts at 100 in 1975 and decreases to 85 in 1977, rebounding to 120 head by 1978. Inventories

remain steady until 1980 and then rapidly decrease to 80 head until 1984, after which they rebound to 120 head until 1993.

Figure 4 compares the cow inventory, bred heifers purchased, and bred heifers raised for the average Kansas producer in the optimal solution. Bred heifers are purchased in 1978, 1979, 1982-1985, 1995, 1996, and 1998 each of which corresponds to a year in the bottom of a price cycle, not in a transitional year. Herd inventory is maintained at maximum levels during profitable years, and liquidated during low price years that are not profitable.

Scenario 2: Constant-Inventory

Figure 5 reports net income and cow inventory for the constant-inventory producer. Net income is positive from 1978 to 1980, in 1982, from 1986 to 1993, and in 1997 and 1999. Here, of course, inventories are constant over time.

Scenario 3: Counter-Cyclical

Figure 6 presents net income and cow inventory for the counter-cyclical producer. Net income is positive from 1978 to 1980, 1986 to 1994, and in 1997 and 1999. Breeding cow inventory starts at 91 in 1975 and increases to 105 in 1979. Inventory drops to 99 by 1981. Inventories remain steady until 1984 and then rapidly increase to 106 head in 1988 until it begins decreasing in 1991. Inventory bottoms out at 94 head in 1996, and remains at 95 to 96 head until 1999.

Figure 7 compares the cow inventory, bred heifers purchased, and bred heifers raised for the counter-cyclical Kansas producer. The counter-cyclical strategy keeps some heifers each year as herd size never decreases by more than 15%, the number culled, in a given year. Thus, even during unprofitable periods the herd is not fully liquidated. The

counter-cyclical model also chooses to purchase bred heifers rather than raise them during years that correspond to the bottom of the price cycle, i.e. 1976, 1983, 1984, 1994-1996, and 1998. Herd inventory moves counter-cyclical to the price cycle, changes in herd inventory occur rather slowly. Herd inventory never deviates from average herd inventory by more than 9%.

Scenario 4: Dollar-Cost-Averaging

Figure 8 presents net income and cow inventory for the dollar-cost-averaging producer. Net income is positive from 1978 to 1980, in 1982, 1986 to 1993, and in 1997 and 1999. Breeding cow inventory starts at 100 head in 1975 and increases to 107 head by 1978. Inventory then falls to 97 head in 1982, rebounding to 106 head by 1988. Inventories again begin decreasing until 1994, where they bottom out at 100 head. Inventories then increase throughout the rest of the period ending at 116 head in 1999.

Figure 9 compares the cow inventory, bred heifers purchased, and bred heifers raised for the dollar-cost-averaging producer. The model of the dollar-cost-averaging strategy, also chooses to purchase bred heifers as opposed to raising them in several years that correspond to the bottom of the price cycle (1976, 1981, 1983, 1984, 1994-1996, and 1998). Herd inventory in the dollar-cost-averaging strategy also moves counter-cyclical to the price cycle. Herd inventory trends slightly upward during the time period, a result of slightly more heifers being kept due to the cost savings of purchasing bred heifers in the years indicated.

Discussion

Table 2 contains the net present value of return on investment per head (discounted at 8%, 1975 dollars) and average net income per head per year (GDP deflated, 1996 dollars) over the period from 1975 to 1999. The net present value amounts reflect the return on investment per head expressed in 1975 dollars. The highest return is profit maximization, followed by dollar-cost-averaging, constant-inventory, and counter-cyclical strategies. The NPV of the profit maximizing strategy in 1975 is \$271.37. Thus, a profit maximizing producer could invest as much as \$271.37 per bred female and break-even (no return to labor and management) during the 1975-1999 time period. For reference, the average price of a bred heifer in 1975 was \$271.82. These results indicate that markets are efficient and the average producer is at least similar to our profit-maximizing producer. The results also indicate that on average return to labor and management is near \$0. Thus, a producer must have a comparative advantage (efficient production or low costs) to receive positive returns to labor and management.

Next, we compare the average net income that is expressed in 1996 dollars across the management strategies. The constant-inventory manager receives on average \$4.03 per head less than the counter-cyclical inventory manager and \$0.51 less per head than a manager using a dollar-cost-averaging strategy. However, the NPV of all income during the period is \$1.44 more per head for the constant-inventory manager than for the counter-cyclical manager. The profit maximization strategy yields the highest net income for the period, followed by the dollar-cost-averaging, counter-cyclical, and constant-inventory strategies respectively.

Figure 10 reports the annual net income across the study period for each scenario. For the most part, net income from each strategy follows the same general pattern from 1975 to 1999. The profit maximizing sequence of net income exhibits the most extreme changes, which coincides with its more extreme changes in inventories as shown in Figure 5 and Figures 11 and 12 discussed below.³

Figures 11 and 12 present the annual cow and bred heifer replacement inventories across the study period for each scenario. Cow and bred heifer replacement inventories of dollar-cost-averaging and counter-cyclical management strategies have some qualitative similarities to that of profit maximization. However, the figures exhibit stark differences in replacement inventories. The dollar-cost-average and counter-cyclical producers inefficiently allocate input resources by acquiring replacements in an ill-timed manner at an inappropriate rate, thereby reducing net returns over the study period.

Although these results illustrate important limitations of constant-inventory, dollar-cost-averaging, and counter-cyclical management strategies, it is important to point out that the profit maximization model also has limitations. Here, it is assumed that producers have perfect information over the study period (e.g., perfect foresight of prices). In this respect, it is appropriate to interpret the profit maximization model as an intertemporal economic *planning model* (Pindyck 1973).

Nevertheless, an important point is that profit maximization offers insight into the flexibility and opportunity of cow-calf producers to allocate resources by acquiring replacements in an economically efficient manner not achievable by the other strategies. The profit maximizing solution attains a NPV of net income more than \$150 greater and

³ Because the optimal producer chooses a sequence of replacement heifers to maximize profit over the entire time period, profit for a single year may be less than the constant-inventory, dollar-cost-averaging, or counter-cyclical

an average net return of more than \$17 greater than the next best strategy. This suggests cow-calf producers that apply either constant-inventory, dollar-cost-averaging, or counter-cyclical management strategies may incur an opportunity cost that is positive and large in magnitude.

Both Hamilton and Kastens (2000) and Lawrence found differences between strategies to be larger than the results of this analysis. Hamilton and Kastens found the counter-cyclical strategy to return \$11.93 more than the constant-inventory strategy, while we found the difference to be only \$4.03. Lawrence reported the dollar-cost-averaging strategy returned \$0.64 per head more than the constant-inventory strategy on average, while we found the difference to be only \$0.51. A possible explanation for these differences is that we incorporate age dynamics of the breeding herd into the model. Accounting for weaning weight differences between old and young cows may have limited the benefit of counter-cyclical strategies. As counter-cyclical strategies increase herd size during high-price periods, herd dynamics shift, resulting in a lower average cow age, thus a lower average weaning weight.

Conclusions

The study period from 1975 to 1999 included 2 1/2 “cattle” cycles of about ten years per cycle. Dollar-cost-averaging outperformed counter-cyclical and constant-inventory strategies over this period. We point out that analyzing alternative study periods may possibly influence the magnitude of differences between strategies considered in this analysis.

management strategies. This is exhibited clearly by net income values in 1996.

Practical implementation of replacement management strategies requires resource flexibility. Constant-inventory, dollar-cost-averaging, and counter-cyclical strategies tend to limit resource flexibility and use replacement decision rules that don't specifically relate to profit maximization. The failure of these strategies to include costs of production in their decision rules leads to investing in replacement heifers that do not cover variable costs, which strictly violates profit maximization theory.

Perhaps the most important message is the potential limitations of dollar-cost-averaging, counter-cyclical, and constant-inventory strategies relative to the optimal decisions. Profit maximizing producers benefit from incorporating output and input price signals into the timing and rate of their capital replacement decisions. In addition to cattle prices, costs of production are important determinants of profitable replacement strategies. Ignoring a subset of price signals in the dollar-cost-averaging and counter-cyclical strategies and all price signals in the constant-inventory strategy limits net return, imposing an opportunity cost on the producer that is positive and potentially large in magnitude.

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Table 1. Parameter Values for Empirical Model.

Parameter	Description	Units	Value
x_t	Total breeding herd	Head	Initial=100
y_t	Young cow inventory	Head	
o_t	Mature cow inventory	Head	
b_t	Bred heifer inventory	Head	
r_t	Replacement heifer inventory	Head	
p_t	Bred heifers purchased	Head	
γ^o, γ^y	Mature, young cow cull rate	%	15
λ	Heifer cull rate	%	21
ϕ	Cow and Heifer death rate	%	1
α	Discount rate	%	8
ω_t	Feed expense	\$	
σ_t	Operating expense	\$	
ψ_t	Fixed cost	\$	
ρ	Interest on feed and operating expenses	%	10
V	Ending breeding herd value	\$	
$c_{t,y}$	Young cow culls	Head	
$s_{t,y}$	Steer calves of young cows	Head	
$h_{t,y}$	Heifer calves of young cows	Head	
$c_{t,o}$	Mature cull cows	Head	
$s_{t,o}$	Steer calves of mature cows	Head	
$h_{t,o}$	Heifer calves of mature cows	Head	
$P_{t,o}^H$	Value of heifer calves of mature cows	Head	
$P_{t,o}^S$	Value of steer calves of mature cows	Head	
$P_{t,o}^C$	Value of mature cull cows	Head	
$P_{t,o}^H$	Value of heifer calves of young cows	Head	
$P_{t,o}^S$	Value of steer calves of young cows	Head	
$P_{t,o}^C$	Value of young cull cows		

Table 2. Comparison of Net Present Value and GDP Deflated Average Net Income.

	Profit Max (Optimal)	Dollar- Cost	Constant- Inventory	Counter - Cyclical
Net Present Value (1975 dollars)	\$271.37	\$116.32	\$85.98	\$84.54
GDP Deflated Net Income (1996 dollars)	\$26.80	\$5.43	\$4.92	\$8.95

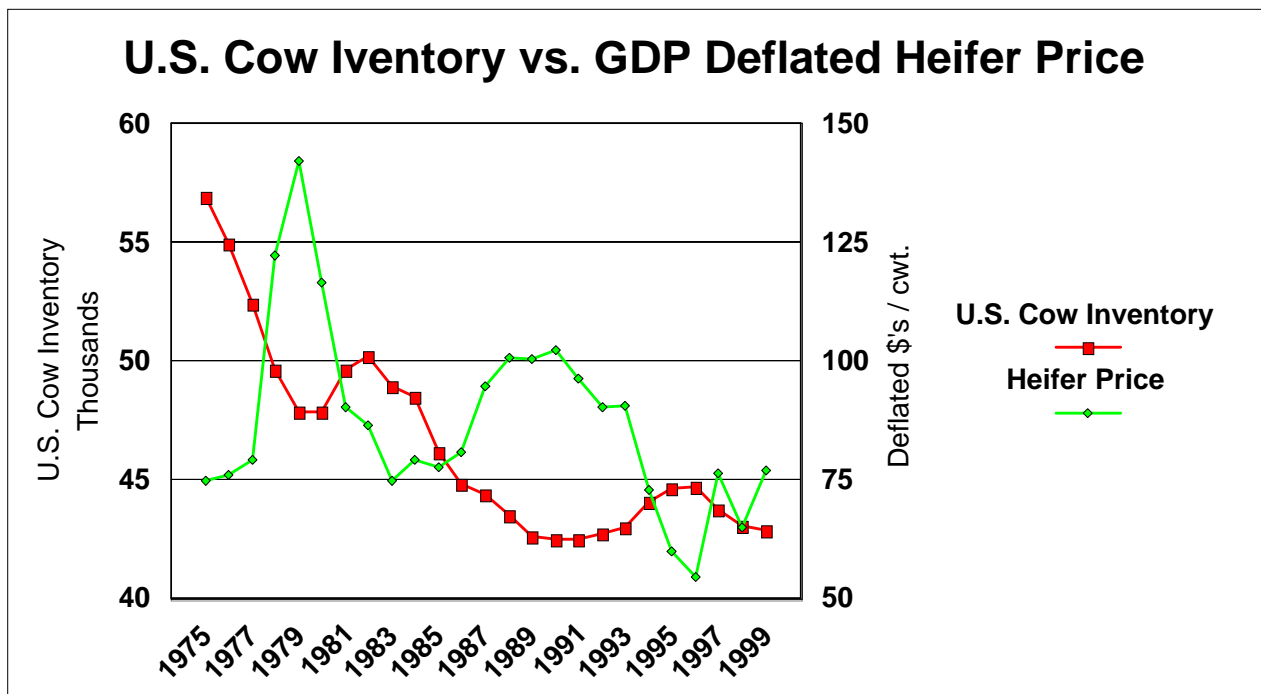


Figure 1. US inventory and GDP deflated heifer price series.

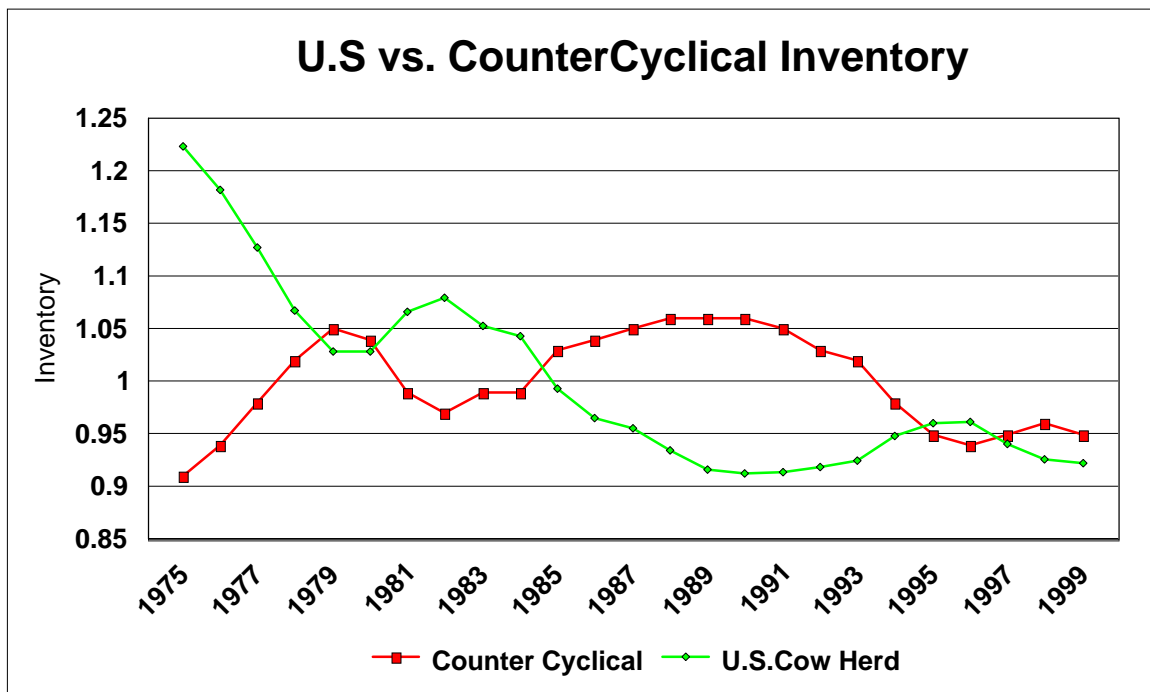


Figure 2. US cow herd inventories and counter-cyclical inventories.

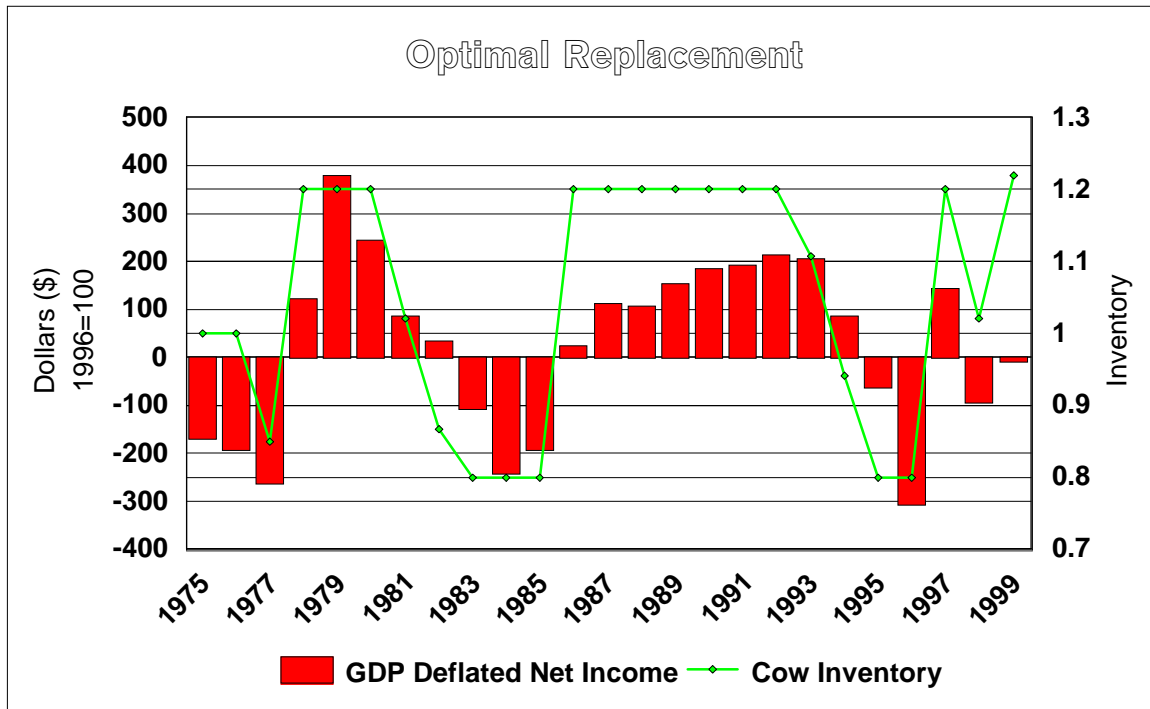


Figure 3. Net income and cow inventory for the profit maximizing or optimal producer.

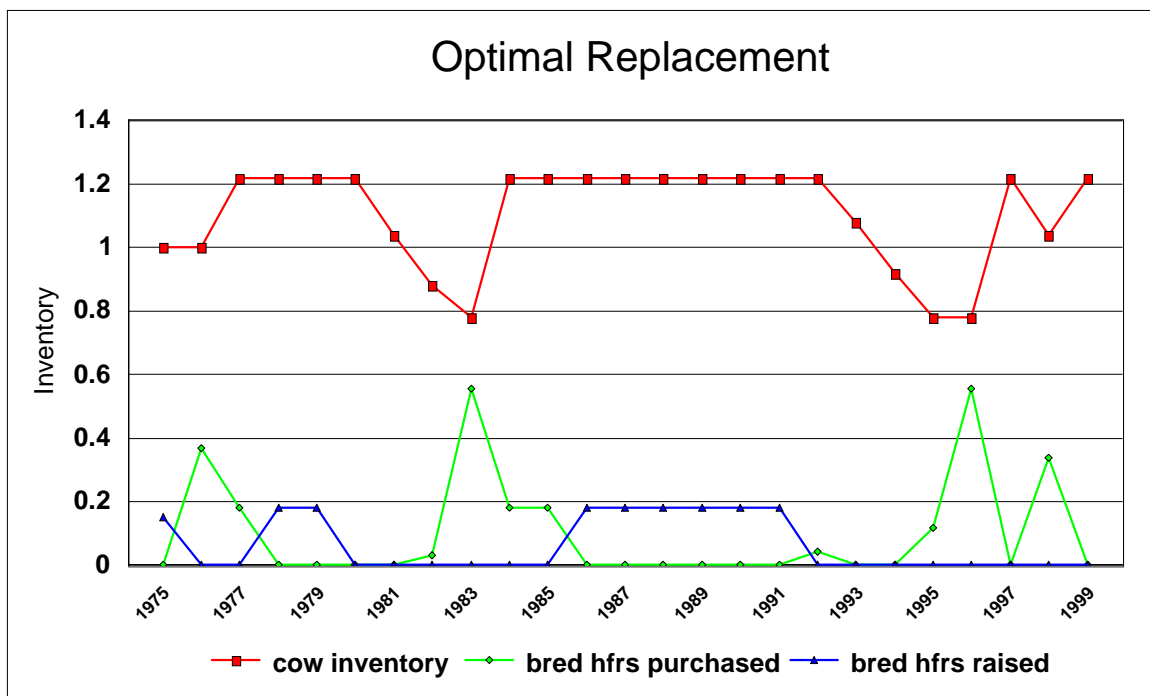


Figure 4. Cow inventory, bred heifers purchased, and bred heifers raised for the profit maximizing or optimal producer.

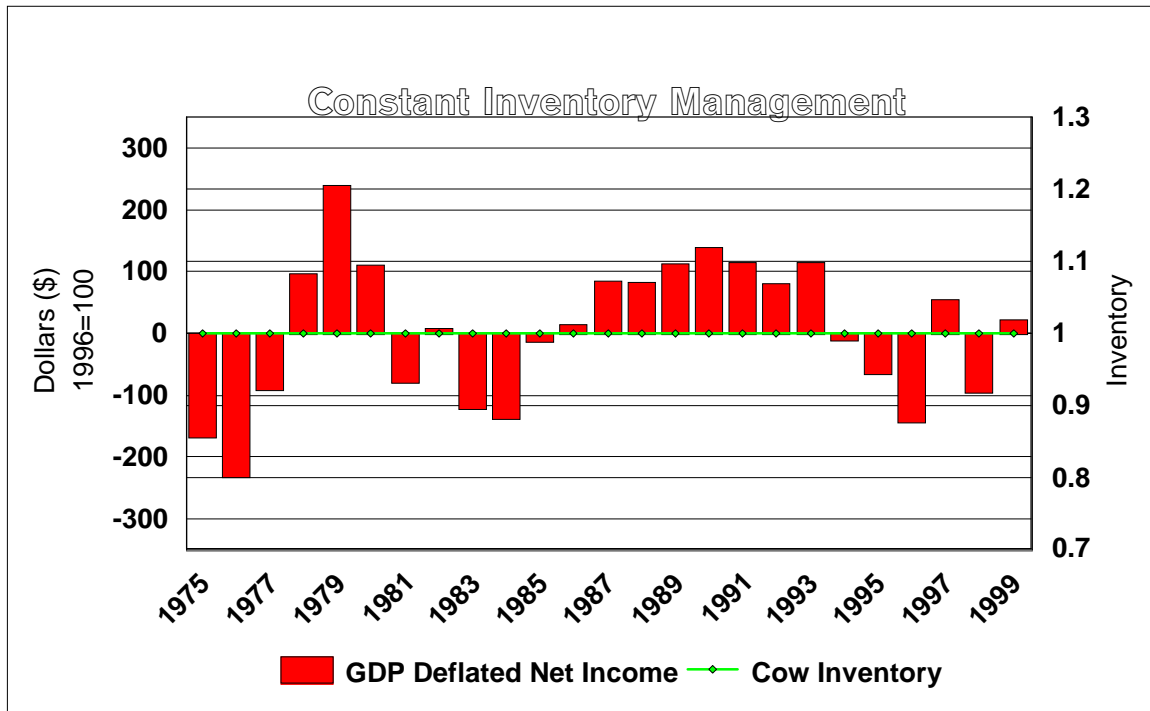


Figure 5. Net income and cow inventory for the constant-inventory producer.

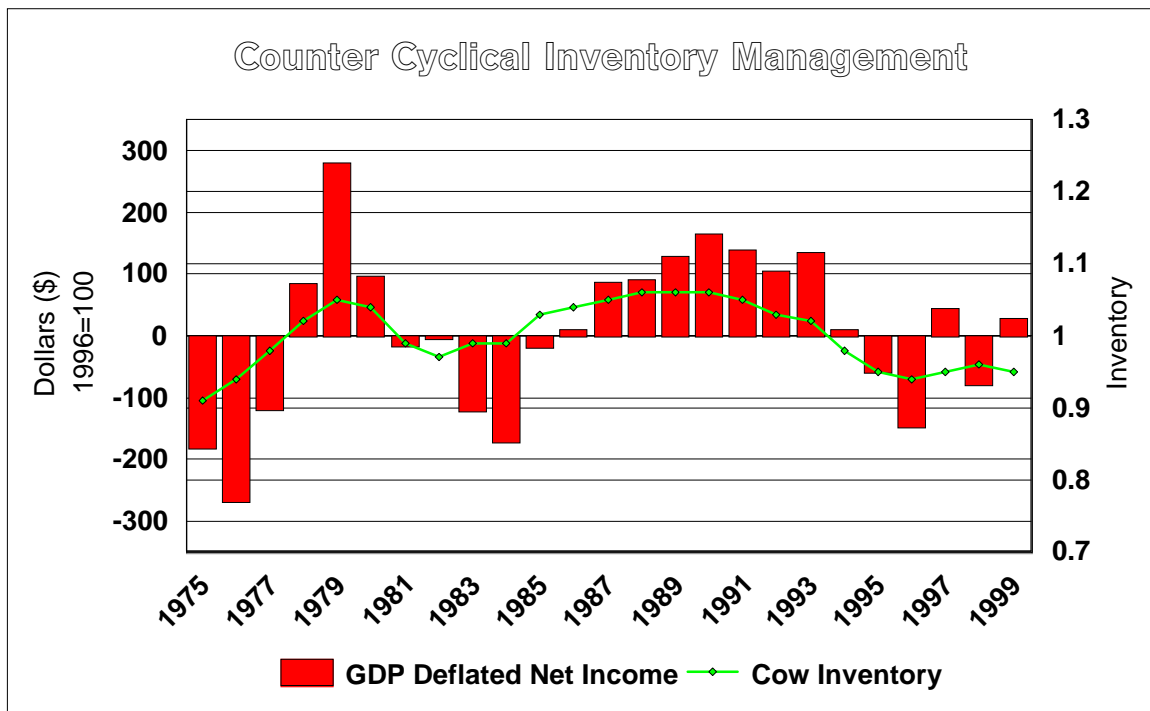


Figure 6. Net income and cow inventory for the counter-cyclical producer.

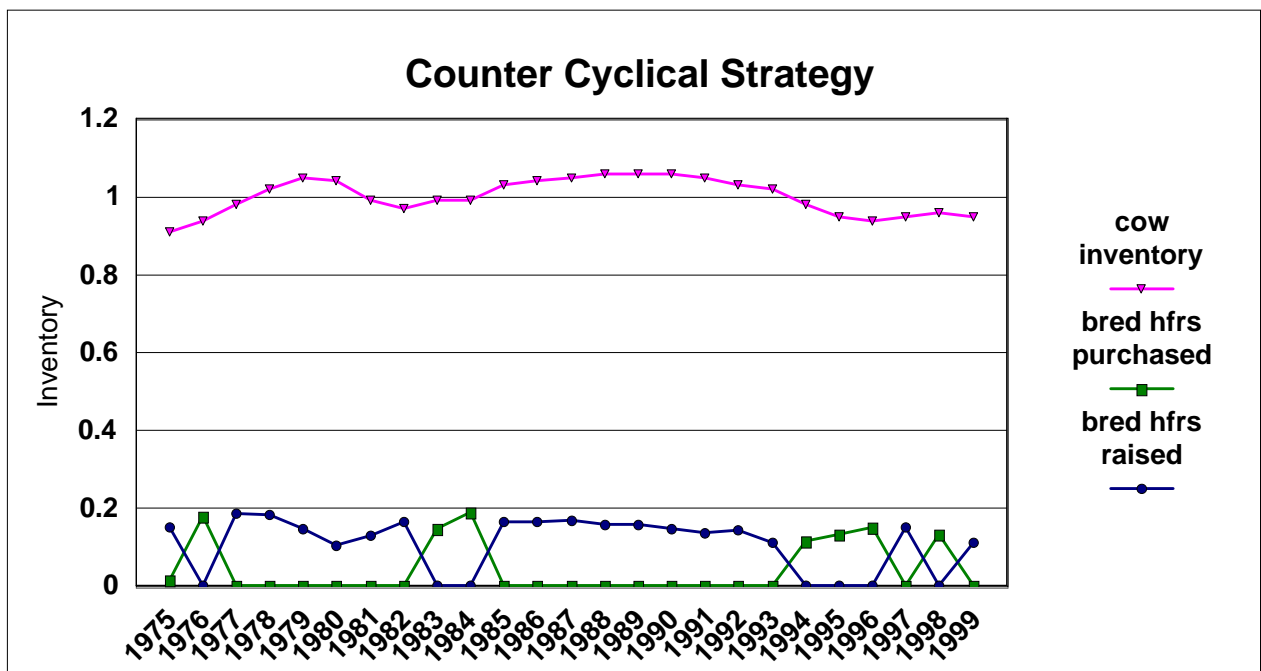


Figure 7. Cow inventory, bred heifers purchased, and bred heifers raised for the counter-cyclical Kansas producer.

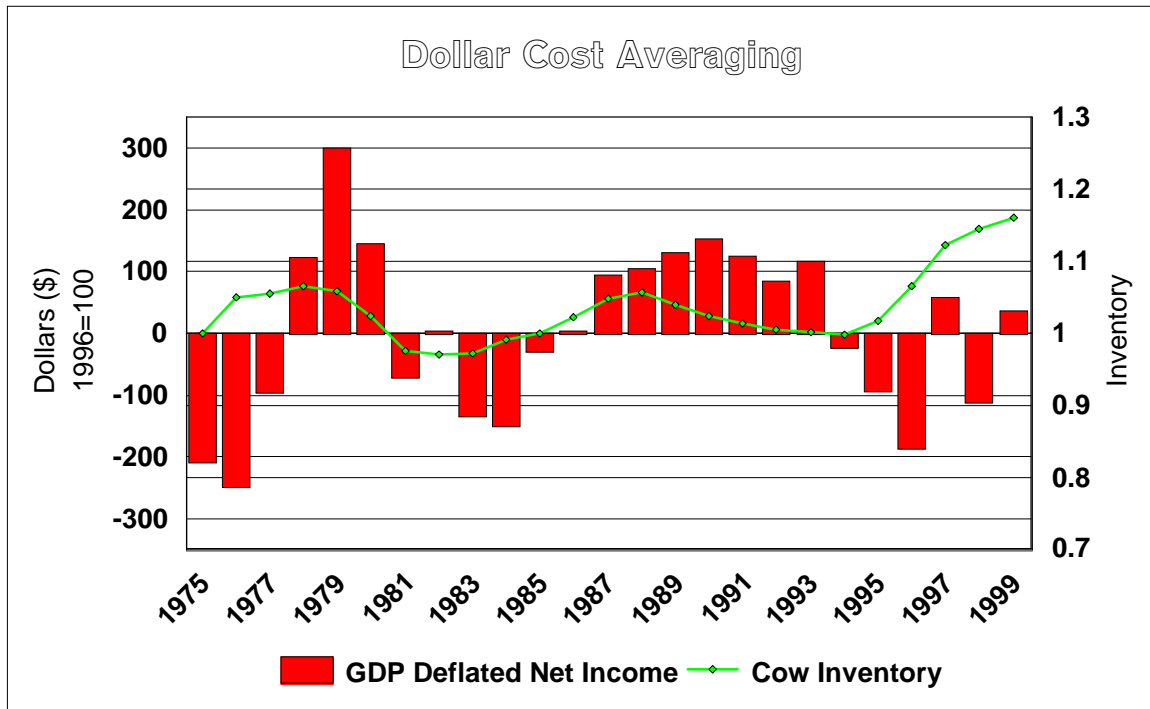


Figure 8. Net income and cow inventory for the dollar-cost-averaging producer.

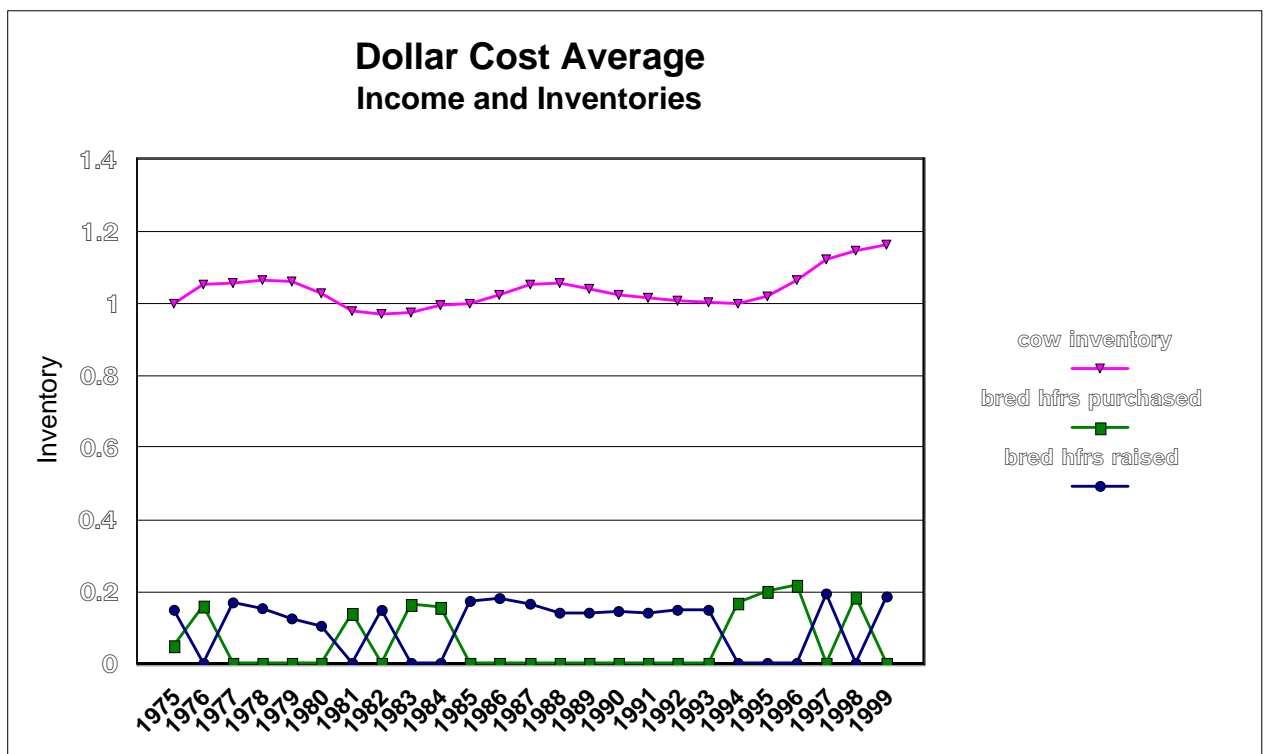


Figure 9. Cow inventory, bred heifers purchased, and bred heifers raised for the dollar-cost-averaging producer.

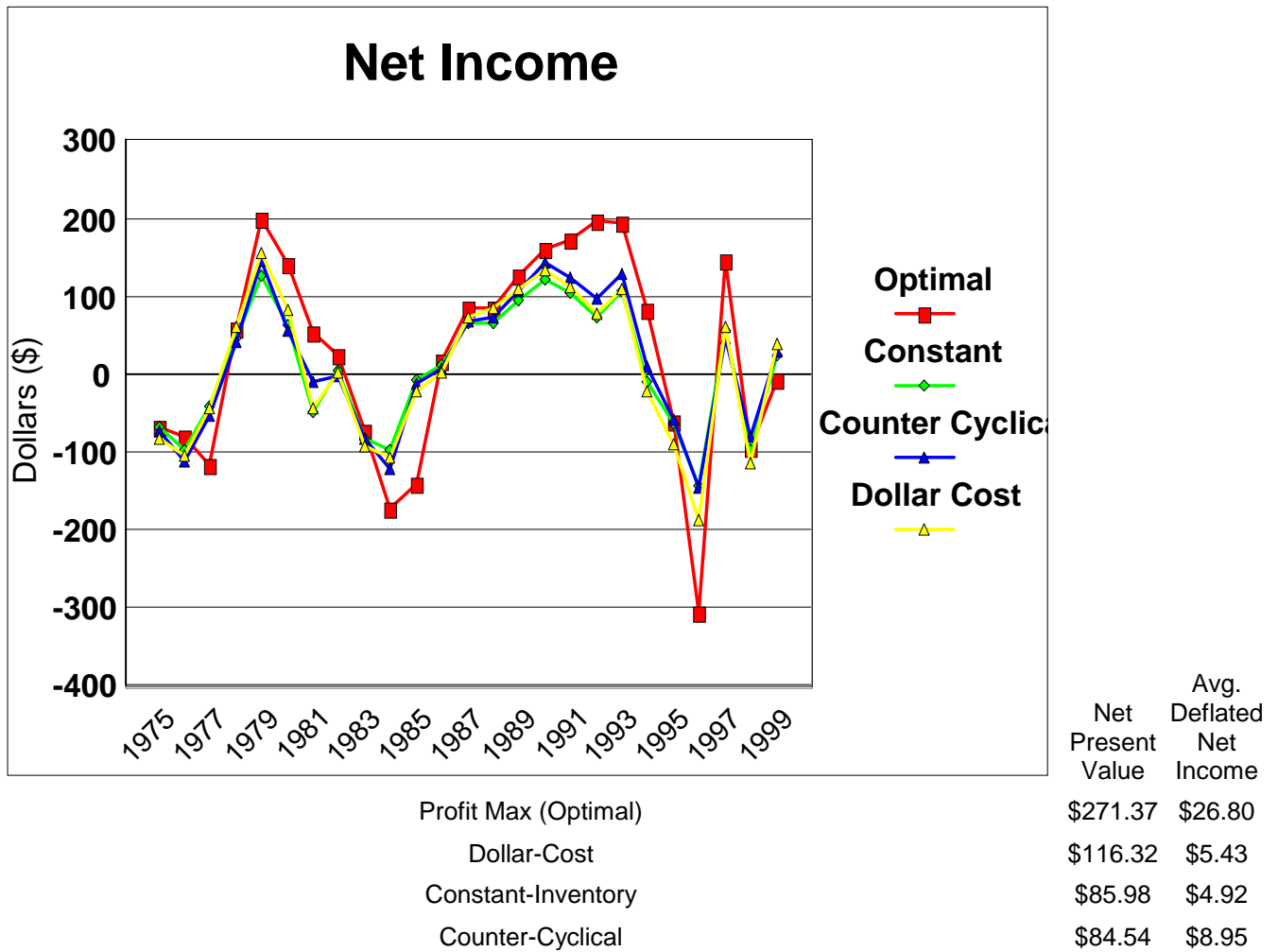


Figure 10. Annual net income across the study period for each scenario.

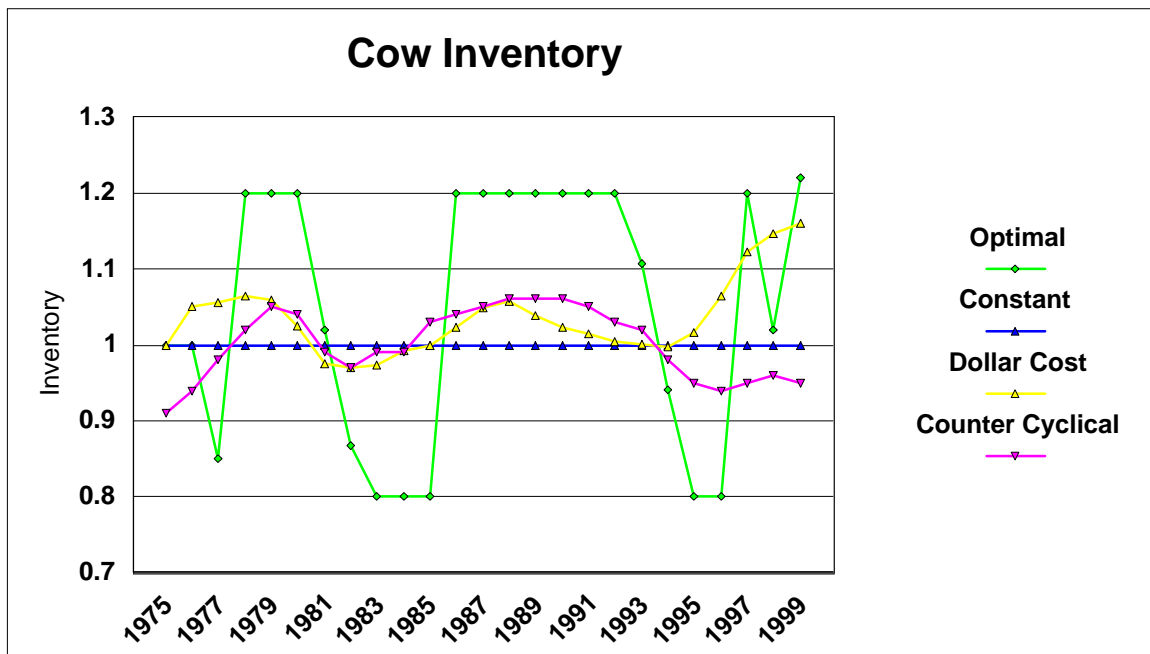


Figure 11. Annual cow inventories across the study period for each scenario.

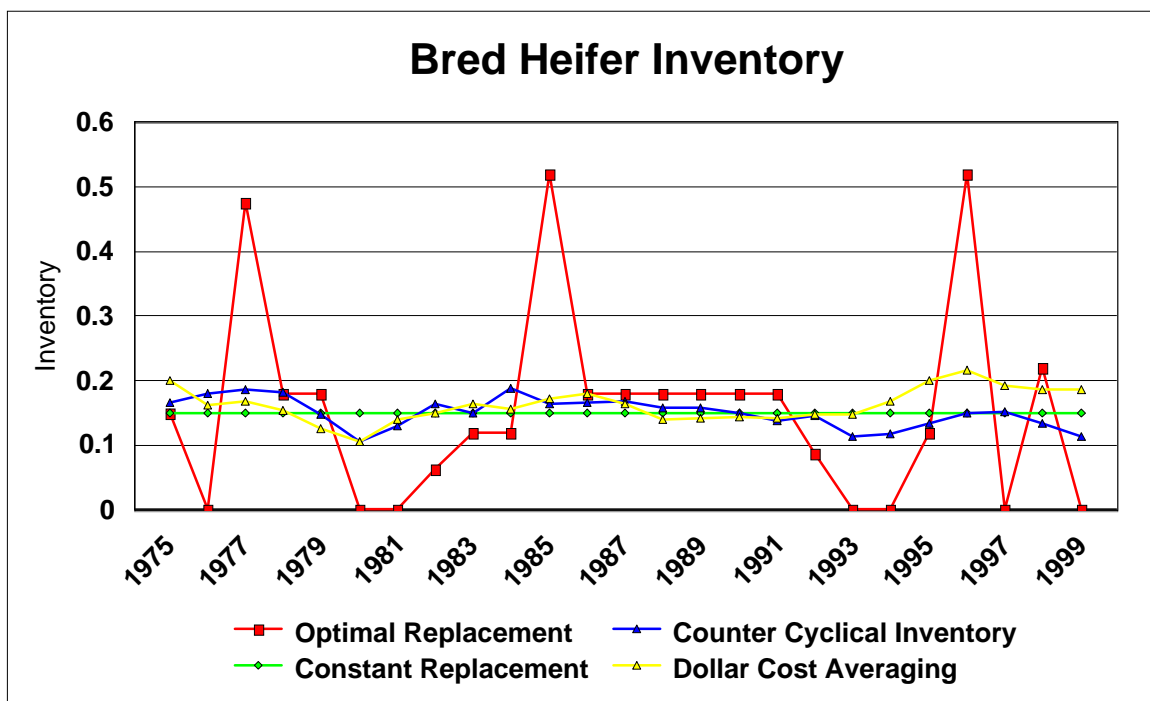


Figure 12. Annual bred heifer replacement inventories across the study period for each scenario.