Adjustments in a Beef/Sheep Farm in Response to the Cattle Cycle: The Potential for Increased and More Stable Income

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A dynamic (multi-period) linear programming model of a beef/sheep farm was used to evaluate the potential for increasing income and for maintaining a specified level of annual income during a cattle cycle. Results indicate that both objectives may be accomplished by adjusting animal numbers in response to changing price ratios: a higher proportion of cows should be kept during the accumulation phase of the cattle cycle, and a higher proportion of ewes should be kept during the liquidation phase.

Much of the land in the northeastern region of the United States is suitable for forage and livestock enterprises. Beef, sheep, and dairy are the primary forage consuming enterprises, but cow-calf production has been associated with low returns and variation in annual income.

Historically, the cattle industry in the United States has been characterized by cyclical patterns in numbers of animals and prices (Breimyer, Purcell and Holmes). Cattle cycles may be divided into two phases: an accumulation phase in which cattle prices are relatively high and cattle numbers are increasing, and a liquidation phase in which cattle prices tend to be lower and cattle numbers are decreasing.[1] At the time this study was initiated, the most recently completed two-phase cattle cycle had lasted twelve years, the accumulation phase starting in 1967 and the liquidation phase ending in 1978 (McCoy, pp. 62–72).

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[1] While the cattle cycle is most commonly divided into two stages, Beale et al. mention that it has also been divided into three stages. The three stages are the rapid growth stage, the deceleration stage, and the turnaround stage.

In contrast to the cycle in cattle numbers, sheep numbers between 1967 and 1978 steadily declined. But the ratio of the values and prices of beef to sheep followed a definite cycle—a relatively high ratio during the accumulation phase of the cattle cycle and a relatively low ratio during the liquidation phase (Table 1 and Appendices 1 and 2). A similar cyclical pattern in the ratio of cattle to sheep values has occurred during the last three cattle cycles (Wollo).

The liquidation phase of the cattle cycle has been associated with reduced income for many cow-calf producers. Since beef and sheep production require many of the same physical resources and management skills and since the beef/sheep price ratio tends to favor sheep during the liquidation phase of the cattle cycle, a cow-calf producer might increase his income or maintain a more stable annual income by using sheep to adjust his enterprise combination in response to the cattle cycle.

Three related studies have been considered. Bentley and Shumway used a dynamic simulation model to explore how a beef farmer might adapt to the cattle cycle. Sharp and Boykin employed a dynamic programming model to evaluate investments in brush control and in several beef cattle systems. But these studies did not address the possibility of diversification into sheep production. Holder used stepwise regression to show that the retail price of lamb is closely related to the retail price of

Table 1. Annual Changes in Cattle and Sheep Inventory and Value in the U.S. and Ratio of the Value of Cattle to Sheep During the 1967–1978 Cattle Cycle

Year	Annual Change in Inventory and Phase of the Cattle Cycle		Value per Head		Ratio of Value of Cattle to Sheep
	Cattle	Sheep	Cattle	Sheep	
	------------1,000 head-----------		-----------Dollars------------		
	Accumulation				
1967	588	−1,730	149.00	19.80	7.52
1968	644	−873	148.00	19.20	7.71
1969	2,354	−927	158.00	22.00	7.18
1970	2,209	−692	179.00	25.10	7.13
1971	3,284	−992	184.00	23.60	7.80
1972	3,677	−1,098	208.00	22.90	9.08
1973	6,249	−1,331	252.00	26.70	9.44
1974	4,240	−1,795	293.00	32.80	8.93
	Liquidation				
1975	−4,048	−1,204	159.00	30.50	5.21
1976	−5,170	−589	190.00	37.30	5.09
1977	−6,435	−301	206.00	42.50	4.85
1978	−5,511	−56	232.00	51.50	4.50

Source: Taken or derived from U.S. Department of Agriculture. *Agricultural Statistics 1981*, pp. 299 and 323.

beef. But the Holder study was not concerned with farm-level adjustments in response to changing price ratios.

This study explored the hypothesis that a livestock farmer can increase his total income or maintain a given level of annual income by combining cattle and sheep enterprises and by adjusting beef cow and ewe numbers in response to price changes during a cattle cycle. Specifically, this study sought answers to the following questions. Given historical prices of cull beef cows, replacement heifers, calves, cull ewes, replacement ewes, and lambs, how might a farm operator adjust his beef cattle and sheep numbers in order to maximize income or maintain a specified level of annual income? If a farmer has the objective of maximizing income or maintaining a specified annual income level, what levels of annual and total income might be attained? And what are the magnitudes of variations in annual income?

Mathematical Model and Data

This analysis is a case study of a beef and sheep farm located in southeastern West Virginia. A perfectly competitive market structure of the beef and sheep production industries was assumed. A dynamic (multi-period) linear programming (DLP) model during the 1967–1978 cattle cycle served as the analytical tool. The word "dynamic" is used here as suggested by Hicks (p. 115); i.e., returns and costs are dated according to the year of the cattle cycle in which they occur. Three versions of the model were used to explore possibilities for increasing income and stabilizing annual income by adjusting cow and ewe numbers.

The base model (Model I) may be represented mathematically as follows.

(1) Maximize $PV = \sum_{i=1}^{I} \sum_{t=0}^{T} R_i^t\, Y_i^t \left[\frac{1}{1+r}\right]^t$

(2) Subject to $a_{ij}^t\, Y_i^t \leq B_j^t$

(3) $Y_i^t \geq 0$

(4) $C^t = C^*$

(5) $E^t = E^*$

where

PV = Present value of returns to fixed resources

R_i^t = Discounted returns to fixed resources for the i^{th} DLP activity in the t^{th} year

Y_i^t = Activity level for the i^{th} DLP activity in the t^{th} year

r = Discount rate

a_{ij}^t = Amount of the j^{th} resource used in the i^{th} DLP activity in t^{th} year

B_j^t = Amount of the j^{th} resource available during the t^{th} year

C^t = The number of beef cows in year t
C^* = A specified, constant number of beef cows
E^t = The number of ewes in year t
E^* = A specified constant number of ewes

Thus, model I maximized the present value of returns to fixed resources (1) subject to resource constraints (2), nonnegativity constraints (3), and a constant number of beef cows (4) and ewes (5). Model I represents a farm on which animal numbers were not adjusted in response to changing prices over the cattle cycle.

In models II and III, beef cow and ewe numbers were allowed to vary in response to changes in annual prices. Model II may be represented by equations (1), (2), and (3). A set of annual income constraints (6) was added to equations (1), (2), and (3) to specify Model III. The purpose of using annual income constraints was to force the model to maintain a specified minimum level of annual income.

$$(6) \qquad \sum_{i=1}^{I} R_i^t Y_i^t \left[\frac{1}{1+r}\right]^t \geq R^*$$

where R^* = A specified, constant annual income level.

Activities

The DLP activities are based on budgeted costs and returns information for the example farm. Technical data were obtained from Willow Bend Farm records[2] and consultations with agricultural scientists at West Virginia University. Included in each budget are receipts, operating costs, and returns to fixed resources (land, buildings, machinery, equipment, overhead, management, and on-farm labor).

Budgets were generated for the following crops: mixed grass hay, alfalfa hay, and pasture. Alfalfa hay and grass hay buying activities, and a grass hay selling activity, were included in the model.

Livestock budgets were prepared for cow-calf and ewe-lamb enterprises and for purchasing replacement heifers and replacement ewes. A 92 percent marketable calf crop and an average market weight for the feeder calves of 5.18 hundredweights were assumed. A 123 percent marketable lamb crop was assumed. The average market weight for slaughter lambs was 1.04 hundredweights. Annual cull rates of 15.0 percent for cows and 20.0 percent for ewes were used. Annual death rates for cows and ewes were 0.7 and 5.0 percent, respectively. First-born calves and first-born lambs tend to be smaller than calves or lambs born to more mature animals. Therefore, on the basis of consultations with livestock specialists familiar with performance testing, a replacement heifer's calf weight was reduced by 57 pounds and a replacement ewe's lamb weight was reduced by 31 pounds.

Price Data

Livestock prices were yearly average data for West Virginia, obtained from Crop Reporting Bulletins 8, 9, 13, and 14. Prices for shorn and unshorn wool were national price support data from *Agricultural Statistics 1982*. Input cost data were calculated from recent Willow Bend Farm cost information (Pell and Burton) and USDA index numbers. Bull and ram costs were based on breeding fees reported in Reda.

Because state average replacement prices were not available, the authors, after consulting livestock extension specialists, specified annual replacement ewe prices as 10 percent greater than lamb prices and annual replacement heifer prices as 10 percent greater than calf prices. The average price of all hay, found in Crop Reporting Bulletins 8, 9, and 14, was used for the price of grass hay. The alfalfa hay price was derived from the price of all hay by using differences between national average prices for alfalfa and other hay found in various issues of *Agricultural Statistics*. Prices used for calves, lambs, cull cows, and cull ewes, and the price ratio of calves to lambs and cows to ewes, are shown in Appendices 1 and 2.

Based on the production credit association's average cost of loans during the 1967–1978 cattle cycle (U.S. Department of Agriculture 1981, p. 481), a discount rate of 8 percent was used.

[2] Willow Bend Demonstrational Farm is the example farm on which this case study is based. Owned and operated by West Virginia University, this farm is used to demonstrate to beef and sheep producers recommended management practices. The authors feel that the quality of land found on Willow Bend farm is typical of other livestock farms in southern West Virginia. However, comparisons of Willow Bend farm data with hay and livestock production data published by Baker et al. and with state average hay production data suggest that the level of management on Willow Bend farm is higher than the level of management typically found on livestock farms in West Virginia.

Resource Restrictions

The resource restrictions associated with the farm operation included land, labor, and operating capital. Land availability on the example farm included 69 acres of hay land and 169 acres of pasture land.

The operator provided 60 hours of labor per week during the lambing and calving season (March-April), and 40 hours per week in the other ten months. Additional labor could be hired if profitable.

Operating capital was assumed to be generated from the farm operator's own sources. Since many farmers in West Virginia are reluctant to borrow money for farm operations, no capital could be borrowed. The farm operator started with $8,841, a figure based on recent farm expense information which was back-dated to 1967. The model was structured so that operating capital available for each year after 1967 was the sum of 50 percent of the previous year's returns to fixed resources plus the unused operating capital from the previous year.

Based on the numbers of mature animals on the farm in 1981, 58 beef cows and 80 ewes were specified for 1967 in all three models. Balance rows were specified so that the number of cows (or ewes) retained each year after 1967 could be no greater than the number of the previous year's cows (or ewes), minus death losses and culls, plus replacements purchased. Annual animal numbers were held constant in Model I, but allowed to vary after 1967 in Models II and III. Sales of cull animals greater than the specified cull rates and replacement purchases were not allowed in the final year, 1978. Annual income in Model III was not allowed to go below $7,675. The $7,675 annual income level was selected after several DLP runs with different annual income constraints were used to find an annual income level as high as possible. A minimum annual income level $10 greater than $7,675 resulted in an infeasible DLP solution.

Results

Model I

Model I is a profit maximization model in which the farm operator keeps the same number of cows and ewes throughout the 12-year cattle cycle. The present value of discounted total income for Model I was $77,947 (Table 2). The levels of discounted annual income ranged from a high of $9,851 in 1978 to a low of $2,689 in 1975. The annual numbers of beef cows and ewes were held constant at 58 and 80, respectively.

Model II

Model II is a profit maximization model in which the numbers of cows and ewes were

Table 2. Comparisons of Discounted Annual and Total Incomes for Three Dynamic Linear Programming Models of Example Farm[a]

	Model I	Model II		Model III		
Year	Income	Income	% of Model I	Income	% of Model I	% of Model II
	Dollars	Dollars		Dollars		
1967	7,309	11,087	152	10,440	143	94
1968	6,838	7,241	106	7,675	112	106
1969	7,304	7,868	108	7,675	105	98
1970	7,238	7,830	108	7,675	106	98
1971	6,993	7,578	108	7,675	110	101
1972	8,242	8,711	106	7,675	93	88
1973	9,637	26,963	280	7,675	80	28
1974	4,690	−2,511[b]	—	7,675	164	—
1975	2,689	7,986	297	7,675	285	96
1976	3,411	5,880	172	7,675	225	130
1977	3,745	10,632	284	7,675	205	72
1978	9,851	7,018	71	7,675	78	109
Total	77,947	106,283	136	94,865	122	89

[a] Income refers to returns to fixed resources—land, buildings, machinery, equipment, overhead, management, and on-farm labor. In Model I, animal numbers were held constant. In Models II and III, animal numbers were allowed to vary. In Model III, annual income was not allowed to go below $7,675.

[b] A percentage is not calculated since income was negative.

Table 3. Annual Animal Numbers From Two Dynamic Linear Programming Models of the Example Farm[a]

	Model II						Model III					
	Beef			Sheep			Beef			Sheep		
Year	Cows Ret.	Repl.	Cows Sold	Ewes Ret.	Repl.	Ewes Sold	Cows Ret.	Repl.	Cows Sold	Ewes Ret.	Repl.	Ewes Sold
	Head											
1967	58	3	9	80	0	16	58	4	9	80	0	16
1968	52	13	8	60	0	12	53	12	8	60	0	12
1969	57	11	9	45	0	9	56	12	8	45	0	9
1970	59	11	9	34	0	7	59	12	9	34	0	7
1971	61	11	9	25	0	5	62	4	9	25	50	5
1972	62	11	9	19	0	4	56	0	8	69	108	14
1973	64	0	64	14	125	3	47	0	22	160	212	32
1974	0	0	0	136	268	27	25	0	25	332	83	66
1975	0	0	0	370	0	74	0	7	0	332	0	66
1976	0	19	0	277	0	55	7	0	7	249	53	50
1977	19	0	19	208	0	42	0	2	0	240	0	48
1978	0	0	0	156	0	31	2	0	0	180	0	36

[a] In Model I, annual animal numbers were held constant at 58 cows and 80 ewes. In Models II and III, animal numbers were allowed to vary. In Model III, annual income was not allowed to go below $7,675. All three models included death losses of 0.7 percent for cows and 5.0 percent for ewes, and cull and replacement rates of 15.0 percent for cows and 20.0 percent for ewes. The words "retained" and "replacements" are abbreviated "Ret." and "Repl." respectively.

allowed to vary. Cows were retained from 1967 through 1973 and in 1977 (Table 3). The number of retained ewes increased in 1973 and 1974. In 1973, one year prior to the end of the accumulation phase of the cattle cycle, the model chose to sell all cows. Except for 1977 when 19 cows were kept for calf production, in every year following 1973 Model II produced all sheep.

Annual income levels changed drastically over the cattle cycle. Income was negative in 1974 when 268 ewes were purchased, but quite high in 1973, when 64 cows were sold. Total discounted returns to fixed resources ($106,283) were 136 percent of Model I income (Table 2).

Model III

Model III is a profit maximization model in which the numbers of livestock were allowed to vary but annual income was not allowed to fall below a specified level. A variable number of beef cows was retained from 1967 through 1974. In 1974 all cows were sold, but small numbers of cows were kept for calf production in 1976 and 1978. Sheep production increased dramatically after 1972. During the liquidation phase, Model III primarily produced sheep.

Annual incomes obtained in Model III did not go below $7,675 because of the annual income constraint. Total net income ($94,865) was 122 percent of Model I income.

Value of Breeding Animals in Final Year

Because this study focuses on increasing income and stabilizing annual income and because breeding animals left on the farm for future production do not provide income, sales of cows and ewes greater than the specified cull rates were not allowed in the final year of the cattle cycle. The analysis thus did not account for the value of breeding animals left on the farm. But cows have a higher value than ewes; so the value of the cows and ewes remaining on the farm in 1978 was much greater in Model I than the value of the ewes left in Models II or III. Therefore, the analysis was rerun allowing sales of all cows and ewes in 1978 in order to consider the value of these animals as income.

When all cows and ewes were sold in 1978, total incomes for the three models were as follows: Model I—$89,716, Model II—$112,534, and Model III—$102,414. Thus, incomes for Models II and III were 25 and 14 percent greater, respectively, than income for Model I. Model II sold all cows in 1973 but retained 48 cows in 1976 and 74 cows in 1978. Model III retained no more than 6 cows per year after 1973.

Discussion of Results

The results of the three models are used to address the question of whether a livestock farmer might increase his total income or maintain a more stable annual income by adjusting cow and ewe numbers in response to the cattle cycle. As the information in Tables 2 and 3 indicates, a farm operator can increase his total income and maintain a specified level of annual income over the cattle cycle by producing a combination of beef and sheep during the accumulation phase when beef prices are relatively high, and by emphasizing sheep production during the liquidation phase when beef prices are relatively low.

Coefficients of variation (CV) were calculated to measure the variability in annual income for the three models. The CVs for the three models are the following: Model I—36.3, Model II—74.9, and Model III—10.1. As expected, the variability of income was lowest in Model III and highest in Model II.

The minimum annual income level of $7,675, specified for Model III, may be too low to provide an adequate living for many beef/sheep producers.[3] For farmers who wish to maximize profits and maintain the specified level of annual income, however, Model III is an improvement over Model I for two reasons. First, annual income in Model I fell below $7,675 in nine of the twelve years. Second, total income over the cattle cycle was 22 percent higher for Model III than the total income for Model I.

When all cows and ewes were sold in 1978, the income differences between models were not as large as the differences when the value of remaining breeding animals was not included as income in 1978. But the overall conclusion was the same regardless of whether breeding animals remaining in the final years were sold: total income may be increased and annual income stabilized over a cattle cycle by varying animal numbers.

Some aspects of beef and sheep production are beyond the scope of this research. This study does not consider fixed costs. Consequently, the models did not measure whether losses or profits were realized over the 12 year time period. While facilities for lambing currently exist on the farm, these facilities would need to be expanded to handle large increases in the number of ewes during the current lambing season. Additional fixed costs would thus be incurred. Current lambing facilities would be adequate to handle the increased sheep production suggested by this study if the lambing season was expanded beyond the March-April lambing season. Different lambing periods, however, would result in different levels of costs and returns. Of course, hired labor would have to be available, as assumed in this study, to increase sheep production. Thus, fixed costs and labor considerations might discourage farmers from increasing sheep production to the levels suggested by this study. In addition, this farm level analysis does not measure the aggregate impacts on livestock prices which would occur if a large number of farmers were to emphasize sheep production during the liquidation phase.

The DLP models are a simplification of reality. A cow-calf farmer may lack the desire or lambing facilities and fencing necessary to produce sheep (Hedrick and Colyer). Since historical prices and technical data were used, future prices and input/output coefficients were known. Because of real-world uncertainties which were not considered by the models, farm operators may not be able to attain as high an income or be as effective in maintaining an annual income level as the DLP models suggest. But Beale et al. have identified seven indicators which producers may use to "track the progress of future cycles." Use of these indicators is expected to help producers make decisions about timing of the management strategies suggested by Beale et al., as well as timing of the selling of cows and the purchasing of ewes during the last few years of the accumulation phase, as suggested by this study.

The input/output data are based on a specific size of operation in the southern part of the northeastern region. Larger operations might favor beef since sheep require more health care and more attention when lambing than the amount of care and attention required by cattle. But use of technical data based on farm records and recommended practices, and use of state average prices, extend applicability to other beef and sheep farms which have a management level and resource base similar to the management and resources found on the example farm.

[3] The $7,675 is based on costs and returns figures discounted to 1967 using a discount rate of 8 percent. Converting $7,675 from 1967 to 1983 dollars using the consumers' price index, results in an annual return to fixed resources of $22,902. This amount would be available to the farm operator to cover fixed costs, family living expenses, and operating capital requirements for the next year.

Conclusions

The results of this research indicate that the level of total income was higher when animal numbers were allowed to vary than when cow and ewe numbers were held constant. Consequently, to maximize income during a cattle cycle, a beef farm operator should, in a given year, produce a combination of beef and sheep, or all sheep, in response to changing price ratios. A farm operator may also maintain a specified level of income over the cattle cycle by allowing animal numbers to vary. However, the highest total income over the cattle cycle will occur when both animal numbers and annual income are allowed to vary. If a farmer is able to discern the progress of the cattle cycle, he may be able to increase his income level and to maintain a specified level of annual income by producing relatively more beef during the accumulation phase of the cattle cycle and by producing relatively more sheep during the liquidation phase.

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Appendix 1. Prices Used for Calves and Lambs and Price Ratio of Calves to Lambs, West Virginia, 1967–1978

Year	Calves	Lambs	Price Ratio of Calves to Lambs
	Dollars per cwt.	Dollars per cwt.	
1967	29.20	22.70	1.29
1968	29.70	24.30	1.22
1969	32.80	26.60	1.23
1970	35.40	25.10	1.41
1971	36.80	25.30	1.45
1972	46.30	28.60	1.62
1973	57.50	34.00	1.69
1974	35.70	35.50	1.01
1975	27.40	41.20	.67
1976	31.70	42.20	.75
1977	34.50	46.80	.74
1978	57.90	57.20	1.01

Sources:
U.S. Department of Agriculture cooperating with The West Virginia Department of Agriculture. *Crop Reporting Bulletin 8*, 1969.
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Appendix 2. Prices Used for Cull Beef Cows and Cull Ewes and Price Ratio of Cows to Ewes, West Virginia, 1967–1978

Year	Cows	Ewes	Price Ratio of Cows to Ewes
	Dollars per cwt.	Dollars per cwt.	
1967	19.00	6.10	3.11
1968	19.40	5.80	3.34
1969	21.60	6.90	3.13
1970	23.20	6.80	3.41
1971	24.70	6.00	4.12
1972	30.00	7.20	4.17
1973	40.20	12.70	3.17
1974	29.00	9.90	2.93
1975	22.40	11.20	2.00
1976	26.20	11.70	2.24
1977	27.10	11.80	2.30
1978	41.10	20.00	2.06

Sources:
U.S. Department of Agriculture cooperating with The West Virginia Department of Agriculture. *Crop Reporting Bulletin 8*, 1969.
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