



Supply response function for beef in Botswana : an economic analysis and policy implication
by Loftus Othogile Ndzinge

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Applied Economics

Montana State University

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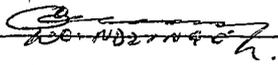
Abstract:

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Cattle inventory was found to be significantly influenced by cattle prices. Cattle slaughter was found to be significantly affected by both price and rainfall index. Road development and trend showed no explanatory power in the model. Interpretation of the results is offered in the body.

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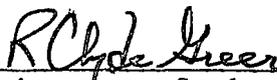
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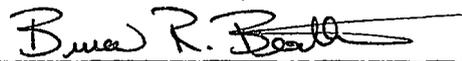
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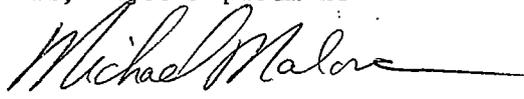
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ABSTRACT

The purpose of this study was to identify the factors that determine beef cattle inventory and beef cattle slaughter behavioral relationships in Botswana, and to derive the impact of changes in these factors on the cattle industry. A dynamic production model consisting of two structural equations, cattle inventory and cattle slaughter, and an identity equation of total meat production was formulated, based on the theory of the firm. The independent variables included deflated cattle prices, rainfall index, road development and trend. The model was estimated using a nonlinear least squares algorithm.

Cattle inventory was found to be significantly influenced by cattle prices. Cattle slaughter was found to be significantly affected by both price and rainfall index. Road development and trend showed no explanatory power in the model. Interpretation of the results is offered in the body.

Chapter 1

INTRODUCTION

Botswana is among the leading African countries in beef cattle production and beef exports. The technology of beef production in Botswana is characterized by land extensive beef ranching, which depends entirely on the vast native rangeland resources. The country is basically divided into three categories of land tenure. First, is state lands held by the national government comprising 23 percent of the country. Second, freehold land which is held by private owners and accounts for 6 percent of the country. The third category, accounting for 71 percent of the country, is not owned by individuals but is held in trust by District Land Boards for the people of the tribe. Individuals may apply for and be granted the use of areas for drilling boreholes for watering cattle.

Traditionally, cattle were kept for a variety of reasons such as milk, meat, hides and draught power. However, with the development of a modern cash economy, provision of consumer goods, and European influence, cattle have become a commercial asset as well as a subsistence resource.

The beef cattle industry accounts for a majority of the agricultural output and is a major source of domestic income and wealth. It produces four-fifths of agriculture's contribution to Gross Domestic Product. In spite of the discovery and rapid development

of major mineral resources, beef cattle production still contributes more than a third of the national exports.

Between 70 and 80 percent of Botswana's population is in agriculture, and cattle are their largest source of agricultural income. Although the Rural Income Distribution Survey [11] in 1974/75 found cattle ownership to be highly skewed (half the cattle surveyed were owned by 5 percent of the households and 45 percent of the rural households had no cattle), about 80 percent of the population are still directly or indirectly dependent on cattle through either sales revenue, draught power, milk or other subsistence needs.

Due to the relative importance of the cattle industry, the Botswana Government attaches considerable importance to it, both as an export revenue earner and a vital sector for development.

During the last two decades, the nature of Botswana's beef cattle industry has been undergoing rapid changes. Technological changes have been introduced, e.g. new breeds, intensified disease control and improvements in the transportation system. Government assistance has been part of the livestock development policy in order to facilitate structural changes in this subsector. Government assistance to producers through input subsidy programs and the extensive development of a network of livestock advisory centers, has affected both the risks faced by producers and their costs of production. The same period also witnessed market development

including building auction saleyards, the improvement of railway handling and loading facilities and the expansion of slaughter facilities. A large proportion of government development expenditures during this period has been providing and improving the country's infrastructure to facilitate rapid economic development and industrialization. This development has had an effect on the aggregate demand for agricultural products and on producers' incentives.

The overall production response of beef to these factors has not been estimated. This study will focus on the beef producers' responsiveness to changes in prices, range conditions, and government expenditure on infrastructure with subsequent policy implications.

Problem Statement

The export nature of the beef cattle industry in Botswana makes it vulnerable to exogenous shocks in international beef markets. Beef price change in the international market has significant economic impacts on Botswana producers and the economy as a whole through income multiplier effects.

Since Botswana's beef cattle sector is significantly influenced by factors outside the domestic economy plus the resource allocation problem facing the government, it is necessary to formulate models which will serve as planning tools in evaluating the future of Botswana's beef cattle industry. These models will also provide

valuable information needed to fully understand the dynamic nature of the beef cattle industry. In addition, they will provide policy makers and planners with a framework for predicting the effects on production, resource adjustment and exports due to changes in important variables such as prices, government programs, technology and forage production. Thus facilitating government policy decisions with regard to livestock development.

Objectives

The purpose of this study is to develop a model for the Botswana beef industry that measures the responsiveness of beef cattle supply to changes in prices, range conditions and level of government investment in infrastructure. Specifically the objectives are:

1. To formulate a dynamic supply model of the Botswana beef cattle sector that estimates beef supply responsiveness to various exogeneous factors and economic incentives;
2. To estimate supply elasticities for relevant variables with respect to the supply of beef cattle in Botswana;
3. To carry out an impact multiplier analysis for the beef cattle sector; and
4. To discuss results and policy implications of the study.

A survey of previous literature relevant to the present study is briefly reviewed in Chapter 2.

In Chapter 3 the dynamic supply model on which this study is based is developed. The model incorporates annual time-series data on cattle prices, rainfall index (used as a proxy for range condition), and government development expenditure on infrastructure. Annual time series data are used to estimate the equations of the model. The first section of this chapter discusses the specification of the model. The second section discusses the data employed and the estimation of the structural parameters using appropriate statistical procedures. In the third section, supply elasticities at the means of the respective variables are calculated using estimated coefficients of the model. The final section of this chapter considers the time response pattern of beef cattle supply to a one time change in the values of some of the exogeneous variables (impact multiplier analysis).

The fourth chapter presents a summary of the results and discusses policy implications from the study.

Chapter 2

REVIEW OF THE LITERATURE

This chapter reviews previous work specific to agricultural supply response, particularly those directly related to the livestock sector and distributed lag models.

Early studies of supply response started with forecasting crop yields and prices, and studies of the correlation between the first differences of acreages and first differences of price lagged one year, H. L. Moore [26] and John D. Black [1]. According to Moore [26] they believed that, "There should . . . in normal times be some relation between the percentage change in the price of cotton last year over the preceding year and the percentage change in the acreage of cotton this year over last year." (p. 87).

Professional agricultural economists since the late 1930's to the present day have debated the question of farmer responsiveness to price changes and resource adjustment in production resulting from product/factor price changes. Some have argued that farmers are not responsive to prices because of asset fixity and the long biological nature of agricultural production, John K. Galbraith and John D. Black [12]. Willard W. Cochrane [5] asserted that it is "the peculiar unity of occupational functions (labor, technological and business management), the fixity of labor supply, and the importance of overhead

costs as compared with operating costs on family farms that argue for the plausibility of an inelastic aggregate output curve" (pp. 384-358).

There is an ongoing policy analysis debate in less developed countries concerning the appropriateness of price as a tool in policy options and programs which promote agricultural production and development. Doran, Low and Kemp [6] asserted that beef cattle producers in Swaziland were not responsive to prices. They argued that because of this non-responsiveness to price many livestock developments have been counterproductive. They argued that the programs have exacerbated rather than improved the overgrazing situation by stimulating producers to increase the number of animals owned for nonproductive purposes. The overgrazing resulted in a declining offtake rate for the herd.

These few illustrations show that the dynamic nature of the agricultural sector is not yet fully understood. Factors identified theoretically as responsible for the dynamic character include: fixed assets; a long production period; inelastic supply function for agricultural labor; technological advance; and price and weather uncertainties [LaFrance 21)]. However, since the classical work of Marc Nerlove [27], many statistical studies of dynamic demand and supply response of agricultural commodities have been undertaken. These studies attempted to improve understanding of the behavioral and economic forces underlying distributed lag concepts. Estimates of the parameters of supply response and demand are beneficial in

improving the quality of forecast and outlook information for products as well as providing input into choosing between alternatives in formulating national commodity policies.

Econometric studies of the livestock sector investigating supply response and inventory functions with respect to own price and feed costs are common in the literature. Kulshreshtha and Wilson [18] estimated simultaneously the relationship among demand, price, supply and export variables in the Canadian beef sector. They found that grain prices had a negative yet minimal effect on inventory levels, whilst the expected price of beef had a supply elasticity of 0.2149. Peter Tryfos [31] in 1974 investigated Canadian supply functions for livestock and meat by developing livestock supply and inventories in which he assumed "desired" livestock inventories as dependent on the expected live animal prices and expected feed costs. Current price and feed costs were used as proxies for expected price and feed costs. He then used first order difference equations in which inventory at the end of a given period was a function of average prices and feed costs during that period and inventory at the end of the preceding period. The results were consistent with previous studies in that short run livestock supply is related to prices and feed costs of previous periods, rather than to current prices and costs. Langemeier and Thomson [22] in their study of demand, supply and price relationships for the beef sector in the post World-War II period, concluded that

there was an inverse relationship between the supply of nonfed beef and the price of nonfed beef and range conditions in the previous year. Schlomo Reutlinger in 1966 [28] estimated a short-run supply elasticity of beef which indicated that a demand existed for cows and heifers as investment goods as well as consumption goods. He then developed separate models for the individual components of beef supply response which resulted in a positive elasticity of response to price changes for steer slaughter and negative elasticity for cow slaughter. A combined equation yielded a very small negative aggregate elasticity of response.

Freebairn [10] estimated supply and inventory response functions for cattle and sheep sectors of New South Wales and concluded that the closing stock of breeding beef cows was positively related to the expected profitability of beef production relative to competing enterprises and favorable seasonal conditions. In other words, the number of beef cows increased with the price of beef but declined with prices of substitutes. This study supports the hypothesis that variability of prices has some explanatory power in describing aggregate supply and inventory response of beef cattle. It also showed that seasonal conditions have an important influence on the supply of beef and on the rate of growth of the beef cattle inventory.

The basic methodology employed in these studies for estimating supply response functions utilized the adaptive expectation type of

distributed lag model. The pioneering works of Irving Fisher and Tinbergen [Griliches; p. 109 (14)] marks the beginning history of distributed lag models. "But the recent popularity of distributed lag as a workable econometric technique is mostly due to the work of Koyck, Cagan and Nerlove." [Griliches p. 109]. In general, the following quote illustrates the theory of the distributed lag model.

Day to day observations in a competitive market reveal that a change in the price of a commodity affects its quantity demanded. . . . If we observe this demand-price relationship over time we shall often note that the response of demand to a change in price of a commodity which persists over a sufficiently long period is gradually adaptive rather than instantaneous. For example, consider the response of a large number of consumers to a sudden fall in the price of one commodity, say tea. Obviously, all the consumers will not react to it at once and at the same point of time. Some will react immediately or after a short time and some slowly for obvious reasons. They may delay their response for lack of precise knowledge of the market and may take some time to learn and then to find alternative choices before they are able to act. The remaining ones may not respond at all for known and unknown reasons. Consequently, the total reaction of all consumers will be spread over some length of time. Sometimes effect will be confined to a short interval but in many cases the adjustment process will be distributed over a long period of time. While studying the behaviour of producers and suppliers with respect to changes in price we come across a similar situation. This type of behavior of consumers or producers gives rise to a 'distributed' lag.

(Gupta, [15], p. 17).

Reasons for the existence of distributed lags are generally broken into three broad categories:

- (1) Technological - where production requires time, and durable goods last more than one production period.

Thus, agricultural supply depends on lagged variables since these variables influence decisions to produce certain commodities rather than others and time must elapse between planting and harvesting. The durability of capital goods implies that output depends in part on past investment decisions.

- (2) Institutional - where it takes time to respond to external events such as government regulations and customs, to adjust contracts and certain rules.
- (3) Psychological - where factors such as habit, persistence, inertia and imperfect knowledge of the market exist.

Fisher [9] assumed a general form of the distribution of lag which could be approximated by means of a "logarithmically normal" probability curve. This distribution implies that the effect of a given variable is very small at first, rises fast to its mode and then decreases gradually.

Koyck [Maddala, p. 363] developed a distributed lag model with a geometric lag distribution structure by suggesting that restrictions be imposed on the reaction coefficients of the linear model

$$(1) \quad Y_t = \alpha_0 X_t + \alpha_1 X_{t-1} + \dots + \mu_t$$

such that

$$\alpha_{k+1} = \alpha \beta^i, i = 0, 1, \dots$$

where $0 \leq \beta < 1$ and the index k represents the point from which the parametric approximation starts. He showed that if this restriction is substituted into equation (1), it can easily be reduced to

$$(2) Y_t = \alpha X_t + \beta Y_{t-1} + \mu_t - \beta \mu_{t-1}$$

which is much simpler to estimate than (1) except for the problem of correlation between Y_{t-1} and the composite error term which makes ordinary least squares estimates biased and inconsistent.

Cagan [3] developed the adaptive expectation model in which price expectations (P^*) are revised each period in proportion to the error associated with the previous level of expectations.

$$(3) P_t^* - P_{t-1}^* = \beta(P_{t-1} - P_{t-1}^*), \quad 0 < \beta \leq 1$$

which leads to an exponentially decaying lag structure for expected price as a function of all past prices

$$(4) P_t^* = \beta \sum_{i=0}^{\infty} (1-\beta)^i P_{t-i}$$

$$\text{or } P_t^* - P_{t-1}^* = \beta (P_{t-2} - P_{t-1}^*)$$

Thus, revised expectations of price in period t are in proportion to the difference between price in period $t-2$ and previously held price expectation, P_{t-1}^*

$$(5) P_t^* = \beta P_{t-2} + (1 - \beta)P_{t-1}^*$$

When (5) is substituted into a more general linear model of the form

$$(6) Y_t = \alpha + \beta P_t^* + U_t$$

the Koyck transformation can be applied giving

$$(7) Y_t = \alpha_0 + \alpha_1 [\beta P_{t-2} + (1-\beta) P_{t-1}^*] + \alpha Y_{t-1} + \mu_t - (1-\alpha)\mu_{t-1}$$

If this model is operationally feasible, then in trying out different β 's on the interval (0,1) and choosing that β which gives the highest R^2 yields maximum likelihood estimates of the parameters.

Nerlove's partial adjustment model also leads to a declining distributed lag structure. He assumes current values of the independent variables determine the desired values of the dependent variable.

$$(8) Y_t^* = a + b X + \mu_t.$$

But because of fixities and adjustment costs, only some fraction of the desired adjustment is accomplished within any particular time period.

$$(9) Y_t - Y_{t-1} = \gamma(Y_t^* - Y_{t-1}), \quad 0 < \gamma \leq 1,$$

which reduces to exactly the same reduced form as the adaptive expectations model, except that it does not induce additional correlation in the stochastic error term if there was none from the beginning. Nerlove's model combined the Cagan adaptive expectations model with Koyck's reduction procedures to provide both an acceptable rationale and a feasible estimation procedure applicable to a wide range of problems (Griliches, [7] p. 110). The desired value of the dependent variable is determined by the unobserved expected value of the independent variable. Mathematically, it is expressed as follows:

$$(10) Y_t^* = a + b P_t^* + \mu_t$$

which reduces to

$$(11) Y_t = \alpha\beta a + \alpha\beta b + (2 - \alpha - \beta) Y_{t-1} - (1-\alpha)(1-\beta)Y_{t-2} + v_t$$

where the error term $v_t = \alpha v_t - \alpha(1-\beta)\mu_{t-1}$.

Because α and β enter (11) symmetrically, it is not possible to distinguish between the two cases if either $\alpha = 1$ or $\beta = 1$, creating an identification problem with respect to these parameters (Nerlove [27], p. 64).

From the early development of statistical economic models, the problem of obtaining consistent and efficient estimates of the coefficients has been addressed by many researchers. Given a general distributed lag of the form

$$(12) Q_t = \beta_1 + \beta_2 X_t + \beta_3 X_{t2} + \dots + \beta_k X_{t-k-1} + e_t,$$

estimation of the coefficients would present a degree of freedom problem because there would be an infinite number of regressors and finite sample size. Secondly, there would likely be multicollinearity between the X's. Early attempts at estimation began by imposing restrictions (Koyck) on the formulation such that $Q_t = \alpha \sum_{i=0}^{\infty} \lambda^i X_{t-1} + e_t$ which follows a geometric distribution function. Estimates of the λ 's were still biased and inconsistent because of contemporaneous correlation between Q_{t-1} and the composite error term e_{t-1} . Lawrence R. Klein [17] recognizing that Koyck's proposals could produce either generalized least squares or maximum likelihood estimates proposed an iterative technique for obtaining coefficients when the correlation coefficient of the original error is not known. Malinvaud [24]

subsequently showed that the method did not yield consistent estimates.

Attempts to find unbiased, consistent and efficient estimates of parameters were extensively covered in most early and current works on distributed lag models. To mention a few, Robert Solow's [30] work on the use of the Pascal distribution and Zvi Griliche's work on the problem of serial correlation in the error terms. Also, Wayne Fuller and James Martin [11] were interested in maximum likelihood estimates of coefficients in first order difference equations with a first order autoregressive error structure.

Having recognized the fact that many of the early attempts failed to provide a satisfactory solution to the estimation problem of correlated error terms, Nissan Livitan [Gupta, p. 43] proposed a simple instrumental variables approach which yielded consistent estimates of the parameters. His technique was independent of the autocorrelation properties of the disturbances. Although Livitan's estimates were consistent, they were not efficient.

Hannan [19] later derived the asymptotic distribution of Livitan's estimates under general conditions. He drew upon the theory of spectral techniques to develop efficient estimators with serially correlated error terms.

Drymes [8] while searching for a method of estimating distributed lag models with autocorrelated errors came up with a procedure that obtained maximum likelihood estimates that "globally maximize the

likelihood function for every sample size". His procedure involved a two stage iterative process which yielded consistent and efficient estimates. Jorgenson proposed the use of rational distributed lag functions to solve problems attempted by Koyck and Solow.

In 1978, Oscar Burt [2] reviewed the problems of estimating agricultural supply response and proposed the use of nonstochastic difference equations. He pointed out the justification for using difference equations in agriculture. He then developed a non-linear least squares estimation procedure which could jointly handle lagged expectations on the dependent variable and autocorrelation in the disturbance.

Chapter 3

MODEL DEVELOPMENT

In this chapter, a model specification employed for this study is developed. The chapter is divided into four sections, namely model specification, an outline of the data and estimation of the structural parameters, the derivation of supply elasticities and evaluation of impacts of change in exogeneous factors (multiplier analysis).

The production and marketing decisions of beef cattle producers in Botswana are heavily influenced by fluctuating prices and range conditions. These fluctuations, particularly the latter, sometimes lead to significant changes in the amount of beef produced. Likewise there is an impact on prices received for beef cattle and in the number of breeding animals retained for future production. Indirectly these factors influence returns to the beef cattle sector, the utilization of slaughtering facilities, the amount of beef and beef by-products for export and the general economic development of the country.

This study is concerned with the determination of cattle inventory response, supply (slaughter) response and quantity of meat produced. The beginning year cattle inventory and range grazing conditions provide a measure of output capacity for the supply function. According to economic theory, the normal response of a producer to an increased/decreased price is to increase/decrease

output. However, certain physical as well as biological peculiarities of beef cattle production dictate that an increase in output can only be accomplished by first reducing current beef supplies. This is accomplished via reduction in cull cow slaughter and increasing heifer retention for herd breeding purposes.

As a result of biological production constraints and lags in economic adjustments world beef production and trade system is marked by distinct cycles. The beef cattle cycle is divided into three stages. First, the rapid growth stage which is characterized by favorable beef prices and rapid increases in cattle numbers. Usually there are low ratios of slaughter to inventory and higher than average financial returns to beef cattle producers. Second, as more animals start reaching the market from herd build up, the deceleration stage of the cycle begins. The characteristics of this stage include lower cattle prices and a decline in herd sizes and inventories. Usually there is an increasing ratio of slaughter to inventory and below average returns to beef cattle producers. Third, there is the turn around stage with prices recovering from low levels. Herd sizes stabilize, the slaughter to inventory ratio is around normal and returns to beef cattle producers are about average. The beef cattle cycle illustrates that physical and biological constraints are partly responsible for the lag between the changes in price expectations and producer response.

Many investment models have been developed and used in manufacturing. Jarvis [15] and Freebairn [10] applied similar models in studying livestock inventory and supply responses to changing economic and range conditions. The methods and assumptions employed by Freebairn appear to be theoretically acceptable for modelling livestock investment decisions in this study.

Certain underlying facts are important in quantifying cattle producer decision behavior. Beef cattle usually serve a dual purpose as both capital goods and consumption goods [Jarvis]. On this basis, it is apparent that price changes will have two opposite effects on the producer's decision. That is, an increase in price would lead the producer to increase the size of his herd so that he can take advantage of future returns - thus beef cattle are viewed as a capital good. Alternatively, the price increase would make the producer want to sell immediately to take advantage of the current high price - in this case beef cattle are finished consumption goods. As a result at any point in time the animals may either be slaughtered for current beef production, or be retained for breeding or future beef production or other derived benefits. The assumptions of this study concur with Jarvis that "beef cattle serve a broader function of benefits such as money substitutes and those received directly from ownership, such as security and prestige. . . that cattle serve as a store of wealth because they are perceived to be productive assets. Their exchange

value, determined chiefly by their use as a source of milk, beef and hides and as draught animals is established in orderly markets - - wealth can be invested in cattle with the likelihood of increasing, not just for preservations. - - - owners derive security from exchange value of their animals, and may obtain status and prestige among other persons because of this economic wealth. - - - owners will find it profitable to prolong the life of an individual animal only as long as its daily production (including future beef) exceeds its current value as beef and hide and other benefits."

Beef cattle producers' decisions are cast into the framework of a discrete, multi-period mathematical optimization problem. The producer's problem involves choice of values for a time sequence of decision variables which maximize an objective function subject to a set of constraints. The producers' principal decision variables are annual number of beef animals (Q_{sl}) to sell for slaughter and the closing inventory of the beef herd (Q_{cp}) to retain for future production (in order to maximize the expected utility of a stream of annual net returns). Net returns are specified as gross returns less variable costs. This argument of an objective function allows for the inclusion of terms measuring expected values and expected variance of the uncertain elements in a livestock production model, namely market prices. The aggregate objective function of a beef cattle producer is the maximization of

$$(14) J = \{E (\pi_1, \pi_2, \dots, \pi_t), \text{Var.} (\pi_1, \pi_2, \dots, \pi_t)\}$$

with

$$(15) \pi_t = \Sigma (P_t \cdot Q_{sl_t} + K_{bt} \cdot P_{bt}) - RC(Q_{cp_t}) - AC(\Delta Q_{cp_t})$$

where

π_t = net ranch income in period t

P_t = ranch price recieved for beef cattle in period t

Q_{sl_t} = quantity of beef cattle supplied in period t

Q_{cp_t} = beef cattle inventory in period t

RC = variable cost function

AC = adjustment cost function

E = expectation operator

Var = variance operator

Δ = change in operator

K_{bt} = other benefits from the nth class of animal in period t
such as milk and draught power

P_{bt} = average value of all other benefits from the nth class of
animal in period t

The rancher acts to maximize his net worth, defined as the present value of all future net cash flows. Thus, present value of the future income stream (PV) is given by

$$(16) PV = \sum_{t=1}^{\infty} \frac{\pi_t}{(1+\gamma)^t}$$

where γ is the discount factor.

The planning horizon faced by the beef cattle producer is then modelled by selecting some appropriate number of years, say T, over which the yearly net revenue is explicitly accounted for. At the end of year T, the future income from all the classes of animals in the inventory in year T is valued. Then the objective is to maximize explicitly the present value of the income stream of all years in the planning period.

$$(17) \text{ PV} = \sum_{t=1}^T \frac{\pi_t}{(1 + \gamma)^t} + \sum_{k=1}^P \sum_{n=1}^q V_n \cdot Z_{kn}$$

where

Z_{kn} = number of animals in class n left in inventory in year T from the kth management system.

V_n = inventory value of an animal in the nth class ($n = 1, \dots, q$) where classes are based upon sex and age.

The inventory value becomes the discounted expected future return to the producer. For those animals whose sale value is as slaughter beef, the return will be the discounted profit on the animal when sold at slaughter which is a measure of income of the process in that period. The inventory value for other animals is similarly derived except future offspring are taken into account. The inventory value gives the valuation of stock at a particular time and could be considered a measure of wealth or store of wealth at that time.

The attainment of this objective function is constrained by resource limitations and technical production factors which when

combined with the beginning inventory delineate the production possibility surface. The availability of range grazing is assumed to be the most limiting resource in range beef production. Technical constraints include calving and death rates, output production relations, and inventory accounting relations.

$$(18) \quad g(Q_{cp_t}) \leq FR_t$$

$$(19) \quad Q_{cp_t} = (1 + C_{cp} - D_{cp}) Q_{cp_{t-1}} - Q_{sl_t}$$

$$(20) \quad Q_{sl_t} = f(Q_{cp_t}, FR_t)$$

where

FR = range resources (grazing availability)

C_{cp} = calving rate

D_{cp} = death rate

Q_{sl} = number beef cattle sold in period t

Q_{cp} = inventory in period t .

The general aggregate values for t -th period decision variables, ending inventory of beef cattle (Q_{cp_t}) and annual quantity of beef supply (Q_{sl_t}) can be expressed in terms of the opening inventory ($Q_{cp_{t-1}}$) expected current and future beef cattle prices ($E(P_t, P_{t+1}, \dots, P_{t+n})$) the expected variance of the price ($\text{Var}(P_t, P_{t+1}, \dots, P_{t+n})$) and the level of grazing resources (FR_t) and other exogeneous shifters like government programs.

Model Specification

In this study, the Botswana beef cattle industry is divided into three subsectors; the cow herd inventory, the slaughter supply and the meat production. The hypothesized inventory response model is one in which expectations of beef cattle prices, range conditions, other exogeneous shifters (such as past government development expenditures on infrastructure) and past inventory levels are explanatory variables. The cow herd inventory equation in period t is represented by

$$(21) \quad Q_{cp_t} = \alpha + \beta_1 \text{Price}_{t-j} + \beta_2 R_{\text{index}_{t-1}} + \beta_3 Q_{cp_{t-j}} + \beta_4 G_{DF_{t-j}} + \beta_5 T + e_t$$

$$j = 1, 2, \dots, k$$

where

- Q_{cp_t} = desired herd size in period t
- Price_{t-j} = expected beef cattle price in period $t-j$
- $R_{\text{index}_{t-1}}$ = rainfall index (proxy for forage production)
- $Q_{cp_{t-j}}$ = past inventory levels in period $t-j$
- $G_{DF_{t-j}}$ = past levels of government development expenditure on infrastructure in period $t-j$
- T = a measure of technological change (trend variable)
- e = disturbance term

It was hypothesized that changes in beef cattle numbers could be initiated either by deliberate policy on the part of producers, or by

physical factors such as drought (induced by the amount and timeliness of rainfall) and outbreak of diseases. It was assumed that producers base their decisions about herd size on their expectation of future beef cattle prices. As already indicated price changes could have two different effects on producer decisions.

The amount of rainfall in a given year is a major determinant of cattle numbers under native range beef production. This is especially true in Botswana where existing management of cattle production does not have built-in strategies for hedging against a natural disaster such as drought. It was assumed that years with below average rainfall would result in increased marketings and high death losses, both of which affect the breeding herd and the capacity for expansion in the subsequent years. The distribution and duration of rainfall plus temperature and climatic factors, all of which determine forage production, are influential in range beef production.

The effect of past herd size on inventory in time period t depends on the composition and age structure of the herd. Past herd sizes also give some indication of capacity at that time.

Past government programs can affect inventory levels in period t in two ways, depending on their impact on the long run costs of production. The location of the export abattoir in Lobatse, Southern Botswana, which is of considerable distance from most of the beef cattle producing areas, makes transportation availability and cost a

major determinant of beef supply. McGowan and Associates [13] in a study of drought relief and contingency measures relating to the livestock sector of Botswana reported that livestock producers in Northern Botswana pay 8 to 10 percent of their gross sale proceeds to transport animals to the abattoir. Producers in the most extreme areas pay about 25 percent of their gross proceeds to move cattle to market. It was therefore hypothesized that the improvement of existing and the development of new roads would have a significant effect on the profitability of beef production.

A trend variable was included in the model to capture technological changes that have taken place. The changes have enabled ranchers to gradually increase output from given herds and forage supplies. The net effect of technological change was regarded as a linear function of time.

The second equation explains the slaughter herd (Q_{sl_t}) in period t as dependent on current inventory level, the price of beef cattle, past quantities slaughtered and range condition.

$$(22) Q_{sl_t} = \alpha + \beta_1 \hat{Q}_{cp_t} + \beta_2 Price_t + \beta_3 Q_{sl_{t-j}} + \beta_4 R_{index_t} + e_{2t}$$

where

\hat{Q}_{cp} = current level herd size

$Price_t$ = price of beef cattle in period t

$Q_{sl_{t-j}}$ = past quantity slaughtered in period $t-j$

e_t = disturbance term

The third equation is an identity which explains the quantity of meat produced in period t (Q_m) as a function of the number beef cattle slaughtered and also the slaughter weights (average dressed weight).

$$(23) \quad Q_m = \hat{Q}_{sl} \cdot A D W_{sl}$$

where

\hat{Q}_{sl} = quantity slaughtered in period t

$A D W_{sl}$ = average dressed weight

The development of a theory of producer behavior in response to price changes and other exogenous influences should begin at the individual farm level. For example, consider an adaptive expectations model for the purpose of allowing uncertainty and discounting of current information to enter the decision environment, and to show the distinction between the expected and actual output. "Man adapts current behavior not only to past experiences but also to future expectation." [Dutta, p. 191]. Assume a model

$$(24) \quad Q_{cp} = \alpha X_t^* + \mu_t$$

Let Q_{cp} be the current quantity of beef produced for rancher i in year t , X_t^* is the expected price and μ_t is a random variable reflecting exigencies of uncertainties. We assume

$$E(\mu_t) = 0; E(\mu_t, \mu_{t'}) = 0 \quad (t \neq t'), E(\mu_t^2) = \sigma^2 \quad \text{for all } t$$

A rancher in his production planning estimates output for the next period, $t + 1$, in the current period. Let X_t^* be the level of expected price in current period to be received in the next period and X_t be

the actual price in the current period. Here it is assumed that the expected average impact of the random variable μ_t is zero. If the rancher adapts his current expectations for the next period on the basis of how closely the expectations for the current period are matched by actual prices, then the adaptive expectation relationship is given by

$$(25) (X_t^* - X_{t-1}^*) = \rho (X_t - X_{t-1}^*) \quad 0 \leq \rho < 1$$

The difference between the actual price X_t and the price expected in the preceding period for the current period, that is the expected price in the previous period X_{t-1}^* , indicates the degree of fulfillment of expectation. Based on this experience, the rancher revises his present expectation of price X_t^* . The adjustment between his past expectation X_{t-1}^* and present expectation X_t^* is assumed to be proportional to the experience with the difference between expectation and actuality in the current period t .

$$(26) X_t^* = \rho X_t + X_{t-1}^* - \rho X_{t-1}^* \\ \rho X_t + (1 - \rho) X_{t-1}^*$$

and if this process is repeated for $t-n$ we get

$$X_t^* = \rho \sum_{i=0}^{\infty} (1-\rho)^i X_{t-i} \text{ which is similar to equation (4).}$$

This equation can be substituted into a general autoregressive model

$$C_{cp_t} = \delta X_t^* + \mu_t$$

to give

$$Q_{cp_t} = \delta \left[\rho \sum_{i=0}^{\infty} (1-\rho)^i X_{t-i} \right] + \mu_t$$

If we define $\lambda = 1-\rho$ and $\beta = \rho\delta$, then the equation becomes

$$Q_{cp_t} = \beta \sum_{i=0}^{\infty} \lambda^i X_{t-i} + \mu_t$$

which is the same as the Koyck transformation of the distributed lag model. Namely,

$$(27) \quad Q_{cp_t} = \delta X_t + \lambda Q_{cp_{t-1}} + \mu_t - \lambda \mu_{t-1}$$

which is similar to equation (2).

Noting that $Q_{cp_{t-1}} - \mu_{t-1} = E(Q_{cp_{t-1}})$, equation (27) can be rewritten as a homogeneous nonstochastic difference equation

$$(28) \quad Q_{cp_t} = \beta X_t + \lambda E(Q_{cp_{t-1}}) + \mu_t$$

which has the stochastic and systematic components of the model well delineated. The disturbance term is simpler and has the same properties as in the equation $Q_{cp_t} = \delta X^* + \mu_t$.

LaFrance (1979) suggested that the correct behavioral response variable for farmers in a distributed lag model was expected normal (or planned) output rather than actual output. He showed that the proxy used for planned output is approximated in the aggregate for the industry by the nonstochastic lagged dependent variable. Further, he argued that a nonstochastic difference equation implied output in the current period is affected by the "planned or expected levels of output in previous periods rather than by the actual levels."

Another theoretical explanation of the theory of producer behavior is through the partial adjustment hypothesis which assumes

that technological, institutional and psychological impediments prevent producers from making adjustments to a change instantaneously, thus actual output is equal to the desired output multiplied by an adjustment coefficient.

Both the adaptive expectations and partial adjustment hypotheses or their combination are appropriate in explaining cattle inventories since both physical rigidities and uncertainty enter into the decision variables of the cattle producer.

Outline of the Data

Time series studies are often constrained by data availability. This study was no exception. Data used in this study consisted of observations over time on all the variables in the economic model specified on pages 24 and 28. The purpose of this section is to describe the sources of data and present some rationalization of the choice of measurements.

The sample period for the model are years 1966 to 1980. The choice of 1966 as the initial observation was mainly conditioned by the availability of data and the fact that 1966 was the year the Republic of Botswana gained the status of self government from the British Crown. It was therefore of particular interest to this study to investigate structural changes in Botswana's livestock industry after independence.

Data on cattle numbers was available from the Agricultural Statistics Unit of the Ministry of Agriculture. The published data on production of beef cattle include the total number of cattle at the end of year by regions.

The rainfall index was calculated by a weighting scheme in which the average rainfall from representative centers in each region was multiplied by the total number of cattle in that region, then summed over regions, and finally divided by the total national herd. This figure gave the relative effect of rainfall distribution in all beef producing districts.

$$\text{Rainfall index} = \frac{R_1 \cdot C_{11} + R_2 \cdot C_{12} + \dots + R_i \cdot C_{in}}{\text{Total number of cattle/year}}$$

where

R_i = rainfall index to average rainfall

C_{in} = cattle number in a region

The annual rainfall figures were available from the Meteorological Bureau.

The Botswana Meat Commission reports floor prices received by farmers for each class of beef cattle. Again a weighted average animal price was calculated. A weight for each grade was calculated by adding over a period of years and averaging the annual percent of animals killed in each grade category. These weights were then multiplied by each class price and summed by category to obtain the

weighted annual price per 100 kg.

A variable to measure the impact of road development was included in the analysis. The data used for this variable were the actual annual expenditures on road infrastructure development from the Botswana Government Annual Statements of Accounts 1965/66 through 1980/81. It was assumed that the trend variable followed a linear function over the sample period.

Estimation of Structural Parameters

Estimation procedures suggested by Burt [2] using nonstochastic difference equations were applied in this study. The procedure involves the removal of the stochastic component from the lagged dependent variable and uses the resulting nonstochastic variable as a regressor. This delineates the stochastic and nonstochastic components of the equation. "In a stochastic difference equation, the lagged values of the dependent variables contain a random, as well as a systematic element, implying that the delineation is not well defined. In a nonstochastic difference equation, the lagged dependent variables only contain a systematic component" [Rucker (30), p. 89].

Gagan and Nerlove (1956) argued that models in which the distributed lag on the independent variable is infinite could be converted to low order difference equation. Jorgenson [12] in 1966 showed by approximation that any arbitrary infinite distributed lag function

could be approximated to any desired degree of accuracy by a rational distributed lag function. This could be achieved by the introduction of a lag operator (L) which provides a simple notational means of specifying any desired degree of lag on a variable by being defined such that

$$(29) \quad LX_t = X_{t-1}, L^2X_t = X_{t-2}, \dots, L^jX_t = X_{t-j}.$$

For this study, a rational distributed lag model was selected for estimating the herd inventory and slaughter response functions where the sequence (β_k) of coefficients had a rational generating function.

Letting the generating function of the sequence (β_k) be represented by $P(s)$ where

$$P(s) = p_0 + p_1s + p_2s^2 + \dots;$$

and if we assume the function to be rational

$$P(s) = \frac{M(s)}{N(s)}$$

where $M(s)$ and $N(s)$ are polynomials in S

$$M(s) = m_0 + m_1s + \dots + m_t s^t$$

$$N(s) = n_0 + n_1s + \dots + n_u s^u$$

when N_0 is normalized at unity and the polynomials $M(s)$ and $N(s)$ are assumed to have no characteristic root in common, we may represent a rational function as the ratio of the two polynomials. By letting inventory (Q_{cp}) be a function of past prices only, we get

$$\begin{aligned}
 (30) \quad Q_{cp} &= \beta_0 P_t + \beta_1 P_{t-1} + \beta_2 P_{t-2} + \dots + \beta_k P_{t-k} = \\
 &\quad \beta_0 P_t + \beta_1 L P_t + \beta_2 L^2 P_t + \dots \\
 &= [\beta_0 + \beta_1 L + \beta_2 L^2 + \dots + \beta_k L^k] P_t
 \end{aligned}$$

where L is the lag operator.

Assuming the sequence (β_k) has a rational generating function

$$(31) \quad Q_{cp} = \beta(L) P_t = \frac{M(L)}{N(L)} P_t$$

Let $M(L) = \alpha_0 + \alpha_1 L + \alpha_2 L^2$ and $N(L) = 1 - \lambda_1 L - \lambda_2 L^2$, then multiplying both sides of the equation by the denominator of the rational lag function gives rise to a difference equation.

Burt [1978] argued that the use of a polynomial rational lag operation had the advantage of smoothing the coefficients of the lagged values of exogenous variables and partially solves the problem of degrees of freedom and large samples needed in complete specification. In order to achieve a low order difference equation for each the inventory and slaughter equations, a common denominator was forced on the rational lag function associated with each exogenous variable. In terms of the lag operator, the inventory equation at period t becomes

$$(32) \quad Q_{cp} = \frac{\delta_1 + \delta_2 L}{1 - \lambda_1 L - \lambda_2 L^2} P_t + \frac{\delta_3 + \delta_4 L}{1 - \lambda_1 L - \lambda_2 L^2} X_t + \delta_5 R_{t-1} + \delta_6 T + e_t$$

For ease of estimation, we multiply both sides by $1 - \lambda_1 L - \lambda_2 L^2$ to get a second order stochastic difference equation

$$\begin{aligned}
 (33) \quad Q_{cp_t} - \lambda_1 Q_{cp_{t-1}} - \lambda_2 Q_{cp_{t-2}} &= \delta(1 - \lambda_1 - \lambda_2) + \delta_1 P_{t-1} + \delta_2 P_{t-2} \\
 &+ \delta_3 X_{t-1} + \delta_4 X_{t-2} + \delta_5 (1 - \lambda L - \lambda_2 L^2) R_{t-1} \\
 &+ \delta_6 (1 - \lambda_1 L - \lambda_2 L^2) T_t \\
 &+ (1 - \lambda_1 L - \lambda_2 L^2) e_t
 \end{aligned}$$

$$\begin{aligned}
 Q_{cp_t} &= \delta_0 + \delta_1 P_{t-1} + \delta_2 P_{t-2} + \lambda_1 Q_{cp_{t-1}} + \lambda_2 Q_{cp_{t-2}} + \delta_3 X_{t-1} \\
 &+ \delta_4 X_{t-2} + \delta_5 (1 - \lambda_1 L - \lambda_2 L^2) R_{t-1} + \delta_6 (1 - \lambda_1 L - \lambda_2 L^2) T_t \\
 &+ v_t
 \end{aligned}$$

$$\text{where } v_t = \lambda_1 e_{t-1} - \lambda_2 e_{t-2} + e_t$$

Burt (1978) argued for the use of nonstochastic difference equations in estimating distributed lag models. In a stochastic difference equation, both the random error term e_t and the lagged dependent variables $Q_{cp_{t-1}}$ and $Q_{cp_{t-2}}$ enter directly as independent variables.

If we define the unconditional expectation of $Q_{cp} = \theta_t = \frac{\alpha P_t}{1 - \lambda_1 L}$ which gives a first order difference equation

$$(34) \quad \theta_t = \alpha P_t + \lambda \theta_{t-1} \text{ for } E(Q_{co}),$$

and if iterated by successive substitutions, the result gives

$$\begin{aligned}
 \theta_t &= \lambda[\lambda \theta_{t-2} + \alpha P_{t-1}] + \alpha P_t \\
 &= \lambda^2 [\theta_{t-2} + \alpha \lambda P_{t-1} +
 \end{aligned}$$

$$\theta_t = \alpha [P_t + \lambda P_{t-1} + \lambda^2 P_{t-2} + \dots + \lambda^{t-1} P_0] + \lambda^t \theta_0$$

which shows that the unconditional expectation of Q_{cp} is dependent only on the historical series of the exogenous variables [Burt, p. 15].

This is interpreted to mean that a one time change in the explanatory variable such as price, while all other variables remained constant changes inventory level Q_{cp} in period t by

$$\alpha(\Delta P)$$

and in period $(t+1)$ inventory level would change by

$$\alpha(\Delta P) (1 + \lambda)$$

while the total long run response would be

$$\alpha(\Delta P) (1 + \lambda + \lambda^2 + \dots)$$

This suggests that the long run price elasticity from this formulation of the statistical model would be

$$E_{LR} = \frac{\alpha}{1-\lambda} \cdot \frac{\bar{P}}{\bar{Q}_{cp}}$$

If the iterations in the substitutions in equation (34) are truncated when $\lambda^t \theta_0$ appears, the result is

$$\theta_t = \alpha (P_{t-1} + \lambda P_{t-2} + \dots + \lambda^{t-1} P_0) + \lambda^t \theta_0$$

If the parameter α and λ were known together with θ_0 , θ_t could be easily calculated for difference sample points. The same argument could be extended to second order difference equation giving

$$(35) E(Q_{cp}) = \delta_0 + \delta_1 P_{t-1} + \delta_2 P_{t-1}^2 + \lambda_1 E(Q_{cp-1}) + \lambda_2 E(Q_{cp-2}) + \delta_3 X_t + \delta_4 X_{t-1} \\ + \delta_5 (1 - \lambda_1 L - \lambda_2 L^2) R_{t-1} + \delta_6 (1 - \lambda_1 L - \lambda_2 L^2) T + \mu_t$$

This type of formulation is plausible since it captures most of the information on rigidities in the industry due to institutional impediments, inertia and technological change. Additionally, it accounts for the age distribution problem in the national cattle herd.

The structural equation [21] is now in a form suitable for estimation as a non-stochastic difference equation but some properties of the error term need to be specified. The expectation of Q_t is defined as $Q_t - U_t$. Therefore, the non-stochastic difference equation could be estimated with U_t having the classical properties $E(U_t) = 0$ and $E(U_t^2) = \sigma^2$ for $t = 1, 2, \dots, t$, and $E(U_t U_j) = 0$, $t \neq j$. In this case we are assuming that the two components of the error term (random elements and factors left out of the model) have zero value implying the planned output equals the actual output. The procedure utilized to estimate the unknown parameters of the model is a modified Marquardt generalized non-linear least squares algorithm which uses the maximum likelihood technique.

Supply Elasticities

Supply elasticity measures the percentage change in output (dependent variable) associated with a unit percent change in any of

the explanatory variables, all other factors held constant. Estimates of supply elasticities are useful in analyzing public programs dealing with agricultural price and income policy, both for short-term forecasting and for long-range projections of resource use and needs. Supply elasticity estimates can be an indication of the level and productivity of farm resources since they indicate output adjustments in response to changes in product prices and government programs. In this case the importance of supply elasticity for public policy becomes evident because it measures the ability of farmers to adjust production to the changing economic environment that perpetually confronts them in a dynamic world. For the beef cattle industry, beef output and inventory levels need to be projected under alternative levels of prices, government programs, input costs and technology.

Agriculture has great flexibility in substituting one commodity for another over the long run. Therefore, in the long run comparable resources in agriculture should earn similar rates of return in the production of each product. However, supply elasticity, or the rate of adjustment of total farm resources is dependent on the relative size of that particular commodity to total farm production, the alternatives that are easily substitutable in production, the length of the production period of that commodity and the range of resources that could be used to produce the commodity.

There are several methods of deriving supply elasticities. One

method is to derive it by least-squares estimates of the price parameters in the supply function. Another way of looking at supply elasticities is to separate the yield and the basic production unit into components of supply. This is common in livestock response studies where the output per animal could be more responsive to an exogenous variable than is the number of animal units in the short run, and the reverse is true in the long run. That is, producers could see a greater potential for expanding livestock production by increasing the number of animals on the farm than by increasing output per animal unit over a long period. The supply elasticity of livestock output is the summation of the basic production unit and the output component.

Supply elasticity has also been derived from the elasticities of production and elasticities of input demand with respect to prices received by producers. In this case we are measuring the degree of responsiveness between output and input. In other words, output is a function of the productivity of an input and its level of use and the level of use is a function of product prices and input prices [Tweeten, (33)].

In this study elasticities are derived from the direct least squares estimates of the structural equations since all functions were transformed into log form. If we take our estimated inventory

equation

$$Q_{cp} = \hat{\delta}_0 + \hat{\delta}_1 P_{t-1} + \hat{\delta}_2 P_{t-2} + \hat{\lambda}_1 E(Q_{cp,t-1}) + \hat{\lambda}_2 E(Q_{cp,t-2}) + \hat{\delta}_3 X_{t-1} \\ + \hat{\delta}_4 X_{t-2} + \hat{\delta}_5 (1 - \hat{\lambda}_1 L - \hat{\lambda}_2 L^2) R_{t-1} + \hat{\delta}_6 T,$$

we can derive short run elasticities by taking partial derivatives with respect to any of the independent variables.

For example, the short-run elasticity with respect to last year's price would be $\hat{\delta}_1$.

The long-run direct elasticity allows for a complete adjustment to a one time change in the own price variable, all other factors held constant. For simplicity, if we take equation (34) as a first order non-stochastic difference equation with only price as the independent variable, we get

$$Q_{cp} = \hat{\delta}_0 + \hat{\delta}_1 P_{t-1} + \hat{\delta}_2 P_{t-2} + \hat{\lambda}_1 E(Q_{cp,t-1}).$$

To solve for the long-run elasticity the long-run equilibrium output is first derived:

$$Q_{\mu} = \frac{\hat{\delta}_0}{1 - \hat{\lambda}} + \frac{\hat{\delta}_1}{1 - \hat{\lambda}} P_{t-1} + \frac{\hat{\delta}_2}{1 - \hat{\lambda}} P_{t-2}$$

therefore the long-run price elasticity

$$\frac{\hat{\delta}_1 + \hat{\delta}_2}{1 - \hat{\lambda}}$$

where $1 - \hat{\lambda}$ is the coefficient of adjustment.

Dynamic Multiplier Analysis

The complex nature of beef cattle production and its multi-year production process confronts policy makers with a difficult problem of evaluating proposals relating to the beef cattle subsector. Because beef cattle production involves a complex and interdependent production system, government intervention in the system may take several years to realize the full impacts. This makes it difficult to evaluate policy proposals to the industry since economic planning requires some analysis of how current plans, policies, programs will affect future production, prices, consumption and foreign trade. In this section the dynamic nature of Botswana's beef cattle industry is reviewed by examining changes in the explanatory variables over time.

Interest is focused on forecasting industry equilibrium from a one time change in price (or other supply and inventory determining exogenous factors), or changes in government policy. The policy maker would want to make quantitative statements about the dynamic response over time to particular variables. One method of quantification would be to calculate the multipliers associated with the model's exogenous variables. For example, it is of interest to determine the effect on inventory Q_{cp} and quantity slaughtered Q_{sl} of a one Pula increase in the price of beef. Assuming the model parameters are stable, one would expect that the initial increase in price would result in ever declining increases in Q_{cp} or Q_{sl} . These changes in Q_{cp} or Q_{sl} are

referred to as dynamic multipliers over time.

In general, the impact multipliers are obtained directly from the reduced form of the estimated structural equations. In analyzing the dynamic nature of the industry, we are interested in the time path of the number of cattle supplied for slaughter or changes in inventory over time (rates of adjustments). These can be calculated as shown in the table below.

Rates of Adjustment Over Time

<u>Number of Years Since Change</u>	<u>Actual Adjustment Since Initial Change</u>	<u>Percent of Ultimate Adjustment Since Initial Change</u>
1	$(\Delta P)(\beta)$	%
2	$(\Delta P)(\beta)(1+\lambda)$.
3	$(\Delta P)(\beta)(1+\lambda+\lambda^2)$.
4	$(\Delta P)(\beta)(1+\lambda+\lambda^2+\lambda^3)$.
.	.	.
.	.	.
.	.	.
	$(\Delta P)(\beta)(1+\lambda+\lambda^2+\dots) = \frac{(\Delta P)(\beta)}{1-\lambda}$	100%

where percent of adjustment completed = $\frac{\text{actual adjustment completed}}{\text{total ultimate adjustment}}$

Therefore the rate of adjustment in period one is

$$\frac{(\Delta P)(\beta)}{(\Delta P)(\beta)} = (1-\lambda)$$

This dynamic nature of supply may also be looked at as follows

$$E_p(\tau) = \frac{\bar{P}_t}{\bar{Q}_t} \cdot \frac{Q_{cp_{t+\tau}} - Q_{cp_t}}{\Delta P}$$

Where $Q_{cp_{t+\tau}}$ = the adjustment in number of cattle between the initial price change at period t and the number of time periods over which the adjustment has occurred (τ).

ΔP_t = initial price change which is assumed to change by ΔP and remain at the new level indefinitely.

$\frac{\bar{P}_t}{\bar{Q}_t}$ = the ratio of the mean values of price and number of cattle over the time of analysis.

τ = number of period of adjustment under consideration.

Thus, in period one

$$E_p(1) = \frac{\bar{P}_t}{\bar{Q}_t} \cdot \frac{Q_{cp_{t+1}} - Q_{cp_t}}{\Delta P_t}$$

but $Q_{cp_{t-1}} - Q_{cp_t}$ is equal to $(\Delta P)(\hat{\beta})$

therefore $E(p)1 = \frac{\bar{P}_t}{\bar{Q}_{cp_t}} \cdot \frac{(\Delta P)(\hat{\beta})}{\Delta P}$
 $= \frac{\bar{P}_t}{\bar{Q}_{cp_t}} \cdot \hat{\beta}$ which is the short-run elasticity for
 time period one or just $\hat{\beta}$ if the function was
 transformed into its log form.

For period 2

$$E(p)2 = \frac{\bar{P}_t}{\bar{Q}_{cp_t}} \cdot \frac{Q_{cp_{t+2}} - Q_{cp_t}}{\Delta P}$$

$$= \frac{\bar{P}_t}{\bar{Q}_{cp_t}} \cdot \frac{(\Delta P)(\hat{\beta})(1+\lambda)}{\Delta P}$$

$$= \frac{\bar{P}_t}{\bar{Q}_{cp_t}} (\hat{\beta})(1+\lambda)$$

hence the ultimate adjustment to an initial change in price

$$\lim E(p) = \frac{\bar{P}_t}{\bar{Q}_{cp_t}} \frac{(\Delta P)(\hat{\beta})(1+\lambda+\lambda^2+\dots)}{\Delta P}$$

$$= \frac{\bar{P}_t}{\bar{Q}_{cp_t}} \cdot \frac{\hat{\beta}}{(1-\lambda)} \text{ which gives the long-run price}$$

elasticity of supply.

Chapter 4

RESULTS AND IMPLICATIONS

In chapter three, the theoretical development of the model used for this study was presented. The statistical results from the estimated equations and their implications are discussed in this chapter. The model consisted of two structural equations, one for the cattle inventory response and another for the beef cattle slaughter response, plus an identity equation for the annual quantity of beef produced.

Beef Cattle Inventory

Many versions of the Botswana beef cattle inventory equation were tested in an effort to determine the "best empirical model" that would explain the behavioral relationships. During the preliminary tests some of the variables such as road development and trend were omitted since they were not statistically discernible. In specifying the equation, it was hypothesized that the development of road infrastructure would have an impact on the profitability of the livestock industry. As reported earlier a significant proportion of producer gross sales are taken up by transportation costs, hence the development and improvement of roads was hypothesized to reduce transportation costs significantly. In all specifications tested this variable did not enter significantly different from zero. That is, it added

