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An economic analysis of the optimum sizes, number, and locations of Tennessee livestock auction markets

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To the Graduate Council:

I am submitting herewith a thesis written by Emily A. McClain entitled "An economic analysis of the optimum sizes, number, and locations of Tennessee livestock auction markets." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

Dan L. McLemore, Major Professor

We have read this thesis and recommend its acceptance:

Emmit Rawls, Keith Phillips

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

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Signature Emily A. McClain

Date August 8, 1985

AN ECONOMIC ANALYSIS OF THE OPTIMUM SIZES, NUMBER, AND LOCATIONS OF TENNESSEE LIVESTOCK AUCTION MARKETS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Emily A. McClain
August 1985

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ABSTRACT

An efficient spatial organization of livestock auction markets in Tennessee would improve net prices received by livestock producers and/or reduce the cost of livestock to buyers. This study used separable programming to build a spatial model of Tennessee's livestock auction market industry. The purpose of the model was to determine the optimal sizes, number, and locations of auction markets that minimize the combined annual costs of assembling (transporting) and marketing livestock through auctions in the State. Once this optimal solution was found, the model was re-solved under varying assumptions about livestock numbers and cost levels to analyze the effects of changes in these parameters on the optimal solution. Livestock numbers were both increased and decreased by 10 and by 25 percent. Transportation cost and marketing cost were each increased by 10 and by 25 percent.

Since few barriers to interstate movement of livestock exist, the area of study consisted of Tennessee and parts of surrounding states within 50 miles of Tennessee's border. This area encompassed 238 counties, each of which was considered an origin for livestock and a potential market site in the mathematical model. Data for input into the separable programming model came from several sources. Estimates of the expected annual volume of livestock marketed in the supply area were derived from livestock inventory data for each county. Transportation cost was estimated using an economic engineering approach to

develop transportation cost budgets for "typical" loads of livestock. Transportation cost was estimated to be $0.226 per mile per livestock unit in 1983. These "typical" loads of livestock were identified from the results of surveys of 275 individuals hauling livestock to auction markets in Tennessee. The cost of transportating a livestock unit was computed for all potential market destinations within 50 air-miles of each origin. The cost of marketing was estimated by Spielman in a previous study (1978) and was adjusted to reflect costs in 1983.

The basic model (Model I) was expanded to include the reduction in buyer operating costs due to increased market volume. This modified model was designated as Model II. It was hypothesized that buyers realize cost savings by attending auction markets with "large" volumes. These costs savings were thought to exist for two reasons. One reason is that at "large" sales, buyers should be able to acquire full, uniform loads for shipment, eliminating the cost of intermediate assembly between auction markets. The second reason cost savings may exist is that if a buyer must attend more "small" sales to fill orders than would have been necessary if "large" sales had been attended, extra costs accrue in the form of travel time, mileage, food, and lodging.

The negative relationship between buyer costs and market volume was included in the mathematical model by using a positive relationship between market price and market volume as a proxy for the buyer cost savings attributable to market volume. This positive price--volume relationship was estimated using regression analysis on 1982 and 1983 price and volume data from 16 Tennessee auction markets for feeder cattle, cull sows, and cull cows.

The results of Model I show the optimal number of auction markets in Tennessee to be 47, a reduction of seven from the 54 markets actually in operation during 1983. This solution was somewhat stable in response to changes in the model's parameters. With one exception, in all variations of Model I a reduction from the currently existing market number was shown to be desirable. For the model version with transportation cost increased 25 percent above 1983 levels, an increase in market numbers to 56 was found to be optimal for the State.

For Model II, which considers the reduction in buyer costs associated with larger market volume, the optimal number of markets in Tennessee was found to be 19. This solution was very stable under changes in the cost parameters of the model, but was sensitive to changes in livestock numbers. In response to a 25 percent increase in livestock numbers, market numbers increased by four in the optimal solution for Tennessee. When livestock numbers were decreased by the same percentage, market numbers declined by five.

The results of this study show that improvements in the efficiency of Tennessee's livestock auction market industry are possible through a reduction in the number of markets in the State. The policy implications of this study are that licensing of new markets in the State should be done with consideration of the optimal locations identified in this study, and with the long term goal of reducing the number of auction markets in the State.

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CHAPTER 1

PROBLEM AND OBJECTIVES OF THE STUDY

Introduction

Agriculture is fundamentally dependent on natural resources and climate. As a result, production of a given commodity is usually limited to certain geographic areas. Agricultural production is also characterized by relatively fixed production functions with land as a primary input. This combination of features forces agricultural production to be spatially dispersed.

The areas where production of a commodity will occur are determined not only by climate and resources, but also by the principle of comparative advantage. Basically, this principle allows the most output to be produced from a given amount of resources through specialization and trade. The principle dictates that, given different trading areas, each will produce the products that it is best able to produce, in terms of low resource costs. Trade will occur to distribute products to other areas. In this manner, the greatest total output can be realized from any set of resources.

The types of agricultural production in Tennessee are influenced by the principle of comparative advantage. This influence on types of production is partially expressed through the State's farm receipts by product. In terms of monetary value, the primary agricultural products of the State are livestock, dairy products, tobacco, and soybeans (61, p. 79).

Cash receipts for all of Tennessee's farm products totaled 1,895 million dollars in 1984 (61, p. 79). Cattle and calves provided 18.7 percent of those receipts, the largest portion for a single commodity (61, p. 79). Hogs accounted for another 6.6 percent (61, p. 80). Cash receipts for livestock were 47.8 percent of the total for all agricultural marketings, establishing livestock production as one of the most important agricultural activities in the State. All 95 counties report livestock inventory statistics. The trend in these inventories, at least for cattle, has been upward. Since the 1930's, cattle production for the State has increased an average of 19 percent each decade (38, p. 39).

In order for the livestock industry in Tennessee to prosper, it is important that an efficient marketing system exist. An efficient marketing system is one for which marketing costs are minimized, other things equal. This provides livestock to buyers at the lowest possible prices consistent with the national supply and demand situation, and also provides producers with the highest price for their livestock consistent with national market conditions. Also of importance to producers is the transportation cost of moving animals from farm to market, which is a function of distance. Given livestock locations and densities, marketing costs, and transportation costs, there should exist optimal sizes, numbers, and locations of market outlets to minimize the combination of marketing and transportation costs.

For cattle, calves, and culled breeding hogs the primary market outlets in Tennessee are livestock auction markets (23, p. 1-2; 35, p. 6). This form of livestock marketing is relatively young, becoming popular in the 1930's (51, p. 3). Like many young industries, livestock auction markets experienced a period of rapid growth, both in Tennessee and the nation (51, p. 3). In 1970, Tennessee livestock auction market numbers peaked at 74 (4, p. 2). At the end of 1983, only 54 auction markets were in operation in the State (56). Foreshadowing this decline in market numbers was a 1971 study by Hicks and Badenhop. Their study found Tennessee to have "too many markets to develop an efficient, low-cost livestock auction market system" (23, p. 24). The study recommended a drastic reduction in the number of auction markets in the State.

The decline in livestock auction market numbers following a long period of growth is evidence of industry adjustment. If too many firms exist in a competitive industry in order for them to achieve an efficient scale of production, in the long run, profitability pressure will cause exit from the industry until existing firms are able to achieve available economies of scale (25, p. 319).

While not perfectly competitive due largely to spatial separation, the auction market industry does exhibit characteristics of competition with large numbers of auctions and relatively homogenous services. The assumption that the industry is subject to adjustment pressures toward an optimal situation is not unreasonable. However, neither the existence nor speed of this adjustment is certain.

Statement of the Problem

The spatial diversity of livestock production in Tennessee creates a classic problem in agricultural economics. That is, the optimal (least-cost) spatial organization of an industry (5, p. 1). In defining optimal organization for the livestock auction market industry, the costs to be minimized are the cost of transporting the livestock from farms to markets, and the cost of processing those animals through auction markets.

Economic and location theory predict that assembly (transportation) and processing costs for a market will vary with total volume of livestock handled. In an area with given production densities, the volume of an individual market is affected by its location and the number, locations, and volumes of other markets.

Past research has shown economies of scale to exist in the processing of farm commodities, including livestock auction market operations (51; 67, p. 954). This means average processing costs decline as the volume of animals sold through an auction market increases. These economies of scale further define the relationship between the number of markets and average processing costs. Within a given production area and for a given number of livestock, total processing costs are positively related to the number of markets. Conversely, a negative relationship exists between total assembly (transportation) costs and number of markets in a supply region, due to a positive association between transportation costs per animal and distance to markets.

In summary, a trade-off exists between transportation costs and processing costs with respect to market volume. At some level the decline in per unit processing costs should equal the rise in per unit transportation costs as auction volume increases. At this volume the auction system is operating optimally, as defined by the minimization of the sum of the two relevant costs, assembly and marketing.

Optimal industry organization will consist of the number, sizes and locations of auctions that minimize the combination of total assembly costs and total processing or marketing costs for a given region (11, p. 109; 35, p. 24; 53, p. 631). Implicit in this designation of optimal industry organization is the assumption that the organization of livestock production is efficient.

This assumption is supported by the fact that livestock production is highly competitive. As such, production is highly vulnerable to market forces, making efficient production a requirement for survival. Inputs required for auction market operation have few geographic limits. Though partially competitive and subject to market forces, livestock auction markets have a high degree of asset fixity that slows the adjustment process (23, p. 7). While not strictly competitive, the livestock marketing industry can be beneficially analyzed within a competitive framework. The economic ideal of competition is often used as a benchmark, especially in measures of industry efficiency. A partial measure of an industry's economic efficiency is provided by analysis of the organization of individual firms as it relates to the optimal industry organization defined above (7, p. 113; 9, p. 140; 53, p. 631).

Solution to the problem of identification of optimal industry organization would be useful in providing directional information to decision makers in the position of influencing industry change. If the livestock marketing system can be guided towards a lower cost, more efficient organization, many stand to benefit. However, it should be recognized that the goal of optimal industry organization differs from the goal of optimal firm organization, whether that firm is an auction market or an individual livestock producer.

Review of Literature

The effects of space on economic activity were first articulated by Von Thunen in 1826 (31, p. 35). Further pioneering work in location theory occurred in the first half of the 20th century with the works of Weber (1909), Ohlin (1933), Hoover (1937), and Losch (1944) (31, p. 35). From this point, substantial advances in the area did not occur until electronic computers and algorithms were developed for the testing of theory (6, p. 1379; 21, p. 1380). The most important of these developments was the simplex method for solving linear and nonlinear programming problems (31, p. 35; 39, p. 89).

Following the advent of mathematical programming, many classic articles were published in the area of spatial research. These works by Samuelson, Takayama and Judge, and Stollsteimer are credited with laying the foundation for the methodology of spatial research (47, 55, and 53). Recent research has been patterned on this foundation with some notable improvements. Only in the last two decades have mathematical programming tools been refined to a degree that complex models with practical applicability to the real world could be solved (31, p. 35). Mathematical programming has been found efficient in handling problems of the type addressed in this study, that is, the problem of spatial allocation of agricultural activities (7, p. 113). Most recent applications to this type problem are variations on Stollsteimer's basic model for plant sizes, numbers, and locations.

Stollsteimer's model simultaneously determined

> the number, size, and location of plants that minimizes the combined transportation and processing costs involved in assemblying and processing a given quantity of raw material produced in varying amounts at scattered production points (53, p. 631).

The model was applied to the California pear industry and solved using linear programming (L.P.).

Much research has been done in agricultural economics using Stollsteimer's regional optimization criteria of minimum combined transfer and assembly costs. In a 1964 analysis of the California beef slaughter industry, King and Logan extend Stollsteimer's basic model to include the costs of final shipments. This study uses L.P. to simultaneously consider the costs of shipping raw materials, processing, and final product shipments in determining minimum-cost numbers, locations and sizes of plants (30, p. 94). The results of this California study emphasize the importance of considering transfer costs in location analysis. The authors note that the consideration of economies of scale in processing implies advantages to large, centralized plants. However, some small plants were feasible because the transportation costs to ship to a larger processing region were prohibitive (30, p. 108).

Other research following Stollsteimer's includes: Cobia and Babb's analysis of equilibrium size in fluid milk processing; Von Oppen and Scott's application of quadratic programming to the soybean plant location problem in India; Miller and Henning's 1966 evaluation of Ohio's livestock marketing efficiency; and Kloth and Blakely's separable programming application to dairy plant location in the North-Central region (11, 65, 40, and 32). Studies of this type, which include the costs of processing, assembly and, in some cases, distribution, provide a more comprehensive evaluation of industry efficiency than studies evaluating the efficiency of a specific industry segment, i.e., of transportation or processing alone.

Past research on the operational efficiency of Tennessee's marketing system is limited. Most recently, Spielman, et al., analyzed the costs of operation of Tennessee livestock auction markets using 1978 and 1980 data (52). Results of this analysis indicate that economies of size do exist in the State's auction market industry. Also, it showed that most of the available economies of size could be realized at relatively small annual volume levels, assuming the auction used the most efficient plant size for that volume level (52, p. 17). As indicated earlier, a good evaluation of the efficiency of an industry operating in spatial markets must include costs of transfer.

Such an evaluation was conducted by Hicks and Badenhop in 1970 (23). The combined costs of assembly and selling annual livestock marketings were minimized for Tennessee. The results of this analysis indicated the State's optimal number of livestock auction markets to be 18, a drastic reduction below the 74 existing markets in 1970. The overall results characterize the State's livestock market system as high-cost and inefficient, primarily due to the existence of too many markets (23, p. 25).

In Badenhop's study of the livestock auction market system, the inclusion of transportation and processing costs considers the relevant costs of the seller. The costs of the buyer are not included. The buyer's costs of acquiring livestock partially consist of his travel expenses and increase with number of markets visited. Another component of buyer cost is affected by the ability of a buyer to assemble a full, uniform load of livestock for shipment, that is, if intermediate assembly of livestock between markets is needed. As size (volume) of markets decreases, the need for intermediate assembly, and therefore buyer costs, may increase. If buyer costs are lower at markets with larger volumes due to a reduction in the number of markets visited, and/or in the need for intermediate assembly, then the reduction in costs associated with volume should be considered in a study evaluating optimal auction market size for the industry.

When the Hicks and Badenhop study was conducted, computer limitations restricted the number of potential market locations to 12. The State was divided into three areas so that 35 potential sites were considered in the whole State. No shipments were allowed among the areas, which could bias the solution towards central sites in each area. Not only were intrastate shipments limited, but also interstate movements of animals were prohibited. With the absence of trade barriers, livestock densities around Tennessee should influence the optimal locations of markets in the State.

Many changes have occurred since Hicks and Badenhop evaluated the State's livestock marketing system. Most noticeable is the 27 percent decline in market numbers. Transportation costs have also greatly increased. Most important, however, has been the refinement of mathematical programming such that a more comprehensive model of the

Tennessee livestock auction marketing system can be built with greater realism.

The Objectives of the Study

The general objective of this study was to analyze the organizational efficiency of Tennessee's livestock auction market system within a spatial equilibrium framework. The auction market system is very complex, influenced by varying livestock densities and innumerable points of production and potential market sites, both in and surrounding the State. The results of this analysis should provide a better guide for public policy makers than is otherwise available since the primary factors influencing industry organization can be considered simultaneously. Specific objectives were:

1. to simultaneously determine the sizes, number, and locations of auction markets that minimize the combined costs of assembling and marketing livestock in Tennessee;
2. to compare the optimum solution identified above with the current industry organization;
3. to evaluate changes in the optimum solution under varying assumptions about quantities of livestock, transportation cost, and marketing cost.

The mathematical technique used to solve the spatial equilibrium problem was separable programming. The model is developed and described in Chapter 2. The next chapter describes and analyses the results of the study; and the last chapter presents a summary of the results as well as the conclusions and implications drawn from them.

Following the text are appendixes containing various secondary calculations of model inputs and tables of specific model solutions.

CHAPTER 2

METHODOLOGY

Methods of Spatial Analysis

The problem of least-cost industry organization is broadly classified as an optimization problem. This type of optimization problem also falls into the narrower category of mathematical programming problems, because it is not solvable using classical calculus (20, p. 1).

Mathematical programming models can be efficient in handling the problem of spatial allocation of agricultural activities (45, p. 113). Several alternative techniques for solving spatial models exist. The choice of technique should be made according to specific needs and the degree of refinement desired to describe existing situations.

Three common methods are available for solving problems of spatial organization: linear, separable, and integer programming. The first to be developed was L.P. As defined by Dorfman, it is the analysis of problems in which a linear function of variables is to be maximized or minimized when these variables are subject to a number of linear inequality constraints (13, p. 8).

L.P. offers the advantages of a guaranteed optimal solution (if one exists), flexibility, and the ability to solve large problems. L.P.'s restriction to linear objective functions was considered too limiting for this study considering the existence of economies of scale in marketing cost.

Integer programming differs from L.P. because some of the variables may be restricted to integer values (20, p. 25). This restriction is desirable in many situations, but offers no advantages for the purpose of this study since linear functions are still required.

Separable programming is a method for solving nonlinear programming problems by separating the nonlinear functions into linear segments. For a function to be separable, it must be a function of a single variable, (e.g. x_1^3, ln x_2, exp x_3). Separable, nonlinear functions can appear in the objective function or the constraints of an otherwise L.P. problem (14, p. 59; 20, p. 15; 39, p. 89).

Because size economies in livestock auction market operation cost could be considered, separable programming appeared most applicable to the optimization problem of minimizing combined transportation and marketing cost. In addition, separable programming has L.P.'s advantages of flexibility and the capacity to handle large problems.

The separable programming algorithm is not without limitations. If a problem has more than one local optimum solution, there is no guarantee that the separable programming process will choose the best one (39, p. 92). This limitation may or may not decrease the value of the solution to a separable programming problem. Kilmer and Hahn report, "Even when the conditions for a global optimum are violated, the separable programming technique is recognized as producing acceptable solutions" (29, p. 387).

Hadley proposes two ways of dealing with this problem of local optima. The first is to coarsely separate the function and find an initial solution. Then the function is reseparated into finer segments around the initial feasible solution and the problem resolved (20, p. 110).

The second method is to solve for a feasible solution in the original problem, and then use this as a basic feasible for solving a new problem (20, p. 111). However, it is not possible to restart a separable programming problem. As an alternative to the restart procedure, model variations in this study were solved by constraining the initial feasible solution to current (1983) locations and volumes of livestock auction markets within Tennessee. Parametric procedures were used to remove the current location/volume constraints after the initial feasible solution was found.

In further support of separable programming, Hadley states that the fact that a local optimum is obtained may not be a serious drawback. For some practical problems the value of the objective function at local optimas may be quite close to the global optimum (20, p. 110).

A separable programming procedure is available within the linear programming procedures of I.B.M.'s Mathematical Programming System--Extended (26). That algorithm was used in this study.

Development of the Model

The optimal size, number, and location of auction markets was defined to be the combination that minimized the costs of transportation and selling associated with the annual volume of livestock marketed through auctions in Tennessee. With this definition in mind, the model was developed to include: alternative market locations, quantities of livestock, livestock origins, transportation costs from origins to potential market locations, and marketing costs for various sizes (volumes) of auctions. In some model formulations, the differences in buyer costs associated with purchasing livestock at auctions of differing sizes were included in marketing costs.

The model in equation form may be stated as follows:

$$(1) \quad \text{Minimize TC} = \sum_{i=1}^{m} \sum_{j=1}^{m} t_{ij} a_{ij} + \sum_{i=1}^{m} \sum_{j=1}^{m} c_{nj} a_{ij}$$

subject to

$$(2) \quad \sum_{j=1}^{m} a_{ij} \leqq a_i \quad i = 1, 2, \ldots, m$$

$$(3) \quad \sum_{j=1}^{m} \sum_{i=1}^{m} a_{ij} \geqq A$$

$$(4) \quad \sum_{i=1}^{m} a_i = A$$

where

TC = total annual costs of assembly (transportation) and marketing

t_{ij} = cost of moving one livestock unit from origin i to market destination j

a_{ij} = number of livestock units moved from origin i to destination j

c_{nj} = marketing costs per livestock unit along segment n of the linearized cost function for market j

A = total quantity of livestock available in the area analyzed

a_i = number of livestock units available at origin i

m = the number of origins which equals the number of destinations (m = 238).

Equation (1), the objective function, can be divided into two parts:

$$\sum_{i=1}^{m} \sum_{j=1}^{m} t_{ij}a_{ij}$$

represents the summation of the transportation cost of assembling all livestock units at all markets;

$$\sum_{i=1}^{m} \sum_{j=1}^{m} c_{nj}a_{ij}$$

represents the summation of the cost of marketing all livestock units at all markets.

This objective function was minimized under the constraint that livestock units shipped from any origin to all potential destinations be less than or equal to the available supplies at that origin (equation (2)). Equation (3) requires that the sum of livestock units transported from all origins to all destinations be greater than or equal to the total animals available at all origins. The combination of equation (2), (3), and (4) dictates that every livestock unit will be shipped and marketed, and eliminates the possibility of negative shipments.

Though others have extended the basic least-cost model to include distribution costs, these costs were omitted in this study. This omission was not felt to seriously limit the usefulness of the results for several reasons. A majority of animals sold through the State's auction markets are feeder cattle destined for grazing or feedlots in the Midwest or Great Plains to be fed-out to slaughter weights. The general movement of these animals is westward and northwestward. These animals are transported for long distances. Therefore the location of assembly points within the State should have little affect on total transportation costs from auction to next destination.

The remainder of the animals marketed are bought by local livestock producers or by buyers for local slaughter houses. The transportation costs to move animals from auction to local farm or slaughter house are probably not negligible. However, the costs of data collection and computational complexity of the inclusion of these distribution costs in the model were felt to outweigh any added explanatory benefits that could result. Therefore, the costs of transportation beyond the auction market were considered to be beyond the scope of this study.

Models are simplifications of reality by definition. This means that not every aspect of what is being modeled can be captured. Other than the exclusion of distribution costs, this study also did not account for the social benefits that people receive by attending livestock auction markets.

Definition of the Supply Area

The area of study included Tennessee and all surrounding counties within 50 miles of the Tennessee border as shown in Figure 1. The bordering areas include parts of Kentucky, Virginia, North Carolina, Georgia, Alabama, Mississippi, Arkansas, Missouri, and Indiana. Inclusion of these areas which border Tennessee was considered necessary for two reasons.

First, there are few barriers to interstate movements of livestock to and from Tennessee. The existence of livestock populations and markets in areas which border Tennessee can have a strong influence

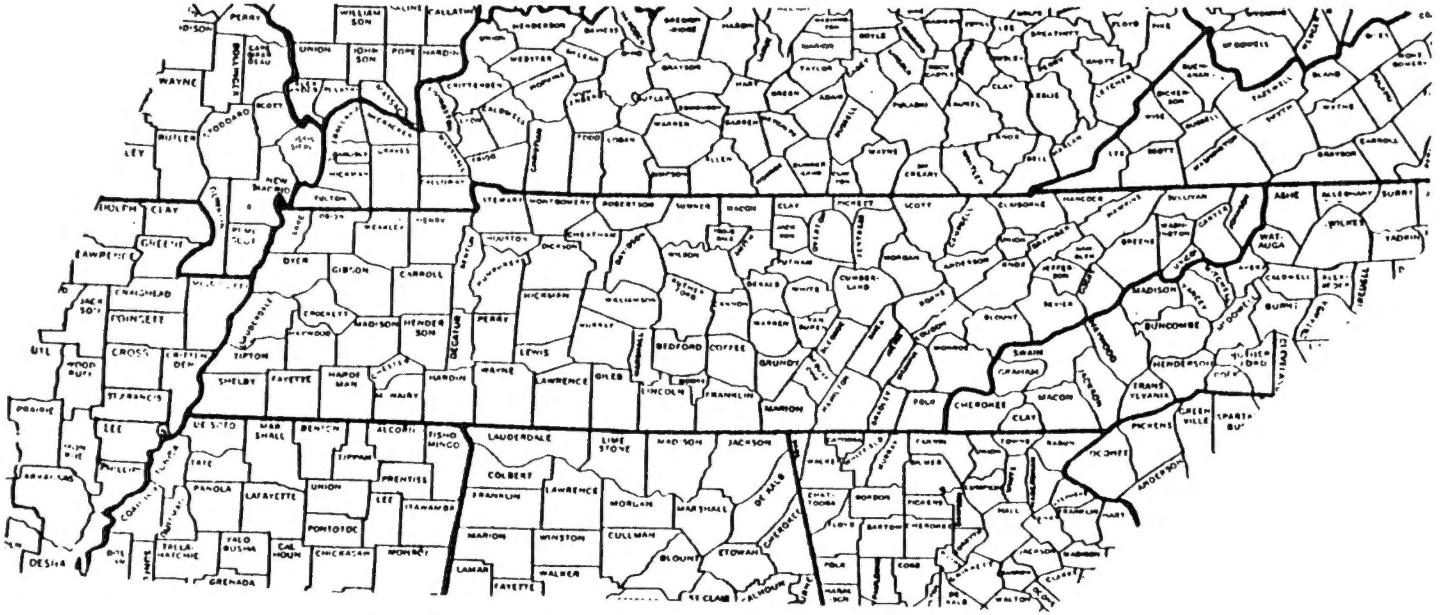

Figure 1. Map of the Supply Area

upon optimal livestock auction market locations in the State since cattle may be shipped across the State line.

Second, any solutions obtained in areas near the edges of the supply area cannot be considered truly optimal. The border imposes unrealistic limits upon the animals available to markets located near it. Inclusion of the area outside Tennessee lessens bias in the optimal solution for the State. With the exception of those counties actually bordering Tennessee, specific results for areas outside the State were not reported.

Origins and Potential Destinations

The supply area delineated for the study contained 238 geographic points which are both origins and destinations. Given the size of the supply area, it was computationally infeasible to consider every potential location for auction markets and every livestock producing farm as an origin. To reduce the alternatives to a manageable number, the geographic center of each county was assumed to be a distinct production point and a potential auction site. The total quantity of livestock available in the county was assumed to be located at that point. Since a county is the smallest area for which livestock inventory statistics are reported, this assumption gives the most accurate reflection possible of nonuniform livestock densities.

A few counties in the supply area but outside of the State reported no livestock inventories. These counties were omitted as potential market sites to further reduce the size of the problem. These omissions should not adversely affect an optimal solution, because common sense suggests an efficient market site would not exist in a county with negligible livestock populations.

To have received consideration as an origin for a potential market site, a county's geographic center must be within a 50 mile radius of that market site. This constraint is consistent with the 50 mile radius around the State used to delineate the supply area. The maximum volume of markets in this study's mathematical programming model was limited to 90,000 livestock units. Livestock density within the supply area allows the maximum volume of livestock units to be obtained by almost every potential market site from areas within a 50 mile radius of a potential site. For these reasons, the 50 mile route limit reduces the size of the problem substantially, without seriously constraining the optimal solution.

Distance and Potential Route Calculation

Geographic centers of counties also served as points of reference to calculate distances between counties. The distance calculation was accomplished with a formula for air-mile distances detailed in Appendix A (62). The primary inputs into this formula were longitudinal and latitudinal coordinates of the geographic center of each county. Air-mile distances calculated in this manner have been shown to closely approximate actual highway mileages (62, p. 176). However, in the mountainous eastern region of the supply area, distances are likely underestimated.

Potential routes between counties were identified to exist if the distance between their geographic centers was no greater than 50 air-miles. This constraint combined with differences in county sizes to result in a variation in the number of potential routes from various origins. Some shipment routes were computed for origins along the Mississippi River that are unrealistic because the River can only be crossed in two places in Tennessee. These routes were included in the model because low livestock numbers west of Tennessee were unlikely to have much effect on the optimal solution for the State.

From the 238 counties considered in the supply area, a total of 3,524 potential routes were identified. This number includes 238 "home" routes, one for each potential market site. Theoretically, any active destination in a cost-minimization solution must receive its "home" county's supply of livestock. Transportation costs as a function of distance could not be calculated for these "home" routes, since origin and destination are the same geographic point. In order to prevent gross underestimation of transportation costs, every "home" route was assigned an arbitrary distance of 10 miles.

Because of the existence some small adjacent counties, a few potential routes were found to exist with distances less than those for the "home" routes. These routes were extended to 10 miles. This 10 mile minimum prevents those short routes from dominating the theoretically least-cost "home" routes.

Sources of Data

Data for the model inputs of transportation cost, marketing cost, and animal supplies were gathered from several sources. These sources are discussed in this section and in the appendixes referred to herein.

Transportation Cost

Transportation costs were estimated to be \$0.226 per mile per livestock unit. Data for this estimate came from cost budgets of "typical" equipment used to move "typical" loads of livestock from farm to auction in Tennessee. These "typical" loads and equipment were defined from 275 personal interviews with individuals hauling livestock to auctions across the State. Details of the data, its sources, estimation procedures, and survey instrument are given in Appendix A.

Market Operations Cost

The most recent estimate of livestock marketing costs in Tennessee is a long run average total cost (LRATC) curve developed by Spielman, et al., for 1978 (52). This cost function was estimated using ordinary least squares to regress cross-sectional data of average costs against market volumes. The resulting LRATC function described auction market operation costs as a nonlinear function of volume in livestock units. The cost function was inflated to 1983 values with the index of prices paid by farmers and multiplied by annual volume (V) to get total annual costs (TC) (63). The marketing cost function is expressed by the following equation:

$$TC_{1983} = 27{,}554.97 + 4.872834\ V - \frac{33{,}686{,}926.42}{V}$$

where

TC = annual total cost of auction market operation

V = annual market volume in livestock units.

This function was used to represent the total cost of marketing livestock for purposes of this study, and is shown graphically in Figure 2. Economies of scale are represented in the TC curve by decreases in the slope of the curve as market volume increases. This diminishing rate of increase in total costs is most clearly evident at the 2,000 to 10,000 volume levels.

Livestock Units

Many types of livestock (cattle, calves, and hogs) are sold through auctions in Tennessee. However, the costs per animal of transportation and marketing vary among animal types. This variance requires that a common unit of equivalence be defined between animal types for comparison purposes. In general, this unit was called a livestock unit.

Two different livestock units were used in this study, one for transportation activities and one for marketing activities. Different livestock units were needed because the magnitude of the cost difference among animal types is expected to vary between transportation cost and marketing costs, because the former is a function of animal size and weight, and the latter is a function of handling difficulty and pen space.

The standard livestock unit is an animal marketing unit (A.M.U.). This unit of measure has been used in many marketing studies and is defined by the U.S.D.A. to be one cow, one calf, or three hogs (51, p. 16). The A.M.U. was used by Spielman in developing the marketing cost function used in the programming model, and therefore was used in association with volumes moved through auctions in this study.

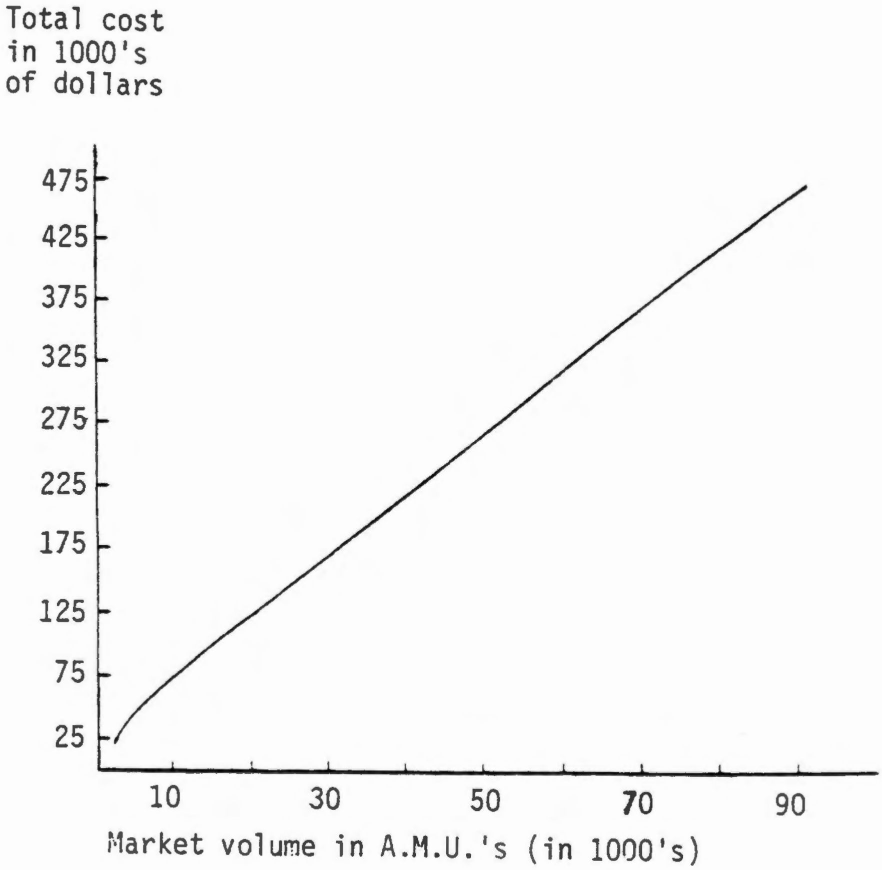

Figure 2. The Total Cost Function of Tennessee Livestock Auction Markets in 1983 Values

The second livestock unit was defined to be an animal transportation unit (A.T.U.) with equivalencies of one cow, two calves, or three hogs. The difference in an A.M.U. and an A.T.U. is the number of calves. The A.T.U. measure attaches more importance to the weight equivalence among animals. Logically, a 400 pound calf cannot be transported at the same costs as a 900 pound cull cow. To have used A.M.U.'s, with the one cow--one calf equivalence, would have inaccurately represented transportation cost. The A.T.U. is also the unit of measurement used for animal quantities available at the origins to be transported to markets.

Once an A.T.U. is transported to a market destination, it was converted to an A.M.U. by multiplying by a factor of 1.2076 as estimated in Appendix B. In other words, one livestock unit transported is equal to 1.2076 livestock units marketed.

Quantities of Livestock at Origins

Data for available quantities of livestock at individual origins came from listings of livestock inventories by county found in state agricultural statistical bulletins (2, 3, 16, 17, 27, 28, 41, 42, 44, 61, and 66). December 1982 hog inventories and January 1983 cattle and calves inventories were used. Inventory numbers for each origin (county) were adjusted by the percentage of annual inventory expected to be marketed, since total inventories are not marketed each year. Estimation of these percentages was done by animal type and is presented in Appendix B. Because quantities at each origin represent animals to be transported, they must be expressed in A.T.U.'s. To calculate supplies in terms of A.T.U.'s, the percentage of inventory expected to be marketed for each animal type was divided by the number of animals in an A.T.U. for that animal type. Then the resulting percentage was applied to the county inventory for that animal type.

Separable Programming

Separable programming allows the inclusion of nonlinear functions within an L.P. format. A nonlinear function must be a function of one variable or a linear combination of such variables to be "separable" (26). To convert these nonlinear functions into the linear format, they are divided into linear segments to form a "polygonal approximation" of the original function. The programming problem is solved like an L.P. problem with the exception that every segment of the approximation becomes an activity in the model formulation.

Model I

The primary model in this study, Model I, was developed to minimize the cost of transporting animals to auction and the cost of marketing those animals for the supply area. For input into the separable programming model, transportation cost per mile per A.T.U. was multiplied by route distance to get the cost of shipping one A.T.U. from origin to destination for each potential route. To convert marketing cost into separable programming format, the nonlinear TC function was separated into segments or grids.

Because the separable programming problem is solved in terms of a polygonal approximation, the solution is only an approximation of the true solution (26, p. 239). The accuracy of the approximation depends on how closely the linearized function describes the original function. In turn, this closeness depends upon the number of segments.

The number and size of segments necessary to define a function is the decision of the analyst. The models developed in this study considered 238 potential market sites. A potential market site was required to have a set of segments to represent marketing activities at that site. This requirement means every segment added 238 columns to the separable programming matrix. Obviously there exists a trade-off between closeness of the approximation to the original function and manageability of the programming problem.

With this trade-off in consideration, the TC function was linearized into three segments as shown in Figure 3. The first segment ends at the volume level of 7,000 A.M.U.'s, and has a slope (marginal cost) of \$8.12. The approximation of this portion of the original function by the first segment is not as accurate as that of the following two segments. The second segment ends at the 20,000 A.M.U.'s level and livestock units along this segment have a marginal cost of \$5.11. This segment very closely approximates that portion of the original function represented. The last segment of the linearized function yields the best approximation because the original function is almost linear over the relevant range of volumes, 20,001 to 90,000 A.M.U.'s. The marginal cost along this segment is \$4.89.

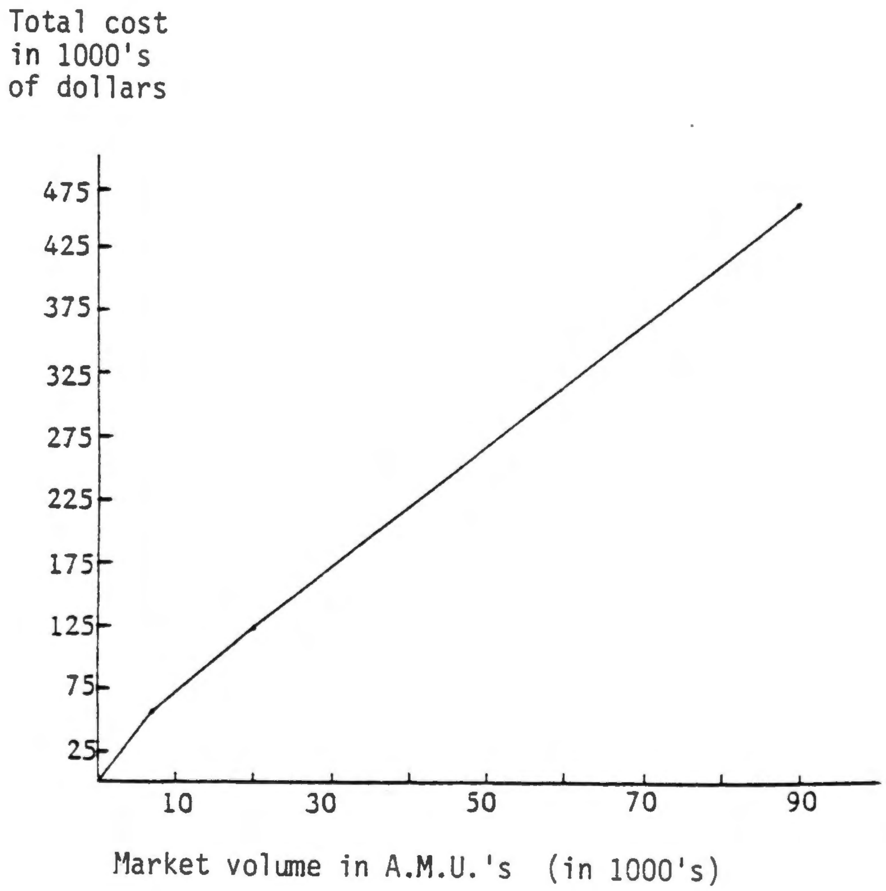

Figure 3. A Piecewise Linear Approximation of the Total Cost Function of Tennessee Livestock Auction Markets in 1983 Values

Model II

Model II was a modification of the primary model. Like Model I, its objective was to minimize the combined costs of transporting and marketing livestock annually within the supply area.

Model II developed from the premise that volume at a given auction may affect the prices buyers are willing and able to pay for livestock at that market. Buyers should be able to fill their orders with less overhead cost per animal purchased at auctions with "large" volumes than at "small" auctions. If this is true, higher prices should exist as market volume increases, other things constant.

Larger volume markets are attractive to buyers because, as more animals are offered for sale, a buyer is more likely to find the exact numbers and types of animals needed to fill his orders. When a buyer attends a relatively small sale, he risks not being able to fill his orders, or filling them with the appropriate quality animals. He also risks increasing his buying costs. When more than one small market must be visited to get the same load of livestock that could have been acquired at a single large market, additional costs accrue in the forms of time, mileage, food, lodging, and possibly intermediate assembly to get a full, uniform load for shipment. Even if it is not necessary to visit additional markets, the risk of having to do so exists, and is likely to affect the price a buyer is willing to bid at small markets.

The ability of a buyer to pay a premium price for animals at large markets due to cost savings does not necessitate his/her doing so. However, the efficiency of attending large sales should result in an increase in the number of buyers in attendance. If, as a result, demand for animals increases relative to their supply, then buyers will not only be able, but also required to pay more for a given animal.

If this price premium at larger markets does represent a reduction in buyer operating costs, then it also represents a reduction in marketing costs for the industry. This reduction in costs should be included in an analysis of industry efficiency.

To determine whether a positive price--volume relationship does exist, and, if so, to quantify it, regression analysis was applied to data on livestock prices at individual auction markets in Tennessee. The data consisted of daily prices of 400--500 pound feeder steers, slaughter cows, and sows under 500 pounds. Prices originated at 16 auction markets during 1982 and 1983, and were collected from unpublished market reports of the Tennessee Department of Agriculture. The 16 markets represented volumes ranging from 7,493 to 63,723 animals, and were geographically representative of the State. Total number of price observations were 1,436 for feeder steers, 1,443 for slaughter cows, and 351 for sows. Separate regressions were used for each of the three types of livestock. For the regressions daily market price for individual markets divided by the weekly average price for all markets was used as the dependent variable. This price index eliminated the problem of autocorrelation which is often present in time series data. The dependent variable was regressed against annual market volume for each of the markets.

In addition to volume differences, the price index for a given type of animal would be expected to vary among markets due to the effects of the day of week on which the sale occurred, and market weighing practice (whether animals are weighed upon arrival or as they are sold). These factors were represented by dummy variables in the regression equations and are detailed in Appendix C.

All three regressions, as well as the estimated coefficients on volume were significant at the 0.01 percent level. The volume coefficients were positive, indicating that price increases as annual volume increases at auction markets. The statistical results are presented in Appendix C.

For purposes of this study, the estimated price increase as market volume increases was viewed as a proxy for a reduction in buyer costs attributable to market volume. To incorporate this cost reduction into the primary model, the marketing costs function was adjusted by an estimate of change in buyer cost. Details of the adjustment of marketing cost are explained in Appendix C. The new cost function is graphically illustrated in Figure 4, and is defined by the following equation:

$$TNC_{1983} = 27{,}554.97 + 12.23071\ V - \frac{33{,}686{,}926.42}{V} - 0.00025391445\ V^2$$

where

TNC = annual total costs of market operation with reduction in buyer cost considered

V = annual market volume in A.T.U.'s.

Total net costs are shown to rise at a decreasing rate, level off, and then decline, becoming negative at volumes greater than 51,000 A.M.U.'s. This negativity results when the reduction in buyer cost is greater than the marginal auction market operation cost at large

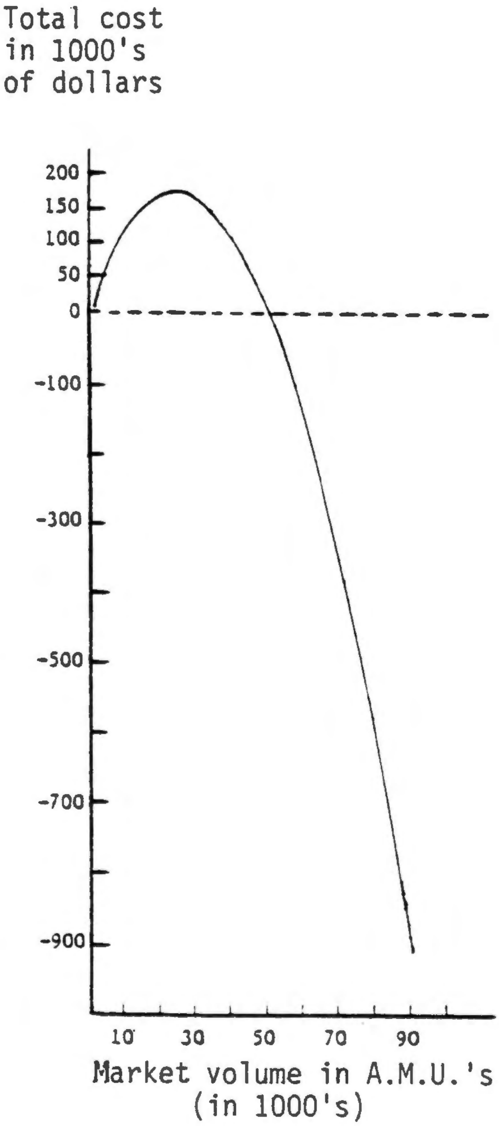

Figure 4. The Total Net Cost Function of Tennessee Livestock Auction Markets Used in Model II in 1983 Values

volumes. Since this function is a combination of the level of marketing costs and the reduction in buyer cost, its absolute level has no meaning except as it is compared with other levels generated by the same function under different volume circumstances. As a result, the level of the objective function value from Model II is also not meaningful except for comparison with other solutions from Model II.

The new cost function was segmented to fit the separable programming input format. The resulting separable programming model was designated as Model II. Seven segments were required to provide an accurate approximation of the original function as shown in Figure 5. The slope and ending volume of each segment are given in Table 1.

Separable Programming Tableau

The separable programming tableau shown in Table 2 represents the two models in general. The notation used is defined as follows:

X_{ij} = a potential shipment between origin i and destination j

t_{ij} = the transportation cost for moving one A.T.U. from origin i to destination j

s_{nj} = the nth special variable in the set of special variables for destination j

c_{nj} = the functional value associated with the nth special variable

g_{nj} = the grid value associated with the nth special variable

M_j = transfer column for market destination j

RHS = right hand side

N = nonconstrained

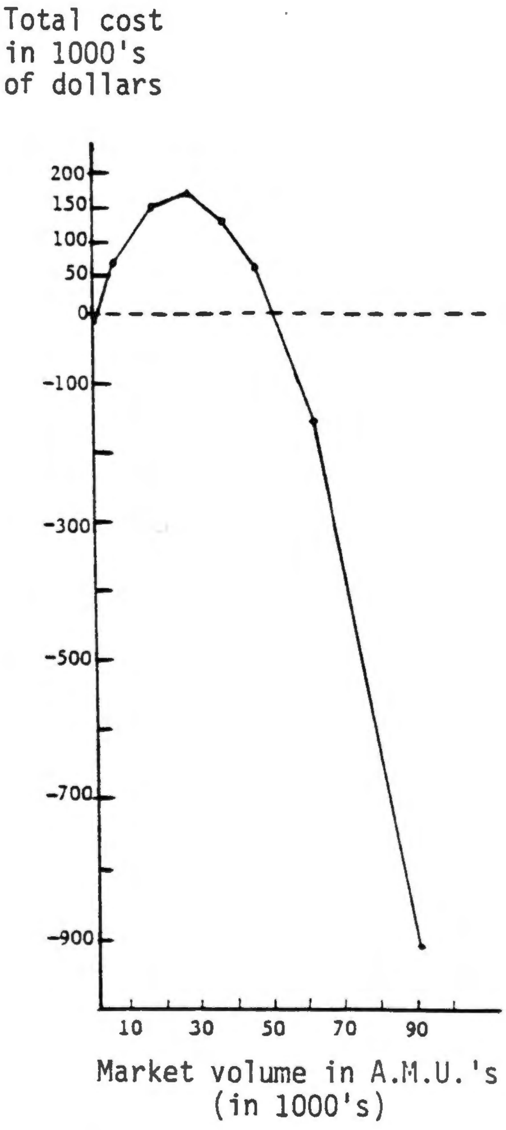

Figure 5. A Piecewise Linear Approximation of the Total Net Cost Function of Tennessee Livestock Auction Markets Used in Model II in 1983 Values

Table 1. Slopes (Marginal Costs) and Ending Volumes for Segments of the Marketing Cost Function for Model II.

Segment Number	Slope (Marginal Cost)	Ending Volume
1	$ 13.70	7,000
2	6.15	18,000
3	1.13	26,000
4	- 2.72	34,000
5	- 7.75	44,000
6	-14.16	60,000
7	-25.85	90,000

Table 2. General Tableau for the Separable Programming Models.

	Transportation Activities from Origin i to Destination j $X_{1j} \cdot\cdot\cdot X_{ij} \cdot\cdot\cdot X_{Ij}$*	Marketing Activities at Destination j $S_{11} \cdot\cdot\cdot S_{n1} \cdot\cdot\cdot S_{1J} \cdot\cdot\cdot S_{nJ}$	Livestock Flows to Destination j $M_1 \cdot\cdot\cdot M_J$	Constraints	RHS
Objective Function	$t_{1j} \cdot\cdot\cdot t_{ij} \cdot\cdot\cdot t_{Ij}$	$c_{11} \cdot\cdot\cdot c_{n1} \cdot\cdot\cdot c_{1J} \cdot\cdot\cdot c_{nJ}$		N	(min)
Supply Constraints for Origin i	1			L	a_1
	1			L	a_i
	1			L	a_I
Livestock Unit Conversions	1.21		-1	E	0
	1.21		. .	E	0
	1.21		-1	E	0
Grid Constraints for Destination j		$g_{11} \cdot\cdot\cdot g_{n1}$	-1	E	0
		. .	. .	E	0
		$g_{1J} \cdot\cdot\cdot g_{nJ}$	-1	E	0
Demand Constraint for Supply Area	1 . . . . 1 1			G	A
Upper Bounds		1 . . . . 1 . . . . . 1 1			
Lower Bounds		0 . . . . 0 . . . . . 0 0			
Change Row Constraints to Tennessee Markets j			1	G	v_j
			. .	G	v_j
			1	G	v_j

* The number of potential destinations j per origin i varies.

L = less than or equal to constraint

G = greater than or equal to constraint

E = equal to constraint

a_i = total animal supplies in A.T.U.'s available at origin i

A = total quantity of livestock in the supply area (equal to the sum of all a_i's)

v_j = the volume in A.M.U.'s sold through current livestock auction(s) at destination j.

This general tableau differs between Model I and Model II only in marketing costs which are represented by sets of special variables. The number of special variables, S_n, required to represent a nonlinear function equals the number of segments in the polygonal approximation of the function. Model I was divided into three segments, while Model II required seven segments to achieve a close approximation of the original function. The transportation coefficients, animal supplies, and total demand were identical for the two models.

Model Constraints to Existing Market Locations

Both Models I and II were forced to consider the currently existing market locations in Tennessee. The models were constrained to ship all of the livestock supplies at Tennessee origins to the destinations (counties) that had an auction market in operation during 1983. These locations are shown in Figure 6, and their volumes listed in Table D-1. The magnitude of the constraint for each current market location was calculated to reflect the actual proportion of total livestock marketed in the State through that particular market in 1983.

to determine the effects of changes in livestock quantities and costs on the optimal solutions. A second reason was to determine whether the optimal solutions responded in the way predicted by economic and location theory. This behavioral analysis is a method of checking the validity of the models.

CHAPTER 3

RESULTS AND ANALYSIS

Model I Results

The solutions for Model I and its variations are summarized in Table 3. For each model, objective function values are listed for comparison. Also listed are separate market numbers and average volumes for Tennessee and areas outside the State.

With current locations as an initial departure point, the optimal solution to Model I identified 47 markets in Tennessee with an average volume of 26,859 A.M.U.'s. This solution for the State and perimeter counties outside the State is shown in Figure 7, with the locations and volumes listed in Appendix D, Table D-2. While 47 equals the number of currently existing locations, a few market sites were relocated to different counties. The effect of this relocation on efficiency was partially indicated by a $384,793 reduction in the value of the objective function from its value at the initial feasible solution constrained to currently existing locations. Because the actual number of markets in Tennessee in 1983 was 54 (some counties had more than one auction market), the optimal solution actually suggests a reduction in market numbers by seven within the State.

Variations in livestock numbers. To determine the effects of changes in livestock numbers on the optimal solution, animal supplies were first decreased by 10 and by 25 percent, and then, increased by the same amounts. Economic theory would predict that market numbers

Table 3. Market Numbers, Average Volumes, and Objective Function Values for Optimal Solutions to Model I and Its Variations.

Model	Number of Tennessee Markets	Average Volumes (A.M.U.'s)	Number of All Markets in Other States	Average Volumes (A.M.U.'s)	Objective Function Value
I -- Primary Model	47	26,859	61	19,657	$21,161,566
I -- Livestock No.s Decreased 10%	45	25,439	56	18,956	19,329,800
I -- Livestock No.s Decreased 25%	44	21,870	73	12,107	16,499,863
I -- Livestock No.s Increased 10%	47	29,147	69	19,386	23,250,432
I -- Livestock No.s Increased 25%	49	32,547	71	20,873	25,879,430
I -- Transportation Cost Increased 10%	48	25,297	78	15,989	21,593,911
I -- Transportation Cost Increased 25%	56	21,726	80	15,101	22,348,537
I -- Marketing Cost Increased 10%	47	26,381	58	21,062	22,577,893
I -- Marketing Cost Increased 25%	43	29,479	56	20,442	24,959,070

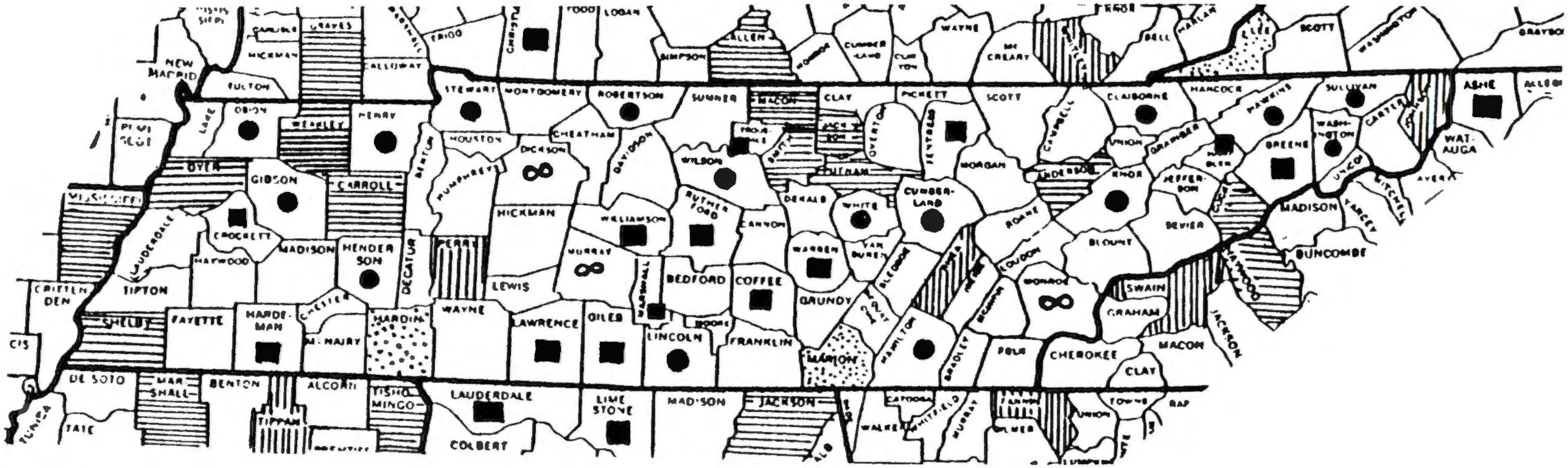

Figure 7. Optimum Livestock Auction Market Locations and Size Categories for Model I

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

and total costs will change in the same direction as the change in livestock numbers.

Tennessee market numbers declined to 45 (see Figure 8 and Table D-3) and the value of the objective function fell in the solution to Model I with animals decreased by 10 percent. When animal numbers were decreased 25 percent, the optimum number of markets in the State dropped to 44 (see Figure 9 and Table D-4), with a concurrent decline in the value of the objective function.

Both versions of the model with livestock numbers increased also behaved predictably. The first increase of 10 percent showed no change in market numbers within the State, but numbers increased outside the State (see Figure 10 and Table D-5). The second increase of livestock numbers of 25 percent changed the optimum number of markets in the State to 49 (see Figure 11 and Table D-6). The objective function values increased for both models approximately in proportion to the increase in animal numbers.

<u>Cost variations</u>. Because history shows declines in costs to be unlikely, the effects of changes in either marketing or transportation cost were examined only for increases from their initial values. For consistency each was varied first 10 and then 25 percent. When transportation cost is increased, location theory predicts an increase in market numbers, and logic predicts an increase in total costs.

With transportation cost increased 10 percent, the number of markets increased by one for the State (see Figure 12 and Table D-7). The objective function increased, as expected, by $432,345 from the

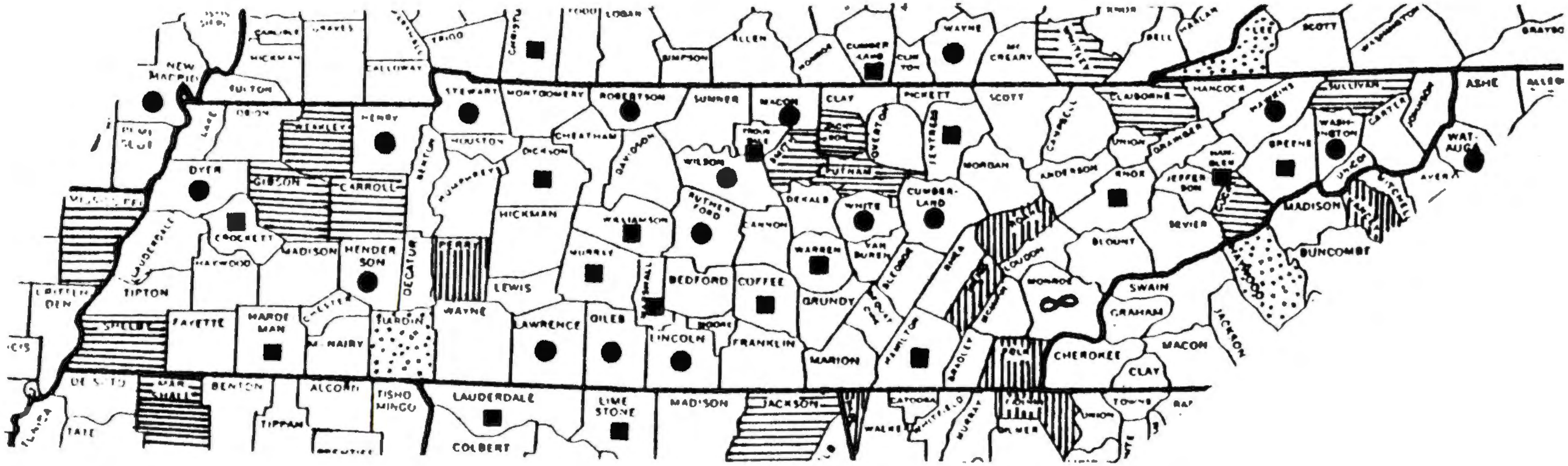

Figure 8. Optimum Livestock Auction Market Locations and Size Categories for Model I with Livestock Numbers Decreased 10 Percent

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

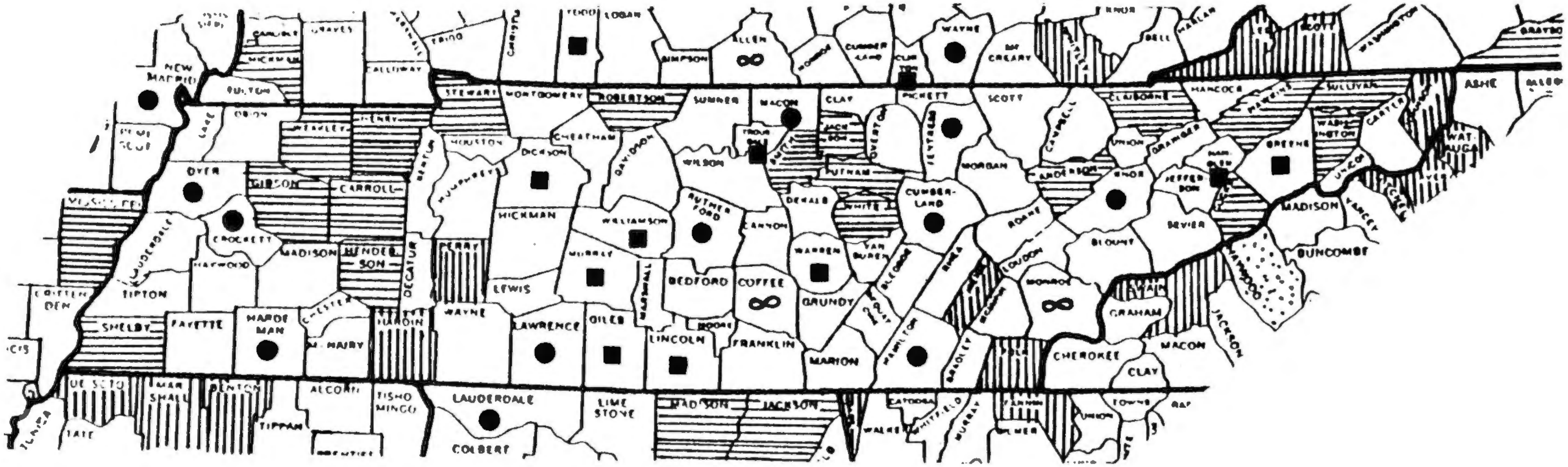

Figure 9. Optimum Livestock Auction Market Locations and Size Categories for Model I with Livestock Numbers Decreased 25 Percent

Key

Volume of Market

(A.M.U.'s)

▥ ≤ 7000

░ 7001 to 10000

▤ 10001 to 20000

● 20001 to 30000

■ 30001 to 50000

∞ 50001 to 80000

★ 80001 to 90000

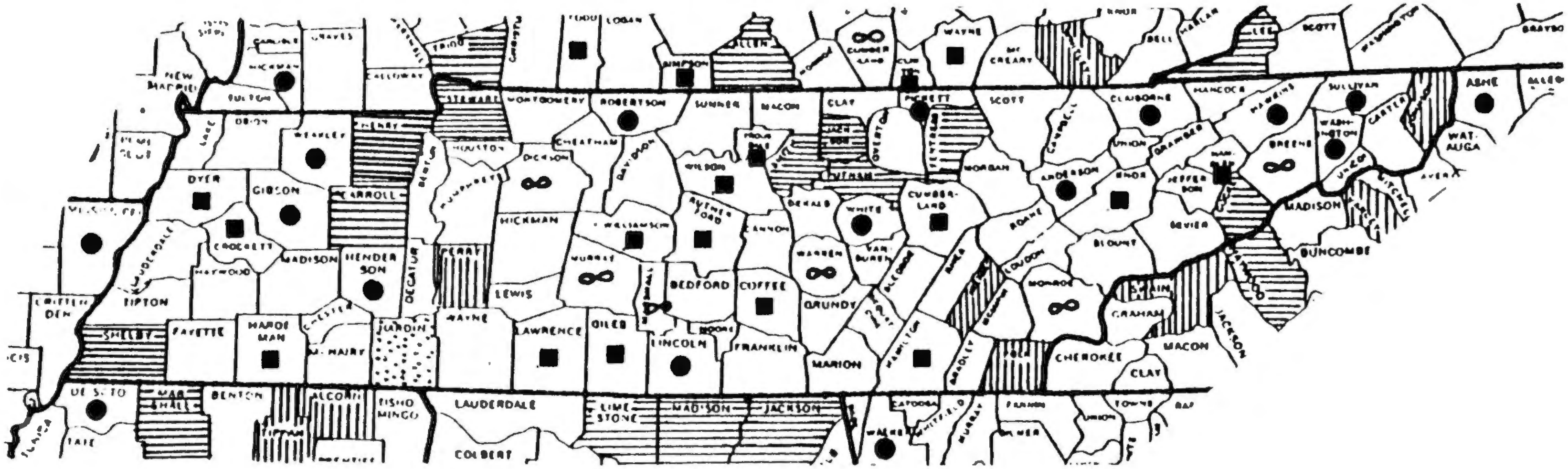

Figure 10. Optimum Livestock Auction Market Locations and Size Categories for Model I with Livestock Numbers Increased 10 Percent

Key

Volume of Market

(A.M.U.'s)

▥	7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

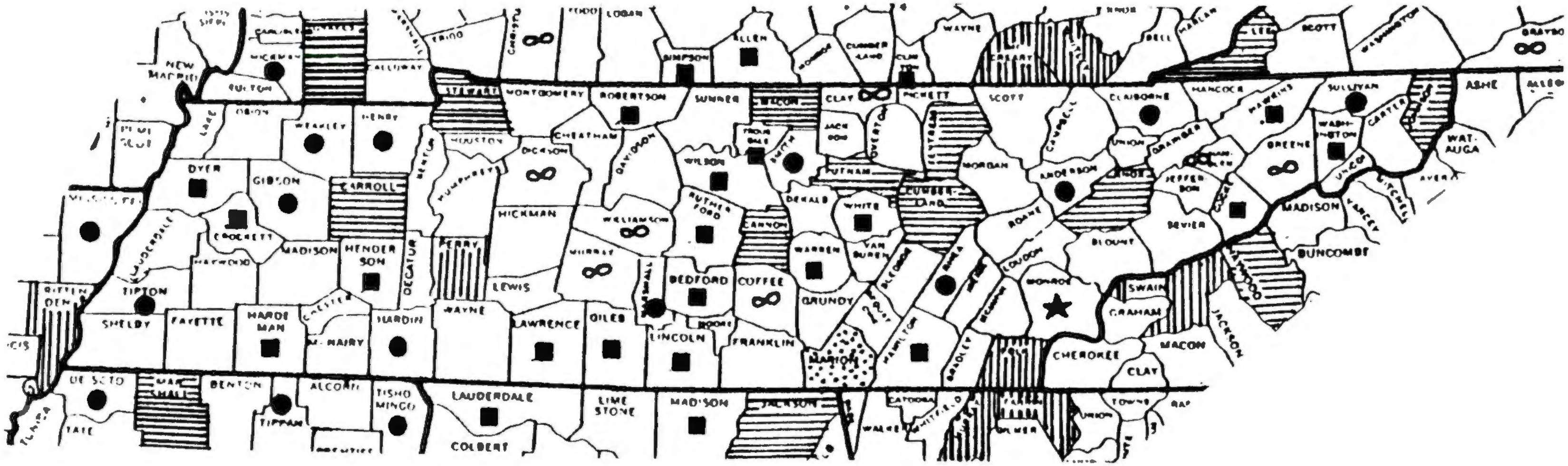

Figure 11. Optimum Livestock Auction Market Locations and Size Categories for Model I with Livestock Numbers Increased 25 Percent

Key

Volume of Market

(A.M.U.'s)

▥ ≤ 7000
░ 7001 to 10000
▤ 10001 to 20000
● 20001 to 30000

■ 30001 to 50000
∞ 50001 to 80000
★ 80001 to 90000

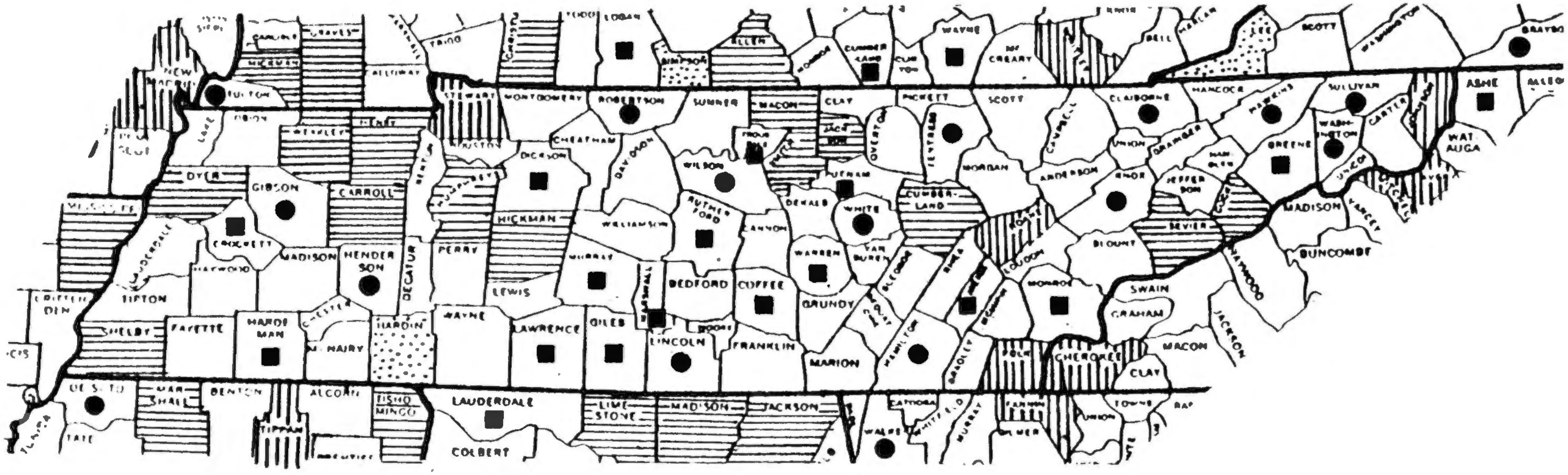

Figure 12. Optimum Livestock Auction Market Locations and Size Categories for Model I with Transportation Cost Increased 10 Percent

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

primary model. The 25 percent increase in transportation costs greatly increased the number of markets and the objective function value. The markets in this solution numbered 56 for Tennessee and are detailed in Figure 13 and Table D-8.

With economies of scale in marketing, an increase in marketing costs should optimally result in fewer and larger markets. Like increases in transportation cost, increases in marketing costs should increase total cost represented by the objective function.

The results for Model I with a 10 percent increase in marketing cost did not behave as predicted for markets within the State. The number of markets in Tennessee did not change from the primary model. The number and average volumes of markets outside the State did decline and increase, respectively, as predicted. The objective function value was higher than that of the primary model. The optimum locations of markets designated by this version of Model I are given in Figure 14 and Table D-9. When marketing costs were increased 25 percent, market numbers fell to 43 for the State as expected (see Figure 15 and Table D-10). The objective function value and average market volumes also behaved predictably.

All of the changes in Model I's primary optimal solution induced by the changes in livestock numbers, transportation cost, or marketing costs are summarized in Table 4.

One of the reasons for varying the model's inputs was to check the validity of the model by determining whether the optimal solutions vary in ways predicted by economic and location theory. Except for the lack of change in market numbers when marketing costs increased

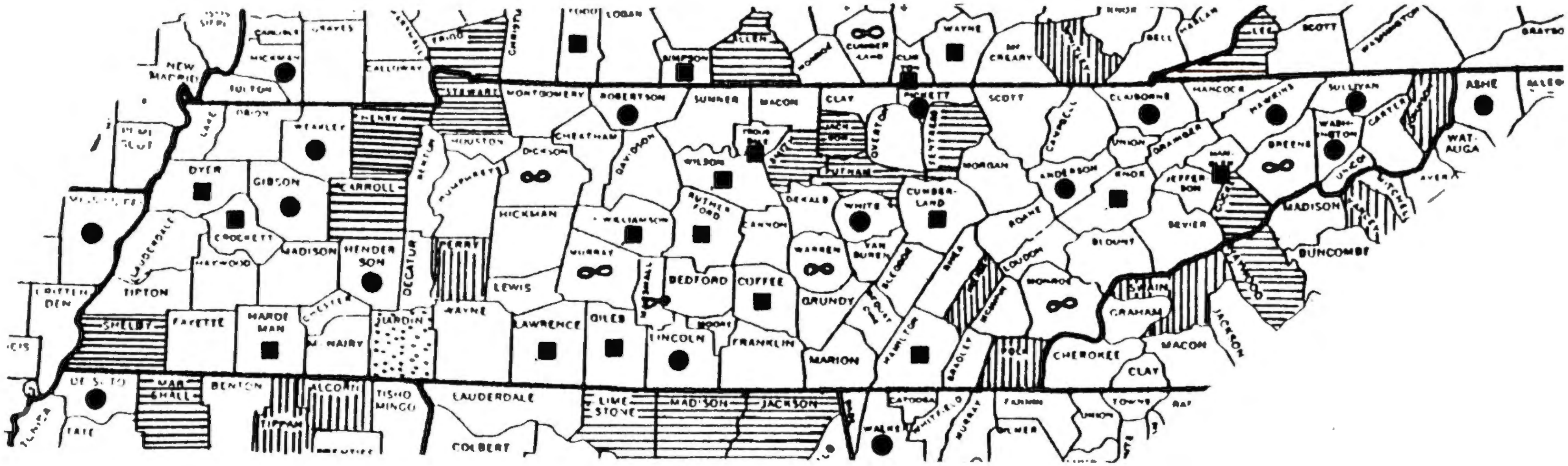

Figure 13. Optimum Livestock Auction Market Locations and Size Categories for Model I with Transportation Cost Increase 25 Percent

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

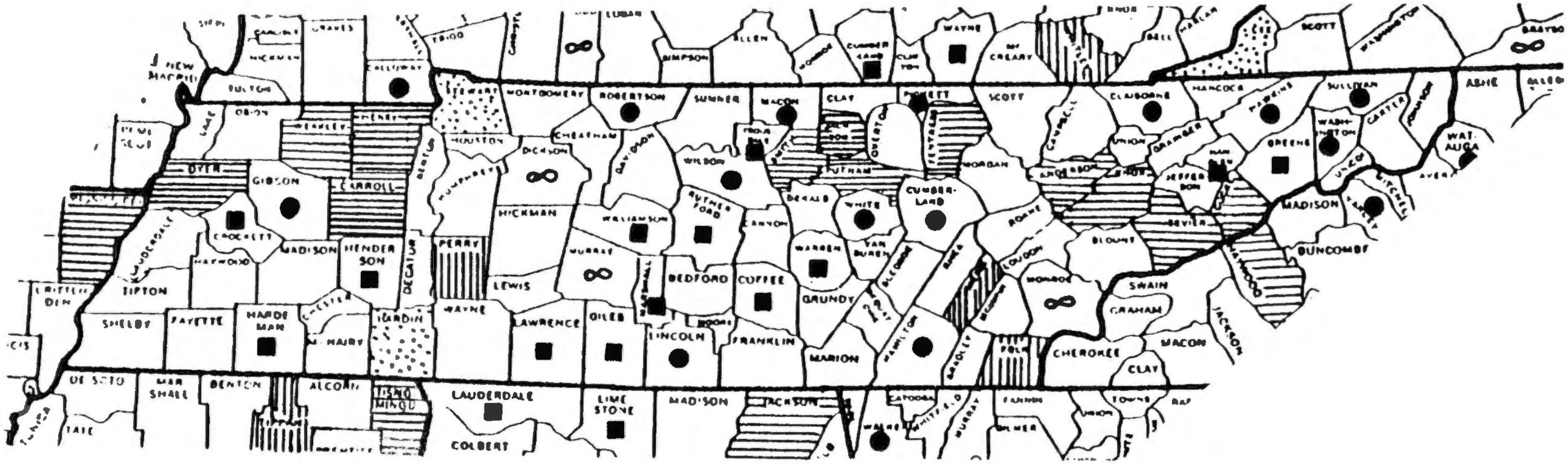

Figure 14. Optimum Livestock Auction Market Locations and Size Categories for Model I with Marketing Cost Increased 10 Percent

Key

Volume of Market

(A.M.U.'s)

▥	7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

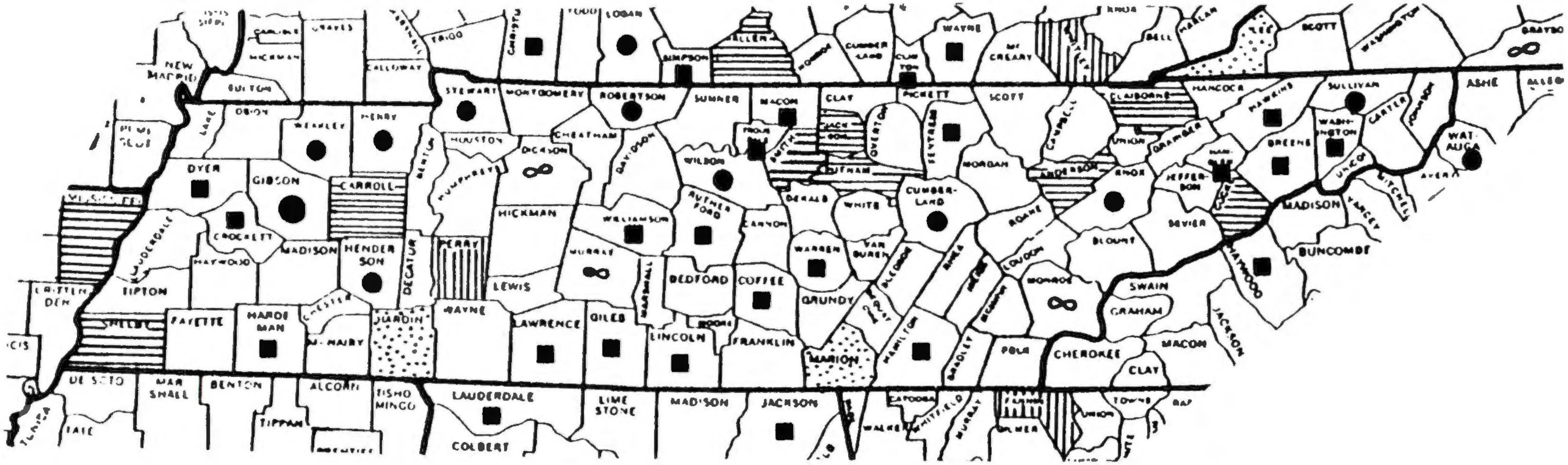

Figure 15. Optimum Livestock Auction Market Locations and Size Categories for Model I with Marketing Cost Increased 25 Percent

Key

Volume of Market

(A.M.U.'s)

▥ ≤ 7000
▒ 7001 to 10000
▤ 10001 to 20000
● 20001 to 30000

■ 30001 to 50000
∞ 50001 to 80000
★ 80001 to 90000

Table 4. Differences in Objective Function Values, and Numbers and Average Volumes of Tennessee Markets Between Solutions of Model I and Its Variations.

Model	Change in the Number of Tennessee Markets	Change in Average Volumes of Tennessee Markets (A.M.U.'s)	Change in Objective Function Value
I -- Livestock No.s Decreased 10%	-2	- 1,420	$-1,831,766
I -- Livestock No.s Decreased 25%	-3	- 4,989	-4,661,703
I -- Livestock No.s Increased 10%	0	2,288	2,088,886
I -- Livestock No.s Increased 25%	2	5,688	4,717,864
I -- Transportation Cost Increased 10%	1	- 1,562	432,345
I -- Transportation Cost Increased 25%	9	- 5,133	1,186,971
I -- Marketing Cost Increased 10%	0	- 478	1,416,327
I -- Marketing Cost Increased 25%	-4	2,620	3,797,504

by 10 percent and when livestock numbers increased by 10 percent, the optimal solutions did change as expected. These results help to validate the model for further analytical purpose. In case of both exceptions, the model responded by showing no change in the number of Tennessee markets and by moving out-of-State numbers in the predicted direction.

Model II Results

The results for Model II and its variations are listed in Table 5. As shown by the negative objective function values for all models, marketing cost was the dominant factor influencing market sizes, because it becomes negative at volumes greater than 51,000 A.M.U.'s. In other words, the reduction in buyer costs offsets the increase in transportation costs of achieving large volumes.

The solution for Model II identified the optimal number of markets for the State to be 19. The locations of these markets are detailed in Table D-11 and Figure 16. The average volume of these markets was 80,562 A.M.U.'s.

Variations in livestock numbers. As for Model I, livestock numbers were varied 10 and 25 percent in both directions. The solution obtained with a 10 percent decrease in livestock numbers is shown in Figure 17 and Table D-12. Tennessee markets declined in number and average volume from the primary solution of 19 at 80,562 A.M.U.'s to 15 with 79,476 A.M.U.'s. The value of the objective function increased, which was expected since fewer numbers imply that lower volumes will be reached. At lower volumes all of the potential cost reduction

Table 5. Market Numbers, Average Volumes, and Objective Function Values for Optimal Solutions to Model II and Its Variations

Model	Number of Tennessee Markets	Average Volumes (A.M.U.'s)	Number of All Markets in Other States	Average Volumes (A.M.U.'s)	Objective Function Value
II -- Primary Model	19	80,562	24	38,781	$- 6,292,223
II -- Livestock No.s Decreased 10%	15	79,476	31	33,005	- 4,664,759
II -- Livestock No.s Decreased 25%	14	82,595	36	19,159	- 2,223,744
II -- Livestock No.s Increased 10%	19	82,218	22	52,065	-10,030,292
II -- Livestock No.s Increased 25%	23	84,398	20	56,781	-12,639,935
II -- Transportation Cost Increased 10%	19	80,871	29	31,892	- 5,128,985
II -- Transportation Cost Increased 25%	19	77,619	27	36,543	- 3,821,748
II -- Marketing Cost Increased 10%	18	83,988	23	41,289	- 8,627,040
II -- Marketing Cost Increased 25%	19	79,085	22	42,960	-11,290,115

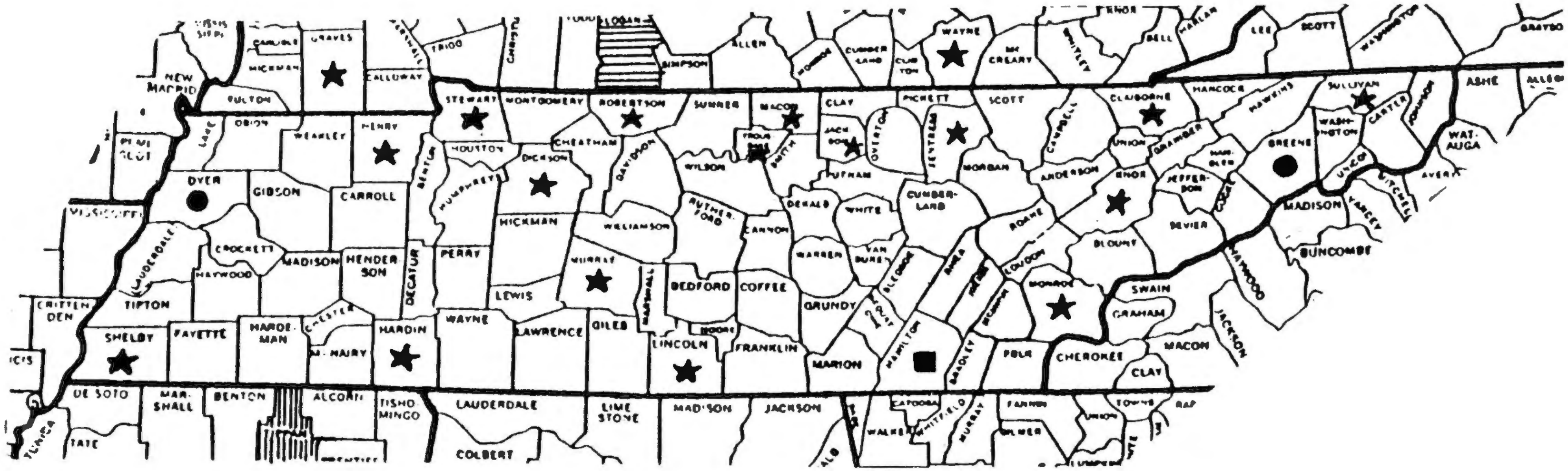

Figure 16. Optimum Livestock Auction Market Locations and Size Categories for Model II

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
☰	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

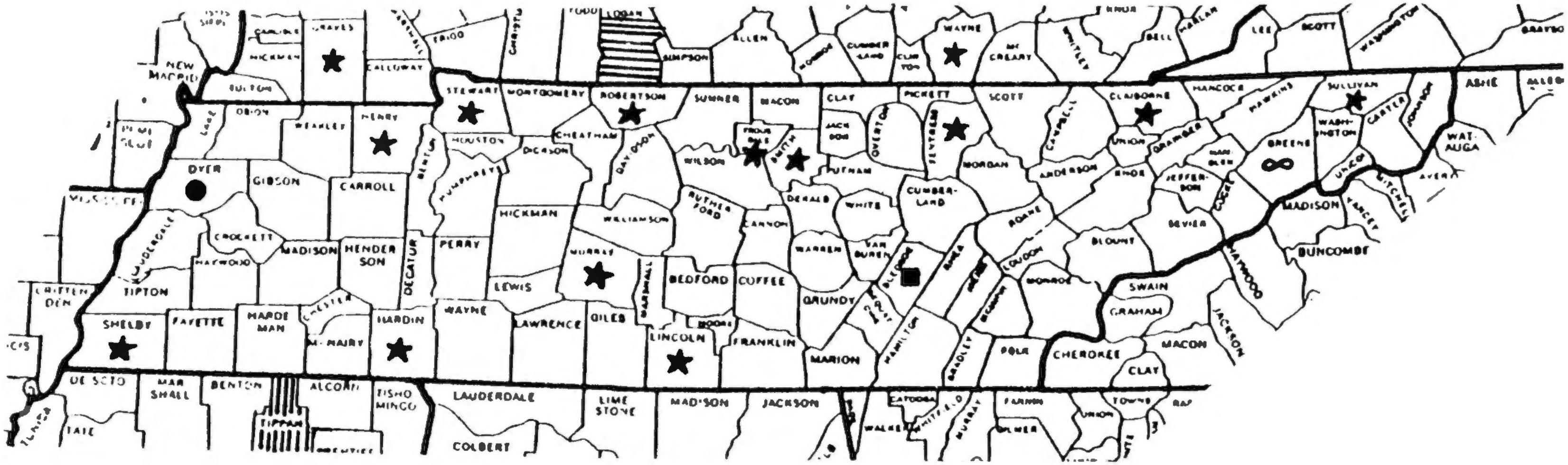

Figure 17. Optimum Livestock Auction Market Locations and Size Categories for Model II with Livestock Numbers Decreased 10 Percent

Key

Volume of Market

(A.M.U.'s)

▥ ≤ 7000

░ 7001 to 10000

▤ 10001 to 20000

● 20001 to 30000

■ 30001 to 50000

∞ 50001 to 80000

★ 80001 to 90000

(economies of scale and lower buyer cost) due to volume will not be realized. Because of the quadratic shape of Model II's marketing cost function, where costs are negative, any changes causing reductions in average market volumes will increase the value of the objective function. As expected, with the 25 percent decrease in livestock numbers, market number in the State declined to an optimum of 14 (see Figure 18 and Table D-13). Average volumes increased slightly for the State, but decreased substantially outside of the State. The objective function increased in value as predicted. As mentioned for Model I, increases in livestock numbers are predicted to increase the number of markets. However, Model II's ability to reach negative marketing cost at large volumes made it possible to increase average volumes with an increase in animal numbers of 10 percent and simultaneously reduce the value of the objective function, with no change in the optimum number of markets for the State (see Figure 19 and Table D-14).

Livestock numbers were also increased to 25 percent above their initial values. Because markets in Tennessee were so close to their maximum limit (90,000 A.M.U.'s) in the initial model, the increase in animals required an increase in the optimal number of auction markets for Tennessee to 23 (see Figure 20 and Table D-15).

<u>Variations in transportation costs</u>. The effects of 10 and 25 percent increases in transportation costs were primarily expressed in an increase in the optimum number of markets outside of the State. The objective function values increased as predicted for both the 10 and 25 percent increases in transportation costs, with the increase most notice-

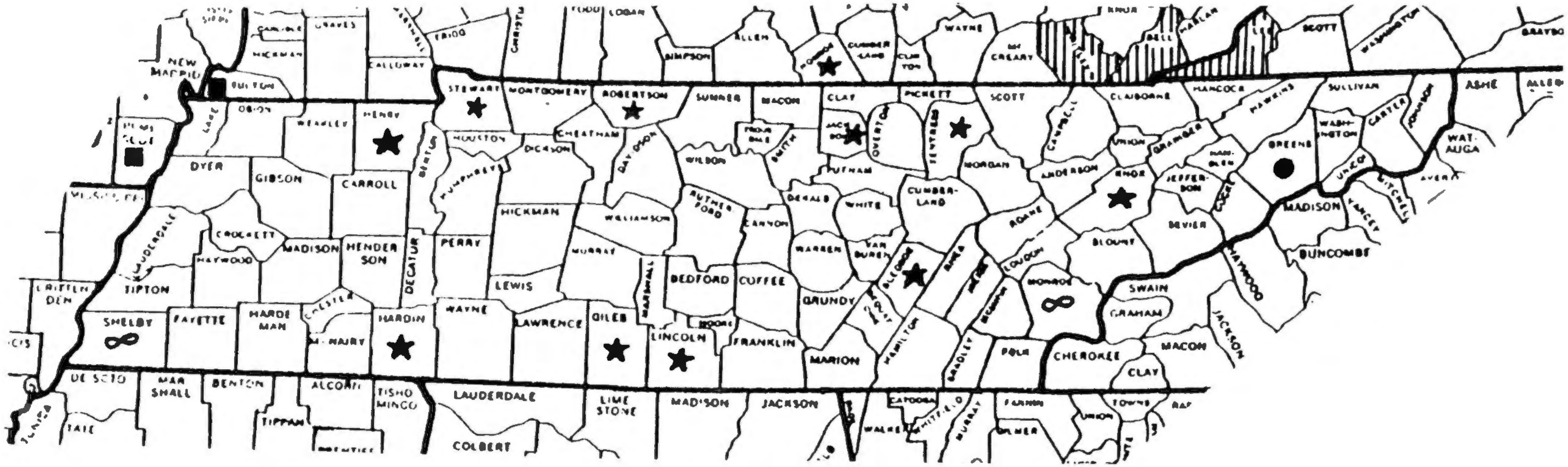

Figure 18. Optimum Livestock Auction Market Locations and Size CAtegories for Model II with Livestock Numbers Decreased 25 Percent

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

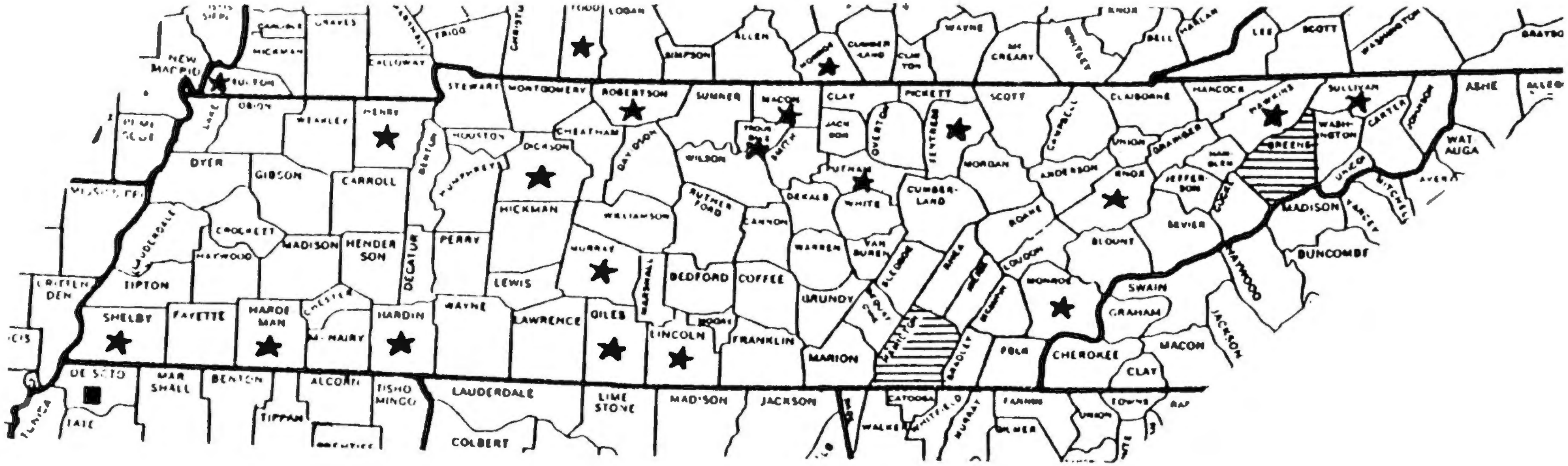

Figure 19. Optimum Livestock Auction Market Locations and Size Categories for Model II with Livestock Numbers Increased 10 Percent

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

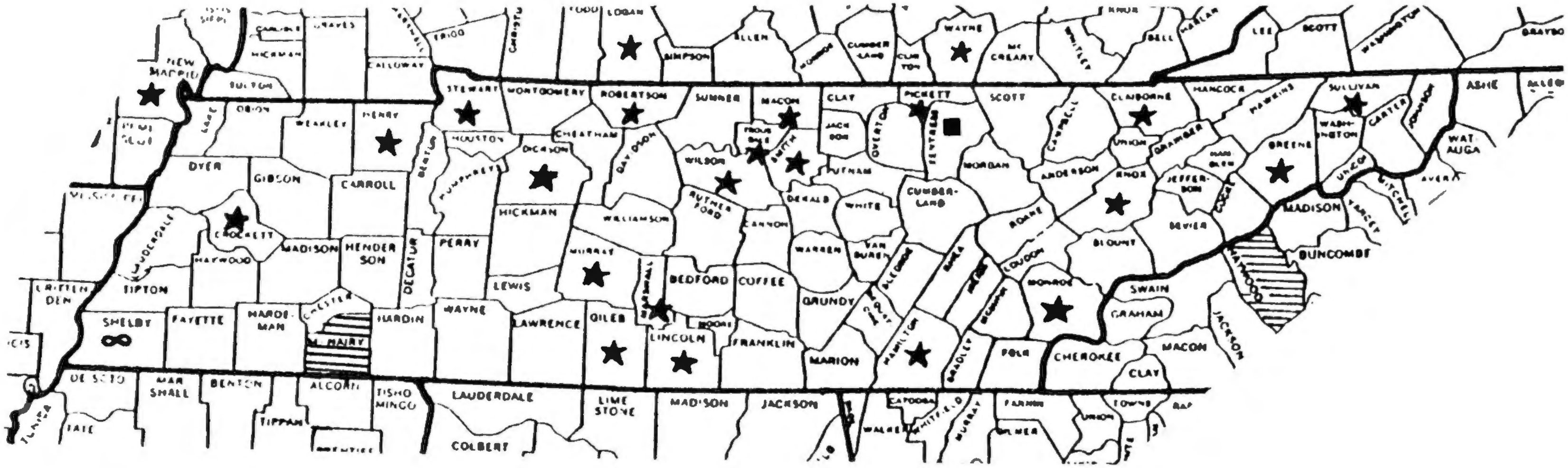

Figure 20. Optimum Livestock Auction Market Locations and Size Categories for Model II with Livestock Numbers Increased 25 Percent

Key

Volume of Market

(A.M.U.'s)

▥	≤7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

able for the 25 percent rise. The market locations for Model II with transportation cost increased 10 percent are shown in Figure 21 and Table D-16. The solution for the 25 percent increase is shown in Figure 22 and Table D-17.

Variations in marketing cost. With increased marketing cost, the effects on the optimal solution were predicted to be: a decrease in market numbers; an increase in average market volume; and, due to the shape of the marketing cost function, a decrease in objective function value. For Model II with marketing cost increased 10 and 25 percent, the objective function values decrease as predicted. Market numbers for the State declined and average volumes increased as predicted after the 10 percent rise in marketing cost (see Figure 23 and Table D-18).

The solution of Model II after the 25 percent increase in marketing cost did not change as expected for the State. Market numbers were stable at 19 and average volumes declined (see Figure 24 and Table D-19). Markets outside the State declined in number and increased in average volumes. The value of the objective function decreased as expected.

Overall, the solutions for Model II were not as predictable as those of Model I in response to various changes in the models' parameters. A summary of these responses for Model II is given by Table 6 which shows the magnitude and direction of change from the basic optimal solution with each model variation. Only changes in the objective function, Tennessee market numbers and average volumes are given.

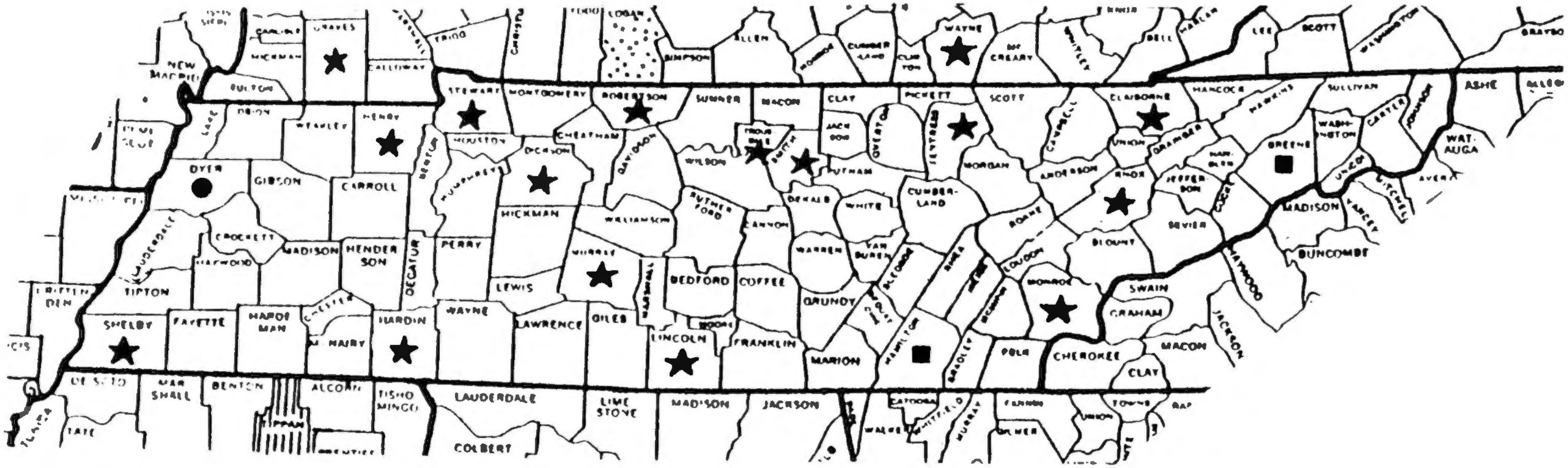

Figure 21. Optimum Livestock Auction Market Locations and Size Categories for Model II with Transportation Cost Increased 10 Percent

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

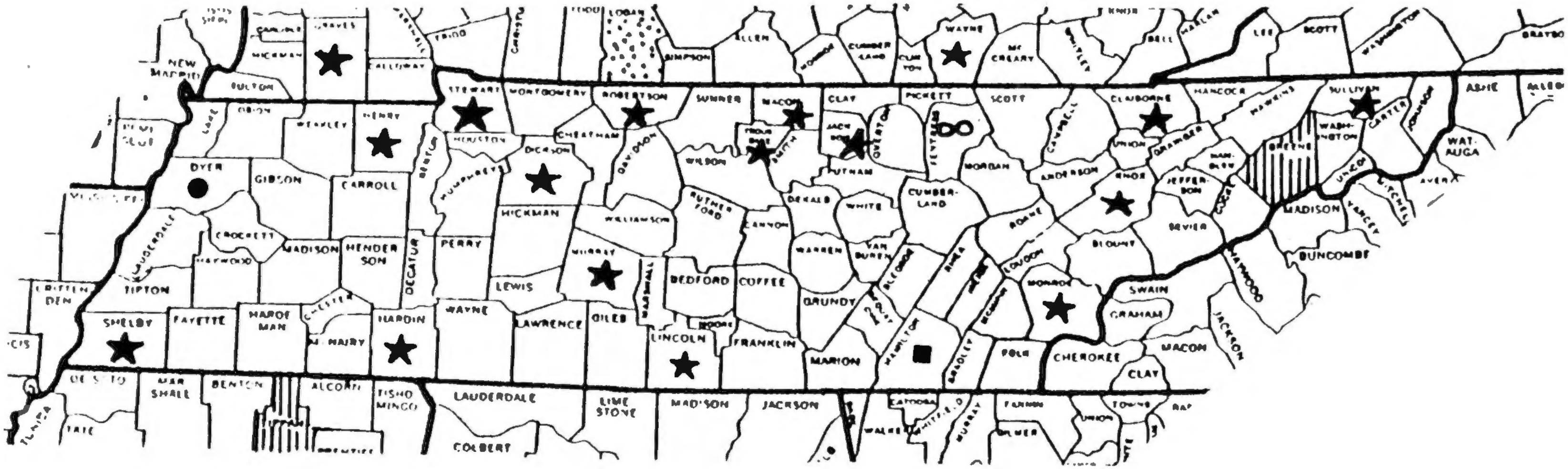

Figure 22. Optimum Livestock Auction Market Locations and Size Categories for Model II with Transportation Cost Increased 25 Percent

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
▒	7001 to 10000	∞	50001 to 80000
☰	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

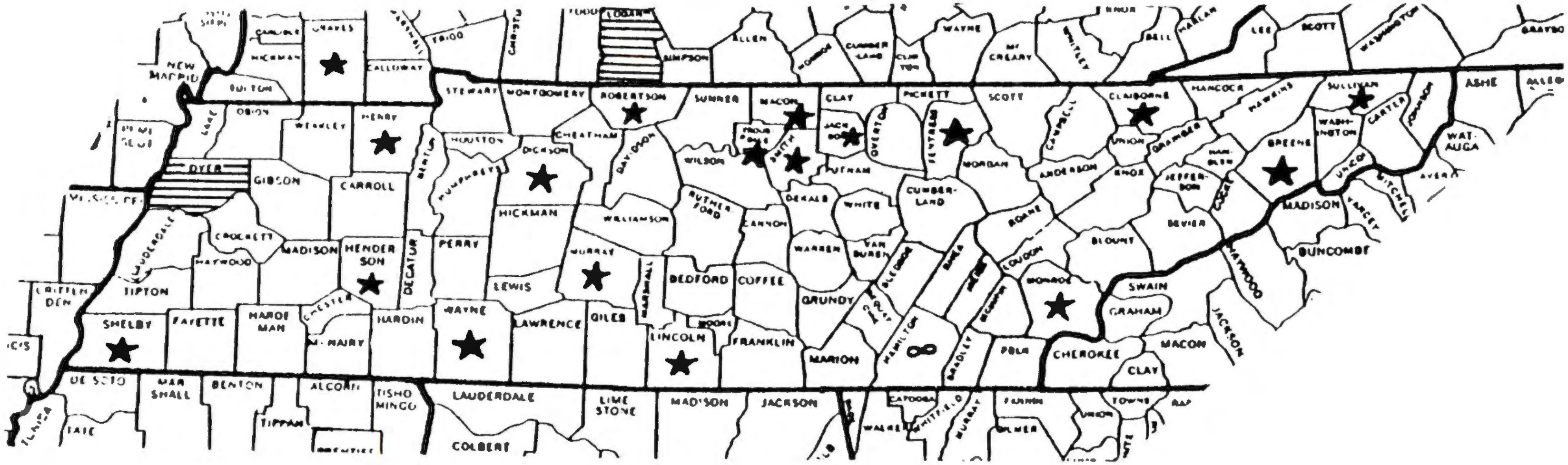

Figure 23. Optimum Livestock Auction Market Locations and Size Categories for Model II with Marketing Cost Increased 10 Percent

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

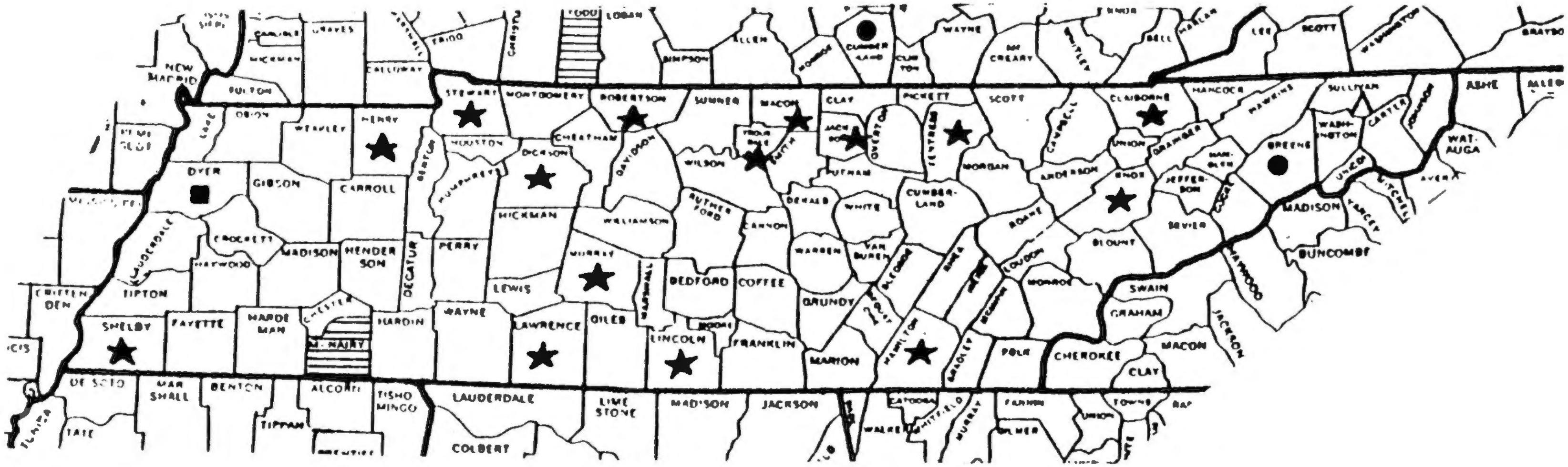

Figure 24. Optimum Livestock Auction Market Locations and Size Categories for Model II with Marketing Cost Increased 25 Percent

Key

Volume of Market

(A.M.U.'s)

▥	≤ 7000	■	30001 to 50000
░	7001 to 10000	∞	50001 to 80000
▤	10001 to 20000	★	80001 to 90000
●	20001 to 30000		

Table 6. Differences in Objective Function Values, and Numbers and Average Volumes of Tennessee Markets Between Solutions of Model II and Its Variations.

Model	Change in the Number of Tennessee Markets	Change in Average Volumes of Tennessee Markets (A.M.U.'s)	Change in Objective Function Value
II -- Livestock No.s Decreased 10%	-4	-1,086	$ 1,627,464
II -- Livestock No.s Decreased 25%	-5	2,033	4,068,479
II -- Livestock No.s Increased 10%	0	1,656	-3,738,069
II -- Livestock No.s Increased 25%	4	3,836	-6,347,712
II -- Transportation Cost Increased 10%	0	309	1,163,238
II -- Transportation Cost Increased 25%	0	-2,943	2,470,475
II -- Marketing Cost Increased 10%	-1	3,426	-2,334,817
II -- Marketing Cost Increased 25%	0	-1,477	-4,997,892

In cases where the solutions for Tennessee values did not behave predictably, a partial explanation is offered. The constraints to current market locations, used to establish an initial feasible solution, direct that an optimal solution will be found in the general area of the existing situation. These initial constraints anchored the optimal market locations for the State in comparison to markets located outside of the State which were very flexible to changes in model parameters.

CHAPTER 4

SUMMARY CONCLUSIONS, AND IMPLICATIONS

Summary

The main objective of this study was to determine the optimal organization of Tennessee's livestock auction markets within a spatial equilibrium framework. Optimal industry organization was defined as the number, sizes, and locations of auction markets that minimize the combined costs of assembling and selling Tennessee's annual livestock marketings that move through auctions. To meet this objective, plant location models were developed to simultaneously consider transportation costs, auction market operation costs, and livestock densities in solving for the optimum market configuration described above.

Transportation costs were developed based on "typical" loads of livestock which were identified from personal interviews with individuals hauling livestock to auction markets. Costs of transportation were estimated using the economic engineering approach.

Livestock densities were included as supplies of livestock in individual counties within the supply area. The supply area was defined to be the state of Tennessee and all adjacent counties within 50 miles of the State border. Livestock data were inventory numbers adjusted by percentages expected to be marketed annually.

Cost of auction market operation were estimated in an earlier study by Spielman, et al., in the form of a nonlinear long run average total cost function (LRATC). Spielman's LRATC function was inflated to 1983 values and converted to total cost for use this study.

The spatial models were solved using separable programming, chosen for its ability to handle large problems and nonlinear functions. Two basic models were examined. Model I incorporated all of the inputs described above. Model II differed only in its marketing cost function which was altered to include an estimate of the change in buyer operating cost which occurs as market volume increases at an individual auction. It was hypothesized that buyers could realize operating cost savings by buying through large markets. The change in buyer cost as volume increased was quantified from a positive relationship between price and volume developed with regression analysis for three animal types.

Model I

The results from Model I in this study suggest that the optimal number of auction markets within Tennessee was 47 with average volume of 26,859 animal marketing units (A.M.U.'s). The number of current market locations used in this study was also 47, but the actual number of markets in the State was 54. Some counties had multiple markets which could only be represented as one market within the programming model.

The responses of Model I's optimal solutions to changes in quantity of livestock and costs were consistent with those predicted by economic and location theory. With declining livestock numbers, the optimal number and average volumes of markets in the State were reduced.

Increases in livestock numbers resulted in larger average volumes and the same number or more markets.

A 10 percent increase in transportation cost increased the optimal market number in the State by one. Model I was most responsive to a 25 percent increase in transportation cost which increased the optimal market number to 56 for Tennessee.

The optimal solutions were not as responsive to varying magnitudes of marketing cost as to transportation cost. When marketing cost increased 10 percent, market numbers were unchanged for the State. A 25 percent increase in marketing cost decreased the optimal market number to 43.

Model II

Model II indicated that 19 was the optimal number of markets in Tennessee. This solution was quite stable for the State under increases in transportation cost, a 10 percent increase in livestock numbers, and a 25 percent increase in marketing cost. The effects of these changes were expressed through changes in average market volumes or changes in market number outside the State.

For other variations in Model II optimal solutions varied as predicted. When marketing costs were increased 10 percent, the optimal market number and average volume declined. Decreases in livestock numbers also decreased the optimal number of markets. Market numbers rose to 23 for Tennessee in the solution of Model II with animal numbers increased 25 percent.

Conclusions

The results of this study show improvements in the efficiency of Tennessee's livestock auction market industry are possible. Decreases in market numbers and relocation of some current markets were found to reduce the combination of transportation and selling costs for the State's annual marketings of livestock.

In 1983, 54 markets were in operation in the State, with an average volume of 21,959 A.M.U.'s. The optimal number of markets was determined to be 47 with an average volume of 26,859 A.M.U.'s, when transportation and marketing costs, and livestock numbers are considered. When the reduction in buyer operating costs associated with large volumes was considered, the optimal number of Tennessee markets was found to be 19 with an average volume of 80,562 A.M.U.'s.

The optimal number of 47 varied by up to three markets with increases or decreases in livestock numbers to be marketed. A slight (10 percent) increase in transportation cost had little affect on the optimal number of markets, but a larger (25 percent) increase raised the number to 56 for the State. A slight increase in marketing cost does not affect the optimal number of 47, but larger increases lowered the number to 43. The optimal number of markets in the State is more sensitive to changes in transportation cost than changes in either marketing cost or livestock numbers.

When the reduction in buyer costs is considered, decreases in livestock numbers up to 25 percent reduce the optimum of 19 markets to 14 for the State. Slight increases in transportation cost have no affect on Tennessee's optimal number of auctions, but increases of 25 percent raise the optimum to 23 markets. Due to the negativity of marketing cost with reductions in buyer cost considered, marketing cost increases do not affect the optimal number of markets in the State.

Implications

The results of the analysis of Tennessee's livestock auction market system imply that the number of markets should be reduced to 47 from the current 54. A policy implication is that licensing of new auction market facilities should be restricted unless livestock numbers or transportation cost increase greatly. If marketing cost alone increases, a further reduction in livestock auction market numbers is suggested.

When the potential reductions in buyer cost associated with large volume markets are considered, market numbers in the State should be reduced to 19. Further reductions would be desirable only if livestock production decreases substantially. This optimal number should be increased only with large increases in livestock numbers and is little affected by increases in either transportation cost or marketing cost.

As a suggestion for further research, the model developed in this study could be expanded to include the cost of livestock distribution from the auction market to its final destination. Consideration of distribution cost should add more realism to the model and improve the accuracy of the optimal solution.

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LITERATURE CITED

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APPENDIXES

APPENDIX A

ESTIMATION OF TRANSPORTATION COST AND AIR-MILE DISTANCES

Estimation of Transportation Cost

The transportation cost of moving one livestock unit from origin to potential auction market destination was estimated for input into this study's separable programming model. The separable programming model was designed to describe the actual cost of transporting livestock and selling livestock at auction markets in Tennessee. For this reason, transportation cost was estimated from a representative, not necessarily most efficient, standpoint.

Sources of Data

Transportation cost data came from several sources. Among these were various government and Extension Service publications, direct price quotations from equipment dealerships and firms, and personal interviews with individuals hauling livestock. The base year of 1983 was used throughout the estimation process in order to be consistent with other parts of the analysis. If data were not available for that year, the most recent data available were adjusted by an appropriate index.

Survey. The basic element in estimating transportation cost was a survey of livestock haulers arriving at auction markets. Results of the survey provided a basis for building cost budgets for various equipment and equipment combinations used to haul livestock from farm to auction market. The results also served as a guide for various simplifying assumptions necessary to the analysis.

For the survey, personal interviews were conducted with haulers at eight Tennessee auction market locations during January and

February of 1984. The auctions visited were located at Scotts Hill, Dickson, Knoxville, Lebanon, Sparta, Newport, and Huntingdon. Separate hog and cattle sales were included at Huntingdon. These markets were chosen to reflect differences in market volume, geographic location, and relative market densities among the three Grand Divisions of Tennessee. A total of 275 persons transporting livestock to the auction markets were interviewed with the questionnaire shown in Figure A-1.

The questionnaire was developed to collect information related to: the number, type and size of animals hauled; the equipment used; the distance and time traveled; the percent of equipment capacity used; and the annual number of market visits by the hauler. Survey results were summarized as shown in Table A-1, and used to identify five typical or characteristic loads of livestock. A transportation cost budget was developed for each of the typical loads identified as follows:

one-half ton truck

one-half ton truck and 16 ft. straight trailer

three-quarter ton truck

three-quarter ton truck and 20 ft. gooseneck trailer

one ton truck

<u>Transportation cost budgets</u>. The transportation cost budgets included both fixed and variable costs. Omitted from the budgets were terminal costs of loading and unloading. These costs are not related to distance and therefore are not affected by market location. Another cost excluded from this study is the cost of shrinkage. As it relates to livestock, shrinkage is a loss of animal weight due to excretion or loss

SURVEY OF PERSONS HAULING LIVESTOCK
TO TENNESSEE LIVESTOCK AUCTION MARKETS

1. How many animals did you bring to market today?

   cattle (> 500 lbs.) ____________ calves (< 500 lbs.) ____________ hogs ____________

2. What is the average weight?

   cattle __________ calves __________ hogs __________ feeder pigs __________

3. What type vehicle was used to transport these animals?
   pickup ____ size (t) ____ trailer ____ size (L) ____
   truck ____ size (t) ____ gooseneck ____ size (L) ____

4. How near full are you?

5. How long did it take you to get here once the animals were loaded?

6. How far did you come?

7. How long do you normally wait in line?

8. Do you normally haul any animals back to the farm?

9. Are these your animals or are you hauling them for someone else?

10. Approximately how many times per year do you go to market?

11. Why did you decide to market today? (Rank)
    Price ____ Animals ready ____
    Convenience ____ Availability of transportation ____

    Other ____

12. Why did you choose this livestock auction market? (Rank)
    Location ____ Number of buyers ____
    Low commissions ____ Management ____
    Higher prices ____ Habit ____

    Other ____

13. What is your source of market price information? (Rank)
    Newspaper ____ Toll-free number ____
    Radio ____ Market operator ____
    Word-of-mouth ____ Newsletter ____

    Other ____

14. Do you prefer auctions to graded sales?
    Yes ____ No ____

15. If yes, why? (Rank)
    Cattle are not graded ____ Sales are not frequent enough ____
    Don't like my cattle mixed with others ____

    Other ____

Figure A-1. Questionnaire Used to Survey Individuals Hauling Livestock to Tennessee Livestock Auction Markets. (Note: Questions 8, 9, and 11--15 were included to gather information for another study.)

Table A-1. Average Survey Responses of Individuals Hauling Livestock to Tennessee Livestock Auction Markets, Winter 1984.

Survey Item	Mean
Animals Hauled (number head)	
Cattle	3.87
Calves	4.85
Hogs	4.21
Average Animal Weights (pounds)	
Cattle	852
Calves	354
Hogs	324
Individuals Surveyed by Equipment Type (percent)	
One-half Ton Truck	29
Three-quarter Ton Truck	12
One Ton Truck*	13
Truck--Straight Trailer	26
Truck--Gooseneck Trailer	20
Utilized Equipment Capacity (percent)	
One-half Ton Truck	53
Three-quarter ton truck	59
One Ton Truck	56
Straight Trailers	56
Gooseneck Trailers	64
Miles traveled (miles)	24
Time Traveled (minutes)	38
Time Waiting to Unload (minutes)	14

* Percentage includes five trucks which ranged in size from 1½ to 2½ tons. Because data on these truck sizes was unavailable, they were included in the one ton truck category for purposes of this study.

of tissue. Tissue shrinkage is increasingly important as travel time increases or as animals are crowded (22, 36). Since this study limited distance traveled to a maximum of 50 miles, and assumed that animals were shipped at less than full equipment capacity, the exclusion of tissue shrinkage was a negligible omission. Excretory shrinkage occurs whenever animals are moved because of stress in handling and loading. Because of its association with terminal activities, excretory shrinkage was considered a terminal cost and also omitted.

Fixed costs. The fixed costs included in the transportation cost budgets were depreciation, interest, insurance, and licenses. Fixed costs are usually calculated on an annual basis and are independent of use. For purposes of this study, these costs were estimated on a per mile basis which required assumptions about useful life and annual mileage.

All trucks were assumed to have annual mileages of 10,000 and a useful life of 10 years (46, p. 11, 10). A useful life of 15 years was used for both straight and gooseneck trailers (46, p. 11). Annual mileage for trailers was derived from the results of the livestock hauler survey. Those surveyed with trailers traveled approximately 400 miles (one-way) to auction markets annually, based on number of visits to market and distance traveled.

Depreciation was calculated by the straight--line method for simplicity. This method expenses the value of an asset in equal amounts per year over its useful life. A zero salvage value was assumed at the end of the equipment's useful life. Original costs were assumed to be the 1983 retail prices of equipment. When more than one price was available, the average was used.

Retail prices for trucks were obtained in phone conversations with five local dealerships. The quotations were given on standard trucks with no special options. Since trucks are primarily used for purposes other than hauling livestock, the costs of any options are considered costs of the alternatives uses. Retail prices for trailers were obtained through phone conversations with nine manufacturing located in the Southeast. Using retail prices and the assumptions given above, depreciation was calculated by the following equation:

$$\text{annual depreciation} = \frac{\text{retail price}}{\text{years useful life}}$$

Insurance cost estimates were obtained from a local Tennessee Farm Bureau representative. Farm Bureau rates are competitive with those of other companies and were assumed representative Statewide. Liability, comprehensive, and collision insurance premiums were quoted under the assumptions that the driver was married, male, and over age 35. Insurance rates for trailers were the same for both straight and gooseneck trailers regardless of value. The following annual insurance costs were used:

one-half or three-quarter ton truck	$290.00
one ton truck	$378.00
straight or gooseneck trailer	$150.00

Interest costs served as a proxy for opportunity costs on invested capital. These costs were calculated on average investment (defined to be one-half of original value), at the 1983 average quarterly interest rate for farm equipment loans of 14.3 percent (64, p. 53).

Licensing costs for all equipment were obtained from the Knox County Court Clerk's Office. The 1983 annual license costs by equipment were:

one-half and three-quarter ton trucks	$20.00
one ton trucks	$35.25
all trailers	$10.75

All annual fixed costs were converted to costs per mile by dividing the annual amount by the assumed annual mileages presented earlier.

Variable costs. The variable costs included in the transportation cost budgets were fuel, oil, and filters, repairs and maintenance, and driver's wages. Gasoline is the fuel used by all trucks in this study. The average retail price in Tennessee for months June through December, 1983, was $1.20 per gallon (63, p. 30). This price included all sales taxes. To convert cost per gallon to cost per mile, miles per gallon (m.p.g.) estimates were needed. For one-half and three-quarter ton trucks, estimates were published at 17 and 15 m.p.g., respectively, by the Environmental Protection Agency (E.P.A.). E.P.A. estimates were not available for one ton trucks; these were obtained from two local truck dealerships and averaged 9 m.p.g.

For truck and trainer combinations, fuel efficiency was decreased by 50 percent in calculating cost per mile (33, p. 5). Oil and filters costs were estimated at 10 percent of fuel costs (46, p. 1).

Total repairs and maintenance costs were estimated at 25 percent of new trailer cost and 60 percent of new truck cost for the life of the equipment (46, p. 11-12). These total costs were first divided by years of useful life and then by annual mileages to convert to cost per mile.

Driver's wages were assumed to $3.99 per hour. This wage was the 1982 wage rate for livestock workers adjusted by the 1983 index of prices paid by farmers (63). Conversion of this hourly wage rate to cost per mile required assumptions about travel speed. An average speed of 37.9 miles per hour was calculated from average miles and time traveled in the survey data. This represents the speed for trucks with and without trailers. Since it is unlikely that a truck--trailer combination would travel as fast as a truck, average speeds of 40 and 35 miles per hour were assumed for trucks and truck--trailer combinations, respectively.

Table A-2 shows fixed, variable, and total costs per mile by equipment type. These costs provide little information about the costs of transporting livestock until equipment capacity is considered.

Equipment capacities in A.T.U.'s.. Capacity for the various transportation methods was based on the area of the truck or trailer bed. The average size of trailers and goosenecks were 16' x 7' and 20' x 7', respectively. According to truck dealerships, the usual bed size of a one ton truck is 10' x 7'. Bed sizes for half and three-quarter ton trucks vary, but generally these trucks can carry approximately two A.T.U.'s. (43, p. 1). Space requirements for one A.T.U. are 20 square feet (43, p. 1) Truck and trailer bed areas divided by the 20 sq. ft. space requirement yielded the following approximate load capacities:

Table A-2. Fixed, Variable, and Total Costs Per Mile by Equipment Type for Hauling Livestock to Markets in Tennessee, 1983.

Cost Category	Cost Item	One-Half Ton Truck ($/mile)	Three-Quarter Ton Truck ($/mile)	One-Half Ton Truck and 16 ft. Trailer ($/mile)	Three-Quarter Ton Truck and 20 ft. Gooseneck ($/mile)	One Ton Truck ($/mile)
Fixed	Depreciation	0.0636	0.0694	0.2000	0.3694	0.1002
	Insurance	0.0290	0.0290	0.1790	0.1790	0.0378
	Interest	0.0455	0.0497	0.2010	0.2452	0.0717
	License	0.0020	0.0020	0.0127	0.0127	0.0353
	Total Fixed	0.1401	0.1501	0.5927	0.8063	0.2450
Variable	Gasoline	0.0706	0.0800	0.1059	0.1200	0.1333
	Oil and Filters	0.0071	0.0080	0.0071	0.0080	0.0133
	Repair and Maintenance	0.0382	0.0417	0.0745	0.1189	0.0601
	Driver's Wages	0.1000	0.1000	0.1140	0.1140	0.1000
	Total Variable	0.2159	0.2297	0.3015	0.3609	0.3067
Total		0.3560	0.3798	0.8942	1.1672	0.5517

one-half ton truck	2 A.T.U.'s
three-quarter ton truck	2 A.T.U.'s
one ton truck	5 A.T.U.'s
16 ft. straight trailer	8 A.T.U.'s
20 ft. gooseneck	10 A.T.U.'s

The above capacities represent full loads. Since transportation cost is being estimated from a representative standpoint, these 100 percent capacities were adjusted to be more representative of typical loads. This adjustment was made using survey data estimates of average percent of capacity used, by equipment type. Survey estimates of average utilized capacity are:

one-half ton trucks	53 percent
three-quarter ton trucks	59 percent
one ton trucks	58 percent
straight trailers	56 percent
goosenecks	64 percent

The above capacity utilization percentages when applied to A.T.U.'s at full capacity yield an estimate of typical loads of livestock in A.T.U.'s. Since the survey data was obtained during winter when volumes of animals marketed are typically lower than volumes in other seasons, the capacity utilization percentages were adjusted upward by 10 percent in order to reflect more normal year-round conditions. After this increase, the following equipment and load size combinations were obtained:

one-half ton truck	1.17 A.T.U.
three-quarter ton truck	1.30 A.T.U.

one ton truck	3.19 A.T.U.
16 ft. straight trailer	4.93 A.T.U.
20 ft. gooseneck	7.04 A.T.U.

These were then divided into the appropriate transportation costs per mile. The results were transportation costs per mile per A.T.U. shown below:

one-half ton truck	$0.3043
three-quarter ton truck	$0.2922
one ton truck	$0.1729
one-half ton truck and 16 ft. straight trailer	$0.1814
three-quarter ton truck and 20 ft. gooseneck	$0.1658

Transportation Cost per A.T.U.

The final step in estimating a representative cost function was to combine the estimates of cost per mile per A.T.U. for individual types of equipment into one "combined" typed of equipment. This combination was achieved by averaging the five costs, with each weighted by the percentage of haulers surveyed who used that type of equipment. Approximate percentages of those surveyed by equipment type were:

one-half ton trucks	29 percent
three-quarter ton trucks	12 percent
one ton trucks	13 percent
straight trailers	26 percent
gooseneck trailers	20 percent

The weighted averaging resulted in a transportation cost of 22.6 cents per mile per A.T.U. This estimate was used in the separable programming model as the cost of transporting one A.T.U. for the distance of one mile. As described in the text, this cost coefficient of 22.6 cents was multiplied by the distance between origin and potential destination to yield the cost of moving one A.T.U. along a route, $_{ij}$.

Estimation of Air-mile Distance

In a paper on "Estimation of Transfer Functions," Tramel and Seale presented a formula for calculating air-mile distances using spherical geometry (62, p. 176). This formula was used to estimate potential route lengths between origins and potential destinations. The formula is expressed as follows (62, pp. 176-177):

$$D_{ij} = RX$$

where

D_{ij} = distance in air miles from point i to point j

R = radius of the earth = 3958.617496 miles,

and

$$X = \frac{\pi}{2} - \sin^{-1} K = \frac{\pi}{2} - \tan^{-1} \frac{K}{\sqrt{1 - K^2}},$$

and

$$K = \sin M_i \sin M_j + \cos M_i \cos M_j \cos(L_i - L_j),$$

and

M_i = latitude of point i in radians

L_i = longitude of point i in radians

M_j = latitude of point j in radians

L_j = longitude of point j in radians

$\pi/2 = 1.570796326795$

and the conversion factors for degrees and minutes to radians are:

1° = 0.01745329293

1´ = 0.00029088821

APPENDIX B

ESTIMATION OF EXPECTED ANNUAL LIVESTOCK MARKETINGS AND LIVESTOCK UNIT CONVERSION FACTOR

Estimation of Expected Annual Livestock Marketings

Annual Marketings of Livestock

The percentage of livestock inventories marketed annually varies in relation to the cattle and hog cycles. When inventories expand, a smaller percentage of inventories are marketed, when they contract, a larger percentage of inventories are marketed. To smooth the effect of variations caused by these cycles, expected annual percentages of livestock marketed through auctions were calculated as average percentages of total livestock inventories weighted by animal type. These weighted average percentages were used to adjust county livestock inventory data to obtain the quantities of livestock to be marketed from each county (origin) in the separable programming model.

Sources of data. Data used to estimate the weighted average percentages were collected from the Tennessee Department of Agriculture's unpublished livestock auction market "Volume of Business" reports and also from the State's agricultural statistics bulletins for years 1973 through 1983. This data are listed in Table B-1.

Estimation of weighted average percentages. To calculate the weighted average percentages, total auction market volumes were expressed as a percentage of total inventory numbers for each year by animal type. Each annual percentage was weighted by the number of animals marketed in that year as a percentage of total marketed for the period. By summing the weighted annual percentages and dividing by the total number of years (11), the weighted average percentages of annual livestock inventories expected to be marketed by animal type

Table B-1. Livestock Inventory Numbers and Auction Market Volumes for Calculating Percentage of Inventory Marketed by Animal Type, 1973 through 1983, Tennessee.

Year	Cattle and Calves Inventory (Head)	Volume of Cattle and Calves Auctioned (Head)	Hog Inventory (Head)	Volume of Hogs Auctioned (Head)
1973	2,936,000	1,011,199	998,000	369,182
1974	3,230,000	1,066,456	1,000,000	439,964
1975	3,550,000	1,588,196	820,000	356,245
1976	3,240,000	1,488,529	1,050,000	313,085
1977	3,240,000	1,724,379	1,200,000	439,128
1978	2,670,000	1,405,107	1,100,000	331,929
1979	2,550,000	1,010,814	1,300,000	354,239
1980	2,300,000	955,051	1,400,000	414,023
1981	2,350,000	988,917	1,140,000	270,927
1982	2,500,000	1,131,231	900,000	202,204
1983	2,675,000	1,133,974	750,000	187,730

were obtained. These percentages were calculated to be 43.2 for cattle and calves, and 36.3 for hogs.

Separation of expected annual marketings of cattle and calves. For the separable programming model, quantities of livestock available at each origin were expressed in A.T.U.'s. Because one cow equals two calves in A.T.U.'s, it was necessary to divide the 43.2 percent of annual cattle and calves inventory expected to be marketed into separate categories for cattle and calves. Without separate cattle and calf percentages, the quantities of livestock available at each origin would have been overestimated since each calf would have been included as one A.T.U.

The combined percentage was separated into one percentage for cattle and one for calves based on data from only those auction markets that reported separate volumes of animals marketed for these two animal types. For the 1973 to 1983 period, an average of 66 percent of all Tennessee markets were listed with separate volumes of cattle and calves in the "Volume of Business" reports (56).

The volume numbers were totaled for each year for both animal types. Each type was expressed as a percentage of the combined total of cattle and calves marketed during each year. The percentages were weighted by the total number of animals marketed that year as a percentage of all animals marketed during the period. The resulting annual weighted percentages of animals marketed by type were summed and divided by the number of years to obtain the weighted average percentages of annual inventory expected to marketed as cattle and as calves. These percentages were 62.5 for cattle and 37.5 for calves. They were used to separate the expected annual marketings of cattle and calves inventory (43.2 percent) into 27.0 percent cattle, and 16.2 percent calves.

Estimation of county livestock quantities to be marketed. County inventory data was multiplied by the percentage of inventory expected to be marketed for each animal type. Estimated earlier, these percentages were 27.0 for cattle, 16.2 for calves, and 36.3 for hogs. The results of the multiplication were the quantities of livestock available to be marketed in each county by animal type on a per head basis. To express these quantities in A.T.U.'s, the quantity for each animal type was divided by the number of animals of that type in an A.T.U. Once converted to A.T.U.'s, the quantities of all animal types in each county could be combined to obtain the total livestock available to be marketed in that county.

Livestock Unit Conversion Factor

Since the mathematical model used A.T.U.'s to measure volume of livestock transported and A.M.U.'s to measure volume of livestock marketed, it was necessary to define a conversion factor between the two types of livestock units. The estimation of this conversion factor was complicated by the fact that changes in the relative proportions of the three animal types, cattle, calves, and hogs, would result in changes in the value of a conversation factor between the two units.

For example, assume 90 animals consisting of 30 cows, 30 calves, and 30 hogs. The number of A.M.U.'s is 70 and the number of A.T.U.'s is 55. In this case, one A.M.U. equals 1.273 A.T.U.'s. Now assume that there are 17 cows, 40 calves, and 33 hogs. The total number of animals is still 90 but there are 68 A.M.U.'s and 48 A.T.U.'s. In this situation one A.M.U. equals 1.417 A.T.U.'s.

To reflect the relative proportion of animal types as accurately as possible for Tennessee, the total numbers of cattle, calves, and hogs marketed from 1973 through 1983 were converted to both types of livestock units and compared. As shown in Table B-2, total livestock units marketed during the period were 14,730,071.7 A.M.U.'s and 12,198,099.2 A.T.U.'s. By dividing the smaller into the larger, the following relationship was obtained:

1 A.M.U. = 1.2076 A.T.U.

This ratio is consistent with the fact that an A.T.U. may consist of two calves while an A.M.U. may consist of only one calf. The two units of measure are the same for cattle and hogs.

Table B-2. Total Animals and Livestock Units Marketed from 1973 through 1983 in Tennessee, and A.M.U. and A.T.U. Equivalencies, by Animal Type.

Animal	Total Number Marketed (Head)	Number of Animals per A.M.U.	Total A.M.U.'s Marketed	Number of Animals per A.T.U.	Total A.T.U.'s Marketed
Cattle	8,439,908	1	8,439,908.0	1	8,439,908.0
Calves	5,063,945	1	5,063,945.0	2	2,531,972.5
Hogs	3,678,656	3	1,226,218.7	3	1,226,218.7
Total			14,730,071.1		12,198,099.2

APPENDIX C

PRICE--VOLUME REGRESSION ANALYSIS AND ESTIMATION OF REDUCTION IN BUYER COST EQUATION

Price--Volume Regression Analysis

As partially described in the text, regression models were developed to determine whether prices vary among auctions in relationship to market volume. Also included in the models were dummy variables to represent price variations caused by differences in sale day and weighing practices.

1982 and 1983 daily prices were collected from unpublished Tennessee Department of Agriculture sources for feeder cattle, slaughter cows, and sows.[1] Each market held only one sale per week. Annual market volumes were obtained from unpublished "Volume of Business" reports (56). Volumes ranged from 7,493 to 63,732 animals (56).

The dependent price variable was expressed as a price index equal to daily price divided by weekly average price. The regression equations were expressed as:

$$\frac{P_{ij}}{\sum_{i=1}^{n} P_{ij}} = \alpha + B_1 \frac{V_i}{\frac{\sum_{i=1}^{n} V_i}{n}} + B_2D_1 + B_3D_2 + B_4D_3 + B_5D_4 + B_6W$$

---

[1] The daily price data specifically applied to 400-500 pound, medium framed, number 1 muscled feeder steers, to all weights of utility grade cows, and all sows under 500 pounds.

where:

P_{ij} = the daily price at the ith auction market during the jth week.

n = the number of markets (n=16)

V_i = annual volume of sales for the ith market

D_1--D_4 = 0, 1, -1 dummy variables for day of the week on which the sale was held (Monday through Friday with Friday omitted).

W = a 1 or -1 dummy variable representing weighing practice (in-weight or out-weight, respectively).

The dummy variable for weighing practice was 1 if in-weight, and -1 if out-weight. This 1, -1 configuration allows for comparisons of each class of dummy variables with the overall mean of all classes (45, p. 136). Dummy variables for day of sale were specified for Monday through Thursday, omitting Friday to avoid singularity. The variables were assigned either a 1 or a 0, except when Friday occurred the other days were assigned a -1 value. The use of these dummy variable configurations allowed the effects of sale day and weighing practice on the dependent variable to be separated from the overall estimate of the intercept.

The regression results were highly significant at the 0.01 percent level indicating a positive relationship between relative price and volume. R^2 values were 0.06 for feeder cattle, 0.25 for slaughter cows, and 0.05 for sows. Volume and intercept coefficients were highly significant as shown in Table C-1.

Estimation of Reduction in Buyer Costs

As mentioned in the text, the positive price--volume relationship served as a proxy for the hypothesized negative relationship between

Table C-1. Volume and Intercept Coefficients and Standard Errors from the Regression Analysis of Daily Price Index on Market Volume from 16 Tennessee Auction Markets, by Animal Type, 1982 and 1983.

Animal Type	Variable	Coefficients	Standard Error
Feeder Cattle	Volume	7.1868^{-7*}	0.00000010
	Intercept	0.9751*	0.00345443
Slaughter Cows	Volume	8.7901^{-7*}	0.00000080
	Intercept	0.9633*	0.00267470
Sows	Volume	1.5544^{-6*}	0.00000040
	Intercept	0.9957*	0.00057023

* Statistically significant at the 0.01 percent level.

buyer operating cost and volume. This substitution was made by equating the difference in buyer cost per cwt. (Δ C) to the negative of the difference in price (Δ P) since prices and buyer costs should move in opposite directions with a given change in volume. To make this substitution, it was necessary to redefine the relationship between the price index and volume (V) into a relationship between Δ P and V.

The price index--volume relationship may be expressed in the following form:

$$\frac{MP}{AMP} = \alpha + bV$$

where

MP is market price per cwt.

AMP is average market price per cwt.

To express the relationship in terms of price, the equation was multiplied by AMP:

$$MP = \alpha \; AMP + bVAMP$$

Since Δ P equals MP minus AMP, subtraction of AMP from both sides will yield the needed equation:

$$MP - AMP = \alpha \; AMP - AMP + bVAMP$$

or,

$$\Delta \; P = AMP \; (\alpha - 1) + bVAMP$$

This equation was multiplied by -1 to replace Δ P per cwt. with Δ C per cwt., and obtain an equation for the difference in buyer cost per cwt (Δ C), as a function of AMP and V:

$$\Delta C = -AMP(\alpha - 1) - bVAMP$$

ΔC equations were developed for each animal type. Estimates of α and b came from the regression analysis results for each animal type. Because the effects of sale day and weighing practice were separated from the intercept, their estimated coefficients could be ignored in deriving ΔC. 1983 average prices from the regression data sets were converted from dollars per cwt. to dollars per A.M.U. using the average animal weights and A.M.U. numbers given in Table C-2. The ΔC equations by animal type are:

Feeder Cattle: $\Delta C = 7.132685 - 0.000206163\ V$

Slaughter Cows: $\Delta C = 12.003663 - 0.000287391\ V$

Hogs: $\Delta C = 1.299063 - 0.000467809\ V$

The cost reduction (ΔC) equations were weighted by the proportion of feeder cattle, slaughter cows, and sows in the annual marketings of livestock to combine the three equations into one. The proportions or percentages were developed in Appendix B from Tennessee auction volume and livestock inventory data for years 1973 through 1983. The percentage was estimated to be 43.232 percent for cattle and calves, and 36.29 percent for hogs. Since separate percentages for feeder cattle and slaughter cows were needed to weight the individual cost reduction equations, the following assumptions about cattle productivity and herd replacement rates were made:

(1) The annual calving percentage is 80 percent.

(2) Breeding cows are replaced every six years.

(3) Bulls are replaced every five years.

(4) The ratio of bulls to cows is one to 30.

Table C-2. Average Animal Prices and Weights for Data Used in the Price--Volume Regression Analyses, 1983.

Animal Type	Average Price ($/cwt.)	Average Weight* (lbs.)	Number of Animals/A.M.U.	Average Price/A.M.U. ($)
Feeder Cattle	63.75	450	1	286.86
Slaughter Cows	38.46	850	1	326.95
Sows	37.62	400	2**	300.95

* Average weights were obtained from a representative of the Tennessee Crop Reporting Service.

** For purposes of calculating reduction in buyer cost only, the number of hogs per A.M.U. was modified from three to two animals. This change was necessary due to the relatively large size of the animals (sows) used in the regression analysis. Otherwise, livestock units are as previously defined.

When the above assumptions are applied to a breeding herd of 1,000 cows, the resulting inventory is 1,000 cows, 33 bulls, and 800 calves. If replacement animals are taken from the annual cālf crop, and 167 cows and 6 bulls are culled, then 627 calves remain to be marketed as feeder cattle. The resulting total animals marketed is 800. Of this number, 22 percent (173 culls) were slaughter cows, and 78 percent (627 calves) were feeder cattle.

Table C-3 shows the total estimated A.M.U.'s marketed and percentages of this total by animal type. These percentages were used to weight the Δ C equations by animal type for their combination into the following equation which is the average change in buyer cost per A.M.U. as volume (in A.M.U.'s) changes:

$$\Delta C = 7.357876 - 0.00025391445 V$$

Before adding this average cost difference to the marketing cost function, Δ C was multiplied by volume to get change in total buyer cost:

$$TC = 7.357876 V - 0.00025391445 V^2$$

This equation was then added to the marketing cost function expressed as:

$$TC_{1983} = 27{,}554.97 + 4.872834 V - \frac{33{,}686{,}926.42}{V}$$

to yield the total net marketing cost function (TNC) for Model II which is:

$$TNC = 27{,}554.97 + 12.23071 V - \frac{33{,}686{,}926.42}{V} - 0.00025391445 V^2$$

The TNC function is graphed in Figure 4, page 31, in the text.

Table C-3. Data Used to Estimate Annual Marketings in A.M.U.'s and Percentages of Annual Marketings by Animal Type.

Category	Feeder Cattle	Slaughter Cows	Sows
1983 Inventory Numbers	2,029,827*	572,528*	866,050
Percent of Inventory Marketed	0.432249	0.432249	0.36207
Total Number Marketed	877,410	247,475	314,296
Number of Animals per A.M.U.	1	1	2**
Percent of Total Marketed	0.68439	0.19202	0.12258

* Reflects separation of the inventory number for all cattle and calves into feeder cattle and slaughter cows as 78 and 22 percent of inventory, respectively.

** In all other sections of this study, three hogs equals one A.M.U. This equivalency was modified for calculation of reduction in buyer cost, due to the large size of the sows in the regression analysis data set.

APPENDIX D

MARKET LOCATIONS AND VOLUMES BY COUNTY AND STATE FOR MODELS I AND II

Table D-1. Actual Livestock Auction Market Locations and Volumes in Tennessee by Counties, 1983.

County	Volume (A.M.U.'s)
Anderson	6,764
Bedford	5,950
Cannon	5,943
Carroll	33,162
Claiborne	13,989
Cocke	10,912
Coffee	13,814
Crockett	23,389
Cumberland	35,938
Dickson	46,047
Dyer	23,455
Fentress	6,092
Gibson	11,425
Giles	22,343
Greene*	37,642
Hamblen	12,785
Hamilton	30,954
Hardemon	8,767
Hardin	14,965
Hawkins	5,042
Henderson*	20,886
Henry	7,811
Jackson	7,615
Knox	51,782
Lawrence	13,883
Lincoln*	84,850
Macon	16,442
Marion	13,178
Marshall	8,754
Maury*	45,272
Monroe	43,041
Putnam	11,632
Robertson	14,252
Rutherford	13,878
Sevier	4,576
Shelby*	69,560
Smith*	53,176
Stewart	10,529
Sullivan	30,064

Table D-1 (continued)

County	Volume (A.M.U.'s)
Tipton	4,556
Trousdale	12,840
Warren	16,989
Washington	15,232
Weakley	1,762
White	20,786
Williamson	13,250
Wilson	6,329

* County had more than one market. Volume is the sum of the volumes for all markets in the county.

Table D-2. Model I: Optimum Livestock Auction Market Locations and Volumes by County and State for Tennessee and Bordering Counties in Other States.

County	State	Volume (A.M.U.'s)
Jackson	AL	15,598
Lauderdale	AL	36,598
Limestone	AL	34,071
Mississippi	AR	18,682
Fannin	GA	2,003
Allen	KY	16,173
Christian	KY	43,424
Cumberland	KY	49,046
Graves	KY	17,266
Whitley	KY	3,565
Marshall	MS	14,452
Tippah	MS	6,109
Tishomingo	MS	18,459
Ashe	NC	33,428
Haywood	NC	13,027
Swain	NC	382
Anderson	TN	18,221
Carroll	TN	15,937
Claiborne	TN	21,000
Cocke	TN	16,773
Coffee	TN	42,552
Crockett	TN	37,092
Cumberland	TN	29,802
Dickson	TN	51,810
Dyer	TN	11,921
Fentress	TN	36,412
Gibson	TN	20,513
Giles	TN	31,719
Greene	TN	40,436
Hamblen	TN	44,090
Hamilton	TN	29,029
Hardemon	TN	36,950
Hardin	TN	8,977
Hawkins	TN	35,900
Henderson	TN	25,730
Henry	TN	22,751
Jackson	TN	13,482

Table D-2 (continued)

County	State	Volume (A.M.U.'s)
Johnson	TN	6,069
Knox	TN	29,351
Lawrence	TN	32,077
Lincoln	TN	25,010
Macon	TN	11,757
Marion	TN	7,085
Marshall	TN	49,093
Maury	TN	50,027
Monroe	TN	68,010
Obion	TN	21,606
Perry	TN	4,781
Putnam	TN	15,618
Rhea	TN	5,630
Robertson	TN	26,074
Rutherford	TN	32,421
Shelby	TN	14,619
Smith	TN	16,013
Stewart	TN	22,310
Sullivan	TN	21,014
Trousdale	TN	35,126
Warren	TN	46,662
Washington	TN	26,378
Weakley	TN	19,952
White	TN	26,249
Williamson	TN	40,757
Wilson	TN	27,566
Lee	VA	9,331

Table D-3. Model I: Optimum Livestock Auction Market Locations and Volumes by County and State with Livestock Numbers Decreased 10 Percent below 1983 Levels.

County	State	Volume (A.M.U.'s)
Jackson	AL	14,038
Lauderdale	AL	32,938
Limestone	AL	30,664
Mississippi	AR	16,797
Dade	GA	1,402
Fannin	GA	1,803
Christian	KY	39,082
Cumberland	KY	44,142
Wayne	KY	27,782
Whitley	KY	11,605
New Madrid	MO	25,521
Marshall	MS	13,007
Haywood	NC	8,306
Watauga	NC	24,321
Yancey	NC	3,660
Carroll	TN	14,344
Claiborne	TN	18,899
Cocke	TN	15,096
Coffee	TN	38,297
Crockett	TN	33,383
Cumberland	TN	26,821
Dickson	TN	46,629
Dyer	TN	27,609
Fentress	TN	32,770
Gibson	TN	18,462
Giles	TN	28,547
Greene	TN	42,274
Hamblen	TN	39,681
Hamilton	TN	31,101
Hardemon	TN	33,255
Hardin	TN	8,079
Hawkins	TN	23,310
Henderson	TN	23,157
Henry	TN	20,476
Jackson	TN	12,134
Knox	TN	31,088
Lawrence	TN	28,869
Lincoln	TN	22,509

Table D-3 (continued)

County	State	Volume (A.M.U.'s)
Macon	TN	25,137
Marshall	TN	44,183
Maury	TN	45,024
Meigs	TN	5,067
Monroe	TN	61,209
Perry	TN	4,303
Polk	TN	3,527
Putnam	TN	14,056
Roane	TN	5,830
Robertson	TN	23,466
Rutherford	TN	29,179
Shelby	TN	13,157
Smith	TN	14,411
Stewart	TN	20,079
Sullivan	TN	18,913
Trousdale	TN	31,613
Warren	TN	41,996
Washington	TN	23,740
Weakley	TN	17,957
White	TN	23,624
Williamson	TN	36,682
Wilson	TN	24,810
Lee	VA	8,397

Table D-4. Model I: Optimum Livestock Auction Market Locations and Volumes by County and State with Livestock Numbers Decreased 25 Percent below 1983 Levels.

County	State	Volume (A.M.U.'s)
Jackson	AL	11,699
Lauderdale	AL	27,449
Madison	AL	13,265
Mississippi	AR	14,012
Dade	GA	1,168
Fannin	GA	1,502
Allen	KY	69,032
Clinton	KY	39,363
Hickman	KY	15,189
Todd	KY	42,630
Wayne	KY	23,524
Whitley	KY	2,674
New Madrid	MO	21,267
Benton	MS	4,049
Desota	MS	6,309
Marshall	MS	6,790
Avery	NC	1,304
Haywood	NC	9,770
Mitchell	NC	1,741
Swain	NC	286
Watauga	NC	3,690
Anderson	TN	13,666
Carroll	TN	11,953
Claiborne	TN	15,749
Cocke	TN	12,580
Coffee	TN	52,939
Crockett	TN	27,819
Cumberland	TN	22,351
Dickson	TN	38,858
Dyer	TN	23,007
Fentress	TN	22,845
Gibson	TN	15,385
Giles	TN	36,077
Greene	TN	30,327
Hamblen	TN	33,068
Hamilton	TN	25,918
Hardemon	TN	27,712
Hardin	TN	6,733

Table D-4 (continued)

County	State	Volume (A.M.U.'s)
Hawkins	TN	19,425
Henderson	TN	19,297
Henry	TN	12,677
Jackson	TN	10,112
Johnson	TN	4,552
Knox	TN	22,013
Lawrence	TN	24,058
Lincoln	TN	34,552
Macon	TN	23,010
Maury	TN	37,520
Meigs	TN	4,223
Monroe	TN	51,007
Perry	TN	3,586
Polk	TN	2,940
Putnam	TN	11,713
Robertson	TN	19,555
Rutherford	TN	24,316
Shelby	TN	10,964
Smith	TN	12,010
Stewart	TN	16,733
Sullivan	TN	15,761
Trousdale	TN	47,019
Warren	TN	34,996
Washington	TN	18,043
Weakley	TN	14,964
White	TN	19,687
Williamson	TN	30,568
Grayson	VA	19,467
Lee	VA	6,998
Scott	VA	6,171

Table D-5. Model I: Optimum Livestock Auction Market Locations and Volumes by County and State with Livestock Numbers Increased 10 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Jackson	AL	17,158
Limestone	AL	18,022
Madison	AL	19,456
Mississippi	AR	20,551
Walker	GA	29,849
Allen	KY	17,790
Clinton	KY	43,465
Cumberland	KY	63,048
Hickman	KY	22,531
Simpson	KY	30,342
Todd	KY	31,796
Trigg	KY	13,742
Wayne	KY	34,502
Whitley	KY	3,921
Tippah	MS	6,720
Alcorn	MS	5,477
Desota	MS	25,957
Marshall	MS	15,898
Ashe	NC	23,050
Haywood	NC	12,337
Swain	NC	420
Yancey	NC	4,473
Anderson	TN	23,550
Carroll	TN	17,531
Claiborne	TN	23,099
Cocke	TN	18,450
Coffee	TN	46,807
Crockett	TN	40,801
Cumberland	TN	32,782
Dickson	TN	56,991
Dyer	TN	33,744
Fentress	TN	13,897
Gibson	TN	22,564
Giles	TN	34,891
Greene	TN	51,668
Hamblen	TN	48,499
Hamilton	TN	32,881

Table D-5 (continued)

County	State	Volume (A.M.U.'s)
Hardemon	TN	40,645
Hardin	TN	9,875
Hawkins	TN	28,490
Henderson	TN	28,302
Henry	TN	18,594
Jackson	TN	14,830
Johnson	TN	6,676
Knox	TN	32,286
Lawrence	TN	35,285
Lincoln	TN	27,511
Marshall	TN	54,002
Maury	TN	55,029
Meigs	TN	6,193
Monroe	TN	74,811
Perry	TN	5,259
Pickett	TN	22,649
Polk	TN	4,311
Putnam	TN	17,180
Robertson	TN	28,681
Rutherford	TN	35,663
Shelby	TN	16,081
Smith	TN	17,614
Stewart	TN	10,800
Sullivan	TN	23,116
Trousdale	TN	38,639
Warren	TN	51,328
Washington	TN	29,015
Weakley	TN	21,947
White	TN	28,874
Williamson	TN	44,833
Wilson	TN	30,323
Lee	VA	10,264

Table D-6. Model I: Optimum Livestock Auction Market Locations and Volumes by County and State with Livestock Numbers Increased 25 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Jackson	AL	19,497
Lauderdale	AL	45,748
Madison	AL	42,589
Crittenden	AR	846
Mississippi	AR	21,126
Fannin	GA	2,504
Murray	GA	3,478
Allen	KY	35,488
Christian	KY	54,281
Clinton	KY	36,940
Graves	KY	14,638
Hickman	KY	25,214
McCreary	KY	621
Simpson	KY	34,480
Whitley	KY	4,456
Desota	MS	29,497
Marshall	MS	11,317
Tippah	MS	21,470
Tishomingo	MS	23,074
Haywood	NC	14,019
Swain	NC	477
Anderson	TN	26,762
Bedford	TN	35,042
Cannon	TN	17,035
Carroll	TN	19,922
Claiborne	TN	26,249
Clay	TN	58,803
Cocke	TN	46,244
Coffee	TN	53,190
Crockett	TN	36,659
Cumberland	TN	14,567
Dickson	TN	64,763
Dyer	TN	38,346
Fentress	TN	15,792
Gibson	TN	25,641
Giles	TN	39,649
Greene	TN	50,546

Table D-6 (continued)

County	State	Volume (A.M.U.'s)
Hamblen	TN	55,113
Hamilton	TN	36,286
Hardemon	TN	36,173
Hardin	TN	21,235
Hawkins	TN	32,375
Henderson	TN	32,162
Henry	TN	28,439
Johnson	TN	15,910
Knox	TN	19,578
Lawrence	TN	40,096
Lincoln	TN	31,263
Macon	TN	14,697
Marion	TN	8,856
Marshall	TN	26,323
Maury	TN	62,533
Monroe	TN	85,012
Perry	TN	5,977
Polk	TN	4,899
Putnam	TN	19,522
Rhea	TN	29,723
Robertson	TN	32,592
Rutherford	TN	40,526
Smith	TN	20,016
Stewart	TN	12,272
Sullivan	TN	26,268
Tipton	TN	29,336
Trousdale	TN	43,908
Warren	TN	41,292
Washington	TN	30,071
Weakley	TN	24,940
White	TN	32,811
Williamson	TN	50,947
Wilson	TN	34,458
Grayson	VA	62,796
Lee	VA	11,663

Table D-7. Model I: Optimum Livestock Auction Market Locations and Volumes by County and State with Transportation Cost Increased 10 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Jackson	AL	15,598
Lauderdale	AL	36,598
Limestone	AL	16,384
Madison	AL	17,687
Mississippi	AR	18,682
Fannin	GA	2,003
Walker	GA	21,887
Allen	KY	16,173
Christian	KY	18,086
Cumberland	KY	35,871
Fulton	KY	27,527
Graves	KY	11,710
Hickman	KY	11,479
Logan	KY	30,501
Simpson	kY	7,903
Wayne	KY	31,366
Whitley	KY	3,565
New Madrid	MO	1,767
Desota	MS	23,598
Marshall	MS	14,452
Tippah	MS	6,109
Tishomingo	MS	18,459
Ashe	NC	31,689
Avery	NC	1,739
Cherokee	NC	3,897
Mitchell	NC	2,321
Carroll	TN	15,937
Claiborne	TN	27,550
Cocke	TN	16,773
Coffee	TN	42,552
Crockett	TN	37,092
Cumberland	TN	11,654
Dickson	TN	42,013
Dyer	TN	11,921
Fentress	TN	21,774
Gibson	TN	20,513
Giles	TN	31,719

Table D-7 (continued)

County	State	Volume (A.M.U.'s)
Greene	TN	44,929
Hamilton	TN	29,892
Hardemon	TN	36,950
Hardin	TN	8,977
Hawkins	TN	25,900
Henderson	TN	24,730
Henry	TN	16,903
Hickman	TN	19,550
Humphreys	TN	15,237
Jackson	TN	13,482
Johnson	TN	6,069
Knox	TN	20,854
Lawrence	TN	32,077
Lincoln	TN	25,010
Macon	TN	11,757
Marshall	TN	49,093
Maury	TN	35,258
Meigs	TN	41,020
Monroe	TN	46,871
Polk	TN	3,919
Putnam	TN	30,256
Roane	TN	6,478
Robertson	TN	26,074
Rutherford	TN	32,421
Sevier	TN	14,070
Shelby	TN	14,619
Smith	TN	16,013
Stewart	TN	4,378
Sullivan	TN	21,014
Trousdale	TN	35,126
Warren	TN	46,662
Washington	TN	24,057
Weakley	TN	19,952
White	TN	26,249
Williams	TN	40,757
Wilson	TN	27,566
Grayson	VA	24,281
Lee	VA	9,331

Table D-8. Model I: Optimum Livestock Auction Market Location and Volumes by County and State with Transportation Cost Increased 25 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Jackson	AL	15,598
Lauderdale	AL	36,598
Limestone	AL	16,384
Madison	AL	17,687
Crittenden	AR	696
Mississippi	AR	18,682
Fannin	GA	2,003
Walker	GA	21,887
Allen	KY	16,173
Calloway	KY	23,114
Clinton	KY	22,900
Logan	KY	30,501
Simpson	KY	41,855
Wayne	KY	31,366
Whitley	KY	3,565
Pemiscot	MO	809
Marshall	MS	14,452
Tippah	MS	6,109
Cherokee	NC	3,897
Haywood	NC	13,027
Mitchell	NC	2,321
Swain	NC	382
Watauga	NC	31,814
Yancey	NC	4,067
Bledsoe	TN	23,778
Campbell	TN	6,552
Carroll	TN	15,937
Claiborne	TN	20,999
Cocke	TN	16,773
Coffee	TN	16,451
Crockett	TN	29,327
Cumberland	TN	11,654
Dickson	TN	42,013
Dyer	TN	11,113
Fayette	TN	16,899
Fentress	TN	12,634
Franklin	TN	20,866

Table D-8 (continued)

County	State	Volume (A.M.U.'s)
Gibson	TN	20,513
Giles	TN	31,719
Greene	TN	40,436
Hamblen	TN	44,090
Hamilton	TN	24,364
Hardemon	TN	12,050
Hardin	TN	8,977
Hawkins	TN	25,900
Henderson	TN	25,730
Henry	TN	16,903
Hickman	TN	14,769
Humphreys	TN	15,237
Jackson	TN	13,482
Knox	TN	20,854
Lauderdale	TN	17,591
Lawrence	TN	32,077
Lincoln	TN	25,010
Macon	TN	30,680
Marion	TN	5,528
Marshall	TN	49,093
Maury	TN	35,258
McNairy	TN	8,011
Monroe	TN	64,113
Obion	TN	21,606
Perry	TN	4,781
Polk	TN	3,919
Putnam	TN	30,256
Roane	TN	6,478
Robertson	TN	26,074
Rutherford	TN	32,421
Scott	TN	3,188
Sevier	TN	13,688
Shelby	TN	4,077
Smith	TN	16,013
Stewart	TN	16,870
Sullivan	TN	21,014
Trousdale	TN	35,126
Warren	TN	51,896
Washington	TN	24,057
Weakley	TN	19,952
White	TN	26,249

Table D-8 (continued)

County	State	Volume (A.M.U.'s)
Williamson	TN	4,067
Wilson	TN	27,566
Grayson	VA	50,237
Lee	VA	9,331

Table D-9. Model I: Optimum Livestock Auction Market Locations and Volumes by County and State with Marketing Cost Increased 10 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Jackson	AL	15,598
Lauderdale	AL	36,598
Limestone	AL	34,071
Mississippi	AR	18,682
Walker	GA	27,136
Calloway	KY	23,114
Cumberland	KY	49,046
Todd	KY	56,841
Wayne	KY	31,366
Whitley	KY	3,565
Tippah	MS	6,109
Tishomingo	MS	18,459
Haywood	NC	11,041
Watauga	NC	27,023
Yancey	NC	21,349
Anderson	TN	11,670
Carroll	TN	15,937
Claiborne	TN	27,550
Cocke	TN	16,773
Coffee	TN	42,552
Crockett	TN	37,092
Cumberland	TN	29,802
Dickson	TN	51,810
Dyer	TN	11,921
Fentress	TN	15,822
Gibson	TN	20,513
Giles	TN	31,719
Greene	TN	46,971
Hamblen	TN	44,090
Hamilton	TN	29,892
Hardemon	TN	42,349
Hardin	TN	8,977
Hawkins	TN	25,900
Henderson	TN	35,730
Henry	TN	16,903
Jackson	TN	13,482
Knox	TN	15,663

Table D-9 (continued)

County	State	Volume (A.M.U.'s)
Lawrence	TN	32,077
Lincoln	TN	25,010
Macon	TN	27,930
Marshall	TN	49,093
Maury	TN	50,027
Meigs	TN	5,630
Monroe	TN	68,100
Perry	TN	4,781
Pickett	TN	20,590
Polk	TN	3,919
Putnam	TN	15,618
Robertson	TN	26,074
Rutherford	TN	32,421
Sevier	TN	13,688
Smith	TN	16,013
Stewart	TN	9,818
Sullivan	TN	21,014
Trousdale	TN	35,126
Warren	TN	46,662
Washington	TN	24,057
Weakley	TN	19,952
White	TN	26,249
Williamson	TN	40,757
Wilson	TN	27,566
Grayson	VA	50,237
Lee	VA	9,331

Table D-10. Model I: Optimum Livestock Auction Market Locations and Volumes by County and State with Marketing Cost Increased 25 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Jackson	AL	32,028
Lauderdale	AL	36,598
Mississippi	AR	18,682
Fannin	GA	2,003
Allen	KY	16,173
Christian	KY	43,424
Clinton	KY	52,484
Logan	KY	28,783
Simpson	KY	41,855
Wayne	KY	31,366
Whitley	KY	3,565
Haywood	NC	41,430
Watauga	NC	27,023
Anderson	TN	11,670
Carroll	TN	15,937
Claiborne	TN	27,550
Cocke	TN	16,773
Coffee	TN	42,552
Crockett	TN	37,092
Cumberland	TN	29,802
Dickson	TN	51,810
Dyer	TN	30,677
Fentress	TN	30,460
Gibson	TN	20,513
Giles	TN	48,103
Greene	TN	40,436
Hamblen	TN	44,090
Hamilton	TN	34,660
Hardemon	TN	42,349
Hardin	TN	8,977
Hawkins	TN	35,900
Henderson	TN	25,730
Henry	TN	22,751
Jackson	TN	13,482
Knox	TN	29,351
Lawrence	TN	32,077
Lincoln	TN	42,697

Table D-10 (continued)

County	State	Volume (A.M.U.'s)
Macon	TN	30,680
Marion	TN	7,085
Maury	TN	50,027
Monroe	TN	71,929
Perry	TN	4,781
Putnam	TN	15,618
Robertson	TN	26,074
Rutherford	TN	32,421
Shelby	TN	14,619
Smith	TN	16,013
Stewart	TN	22,310
Sullivan	TN	21,014
Trousdale	TN	35,126
Warren	TN	46,662
Washington	TN	30,444
Weakley	TN	22,803
White	TN	26,249
Williamson	TN	40,757
Wilson	TN	27,566
Grayson	VA	50,237
Lee	VA	9,331

Table D-11. Model II: Optimum Livestock Auction Market Locations and Volumes by County and State for Tennessee and Bordering Counties in Other States.

County	State	Volume (A.M.U.'s)
Graves	KY	90,000
Logan	KY	14,519
Wayne	KY	90,000
Tippah	MS	6,109
Claiborne	TN	90,000
Dickson	TN	90,000
Dyer	TN	23,584
Fentress	TN	90,000
Greene	TN	29,055
Hamilton	TN	38,034
Hardin	TN	90,000
Henry	TN	90,000
Jackson	TN	90,000
Knox	TN	90,000
Lincoln	TN	90,000
Macon	TN	90,000
Maury	TN	90,000
Monroe	TN	90,000
Robertson	TN	90,000
Shelby	TN	90,000
Stewart	TN	90,000
Sullivan	TN	90,000
Trousdale	TN	90,000

Table D-12. Model II: Optimum Livestock Auction Market Locations and Volumes by County and State with Livestock Numbers Decreased 10 Percent below 1983 Levels.

County	State	Volume (A.M.U.'s)
Wayne	KY	90,000
Graves	KY	90,000
Logan	KY	13,067
Tippah	MS	5,498
Bledsoe	TN	34,634
Claiborne	TN	90,000
Dyer	TN	21,226
Fentress	TN	90,000
Greene	TN	56,275
Hardin	TN	90,000
Henry	TN	90,000
Lincoln	TN	90,000
Maury	TN	90,000
Robertson	TN	90,000
Shelby	TN	90,000
Smith	TN	90,000
Stewart	TN	90,000
Sullivan	TN	90,000
Trousdale	TN	90,000

Table D-13. Model II: Optimum Livestock Auction Market Locations and Volumes by County and State with Livestock Numbers Decreased 25 Percent below 1983 Levels.

County	State	Volume (A.M.U.'s)
Bell	KY	412
Fulton	KY	46,097
Monroe	KY	90,000
Whitley	KY	2,674
Pemiscot	MO	30,989
Bledsoe	TN	90,000
Fentress	TN	90,000
Giles	TN	90,000
Greene	TN	20,966
Hardin	TN	90,000
Henry	TN	90,000
Jackson	TN	90,000
Knox	TN	90,000
Lincoln	TN	90,000
Monroe	TN	68,983
Robertson	TN	90,000
Shelby	TN	76,381
Stewart	TN	90,000
Lee	VA	6,998

Table D-14. Model II: Optimum Livestock Auction Market Locations and Volumes by County and State with Livestock Numbers Increased 10 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Fulton	KY	90,000
Monroe	KY	90,000
Todd	KY	90,000
Desota	MS	40,586
Dickson	TN	90,000
Fentress	TN	90,000
Giles	TN	90,000
Greene	TN	13,410
Hamilton	TN	18,724
Hardemon	TN	90,000
Hardin	TN	90,000
Hawkins	TN	90,000
Henry	TN	90,000
Knox	TN	90,000
Lincoln	TN	90,000
Macon	TN	90,000
Maury	TN	90,000
Monroe	TN	90,000
Putnam	TN	90,000
Robertson	TN	90,000
Shelby	TN	90,000
Sullivan	TN	90,000
Trousdale	TN	90,000

Table D-15. Model II: Optimum Livestock Auction Market Locations and Volumes by County and State with Livestock Numbers Increased 25 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Logan	KY	90,000
Wayne	KY	90,000
New Madrid	MO	90,000
Desota	MS	90,000
Haywood	NC	16,368
Claiborne	TN	90,000
Crockett	TN	90,000
Dickson	TN	90,000
Fentress	TN	41,762
Giles	TN	90,000
Greene	TN	90,000
Hamilton	TN	90,000
Henry	TN	90,000
Knox	TN	90,000
Lincoln	TN	90,000
Macon	TN	90,000
Marshall	TN	90,000
Maury	TN	90,000
McNairy	TN	19,645
Monroe	TN	90,000
Pickett	TN	90,000
Robertson	TN	90,000
Shelby	TN	79,739
Smith	TN	90,000
Stewart	TN	90,000
Sullivan	TN	90,000
Trousdale	TN	90,000
Wilson	TN	90,000

Table D-16. Model II: Optimum Livestock Auction Market Locations and Volumes by County and State with Transportation Cost Increased 10 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Graves	KY	90,000
Logan	KY	8,254
Wayne	KY	90,000
Tippah	MS	6,109
Claiborne	TN	89,402
Dickson	TN	90,000
Dyer	TN	23,584
Fentress	TN	90,000
Greene	TN	38,284
Hamilton	TN	35,286
Hardin	TN	90,000
Henry	TN	90,000
Knox	TN	90,000
Lincoln	TN	90,000
Macon	TN	90,000
Maury	TN	90,000
Monroe	TN	90,000
Robertson	TN	90,000
Shelby	TN	90,000
Smith	TN	90,000
Stewart	TN	90,000
Sullivan	TN	90,000
Trousdale	TN	90,000

Table D-17. Model II: Optimum Livestock Auction Market Locations and Volumes by County and State with Transportation Cost Increased 25 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Graves	KY	90,000
Logan	KY	8,254
Wayne	KY	90,000
Tippah	MS	6,109
Claiborne	TN	84,514
Dickson	TN	90,000
Dyer	TN	23,584
Fentress	TN	78,375
Greene	TN	1,558
Hamilton	TN	30,052
Hardin	TN	90,000
Henry	TN	90,000
Jackson	TN	90,000
Knox	TN	86,670
Lincoln	TN	90,000
Macon	TN	90,000
Maury	TN	90,000
Monroe	TN	90,000
Robertson	TN	90,000
Shelby	TN	90,000
Stewart	TN	90,000
Sullivan	TN	90,000
Trousdale	TN	90,000

Table D-18. Model II: Optimum Livestock Auction Market Locations and Volumes by County and State with Marketing Cost Increased 10 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Graves	KY	90,000
Logan	KY	14,519
Wayne	KY	90,000
Claiborne	TN	90,000
Dickson	TN	90,000
Dyer	TN	11,113
Fentress	TN	90,000
Greene	TN	90,000
Hamilton	TN	60,665
Henderson	TN	90,000
Henry	TN	90,000
Jackson	TN	90,000
Lincoln	TN	90,000
Macon	TN	90,000
Maury	TN	90,000
Monroe	TN	90,000
Robertson	TN	90,000
Shelby	TN	90,000
Smith	TN	90,000
Sullivan	TN	90,000
Trousdale	TN	90,000

Table D-19. Model II: Optimum Livestock Auction Market Locations and Volumes by County and State with Marketing Cost Increased 25 Percent above 1983 Levels.

County	State	Volume (A.M.U.'s)
Cumberland	KY	20,035
Todd	KY	17,356
Claiborne	TN	90,000
Dickson	TN	90,000
Dyer	TN	35,228
Fentress	TN	90,000
Greene	TN	29,055
Hamilton	TN	90,000
Henry	TN	90,000
Jackson	TN	90,000
Knox	TN	90,000
Lawrence	TN	90,000
Lincoln	TN	90,000
Macon	TN	90,000
Maury	TN	90,000
McNairy	TN	12,017
Robertson	TN	90,000
Shelby	TN	90,000
Stewart	TN	90,000
Sullivan	TN	90,000
Trousdale	TN	90,000

VITA

Emily A. McClain was born in Columbia, Tennessee on October 10, 1960. She graduated from Mt. Pleasant High School in 1978, and began her undergraduate studies at The University of Tennessee, Knoxville in the same year.

She received a Bachelor of Science degree in Agricultural Economics in Winter, 1982. After graduation she accepted a Graduate Assistantship position and began the M.S. program with the Department of Agricultural Economics and Rural Sociology. Immediately following completion of the requirements for the Masters degree at The University of Tennessee, Knoxville, in August 1985, she entered the doctoral program in Food and Resource Economics at the University of Florida, Gainesville.