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BEEF PRODUCTIVITY INCREASES IN THE SOUTHEASTERN UNITED STATES SINCE 1920*

> *Cattle are vegetarians, we eat their meat, and thus we live actually on the grass of our pastures.*   Karl von Frisch

The value of the cattle herds in the United States in January 1963 was $14.3 billion—the same as U.S. gold reserves in May 1965. But unlike sterile gold, the U.S. cattle stock now yields a net product equal to 42 per cent of its own live weight each year. The size of the capital stock of cattle and its real rate of production are the highest ever. Changes in productivity and the present rate of production vary considerably among the states, but the causes of progress and backwardness alike remain largely unexplained.

I. INTRODUCTION

In the decade of the 1950's beef production in the United States increased about 30 per cent above the highest level previously attained. Moreover, the expansion took place while prices were falling. Production in animal units (of 1,000 pounds live weight) increased from about 23 million to almost 30 million a year. Although the average farm price of cattle rose to $22 a hundredweight between 1949 and 1952, during the decade of the 1940's it had been closer to $18. Thus, the price decline of 22 per cent to $14 during the years 1953 to 1957 was sharp, and prices recovered to $18 only after 1958.

These facts suggest either that real costs of beef production were drastically reduced or that returns to the fixed capital of beef producers fell during the mid-1950's. The persistent increase in production in the face of falling prices argues that lower costs are the main explanation. If this is true, the industry

exemplifies significant economic progress, and it is important to measure the productivity increase and to discover precisely how it was possible to reduce production costs.

Two broad explanations of increased beef production at lower prices suggest themselves. One clearly is lower feed costs resulting from technical improvements in grass, forage, protein concentrate, and grain production. The other is increased technical efficiency in converting feed into beef—the net result of improved animal breeding and nutrition, and the control of disease and parasites, which reduced death losses. Although all these improvements have occurred, their relative economic importance has never been determined.

Our notorious inability to forecast cattle prices may well be in part due to the fact that the cattle numbers cycle and changes in production techniques sometimes coincide. So far, however, very little progress has been made in measuring technical change in cattle production. One reason for this lag in evaluation is that measuring livestock production is more complex than measuring crop output. The sources of technical improvements in grain production can be assessed directly, because both harvested acreage and yield per acre are measurable (2). In the case of grass, however, estimates of production increases can be made only indirectly, by inference from cattle production, which in turn reflects not only changes in cattle numbers and in the amount of grass grown, but also changes in the efficiency with which animals convert this feed into beef. It would clearly be desirable to estimate the rate of change and to measure the effects of changes in cattle production techniques as a step toward analyzing these forces into their components.

The causes of increased productivity in cow herds in the western rangeland no doubt differ from those that explain more rapid steer fattening in the Corn Belt, or those associated with the marked increase in fat-animal and feeder production in the humid southeastern states. Thus, to study the problem on a national scale it is necessary to study the various geographical regions, searching for the key to increased productivity in the context of each situation. Because of sweeping changes in land use and unusually rapid improvements in cattle production in the southeastern states, as they increased their share of U.S. beef production from 9.6 per cent in 1940 to 12.9 per cent in 1962, the area offers a particularly promising opportunity for study. The present inquiry focuses on the contiguous ten-state area comprised of Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Arkansas, Louisiana, and Florida.

The stock of all cattle on hand January 1 in the ten southeastern states increased from 6.4 million in 1924 to 11.98 million animal units in 1963 (Appendix Table I). At the same time, annual production increased from 1.1 to 4.06 million animal units. Thus, the southeastern states rose in this period from a position of comparative inferiority, measured both in volume and in efficiency of production, to one of much greater prominence. As the relative importance of the region has increased so markedly, an understanding of the factors underlying the increase in productivity would provide insights into the achievements of the entire industry. Moreover, the topographic and climatic features of the area are representative of the humid subtropical climates found in many underdeveloped areas where

livestock industries have yet to achieve the increases in productivity that the southeastern states of the United States have already experienced.

This study accordingly has two objectives. The first is to measure the change in beef production efficiency that has taken place in the ten southeastern states over the past 40 years. The second is to delineate the causes so that their relative importance and the significance of timing can eventually be established.

In order to analyze the changes in efficiency and the factors underlying those changes, several new concepts of measurement are introduced and applied to the statistical data for the years 1924–1963. The basic data and the measurement concepts to which they relate are presented in Appendix Table I.

Before turning in Section III to the quantitative analysis of the key variables responsible for the increase in productivity, the striking changes in the agricultural economy of the region during the past quarter century are reviewed in summary.

II. AN OVERVIEW OF AGRICULTURAL CHANGE IN THE
SOUTHEASTERN STATES, 1939–1963

The Transition from Cash Crops to Livestock Farming

The rise of cattle production in the southeastern states is perhaps the most obvious manifestation of a broad and fundamental change in the area's agriculture between 1940 and 1960. It is beyond the scope of this study to give a thorough account of the changes in the agricultural organization of these states, much less the broader social and economic issues. Yet certain principles of resource use under conditions of changing technology surge to the fore, and I shall sketch what seem to be the central facts required for a coherent account of the transition from crop to livestock farming.

Among the forces dominating the change from intensive crop farming to extensive grass culture was the rise of mechanized cotton production in the Mississippi Delta, and of irrigated and mechanized cotton culture in the Southwest and the West, against which the old plantation Cotton Belt could not compete. Corn, the area's other important, if secondary, intensive crop, lost much of its local market when the horse and mule population declined. And the Southeast had never been able to compete with the Corn Belt in specialized production. Primarily as a result of these two factors, cropland area in the ten southeastern states fell from 57.7 million acres in 1939 to just over 38 million in 1959. In 1939 cropland had accounted for 34 per cent of the land in farms, but the 1959 figure was only 24.5 per cent. Most of the 18.7-million-acre decrease in crops is accounted for by a 14-million-acre increase in permanent pasture, but changes in land use were numerous and complex.

Development of grassland agriculture in the South, with its high density of farm population and small farms, was facilitated by the increased labor mobility accompanying the great industrial expansion of the wartime and postwar periods. In addition, the cotton acreage allotment program stimulated the exodus of workers (*12*, pp. 34, 43). One effect of these forces was the substantial decrease in man-hours of labor used for farm work in the southeastern states; the total fell from 4.3 million man-hours in 1940 to 1.7 million in 1961 (*9*, p. 42). This decrease was accompanied by an absolute reduction in the farm labor force in

the ten states, from 2.24 million to 1.66 million. And there was an increase in average farm size of almost 50 per cent, from 84.8 acres in 1940 to 123.9 acres by 1954. During the period 1940–61, the index of farm output per man-hour rose from 37 to 120 for the United States as a whole, but in the southeastern states it rose 3.8 times, from 33.5 to 130, an impressive testimonial to the effectiveness of more nearly full rural employment and a higher investment per man.

Grass production was increased in various ways over the past twenty years on the reorganized farms in this region. Apart from the increases brought about by transferring land from cash crops to pasture, many thousands of acres of grassland were made accessible, or improved, by reclamation. Reseeding old pastures with new or improved grass or legume varieties, clearing new land, and constructing cattle walkways through marshlands were among the methods used.

While it is impossible to estimate the number of acres of grassland created in the South by private investment alone, it is possible to show that the various government programs supplemented farmers' efforts to an important degree. The Agricultural Conservation Program, initiated in 1936, gave financial assistance averaging $215 million a year after 1949. Moreover, a sample of years shows that, excepting South Carolina and Florida, the southeastern states received 40 per cent more financial support, on the average, than other states in the Union. In 1960, for example, the state-average acreage on which temporary protective covering had been established was nearly 25,000 acres; but it averaged almost 300,000 acres in the southeastern states, excluding South Carolina and Florida (*8*, p. 642). Farmers also made use of the Conservation Reserve Program, initiated in 1956, for removing poor land from cultivation and shifting it to conservation uses. Since World War II, thousands of acres in the middle coastal plain and tidewater regions have been cleared and permanent pastures established. Construction of cattle walkways in the midst of millions of acres of nutritious but generally inaccessible forage contributed a new source of relatively inexpensive but highly advantageous winter forage. Freshwater marsh provides a source of maiden cane or *paille fine* and giant cutgrass which begin growth in late winter and make good forage until midsummer.

Again, well over one-fourth of all U.S. land in drainage enterprises in 1950 was situated in the ten southeastern states, and since 1960 they have accounted for over 60 per cent of the net increase in acreage drained since 1940 (*6*, p. 407). In the year ended mid-1961, of the U.S. total of just over 1.5 million acres on which drainage improvements were made in cooperation with the Soil Conservation Service, 25 per cent were in the ten southeastern states (*8*, p. 653).

The carrying capacity of pasture land in the southeastern states, formerly only one animal unit per ten acres, was increased considerably by introducing improved grasses and legumes suited to the various soils and weather conditions of the region.

Within 20 years after its release in 1939, three million acres of Coastal Bermuda grass had been planted in the South. This acreage was estimated in the early 1960's to have an annual value of more than $50 million above what could have been realized from an equivalent acreage of common Bermuda grass. Coastal Bermuda grass continues to be widely used as pasture and hay for dairy and beef cattle in the southeastern states, and is credited with having encour-

aged the shift from row-crop farming to livestock farming (*11*, pp. 135–36). Coastal Bermuda grass, fed as silage, for example, increased per-acre production of beef to 948 pounds from 457 pounds, when grazed continuously (*3*, pp. 297–300).

Another advantage of this grass is that it is effective in controlling root knot nematode (*4*, pp. 100–04). Introduction of the new species, along with the new methods of fertilizing pastures, has increased the carrying capacity of the pasture by extending the grazing season and raising total grass production.

Several studies have shown tremendous increases in beef yield per acre when fertilizers were applied to permanent pastures. In Georgia, for example, the beef yield per acre increased from 81.8 pounds for unfertilized pastures to 358.6 pounds for pastures receiving 600 pounds of 0-12-6 fertilizer. And farmers applied the knowledge gained from experiments; between 1930 and 1950, the southeastern states were the largest consumers of the principal plant nutrients supplied by commercial fertilizers. Of the total tonnage of phosphorus used in the entire United States in 1943, more than 40 per cent—224,609 tons—was used by seven southeastern states (*10*, p. 555).

Improved pastures also helped to produce better results with breeding animals. In Florida it was found that a calf crop of 50 per cent could be increased to 75 per cent from cows pastured on improved forage species grown on limed and fertilized soils. Thus, although the South traditionally used fertilizers, especially nitrogen for its tilled crops, application of complete fertilizers to pastures has become a general practice only recently (*1*).

In central Kentucky, since 1940, construction of new wells under the Agricultural Conservation Program removed the principal obstacle to increasing pasture acreage. In 1955, for instance, more than 500 wells for livestock water were sunk, and about 900 were put down in Georgia, Alabama, and Louisiana.

In the period under study, in summary, the forces of interregional competition caused the acreage of intensive intertilled crops to decline in the southeastern states, with the result that former croplands were seeded to permanent pasture, wastelands were reclaimed, and poorer pasture lands were given over to reforestation. It is reasonable to conclude that these changes could have increased the total production of forages enough to support a much larger cattle population. As the data show that the cattle population doubled, it seems reasonable to conclude that these measures at least doubled the output of feed energy. Although increased consumption of oil meals and feed-grains imported into the area was a factor, it is also true that feed-energy input per animal increased, and that large numbers of feeder cattle are exported from the area.

The Growth of the Livestock Industry

Cattle raising is, of course, one aspect of land use. Cattle live and grow on feed grown in competition with cultivated crops on the intensive margin and with forests on the extensive margin. Abstracting for the moment from the demand for beef, which so far does not appear to present any long-run problem, the success of cattle in competing for land depends both on the efficiency of the land in producing feed and on the efficiency of animals in converting feed to salable products. The high degree of interdependence between these two sys-

tems—production of raw materials and their processing—creates a delicate balancing problem. Expansion of feed production is pointless unless cattle numbers rise concurrently, and cattle numbers cannot rise beyond the limit set by present feed production. Changes in land use in the southeastern states from unmechanized, intensive, row-crop culture in a depression economy in the 1930's to an agricultural economy supporting a modern cattle industry have been summarized. What were the requisite improvements in cattle breeding and livestock management?

As the focus of this study is on technical change in beef production, our interest in dairy cattle is confined to their contribution to the total supply of beef, namely, steers of dairy origin and cull cows which are slaughtered. A striking feature of the industry, nevertheless, is that the proportion of all cows kept for milk in the ten southeastern states has declined continuously, while the proportion of cows kept for beef production has persistently increased. Thus, even when viewed from the standpoint of beef production, those technical improvements in dairying which led to higher milk output per cow contributed to increased specialization in beef production.

In the mid-1930's the South was not an important part of the U.S. cattle industry. Even though it possessed 14 per cent of the nation's cattle, it accounted for only 9 per cent of the annual output of beef (7, p. 568). Between 1939 and 1959, however, income from cattle and calves as a percentage of total cash receipts rose in all ten southeastern states, and the area accounted for an increased share of the rising national output.

Although British breeds constitute over 95 per cent of the registered cattle in the United States, these breeds were not adapted to the South. They not only lacked resistance to heat and insects, but were also unable to make good use of the coarse, tropical-type forages grown there (7, p. 571; 11, p. 280). Cross-breeding of the local cattle with Indian types resistant to disease proved the most successful method of developing cattle suited to the area. By 1950, 20 per cent of the cattle in the Gulf Coast region had been crossed with Brahmans with good results.

The increased percentage of adapted cows and calves, together with the expansion of fodder supplies, made it profitable to expand the beef industry in the South. And, as the total cattle population in the southeast increased, the *percentage* of beef cows also increased and that of dairy cows declined. As shown in Table 1, the percentage of cows in the total population was almost unchanged, but this conceals drastic changes in type of cows and the purpose for which they were kept. In 1924, 40 per cent of the animals were cows kept for milk. The range was from a low of 11.1 per cent in Florida to 54.5 per cent in North Carolina. By 1963, in contrast, 38.1 per cent of the animals were cows kept for beef production. The range was from 24.9 per cent in North Carolina to nearly 48 per cent in both Florida and Louisiana. Thus, while cows were almost a constant proportion of all animals in both 1924 and 1963 (55.1 vs. 56.3), the relative percentages of milk and beef cows were almost exactly reversed.

Along with the shift in type of cows came crucial changes in calving and calf survival rates. Historically, states specializing in dairy production have had both higher calving rates and higher first-year mortality rates than states spe-

TABLE 1.—TRANSITION FROM DAIRY TO BEEF PRODUCTION AS SHOWN BY
CATTLE HERD COMPOSITION IN 1924 AND 1963*

	Percentage of all cattle numbers classed as						Percentage of 10-state total animal units	
	Milk cows		Other cows		All cows			
State	1924	1963	1924	1963	1924	1963	1924	1963
Kentucky	47.1	23.1	7.2	29.6	54.3	52.7	12.2	15.0
Tennessee	44.0	25.6	6.4	31.0	50.4	56.7	12.6	13.0
North Carolina	54.5	30.7	4.9	24.9	59.4	55.6	6.9	5.7
South Carolina	51.7	20.5	7.4	35.2	59.1	55.7	4.0	3.1
Georgia	36.7	14.8	19.1	36.8	55.8	51.6	12.0	9.2
Alabama	42.8	16.8	12.8	42.1	55.6	58.9	12.1	12.9
Mississippi	41.1	14.4	12.7	42.3	53.8	56.7	10.8	10.4
Arkansas	43.0	15.8	9.4	43.2	52.4	59.0	10.4	8.8
Louisiana	28.0	14.6	27.4	47.8	55.4	62.4	10.0	11.5
Florida	11.1	11.0	43.2	48.0	54.3	59.0	8.4	10.5
Ten-state total	40.0	18.7	15.1	38.1	55.1	56.8	100.0	100.0

* Computed from January 1 cattle numbers as reported by the U.S. Department of Agriculture for 1924 in its Bureau of Agricultural Economics, *Livestock on Farms and Ranches on January 1: Number, Value, and Classes, 1920–39, by States* (Statistical Bulletin 88, 1950), pp. 23–27; and for 1963 in its *Supplement for 1963 to Livestock and Meat Statistics 1962* (Supplement for 1963 to Statistical Bulletin 333, August 1964), p. 7. Cows include heifers two years old and over. See Appendix Table I for definition of animal units.

cializing in beef production. But the change from dairy to beef cows in the Southeast coincided with a trend toward higher calving rates from the better-fed cows of improved breeding and toward greater control of beef-calf mortality rates.

It is therefore clear that the growth of the livestock industry was associated with specialization in beef production. The old cattle industry was based on unspecialized dairy production; the new, on beef-cow herds, grass-fed steers, and feeder cattle for export to the Corn Belt.

III. ANALYSIS OF FACTORS RESPONSIBLE FOR THE INCREASE
IN BEEF PRODUCTION

The number of cattle in the ten southeastern states almost doubled, from just over 8 million in 1924 to slightly more than 16 million in 1963. During the same time period, annual production increased from 1.1 million animal units to 4.1 million animal units, a fourfold increase. As the basic inventory of animals increased only twice, it is evident that the productive efficiency per animal also must have doubled.

But to discover and date the specific technical changes responsible for this inferred improvement in productive efficiency, we need a method for discriminating between the effects of changes in cattle numbers and improvements in the efficiency of feed conversion. The need arises because the data on annual beef production reflect the joint effects of these variables combined.

To be practical, the method must work with the data we have: cattle numbers by age and sex on January 1 by states for each year, and estimates of annual production. The latter take account of year-to-year changes in inventory and inshipments of live cattle into each state. To develop the method, I have used the well-known concepts of production inherited from classical economic theory,

the main categories used in modern aggregative analysis, and some old but little-used methods of statistical inference.

Beef Cattle Production, Investment, and Consumption

The stock, S, of all cattle is an inventory of invested capital, but it is also an inventory of consumer goods. Cattle production, Y, in any year depends on the size of the calf crop, the rate of gain of growing steers and heifers, and on weight changes in breeding animals. Production is therefore closely related to the size of the stock of animals resulting from the previous level of investment, I. Un-like most goods, however, consumption, C, of beef is not restricted to current production because the stock of capital and the final product are, in the last analysis, one and the same. Each decision to increase the stock of capital out of current production reduces current consumption; each decision to slaughter unfinished animals reduces the stock of capital. Inasmuch as the price of cattle for slaughter is determined by the quantity supplied in relation to consumer demand, investment demand may be said to compete with demand for consumption. If current price trends affect future price expectations, then any tendency toward increased investment would be cumulative, because rising prices would raise price expectations, and thereby induce even greater investment, further reducing the number of animals offered for slaughter. The opposite holds for liquidation. Both tendencies seem probable when production techniques, the total supply of resources, and total demand all remain constant.

This relationship between production, consumption and investment is the same as the familiar identity used in national income accounting: $Y = C + I$, where, to repeat, Y represents annual production, C is consumption, and I is the difference between year-end inventories, S, all measured in animal units of 1,000 pounds live weight. When these relationships are used to interpret the published data on January 1 cattle numbers, annual estimates of beef production, and cattle prices, a new view of technical change in cattle production emerges.

The Concept of "Production Rate" Applied to Beef Cattle

Total production per year is defined by the USDA as the net increase in tons of beef on hoof from the animals on hand the previous January first. (See description of column 6 in Appendix I.) To measure changes in *productivity*, reliable estimates of the annual *rate* of production are required. A logical index of pro-ductivity is the percentage rate of increase in the stock of cattle, measured from the January 1 inventory. Two calculations are required to make reported data correspond to this concept. First, the number of head of each of the various cate-gories of cattle into which the January 1 estimate of cattle numbers is divided, must be combined into comparable units. The animal unit concept is applied, and the January 1 inventory figures for the ten southeastern states, for both heads and animal units, are shown in Appendix Table I. Second, production, which is reported in 1,000 pounds live weight (animal units), is shown in column 6, Appendix Table I.

The principal result, the *production rate,* is shown in Appendix Table I, col-umn 7, and in Charts 1 and 2. The *rate* of production, expressed in animal units as a percentage of the January 1 stock, was approximately 17 per cent in 1924,

but by 1963 had risen to 33.9 per cent. This result establishes an estimate of the magnitude of the effects of the various known changes in production methods that have occurred during these 40 years.

The changes in production rate are summarized by a fitted logistic curve in Chart 2, as they are for each state in subsequent charts. The considerations that led to use of the logistic curve are discussed in Appendix II. Since the logistic curve is symmetrical, the location of the inflection point allows one to fix the date when half the attainable progress in a given environmental setting has been made.

It is clear from the doubling of the production rate that production techniques must have been drastically changed. Even so, output could not have been increased so rapidly without the increase in the basic stock of cattle. These facts lead to two fundamental questions. First how was it possible to double the net rate of output per animal per year? Second, what were the main incentives that induced the increase in investment in the basic cattle stock? We now examine the first question.

In a sense, cattle are machines that convert roughages and grain into beef and more machines. As in industry, more highly specialized machines would be expected to yield increased efficiency of operation. The continuing reduction in the number of dairy cows and the increasing relative importance of beef cows, along with improved breeding and selection within beef breeds, were changes of this nature.

CHART 1.—CATTLE PRODUCTION RATE WITH FITTED EXPONENTIAL TREND, TEN SOUTHEASTERN STATES, 1924–63*
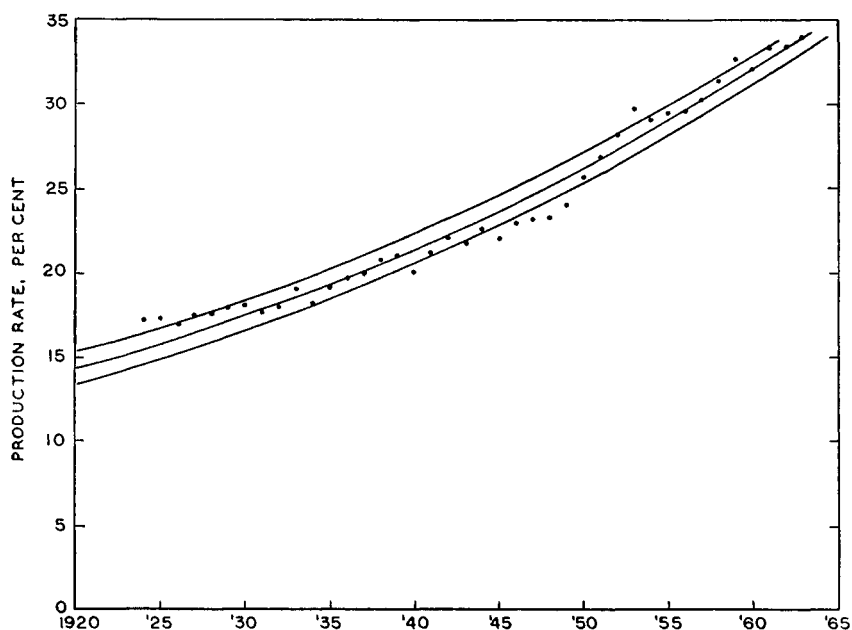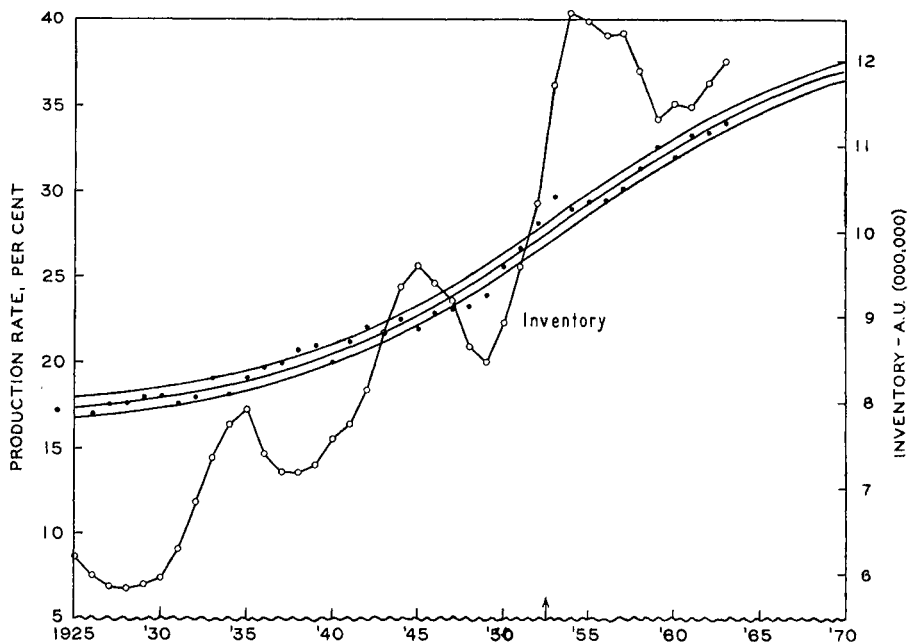

* The solid dots are computed data; figures shown and described in Appendix I. The solid lines are a fitted exponential trend plus and minus one standard error (see Appendix II).

Improved control of death losses and reduced attrition from the numerous diseases and parasites, internal and external, that waste the resources invested in cattle production, work in the direction of increasing the annual rate of production. Improved feeding of young stock hastens maturity and has probably also been a factor in increasing the calving rate of mature cows.

Not only do improvements in nutrition hasten maturity and increase resistance to disease and parasites, but the development of improved rations has increased the efficiency with which the most expensive feed input—corn—is used. The acceptance of the soybean as a field crop, the development of soybean oil-meal as a reliable source of cheap, high-quality protein, and the discovery of protein supplement mixtures served to increase the productivity of pasture, silage, and grain in the conversion process.

The machine analogy sheds some light on the question of how increased production rates were in fact achieved. Production rate is determined by the rate at which new units (calves) are produced and the rate at which they grow. The efficiency of the cow herd, like the efficiency of the machine tool industry, depends on the real cost of producing a unit of product. The energy cost of producing a weaned calf, for example, depends directly on the calving rate and the calf death rate. The annual feed cost of a barren cow or of a cow whose calf dies before weaning must be carried by the survivors. Thus, taking the feed energy cost of

CHART 2.—CATTLE PRODUCTION RATE WITH FITTED LOGISTIC TREND, AND CATTLE INVENTORY IN ANIMAL UNITS, TEN SOUTHEASTERN STATES, 1924-63*

* The solid dots are computed data described, and figures for the ten-state total shown, in Appendix I. The solid lines are a fitted logistic trend plus and minus one standard error; the vertical arrow on the date line indicates the inflection point (see Table 2 and Appendix II). Animal units (AU) are described in Appendix I.

maintaining a cow in the beef herd for a year as 1, the cost of rearing a weaned calf falls from 2, with a 50 per cent calf crop weaned, to 1.1 for a 90 per cent crop. There are also interest charges on the value of the capital in cows and the possibility of capital loss from falling cattle prices. All these costs are reduced when the calving rate is raised or the calf death rate is reduced.

Changes in Net Reproduction Rate

These considerations emphasize the desirability of measuring the change in the net rate of reproduction. To do this, the number of calf deaths was subtracted from the number of calves born, and the net number of new "units" was expressed as a percentage of the January 1 number of animals in inventory. These data together with the fitted logistic trend of the series are shown in Chart 3. (See also column 8 of Appendix Table I.) It shows a dramatic rise from about 30 per cent between 1925 and 1935 to a new plateau near 40 per cent beginning in 1952. The high correlation between the net reproduction rate and the production rate is apparent from comparing Charts 2 and 3 (or columns 7 and 8 in Appendix Table I). Clearly, higher calf crops and lower calf death rates explain an important part of the observed increase in production rate.

Changes in Weight Gain: Production per Reproduced Head

But improvements in reproduction efficiency are only a part of the answer. New units are valuable only if it is profitable to increase their size and weight. This suggests that it would be helpful to ask what has happened to the rate at which animals, on the average, gain weight. One answer is to express production —which measures both gain in numbers and gain in weight—on a per head basis

CHART 3.—CATTLE NET REPRODUCTION RATE WITH FITTED LOGISTIC TREND,
TEN SOUTHEASTERN STATES, 1924–63*
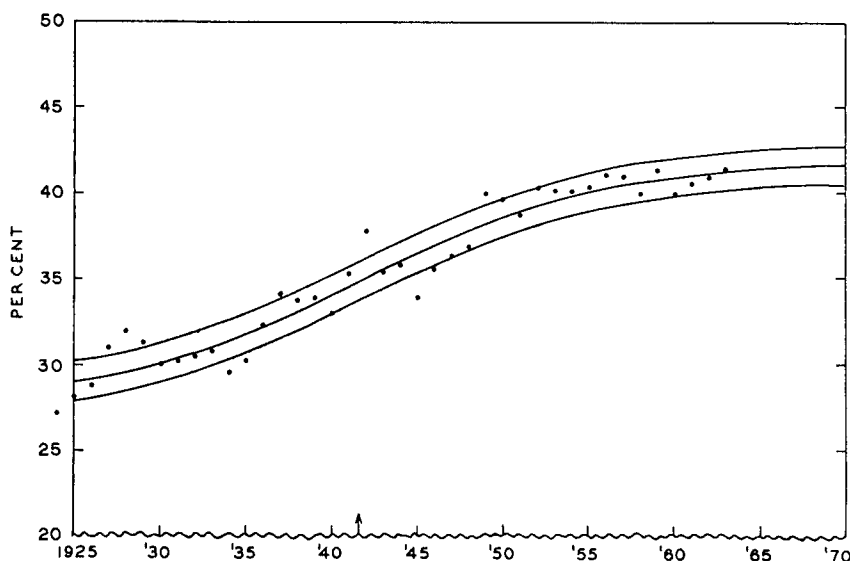
* See note for Chart 2. The figures are shown in Appendix Table I, column 8.

CHART 4.—CATTLE PRODUCTION IN ANIMAL UNITS PER HEAD REPRODUCED WITH
FITTED LOGISTIC TREND, TEN SOUTHEASTERN STATES, 1924–63*
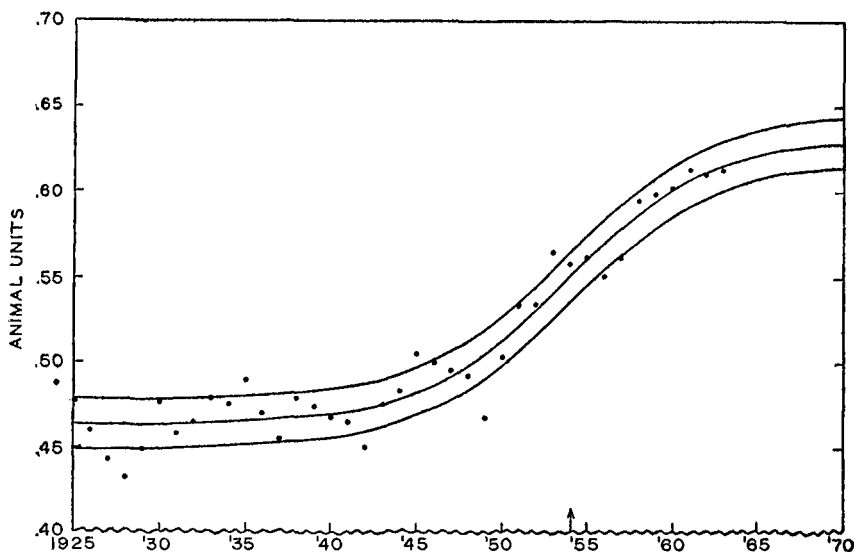
* See note for Chart 2. The figures are shown in Appendix Table I, column 9.

as if it were all attributable to the new additions to the herd (as the greater part, in fact, is). The result of the calculation is shown in Chart 4. (See also column 9 of Appendix Table I.) It shows that production per reproduced head has increased from 487 pounds a year in 1924 to 611 pounds in 1963. The logistic trend of this impressive series is given in Chart 4. It shows annual gains of about 460 pounds a head for the years 1924 to 1944, followed by a rapid rise to about 600 pounds in 1958. The second part of the answer, therefore, is that significant increases in the rate of gain of growing animals occurred after about 1945.

Gross Return and Investment Incentive

The remaining question now is: What were the incentives for increasing cattle numbers in the southeastern states? Although investigation of the demand for beef was not a part of this study, there is no doubt that population growth and rising per capita income led to a large growth in demand. Moreover, the change in demand favoring smaller, leaner beef cuts encouraged slaughter at lower weights and at younger ages. Slaughter of 40 per cent of the beef herd—now usual in the United States—implies a complete rotation of the stock in 2.5 years. The slaughter rate of 30 per cent existing in earlier years implies an average age of 3.3 years, while the 20 per cent rate found in Chile implies an even slower turnover and an average age of five years at slaughter. In addition to saving time, slaughter at lower weights avoids the conversion inefficiency that accompanies fattening to heavy weight. All these considerations suggest that improvements in the techniques of feed conversion may explain cost reductions, but feed costs clearly require attention.

A mature beef animal may consume as much as 3,500 feed units a year. (One feed unit is equivalent to a pound of corn; the source of these units may be grass, harvested forage, or grain.) The annual cost of feeding an animal obviously depends on the number of feed units and their average cost, which in turn depends on their composition. Unfortunately, there is no way of determining the composition nor the average cost of feed units actually used for the ten-state area under study. This difficulty is compounded by the fact that the value of pasture and forage is ultimately determined by cattle prices. It is possible, however, to compute the annual gross return per animal unit of the basic stock. Multiplying the average price received by farmers for cattle by the production rate establishes the gross value of the product per animal unit of the basic stock kept each year. However, this estimate of the value of the physical product must be adjusted for changes in the value of the capital stock from which it flows, because the profitability of keeping cattle depends on the difference between this gross return and the actual cost of maintaining an animal unit. These considerations lead to the following question: Is it possible to infer, from comparing actual cattle investment decisions and simulated rates of return on actual cattle investment, the relative importance of improved conversion efficiency and lower feed cost as inducements to expansion of herds?

"Value per Animal Unit," shown in column 11 of Appendix Table I, is a variable presumably determined by the aggregate supply of stock and slaughter cattle in the United States, interacting with the sum of consumption and reinvestment demand. Value per animal unit—the average price received by farmers for cattle expressed in animal units—increased appreciably throughout this period. Although there are short series of years in which cattle prices, or the value per animal unit, fell sharply, the undeflated average value per animal unit increased from approximately $40.00 in 1924 to $176.80 in 1963; allowing for the fact that the general price level almost doubled in this period, the price in real terms roughly doubled.

The rising rate of production, by increasing the physical product per animal kept, would itself provide an incentive for expanding the cattle population so long as numbers did not outstrip the feed supply, and provided that cattle prices did not break. Column 14, Appendix Table I, was computed to show the average result of holding an average animal unit for a year throughout the period, taking into account changes in capital value of the stock as well as the value of the beef produced per animal unit. The ratio of this value-product, corrected for capital gain (column 14), to the capital value of the animal herd, as given in column 11, expresses average gross return to capital in cattle. The question is whether there is any systematic relationship between this gross rate of return and the rate of reinvestment in cattle themselves. Column 15 is a measure of the rate of investment in cattle. It records the collective results of the individual investment decisions of cattle owners over the 40-year period studied. Since it shows the change in inventory as a percentage of the number reproduced (given in column 5), it measures investment as a percentage of income in real terms—numbers of cattle. These two series are shown in juxtaposition on Chart 5. Gross return, as defined, ranged from a loss of 39 to a gain of 59 per cent during the study period. But in 15 years the return was between 34 and 47 per cent, and in 11 years between 24

CHART 5.—SIMULATED RATE OF RETURN PER ANIMAL UNIT YEAR, AND NET
INVESTMENT IN ANIMALS AS PER CENT OF NUMBER REPRODUCED, 1925–63*
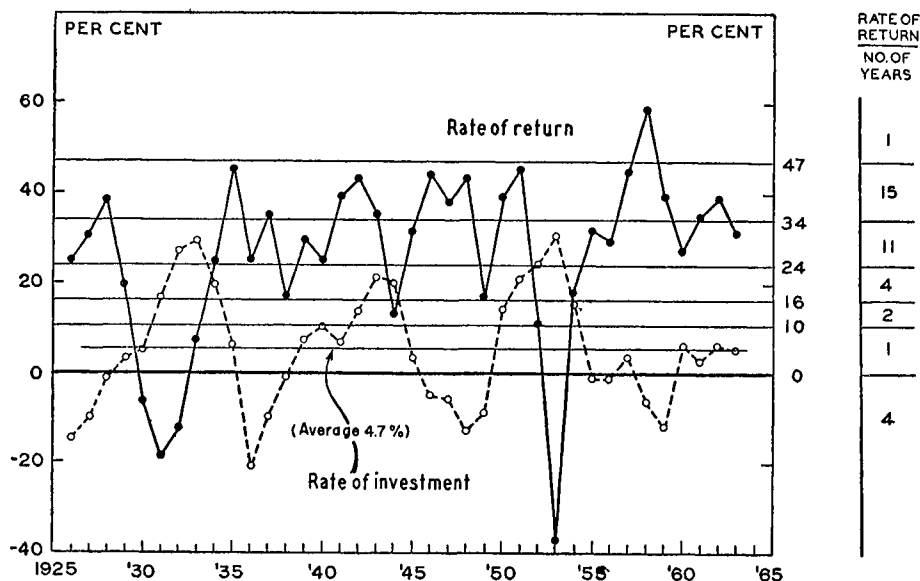
* See text for description.

and 34 per cent. The rate of reinvestment averaged 4.7 per cent per year, but was as high as 30 per cent in 1933 and 1952, and was a minus 10 per cent or lower in 1925, 1926, 1935, 1936, 1947, and 1958.

The ten-state high and low investment rates correspond to years of high and low cattle numbers in the entire United States. The investment rate shows cyclical fluctuation, with three peaks and four troughs in the period studied. The first investment peak for these years came during the depression year of 1932, the second in the war year 1942, and the third in 1952—which was very close to the date at which the rate of improvement in techniques in these states was at its maximum. From this, one must conclude that year-to-year changes in the rate of investment in these states resulted from the same forces that cause the United States cattle number cycle—a phenomenon so far not adequately explained. Gross return averages about 35 per cent. Since this figure is the same for 1963 as it was in 1927, notwithstanding the doubling in rate of production, it seems safe to conclude that increases in animal productivity are promptly reflected in the capital value of cattle herds.

The capital value of stock cattle must always maintain a close relationship with their value as slaughter animals. In view of this relationship and the fact that the deflated price per animal unit doubled over the period of the study, it is evident that the incentives for increasing investment in cattle in the southeastern states came from:

(1) increased demand for the final product;
(2) increased physical productivity per unit of physical capital in cattle; and

(3) expanded feed production, sufficient on the average to support an average annual net reinvestment of 4.7 per cent of the new animals produced.

As will be seen later, the order in which these forces was felt in the various states, and the timing of responses to them, was highly variable.

IV. PROGRESS PATHS FOR THE INDIVIDUAL STATES

The pattern of change has varied considerably among the ten states of the region. The differences are shown by Table 2, which gives the parameters of logistic functions fitted to annual estimates of the production rate for the region and for nine states. The point of inflection, t_i, occurred as early as 1938 in Kentucky and as late as 1961 in South Carolina. The computed values for the upper asymptote also suggest that there are marked differences among the states in their potential rates of production.

As can be seen from the table, the computed value of t_i for the ten-state aggregate is the year 1952.5, but the individual states are arrayed between the extremes mentioned for Kentucky and South Carolina. The other variable of direct interest is column $M + K$, which gives the upper asymptote for each state. The

TABLE 2.—PARAMETERS OF FITTED LOGISTIC FUNCTIONS FOR THE PRODUCTION RATE OF CATTLE IN THE SOUTHEASTERN STATES*†

	t_i	$M + K$	Y_1	$\frac{dy}{dt}$ at Y_1, t_i	K	B	A	M	σ
Ten states	1952.5	39.8	28.2	.68	23.2	1.068	−.1186	16.6	.6
Kentucky	1938.5	36.5	27.3	.41	18.5	.276	−.089	18.0	1.0
North Carolina	1955.9	34.2	25.4	.64	17.7	1.50	−.144	16.5	.8
South Carolina	1961.4	43.0	31.8	.97	22.5	4.3	−.173	20.5	1.6
Georgia	1950.5	35.1	24.0	.95	22.3	.66	−.171	12.8	1.0
Alabama	1955.5	51.8	32.0	1.05	39.7	1.31	−.106	12.1	1.1
Mississippi	1953.2	34.3	26.8	1.43	15.1	1.09	−.38	19.2	1.0
Arkansas	1944.8	38.0	26.7	.77	22.6	.36	−.137	15.4	1.5
Louisiana	1949.7	31.7	24.5	1.08	14.4	.37	−.30	17.3	1.4
Florida	1948.1	28.4	19.0	1.01	18.8	.35	−.216	9.6	1.1

* Computed from data cited for Appendix I. Tennessee is not shown separately because its observed trend is approximately linear and has no definitely logistic parameters. See Appendixes II and III.

† Explanation of parameters:

$$Y = \frac{K}{1 + Be^{A(t - t_0)}} + M$$

Point of inflection, $Y_1 = M + \dfrac{K}{2}$

Year of inflection, $t_i = \dfrac{1}{-A} \operatorname{Ln} B$
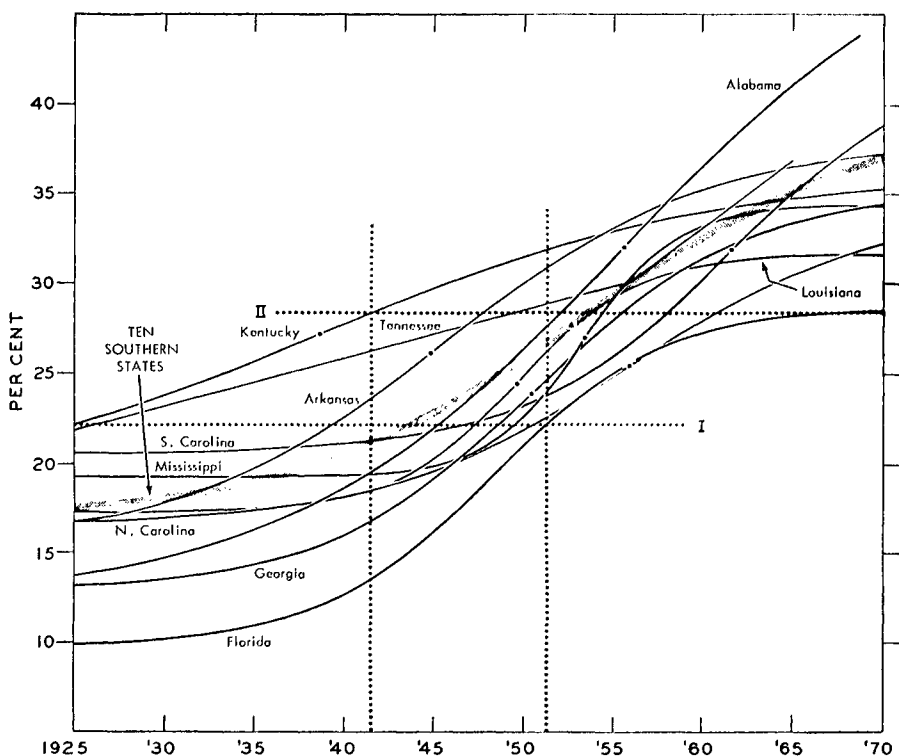
Slope, $\dfrac{dy}{dt}$ at $Y_1, t_i = \dfrac{-AK}{4}$

Upper asymptote $= M + K$

Lower asymptote $= M$

t_0 (origin) $= 1953$

CHART 6.—LOGISTIC CURVES OF CATTLE PRODUCTION RATES FOR EACH OF THE
TEN SOUTHEASTERN STATES AND THE AGGREGATE, SHOWING
POINTS OF INFLECTION, 1925–70*

* See Table 2 and Appendix II; inflection points are indicated by solid dots on the curves. The line shown for Tennessee is two linear segments drawn by sight from the computer plot, since the computed rates are not logistic in character (see Appendix III).

ten-state limit turned out to be 39.8, which is quite close to the current U.S. average. The limits, however, are represented by Alabama, with a value of 51.8, and Florida, with only 28.4. In general, high rates of production tend to be associated with cattle-fattening areas and lower rates with specialized feeder-cattle production.

Superimposed on the graphs of the production rate are the cattle inventories. The object was to search for the relation between increases in productivity and increased investment in cattle.

Scrutiny of Charts 7 through 9, showing changes in production rate and animal numbers by state, together with other relevant information, could be expected to throw light on the relative importance and timing of various determinants of the increase in productivity in the individual states. The differences in timing to be explained are shown in Chart 6.

Line I in Chart 6 was drawn at the level of Kentucky's production rate trend value in 1925—the highest in the group. Line II is drawn at the level of Florida's production rate trend in 1963—the lowest of the group. The logistic curve for Florida crosses line I in 1951; by this measure, Florida attained in that year the

production rate Kentucky had shown 26 years earlier. And Kentucky's logistic curve crossed line II in 1941—a rate of 28.4 per cent, which Florida was to attain 22 years later, in 1963.

The range in production rates was greatest in 1939 and smallest in 1955—at approximately the time when the ten-state logistic reached its point of inflection. And the lowest ranking state in 1963, with a production rate of 28.4, was 6.5 percentage points above the highest of 1924.

The dates and levels at which inflection points occurred for the individual states are shown by the dots which are distributed around 1952 in time and around 25 per cent in production rate. The trend lines for individual states in Charts 7 to 9 (pp. 83–85) are accompanied by dots that permit more detailed scrutiny of year-to-year changes. Superimposed on each of these state graphs is a line showing the cattle inventories for the same 1925–63 period. The juxtaposition of the two lines facilitates attempts to identify relationships between increases in productivity and increased investment in cattle.

Florida ranked lowest in 1924 and, despite the highest percentage of improvement, was still lowest in 1963. As shown in Table 1, the proportion of cows in its cattle population was among the highest—59 per cent—which indicates feeder production, but certainly not inefficiency.

South Carolina was above average in 1924, but below the mean between 1941 and 1963. Mississippi began just above the mean, fell below until 1955, but ended slightly below again.

To explain the "why" of these variations in timing would require investigation of the net reproduction rate and rates of gain for each state, as well as a detailed inquiry into the programs that influenced these variables—investigations beyond the scope of this study. A closer look at the record of the individual states, however, is worthwhile.

Compared with the average rate of production in the ten southeastern states, Kentucky, we have seen, shows a higher-than-average rate throughout the period. The other states, nevertheless, have shown a more rapid rate of increase. In 1926, for example, the production rate in Kentucky was about six percentage points higher than for the entire group of states, and in 1939 was nine points higher, but by 1963 the two rates had practically merged. As in the case of Kentucky, Tennessee also has persistently achieved production rates near the average for the ten states. In 1925 its rate was five percentage points higher, and in 1930 and 1940 it was six points higher. But after that date the average for the ten states rose more rapidly than for Tennessee, and since 1950 differences between the two are almost imperceptible.

North Carolina presents a somewhat different picture. Between 1925 and 1935 production rates were 1.5–2 percentage points lower than the ten-state mean. After 1935, however, the rate of increase in production remained almost constant, while that of the area continued to improve. In 1940, for example, North Carolina's production rate was three per cent below the mean, 4.5 per cent below in 1947, and five per cent below in 1956 and 1961.

In 1925 and 1926 the production rate in South Carolina was little different from that of the ten southeastern states, the values being 23 and 20.2 per cent. Between 1925 and 1950, however, the rate of production in South Carolina shows no perceptible increase, and in 1950 its production rate was nine percentage points

less than that of the other nine states. Since 1950, however, the rate of increase in the production rate has shown a sharp increase, so that South Carolina lagged the group mean by only five percentage points in 1963.

Georgia's path is quite parallel with that of South Carolina except that improvements began earlier—between 1935 and 1940. In 1935 Georgia's lag was greatest, at 7.5 percentage points below the trend value for the group. But by 1962 and 1963, in contrast, its rapid progress had brought it to a level only two percentage points below the trend value of the group.

Alabama displays an unusual pattern. Before 1945 the rate of production was always less than that of the mean of the ten states, usually from three to five percentage points below. Between 1945 and 1955 the performance of Alabama is almost indistinguishable from that of the mean, but after that date the rate of production rose until it exceeded the mean by six percentage points in 1959 and by five in 1963.

Mississippi displays a fascinating picture. With no trend in rate of production between 1924 and 1947, when the average was approximately 19.5 per cent a year, Mississippi was above the mean for the decade 1924–34 and below it for the succeeding decade. After 1947, however, the rate of production increased rapidly to equal the mean by 1953, and, after a slight recession to 1955, again increased rapidly, reaching 34.6 per cent by 1963, a level slightly above the ten-state mean.

Arkansas shows a production rate that differed little from the mean between 1924 and 1934. After that date, however, the rate was consistently three or four percentage points above the mean until 1950, when it had a five-percentage-point advantage, and 1951, when it was nearly eight percentage points higher than the mean. The high of nearly 35 per cent then reached seems, however, to have been a plateau, as the 1963 value was only 35.6, just two percentage points above the group mean.

In general perspective, the performance of Louisiana closely parallels that of the group. In the decade of the 1940's the production rate was from two to six percentage points below the mean of the group, but it was somewhat higher in 1955, and less than three percentage points higher at the end of the period in 1963.

Florida shows the most striking rate of change of any of the ten states studied. The production rate in 1924 was 8.36 per cent, the lowest and fully seven percentage points below the mean value of the group. In the ensuing 17 years the rate slowly climbed to 11.5 per cent, then ten percentage points below the mean trend of the group. After 1941, however, the rate of production rose dramatically, reaching 27.2 in 1959, a figure still four percentage points below the mean trend value. Falling again 7.5 points below the mean trend in 1960, the gap by 1963 had been reduced to five percentage points.

The economic significance of the variation in timing, however, is clear enough. Economic progress, like a chemical diffusion process, is concerned with the time required to pass from one state of equilibrium to another. To the extent the new equilibrium gives more units of goods per unit of scarce input, the change is equivalent to discovering more of the scarce inputs; so time really is equivalent to money, and rapid change itself has a value. Because deeper study in the individual states might reveal the causes of needless delays in bringing average practice closer to proven techniques, it could lead to improved tactics for achieving economic progress.
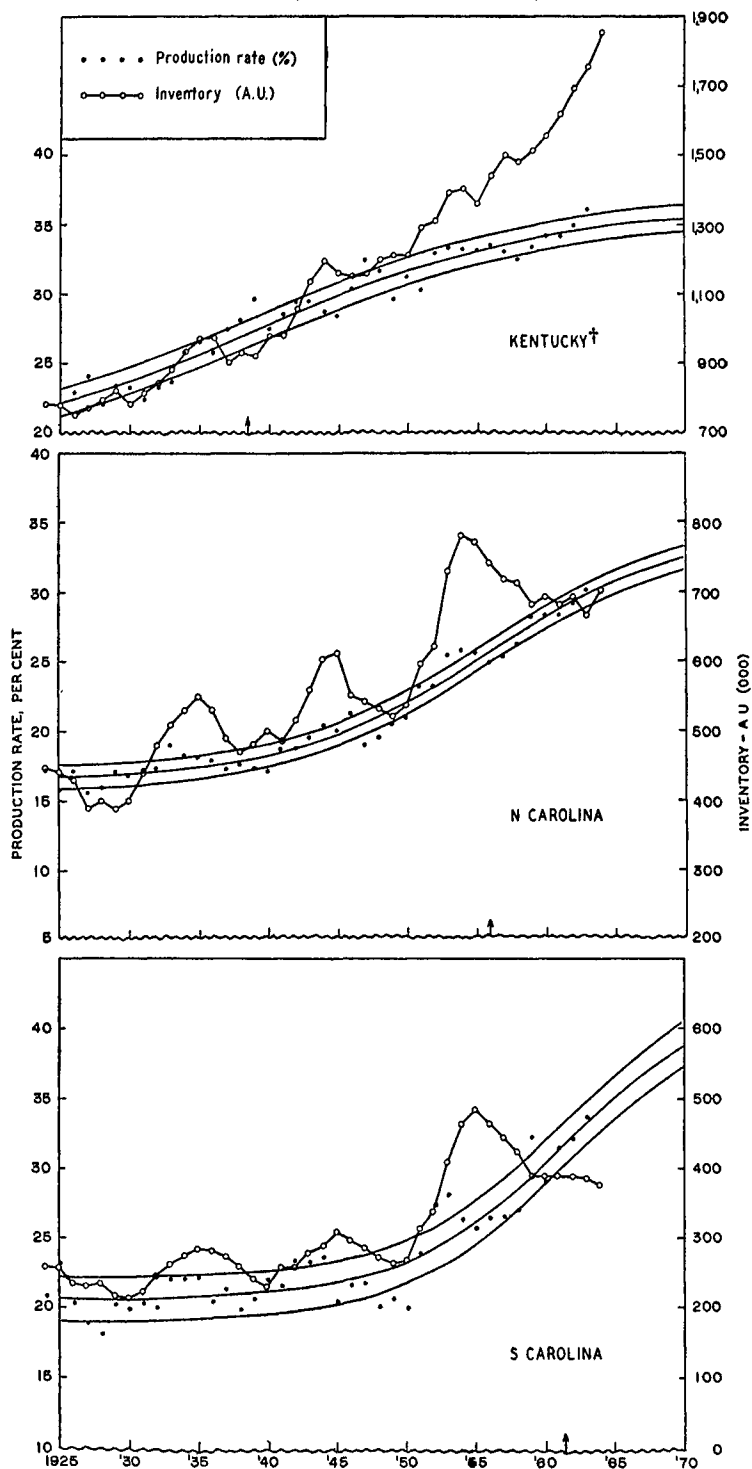
* See note for Chart 2.
† Note that indicated space on right-hand scale represents 200 animal units rather than 100.

* See note for Chart 2.
† Note that indicated space on right-hand scale represents 200 animal units rather than 100.

CHART 9.—CATTLE PRODUCTION RATE WITH FITTED LOGISTIC TREND, AND CATTLE
INVENTORY IN ANIMAL UNITS, ARKANSAS, LOUISIANA, AND FLORIDA, 1924–63*

* See note for Chart 2.
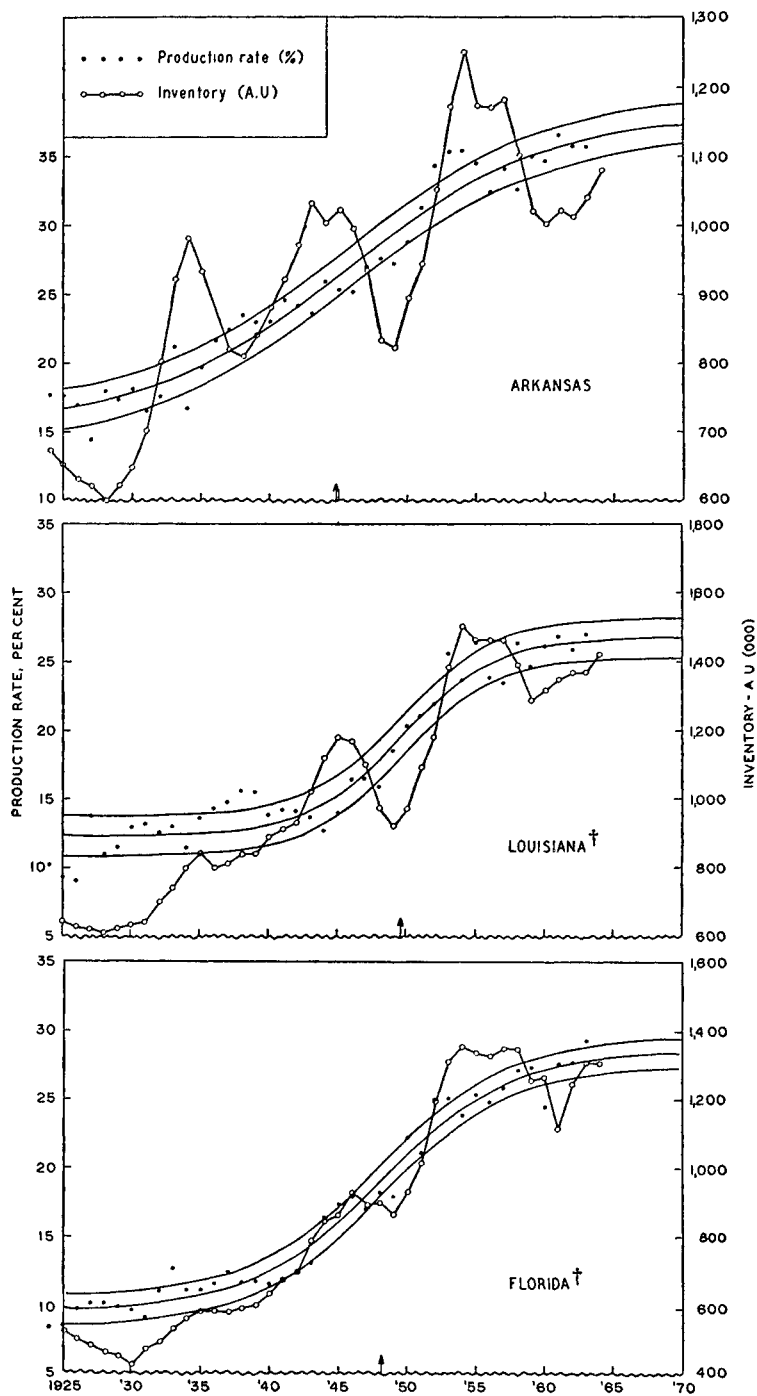† Note that indicated space on right-hand scale represents 200 animal units rather than 100.

V. SOME IMPLICATIONS AND CONCLUSIONS

A Methodological Implication for Studies of Economic Growth

This investigation of the magnitude and proximate causes of increased productivity of beef in the ten southeastern states was based on direct measurement of two physical magnitudes—tons of live animals in inventory and net tons of live animal increase per year. It is an investigation of the behavior of a simple technical relationship over time. The study almost entirely ignores the magnitudes that hold the center of the stage in production economics: the functional relation between inputs X_1, X_2 . . . X_n and output Y at a point in time, or the usual approach in growth studies when the latter is concerned with measuring "input savings" per unit of product over time, envisaged as the consequence of a "shift" in the production function through time.

To the extent that economic growth flows from technical change, we should study technique. The magnificent development of the theory of production, and its marriage to multiple regression, is an appealing technique for relating physical inputs of land, labor, capital, etc., to output. Unfortunately, its applicability is greatly restricted because it must in practice substitute value magnitudes as proxies for physical quantities. The carriers of distinct types of productive services, for example, are represented by estimates of their aggregate capital value. But capital values result from market estimates of probable future technical transformation rates, factor prices, and product prices; and these projected future income streams are discounted to an equivalent present monetary magnitude. The use of such a magnitude to represent physical quantity of productive service in the production function relation is clearly illegitimate, and it should not be surprising that our understanding of the "economics" of technical change has been so little advanced by use of this method.

Capital-output ratios, as a concept for analyzing the economic growth either of economies or industries, illustrate this type of error. This cattle study demonstrates the danger of the approach. Consider these data from Appendix Table I:

	Stock, A.U. (000's)	Production, A.U. (000's)	Capital value of stock ($ millions)
1951	9,621	2,567	$2,389
1954	12,541	3,630	1,426

Whereas the rate of production rose from 26.8 per cent in 1951 to 28.9 in 1954, and the physical stock of cattle increased 30 per cent, the capital value of the stock of cattle fell by 40 per cent. Relating physical output to total capital input (stock) shows use of $931 of capital per animal unit produced in 1951, but only $394 in 1954. Adding more variables like labor and feed, however accurate the data, cannot offset the error of measuring the physical volume of real capital used in the production process in value terms.

This, I believe, is a small demonstration of the larger truth that the study of economic growth often is likely to be more fruitful if the problems are cast in categories employing the concepts of physical equilibrium—as first developed in physics and later adapted to biology—than in the value concepts of economics where the constructs usually hold only under conditions of fixed technology, tastes, and resources.

Policy Implications

It is a matter of some pride among U.S. cattlemen that domestic price support programs have, for the most part, been directed toward crops and not livestock (5). Milk markets, of course, have long been strengthened by marketing orders, and sanitary controls have restricted the importation of beef from countries where foot-and-mouth disease is endemic. From time to time, voluntary import quotas have been agreed to by exporting countries, and in recent years U.S.D.A. purchases of beef for school lunch programs have sometimes lent support to beef prices. But cattle production has never been controlled, and prices have, on the average, been regarded as satisfactory without a complete price support program.

Although I have argued elsewhere (2, p. 764) that the U.S. price support program for corn accelerated the rate at which new techniques were applied, this study shows that cattle production technology in the southeastern states advanced rapidly without direct price supports for beef. The difference, however, is more apparent than real. As has been noted, both the acreage controls that were a result of the support program and the Soil Conservation Program led to expansion of the pasture area in these states, and the latter fostered significant improvements in its quality. There was no real alternative to beef cattle for harvesting this grass. The price support programs for food and feed grains stimulated, first, surpluses at relatively high prices, then surpluses at lower real prices, and cattle were again the final converters of large quantities of these grains. The critical role of nutrition in determining both the net reproduction rate and the average growth rate means that technical improvements in beef production were strongly influenced by technical improvements in crop farming. In this sense, the gains in beef productivity are an index of the agricultural successes that preceded them.

Conclusions

Our measurement of the production rate for the ten southeastern states shows that it doubled from 17 per cent in 1924 to 34 per cent in 1963. In the same time interval the cattle population almost doubled, from six to twelve million head; and production itself increased by 3.7 times in the 39-year interval.

In the usual terminology of economic growth, the doubling of the cattle population represents a simple increase in scale, explained by increases in the level of investment of conventional capital—mainly cattle themselves, and the grains and grasses to feed them. But the doubling of the production rate, a measure of the speed and technical efficiency with which animals reproduce and grow, is the kind of change that has usually been referred to as a shift in the production function, or the result of technical change itself. It is the phenomenon, for example, that is so actively sought in Colombia, Paraguay, and the Sudan.

The *rate of production* is largely determined by two variables. The first is "net reproduction rate," defined as calves born minus deaths of cattle and calves, expressed as a percentage of the January 1 inventory. As defined, this measure reflects the percentage of cows in the herd, the calving rate, and the two mortality rates.

The second component of production rate is "animal units gained per head reproduced." This simply expresses the total weight produced by the entire stock on a per-head basis of the new net additions. It approximates the average weight

gain of the growing animals during the year, and the changes reflect in some degree changes in the average age of the herd.

This study shows the comparative standing of the southeastern states arrayed by their production rates and gives the dates of important changes in the rates. This information should provide a basis for evaluating more precisely the economic significance of private and public programs directed toward helping the cattle industry.

The transition from cash crops to livestock farming in the South was made necessary by technical progress in production techniques for grains and fibers which put the Old South at a competitive disadvantage in producing these crops and by rising income which created an expanding market for the luxury product, beef.

Production of beef, as a source of human food energy, is one of the most inefficient of agricultural processes. Economic progress, nevertheless, has always meant increased demand for beef. Technical successes in producing the more efficient (in terms of energy input) forms of food—from manioc to corn and wheat—increase the potential for producing beef by making the necessary inputs cheaper. Also, in the world at large vast scope exists for improving the efficiency of this transformation. But apart from these advantages, beef is the only large and important agricultural product which to date has never faced a continuing problem of overproduction. For this reason, technical improvements in beef production offer unusual opportunities for attaining higher levels of income, the source of capital accumulation.

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SOURCES FOR APPENDIX TABLE I

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14 ———, Agricultural Marketing Service, *Livestock and Poultry Inventory, January 1: Number, Value, and Classes, by States, 1940–54* (Statistical Bulletin No. 177, June 1956), pp. 22–27.

15 *Ibid., 1955–60* (Statistical Bulletin No. 278, February 1961), pp. 10–15.

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The basic data for the study are shown below in Appendix Table I. The analytical concepts on which the argument is based are summarized in the following paragraphs, along with citation of sources.

Column 1 gives the total number of animals on hand on January 1 in the ten states for the years 1924 through 1963. The states are Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Arkansas, Louisiana, and Florida (13–18). Column 2 shows the change in inventory between successive years.

Column 3 shows the numbers data of column 1 converted into animal units (AU) from data for individual states and classes in the sources cited for column 1. The factors used are as follows:

	Milk animals	Other animals
Cows, heifers, 2 years old and over	1.00	.88
Heifers, 1–2 years old	.88	.60
Heifer calves	.44	...
Calves	...	.33
Steers, 1 year old and over	...	.88
Bulls, 1 year old and over	1.00	1.00

Since these factors are roughly equivalent to the live weights of the specified animals (1,000 pounds per milk cow, etc.), we consider one animal unit equivalent to 1,000 pounds live weight, or column 3 as roughly equivalent to the live weight of the inventory.

Column 4 shows the first differences in the inventory measured in animal units from year to year. Column 5 shows the net number of animals reproduced during the year, being the number born minus the number of calves and cattle that died in the course of twelve months (computed from 19–22, 16–18).

Column 6 shows production for the year measured in animal units (19–22, 16–18). The U.S. Department of Agriculture describes these estimates as follows (22, p. 4):

"Livestock production for each state is the live weight produced on farms and ranches in that State during the calendar year. It is obtained for each State by deducting the weight of livestock shipped into the State from the total pounds of marketings and farm slaughter and adding or subtracting, as the case might be, the difference in the inventory poundage between the beginning and end of the year."

The central measure used in the study is set forth in column 7, entitled "Net Production Rate," in per cent. This figure relates production, measured in animal units, to inventory, measured in animal units. As it reflects the biological processes of each category of animals, it is an average growth rate (column 6 as a per cent of column 3). Column 8 shows the net reproduction rate. This was computed by subtracting from the number of calves born, deaths of cattle and calves during the year, and dividing the difference by the January 1 inventory number (column 5 as a per cent of column 1). Column 9 shows the estimated production in pounds per animal reproduced. This was computed by dividing net production in pounds live weight (column 6) by the net number of animals reproduced (column 5). Column 10 shows the estimated average weight per head in pounds of the inventory on January 1 (column 3 divided by column 1, expressed in pounds). As the conversion factors used for computing animal units were constant throughout the period, the reduction in average weight per head from 770.5 pounds in 1924 to 745.8 in 1963 is explained by an increased proportion of calves and younger animals in the herd.

Column 11 shows the value per animal unit of cattle, based on the U.S. Department of Agriculture figure of average price received by farmers for cattle for all grades sold (an unweighted average of cattle prices shown by states in 19–22, 16–18). The series is given in current dollars, not deflated. Column 12 shows the change in market price per animal unit from year to year. This figure reflects changes in the capital value of the herd, as well as in the current value of finished animals. Column 13 is an estimate of the value-product per animal unit. It was computed by multiplying the yearly average weight produced per animal unit of stock (given as a percentage in column 7, "Net Production Rate") by the average price per animal unit (column 11). Column 14 is the algebraic sum of columns 12 and 13. Accordingly, it shows the sum of the change in capital value of an animal unit plus the value of the average product per animal unit kept in the course of a year, and consequently provides a measure of the average actual results of owning an average animal unit in the year shown. This result presumably affected reinvestment decisions in later periods. Column 15 shows net inventory change—investment or disinvestment—in animal numbers as a per cent of the animal numbers reproduced (column 2 as a per cent of column 5).

TABLE I CATTLE,TEN SOUTHEASTERN STATES AGGREGATE 1924 - 1963

INVENTORY, PRODUCTION AND REPRODUCTION IN THOUSANDS OF UNITS, ONE ANIMAL WEIGHT UNIT=1000 POUNDS LIVE WEIGHT

COLUMN→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	INVEN-TORY,	DELTA INVEN-TORY,	INVEN-TORY,	DELTA INVEN-TORY,	NET REPROD.	NET PRODUCT	NET PROD.	NET REPROD	PROD./ REPROD HD.INV	AV.WT REPROD	VALUE/ AN.UN.	DELTA VALUE/ AN.UN.	PROD. VALUE/ AU/YR.	PRODUCT VALUE + INV./ CAP.GN.	DELTA INV./ NET RE-PROD.
YEAR	NUMBERS	NUMBERS	AV.UNIT	AV.UNIT	NUMBERS	AN.UNIT	RATE %	RATE %	POUNDS	POUNDS	$	$	$	$	%
1924	8334	0	6421.8	0.0	2265	1104.11	17.19	27.18	487	771	39.90	0.00	6.86	6.86	0.0
1925	8032	-302	6235.2	-186.6	2258	1076.29	17.26	28.11	477	776	43.75	3.85	7.55	11.40	-13.3
1926	7699	-333	5998.0	-237.2	2211	1016.52	16.95	28.72	460	779	47.50	3.75	8.05	11.80	-14.7
1927	7475	-224	5856.7	-141.3	2316	1024.86	17.49	30.98	442	784	54.50	7.00	9.53	16.53	-10.1
1928	7446	-29	5841.0	-15.7	2377	1026.84	17.58	31.92	432	784	69.80	15.30	12.27	27.57	-1.3
1929	7537	91	5889.8	48.8	2355	1056.07	17.93	31.25	448	781	71.20	1.40	12.77	14.17	3.8
1930	7661	124	5959.4	69.6	2299	1074.32	18.03	30.01	467	778	57.10	-14.10	10.29	-3.81	5.3
1931	8050	389	6309.7	350.3	2430	1112.67	17.63	30.19	458	784	42.00	-15.10	7.41	-7.69	16.9
1932	8710	660	6852.4	542.7	2650	1229.67	17.95	30.42	464	787	32.15	-9.85	5.77	-4.08	27.2
1933	9503	793	7358.9	506.5	2920	1397.02	18.98	30.73	478	774	28.95	-3.20	5.50	2.30	29.9
1934	10076	573	7781.7	422.8	2975	1412.72	18.15	29.53	475	772	30.90	1.95	5.61	7.56	19.6
1935	10242	166	7937.4	155.7	3096	1512.67	19.06	30.23	489	775	42.10	11.20	8.02	19.22	5.6
1936	9591	-651	7422.4	-515.0	3103	1456.04	19.62	32.35	469	774	44.15	2.05	8.66	10.71	-21.0
1937	9273	-318	7210.2	-212.2	3162	1438.33	19.95	34.10	455	778	52.05	7.90	10.38	18.28	-10.2
1938	9268	-5	7204.5	-5.7	3120	1491.23	20.70	33.66	478	777	50.00	-2.05	10.35	8.30	-0.2
1939	9509	241	7281.3	76.8	3223	1524.16	20.93	33.89	473	766	54.85	4.85	11.48	16.33	7.7
1940	9820	311	7583.3	302.0	3246	1515.33	19.98	33.05	467	772	57.25	2.40	11.44	13.84	9.6
1941	10061	241	7772.7	189.4	3551	1647.29	21.19	35.29	464	773	70.00	12.75	14.84	27.59	7.4
1942	10564	503	8144.2	371.5	3989	1791.40	22.00	37.76	449	771	88.70	18.70	19.51	38.21	14.2
1943	11397	833	8825.1	680.9	4034	1913.91	21.69	35.40	474	774	102.80	14.10	22.29	36.39	20.9
1944	12181	784	9352.9	527.8	4361	2103.11	22.49	35.80	482	768	93.40	-9.40	21.00	11.60	19.4
1945	12322	141	9595.7	242.8	4174	2103.81	21.92	33.87	504	779	103.10	9.70	22.60	32.30	3.2
1946	12081	-241	9402.3	-193.4	4294	2144.43	22.81	35.54	499	778	127.60	24.50	29.10	53.60	-5.8
1947	11825	-256	9189.2	-213.1	4296	2122.34	23.10	36.33	494	777	150.00	22.40	34.64	57.04	-6.0
1948	11237	-588	8768.6	-420.6	4145	2036.94	23.23	36.89	491	780	187.90	37.90	43.65	81.55	-13.7
1949	10882	-355	8474.6	-294.0	4343	2026.10	23.91	39.91	467	779	174.40	-13.50	41.70	28.20	-8.6
1950	11518	636	8950.6	476.0	4562	2288.11	25.56	39.61	502	777	201.50	27.10	51.51	78.61	14.4
1951	12488	970	9621.0	670.4	4829	2567.01	26.68	38.67	532	770	248.30	46.80	66.25	113.05	21.3
1952	13657	1169	10432.7	811.7	5493	2927.49	28.06	40.22	533	764	211.10	-37.20	59.24	22.04	24.2
1953	15378	1721	11726.2	1293.5	6146	3469.23	29.59	40.10	563	763	126.10	-85.00	37.31	-47.69	31.3
1954	16306	928	12541.4	815.2	6524	3630.59	28.95	40.01	556	769	113.70	-12.40	32.91	20.51	15.1
1955	16203	-103	12470.3	-71.1	6533	3659.16	29.34	40.32	560	770	116.50	2.80	34.18	36.98	-1.6
1956	16082	-121	12301.1	-169.2	6596	3620.88	29.44	41.01	549	765	116.20	-0.30	34.20	33.90	-1.9
1957	16194	112	12322.4	21.3	6617	3707.59	30.09	40.86	560	761	132.60	16.40	39.90	56.30	1.7
1958	15688	-506	11893.5	-428.9	6262	3713.53	31.22	39.92	593	758	182.80	50.20	57.08	107.28	-7.6
1959	14938	-750	11327.7	-565.8	6158	3684.32	32.52	41.29	597	758	196.00	13.20	63.75	76.95	-12.0
1960	15310	372	11486.5	158.8	6103	3667.51	31.93	39.86	601	750	170.40	-25.60	54.41	28.81	6.0
1961	15382	72	11479.4	-7.1	6233	3807.87	33.17	40.52	611	746	172.80	2.40	57.32	59.72	1.2
1962	15758	376	11767.5	288.1	6444	3924.10	33.35	40.89	609	747	181.90	9.10	60.66	69.76	6.0
1963	16069	311	11985.3	217.8	6648	4063.63	33.91	41.37	611	746	176.80	-5.10	59.94	54.84	4.8

APPENDIX II

As a guide to discovering the timing of the changes in technique that explain the increase in the rate of production, the time series in column 7 of Appendix Table I was analyzed. The first trial as shown in Chart 1, a graphical presentation of the data in Appendix Table II, was to fit an exponential trend. It indicated that the compound rate of increase in the rate of cattle production in the ten southeastern states was two per cent a year over the 40-year period commencing in 1924. The residuals, given in Appendix Table II, do not appear to be random, and such a function gives no indication that an upper limit is being approached. Under reasonable assumptions, the biological constants in cattle production can be shown to imply a practical upper limit of about 60 per cent for the rate of production.

One method of systematically relating present performance to reasonable bounds is to fit a logistic curve to the observations. As the logistic function is symmetrical, the location of the inflection point allows one to fix the date when half the attainable progress has been made. Appendix Table II gives the coefficients of a logistic curve describing the production rates for the ten southeastern states during the 40-year study period. The low value of the standard error and the randomness of the residuals support the use of this curve to describe this system. According to the fitted values, the upper asymptote is 39.8 per cent, a rate of production close to the present U.S. mean. Of special interest, however, is the estimated value of t_1, the inflection point, which is 1953 ($33.17 + 20 = 53.17$), the year in which the rate of increase in the rate of production reached a maximum 2.4 per cent a year.

NOTES TO APPENDIX TABLE II

* Computed from estimates of annual production in animal units divided by January 1 inventory data (converted to animal units). See Appendix I for sources and description of rate of production (column 7, Appendix Table I).

† From the equation $Y_e = ae^{b(t-t_0)}$

where Y_e = rate of production estimated from the exponential curve, expressed as per cent of animal stock, both measured in animal units of 1,000 pounds live weight

$a = 14.292$, the intercept at t_0

e = natural logarithm base (2.718)

$b = .02007$

t = time   (19)20 = 0

$\sigma = .92$

‡ From the equation $Y_L = \dfrac{K}{1 + Be^{-a(t-t_0)}} + M$

where Y_L = rate of production estimated from the logistic curve of growth

K, the increment of Y between the upper and lower asymptotes = 23.2

B, at point of inflection = 1.068

$a = -.1186$

$t_0 = (19)53$

M, the lower asymptote = 16.62

$K + M$, the upper asymptote = 39.8

$\sigma = .6$

APPENDIX TABLE II.—EXPONENTIAL AND LOGISTIC TRENDS, CATTLE PRODUCTION RATE IN TEN SOUTHEASTERN STATES, 1924-1963

Year	Computed rate* Y	Exponential trend†		Logistic trend‡	
		Y_e	Deviation from trend	Y_L	Deviation from trend
1924	17.19	15.49	1.70	17.28	−0.08
1925	17.26	15.80	1.46	17.36	−1.0
1926	16.95	16.12	0.83	17.46	−0.06
1927	17.49	16.45	1.04	17.56	−0.50
1928	17.58	16.78	0.80	17.68	−0.08
1929	17.93	17.12	0.81	17.81	0.14
1930	18.03	17.47	0.56	17.95	0.10
1931	17.63	17.82	−0.19	18.11	−0.46
1932	17.95	18.18	−0.23	18.29	−0.32
1933	18.98	18.55	0.43	18.48	0.52
1934	18.15	18.93	−0.78	18.70	−0.52
1935	19.06	19.13	−0.25	19.94	0.15
1936	19.62	19.70	−0.08	19.20	0.45
1937	19.95	20.10	−0.15	19.48	0.50
1938	20.70	20.51	0.19	19.80	0.94
1939	20.93	20.93	0.00	20.14	0.83
1940	19.98	21.35	−1.37	20.51	−0.49
1941	21.19	21.78	−0.59	20.91	0.33
1942	22.00	22.23	−0.23	21.34	0.71
1943	21.69	22.68	−0.99	21.80	−0.06
1944	22.49	23.14	−0.65	22.29	0.25
1945	21.92	23.61	−1.68	22.82	−0.85
1946	22.81	24.08	−1.27	23.37	−0.51
1947	23.10	24.57	−1.47	23.95	−0.80
1948	23.23	25.07	−1.84	24.56	−1.28
1949	23.91	25.58	−1.67	25.19	−1.23
1950	25.56	26.10	−0.54	25.84	−0.23
1951	26.68	26.63	0.05	26.50	0.23
1952	28.06	27.17	0.89	27.18	0.93
1953	29.59	27.72	1.87	27.86	1.77
1954	28.95	28.28	0.67	28.55	0.45
1955	29.34	28.85	0.49	29.23	0.15
1956	29.44	29.44	0.00	29.91	−0.43
1957	30.09	30.03	0.06	30.57	−0.45
1958	31.22	30.64	0.58	31.22	0.03
1959	32.52	31.26	1.26	31.85	0.70
1960	31.93	31.90	0.03	32.46	−0.50
1961	33.17	32.54	0.63	33.04	0.16
1962	33.35	33.20	0.15	33.59	−0.22
1963	33.91	33.88	0.03	34.11	−0.18

APPENDIX III

Technical Note: by Omar Snyder

Computation of the parameters of the exponential and logistic functions was accomplished through the use of a nonlinear least squares regression fitting program, called CURVE. This program not only provides least squares fits directly to such highly nonlinear functions as the four-parameter logistic (and to linear functions as well), but also provides plots of the input data and the fitted function with a band of ± one standard error, such as those reproduced in this paper. Multiple regression functions of up to six variables are handled as well as bivariate functions. In addition to values of the fitted parameters, the program also provides values of the standard error, the sum of the squared residuals, the covariance matrix, and a listing of all input data, with the estimated value of the dependent variable for each data point and the value of the residual for that point.

Solutions to nonlinear regression functions are provided by iterative convergence, starting from some reasonable initial value approximations of parameters to be fitted. (This is also true for linear functions, but convergence is always assured at the first iteration, regardless of the initial value assumed.) The approach to convergence is tested at each step, and if convergence is not evident, problem execution is terminated. A consequence of this is that a set of data that do not conform reasonably well to the stated nonlinear function usually cannot be "force-fitted" to the function. An example in this paper is the cattle production rate data for Tennessee. A scatter diagram of the data indicates clearly that the most appropriate function here would be a simple two-parameter linear, though data for the other nine states were clearly logistic in character. In this particular case CURVE readily computed the four parameters of the logistic for these nine states and for the ten-state aggregate, but resolutely refused to provide a logistic solution for Tennessee data, even where given an initial approximation of "force-fitted" parameters computed by another method.

Although many other least squares parameter fitting programs are in existence, CURVE provides a level of convenience, flexibility, and sophistication rarely available. It was written in SUBALGOL by Charles H. Moore, Jr., for the Stanford Computation Center IBM 7090.