TECHNOLOGY: ITS EFFECT ON THE WHEAT INDUSTRY

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

John Bernard Sjo

1960

This is to certify that the

thesis entitled

TECHNOLOGY: ITS EFFECT ON THE WHEAT INDUSTRY

presented by

John Bernard Sjo

has been accepted towards fulfillment
of the requirements for

Doctor of Philosophy degree in Agricultural Economics

Major professor

Date June 29, 1960

O-169

TECHNOLOGY: ITS EFFECT ON THE WHEAT INDUSTRY

By

John Bernard Sjo

AN ABSTRACT

Submitted to the School of Advanced Graduate Studies
of Michigan State University of Agriculture
and Applied Science in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics

Year 1960

Approved ____________________

Abstract

John Bernard Sjo

Economic progress in the production of wheat in selected counties of the hard red winter, hard red spring, white, and soft red areas was determined through an analysis of the effects of technology upon the input-output ratio for the 1924 to 1954 period. Differential rates of technological progress were observed in the analysis among the four areas, thus necessitating an investigation of the factors responsible for the inter-regional differences. Preceding the analysis a careful study of the theoretical and methodological procedures associated with technological research was undertaken to provide a conceptual and procedural basis.

An explanation of technology is the application of knowledge to the organization and operation of production in such a manner as to increase total output without the employment of additional resources or a recombination of the resources in use. Certain innovations will, however, affect the technical production coefficients, making resource adjustments profitable. The most concentrated effort in this study was directed toward an explanation of the effect of such innovations rather than the effect of the recombination or substitution of resources.

Two approaches to the study were used, an historical inquiry into the innovations that have occurred in wheat production and an input-output analysis of the five-year census data. Varietal improvement through selection and scientific breeding was the most significant biological advance that increased yields. The discoveries in the control of disease, insects, and weeds were other important advances that affected yields. Engineering knowledge made possible a complete substitution of mechanical power for animal power and a substantial reduction in the labor requirements in wheat production. An understanding of the nutrient requirements of plants and the chemical composition of soil made possible the rational fertilization of wheat, thus increasing yields through expanding the capital used in wheat production. While these innovations were being made, the size of the farm increased, the number of farms decreased, and the labor requirements fell, yet yield per acre and output per man increased.

The input-output analysis revealed several general tendencies in the effects of technological progress in the wheat industry regardless of whether an individual category of inputs, such as land, labor, or capital, was considered or an aggregate of all inputs was considered. First, technological progress in wheat production occurred in surges, 1934 to 1944, and lapses, 1945 to 1954. The gains in aggregate productivity were largely exhausted by 1945, but the change in production coefficients made profitable resource adjustments which have continued to the present. Second, technological progress occurred at different rates in the separate geographical areas considered. The hard red winter wheat area had the greatest benefits from the application of new knowledge to production problems. The hard red spring area had little benefit and the other two areas, the white and soft red, had moderate increases in productivity. The sporadic and erratic results of technological change over time and by geographical areas were explained by the uneven flow and diffusion of discovery, the unequal applicability of new knowledge to all areas, the variability of available capital by areas and from time to time, the specialization of production and size of unit, and the degree of production uncertainty.

This study is limited in scope by the inadequacies of the data and the procedural difficulties encountered when studying dynamic phenomena. The contribution of this study is twofold. First, methodological problems and data problems were identified which should provide assistance in other inter-regional studies of a particular agricultural product. Second, the understanding of the technological progress made in the production of wheat was furthered.

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ACKNOWLEDGMENTS

Persistence and many evening hours of labor were necessary to accomplish this manuscript. The patience and understanding of my wife, Irma, made possible the continuation of the work until completion. I benefited from her editing suggestions as she typed the final manuscript.

Writing the thesis with several hundred miles separating the major professor and the student did not provide the opportunity to work as closely with Dr. Lawrence W. Witt as I would have liked. His immediate and understanding attention to any problem brought to him was greatly appreciated. It was from my association with Dr. Witt, in his classes 530, 560, 561, and 572, that I was encouraged to look at agricultural problems in their totality and in their relationship to the whole of society.

To Dr. Dale H. Knight, Associate Professor of Agricultural Economics at Kansas State University, I am grateful for many hours of counseling in regard to my research work.

I am indebted to the Departments of Agricultural Economics at Michigan State University and Kansas State University for financial assistance in the support of the research project.

Over the years the following students at Kansas State University assisted by copying census data: James Goering, William Schultz, Philip Warnken, and Roger Bell.

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CHAPTER I

INTRODUCTION

The concerns of agricultural economists have been compartmentalized into historical problem areas: farm management, land economics, marketing, and policy. Each of these problem areas has developed specialized concepts and methodology. Brinegar, Backman, and Southworth in the March, 1959, Social Science Research Council Items propose that these problem areas were vital ones in their time but the problems of today do not fit into these niches.[1] "Changing times call for changing strategies—for reformulation of problems into new categories, and for a corresponding regrouping of our intellectual forces."[2]

They suggest the following reformulation of problem categories:

1) Technological change
2) Agriculture in an economy of abundance
3) Changing structural relationships in agricultural production
4) Agriculture-industrial interrelationships
5) American agriculture in the world economy
6) Income goals for agriculture
7) Systems of thought, research methods, and findings

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[1] Brinegar, George K., Backman, Kenneth L. and Southworth, Herman M., Reorientations in Research in Agricultural Economics, Social Science Research Council Items, March, 1959.

[2] Ibid.

The first, technological change, is the problem with which this study will deal. Brinegar, Backman, and Southworth provided a stimulus for the continuation of this study in the following statement.

> "Technological change. One problem area comprises technological progress and its impact: not technology as a problem of farm management and extension, but as a force of ramifying impact, both macro and micro, a force now left to operate blindly. There are few attempts to anticipate its economic counsequences in general or in particular, much less to prepare the way for coping with them. That traditionally progressive farm groups question the allocation of resources to technological research is but the corollary of this lack of forethought. Such questioning is wholly legitimate in economics. But it requires generalization to the broader problem of optimum allocation of resources in an industry capable of the rapid technological advance of agriculture and having its demand characteristics and other conditions; and to the counterpart questions of optimum organization of production and equitable distribution of returns to both the functional and the human resources in such an industry. The impact of technological change on the beliefs and valuations of farmers and others and the implications for economic organization likewise require investigation. We need, in short, an economics of technological development in agriculture."[1]

Man has cultivated crops for perhaps 10,000 years. Yet only in the last two centuries have there been any significant changes in production techniques. Science only recently has played a role in agriculture. The cultivation of the soil and care of animals had been an art handed down from generation to generation. Change in the art was slow. Not until science was applied to agriculture was the process of change accelerated.

Although today's agriculturalist still produces the same crops and tends the same animals, the methods of production and the characteristics of the plants and animals have been greatly altered.

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[1] Ibid.

New breeds, new varieties, new equipment and wide distribution of old plants[1] and new knowledge have all played a role in transforming agriculture from a subsistence level to a highly commercialized level. Land and labor, in the advanced agricultural areas, are no longer the principal factors of production. Capital has been substituted in a large degree for the other two. New knowledge and the increased capitalization have caused management to become increasingly significant in production. The relative importance of the various factors of production has changed greatly over time as knowledge of production methods grew.

While man was yet in the collectional stage, land was the only factor of production except for the harvesting, where a small quantity of labor was used. Perhaps the greatest technological advance of all time was the introduction of capital and labor into the planting and cultivating stages of the production process. Man had learned that the harvest could be increased if he cultivated the food plants. The relative importance of land in the production process gradually diminished, as has labor to a somewhat lesser degree. Recent technological progress has for the most part been a continuation of this process. New knowledge made possible the harvesting of a larger quantity of product from less land and often from less labor and capital. However, the increased productivity made it profitable to employ more

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[1]Wheat was unknown in the western hemisphere until brought from Europe. Potatoes were introduced to Europe. Coffee was an African crop until introduced to Latin America. East Indian rubber plantations began from South American seedlings.

resources, particularly capital. The earliest technological advances had the effect of increasing the labor requirement relative to land. Later advances made possible the reduction of labor relative to land. Finally labor was reduced relative to both land and capital. However, after the rudiments of husbandrymanship were learned, little change was made in the methods of production. For 3,000 or more years agriculture remained in the wooden plow era.[1] Seed was spread by hand. Harvest was by hand. These were the methods that were brought to America by the European settlers.

In the late eighteenth and early nineteenth centuries a number of inventions were made that were to have far reaching effects on American agriculture.

The invention of the steam engine was one of the earliest inventions that was eventually to revolutionize United States farming methods. However, many decades passed before steam was a source of farm power.

Eli Whitney's cotton gin of 1793 was one of the earliest attempts to mechanize one of the processes of farm production. The grain cradle soon followed. Then came the iron plow and the thresher. By the mid-1800's steam tractors, mowing machines, grain separators, and the reaper were coming into use.

[1]It should be noted that according to Woytinsky, W. S. and E. S., in "World Population and Production", over half of the world's farmers are still in this era.

Mechanization was but one phase of the application of knowledge to agriculture. The findings of Mendel, a Swiss monk, laid the foundation for the work of the plant and animal breeders. Soil science had its beginning in the work of Saussure, Boussingault, and Liebig, who made discoveries regarding the nutrients required by plants.

By the end of the nineteenth century agriculture was in a constant state of changing methods. A steady flow of new inventions, new cultural techniques, and improved strains of plants and animals were becoming available to farmers. This flow of technology has continued at an accelerated pace since then.

The land grant college system, including the experiment stations and extension service, resulted from the pressure of persons interested in seeing changes take place in agriculture.

Agriculture has the distinction of being an industry in which private endeavor of the producers has contributed few technological developments. Publicly supported agencies, the United States Department of Agriculture and the land grant colleges, have been the prime movers in the technological development of agriculture. In addition to the work of the public agencies, industrial corporations supplying agricultural inputs have made important technological contributions. Much of the mechanization has been due to the work of machinery manufacturers. Chemical companies have devoted research efforts to develop fertilizers, insecticides, and weed sprays. Independent inventors, such as Whitney and McCormick, and scientists, such as Burbank, have contributed important new knowledge. Generally, individual farmers have been unable to make significant contributions.[1] Each farmer operated such a small firm that he was unable to develop his own innovations.

Very little is understood about the nature of economic change and progress. Economists have been forced to consider separate points in time, because of the difficulty in analyzing economics through time. The objective of this study is to analyze changes that have taken place in wheat production over time. Analysis may be based on points in time, but it is hoped that something may be learned about the nature of the change in wheat production that may be useful in the study of the nature of change in general.

There is evidence that the new knowledge that may be forthcoming may truly revolutionize future food production. Land may become a relatively less important factor--used only as factory sites. A few thousand acres may suffice for the total food production of the United States. However, this study will be concerned with the shorter run, considering technological changes that affect one sector of agriculture--wheat production.

Agriculture has been affected by many and varied technologies. Many have been off-farm developments such as railroads, use of steel rollers to grind grain, and scores more which have had great effects on agricultural production. Although the impact of these developments is

[1]An exception to the generalization, E. G. Clark, a Kansas wheat farmer, is noted for his selections from Red Turkey such as Chiefkan, Clarkan, Red Chief, and Blue Jacket.

recognized, it will not be the purpose of this study to consider them. The complexities and interrelatedness of the on-farm developments within the wheat-producing portion of agriculture will furnish sufficient challenges and difficulties for one study.

Also, it seems that the researcher who begins the process of turning over technological stones looking for evidence that will explain this dynamic phenomenon must be cognizant of the hazards and limitations contronting him. Man cannot foresee that of which he knows nothing. Much technology of the future will be based upon knowledge not yet known. Therefore, forecasting technology and predicting its results with accuracy is largely beyond the capabilities of the researcher. Even in studying the causal relationships of previous technology and technology just being adopted, the researcher is handicapped by the lack of analytical tools.

Time and again the researcher must rely upon his judgment and ingenuity to solve methodological problems. Measurement and analysis have not been attempted the innumerable times necessary to test the usefulness of a particular approach. Therefore, one of the contributions a study such as this can make is methodological experimentation. The results should be viewed not as definitive answers, but as results of some experimental probing into an area in which there is little understanding. If this study adds even a small portion of understanding or points up the folly of particular procedures, the objective of the author will have been attained.

Although wheat is produced in all sections of the United States, no attempt will be made to consider the entire wheat industry. Four geographical areas representing each of the types of wheat, hard red winter, hard red spring, white, and soft red, will be studied. The wheat speciality counties of Kansas, Nebraska, South Dakota, North Dakota, Oregon, and Washington were selected for study. In the soft red area the 1954 census classed no counties as wheat specialty counties. In Indiana, Michigan, and Pennsylvania the most important wheat counties were selected for study.[1]

Two general approaches will be made to the problem of determining the contribution technology has made to wheat production. An historical approach will be used to determine what progress has taken place and what factors are associated with progress. A statistical approach will be used to measure the rate of change over time and among different producing areas.

It is assumed that technological progress is associated with certain conditions. It shall be the purpose of this study to identify these conditions and to draw conclusions that may be relevant to private and public policy decisions.

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[1]See Figure 18 for location of the counties studied.

CHAPTER II

THE NATURE OF TECHNOLOGICAL PROGRESS

In order to study the technological changes affecting wheat production in the United States it is necessary to establish a working concept of technology. Economic literature, as well as literature in the production fields, is filled with references to the benefits of technology. Yet, seldom is the term conceptually defined. It has a general reference to "improved ways of doing things" usually referring to mechanization, new varieties, fertilization, and improved feeding practices. In this study it is necessary to have a more refined conceptualization of technology within an economic framework.

In general, the classicists considered technology to be one of the influences that was fixed or moved by discrete jumps for most of the analysis. General equilibrium theory was limited to a point in time. The economic pendulum, when bumped by an exogenous factor such as technology, soon slowed down toward an equilibrium position, perhaps different from the old position. Classical economics analyzed these different positions, but did little to analyze the continuous flow of economic change. Even so, economic writers were not unconcerned with the limitations of statics and comparative statics.

Economic literature, since Adam Smith, has been filled with the work of economists concerned with the dynamic processes.[1] Conceptualization of the effects of change and uncertainty on economic organization has been difficult. A general theory of economic progress is yet to be formalized, though increasing effort is being given to this problem.[2]

Although, historically, that portion of economic theory spoken of as statics has received greater attention from the theorists than has that portion designated as dynamics, economists have recognized the existence of change and progress.

One of the early essayists who gave attention to progress was John Stuart Mill, who in 1848 devoted Book IV of his "Principles of Political Economy" to "Influences of the Progress of Society on Production and Distribution."

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[1]The first comprehensive treatise in economics was Adam Smith's "An Inquiry into the Nature and Causes of the Wealth of Nations," which was published in 1776. Not only did the title of the treatise indicate a concern for progress, but several sections dealt with dynamic conditions. For example, the title of Book I is "Of the Causes of Improvement in the Productive Powers of Labour, and of the Order According to which its Produce is Naturally Distributed among the Different Ranks of the People." Book III, "Of the Different Progress of Opulence in Different Nations," deals with the nature of progress, particularly the movement from an agricultural stage, to a manufacturing stage, to a trading stage.

[2]See for example, Baumol, William J., Economic Dynamics, The Macmillan Company, New York, 1952. In this book Baumol undertakes the task of developing a model for a progressive economy.

> "...We have still to consider the economical condition of mankind as liable to change, and indeed (in the more advanced portions of the race, and in all regions to which their influence reaches) as at all times undergoing progressive changes. We have to consider what the changes are, what are their laws, and what their ultimate tendencies; thereby adding a theory of motion to our theory of equilibrium - the dynamics of political economy to the statics."[1]

Mill wrote not only of the changes that are taking place in the economy, but of those destined to take place. Progressive movement, he wrote, was especially true in the leading countries and that this progress seeped to the other nations.

> "...There is at least one progressive movement which continues with little interruption from year to year and from generation to generation; a progress in wealth; and advancement in what is called material prosperity."[2]

To Mill, this progress consisted of two segments, increased population and increased production. He wrote that increased production took place due to:

a. New knowledge

b. Security of person and property

c. Improvements of business capacities of the general mass of mankind

d. Continued growth of the principle and practice of cooperation.

Mill anticipated the need for dynamics. He used the term dynamic and contrasted it to static. Dynamics he associated with progressive change.

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[1]Mill, John Stuart, Principles of Political Economy, Vol. II, D. Appleton and Company, New York, 1881, Book IV.

[2]Ibid.

"...of the features which characterize this progressive economical movement of civilized nations, that which first excites attention, through its intimate connexion with the phenomena of production, is the perpetual, and so far as human foresight can extend, the unlimited, growth of man's power over nature."

"...it is impossible not to look forward to a vast multiplication and long succession of contrivances for economizing labour and increasing its produce; and to an ever wider diffusion and benefit of those contrivances."[1]

Economic Progress

Economic progress occurs when there is an increase in ends relative to the means.[2] Whenever a change occurs that makes possible the attainment of a given quantity of a product with the use of a smaller quantity of factors, or conversely, the attainment of a greater quantity of a product with the same quantity of factors, there has been economic progress. This type of progress assures an increase in the general welfare of society. This means that economic progress provides for a rising level of both total and per capita consumption or real income.

Efficiency can be expressed as a ratio:[3]

$$\frac{\text{Ends produced}}{\text{Means used}} = \text{the efficiency ratio.}$$

The significance of the ratio depends on the definition of the ends and the means. The ends are the output of a process; the means are

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[1]Ibid.

[2]Boulding, Kenneth E., Economic Analysis, 3rd edition, Harper and Brothers, New York, 1955, p. 716.

[3]Ibid.

the input. The efficiency ratio is the output per unit of input.

Technical efficiency uses physical measures; that is, the bushels of wheat divided by the acres of land. Economic efficiency considers the price of wheat and the price of land. A new process may increase technical efficiency but not increase economic efficiency.

If we accept that the ultimate output is utility and the ultimate resource is human time, a measure of economic efficiency is utility output per man-hour input. Even though utility as yet has not been successfully measured, an approximation can be made if we use the rate of change of an index of physical output per man hour.[1]

Economic progress, Heady theorizes, is possible through discovery, innovation and capital accumulation.[2] Classical theory was primarily concerned with capital accumulation as a means of economic growth. The state of the arts, discovery and innovation, were assumed fixed.

Boulding summarizes the basis of economic progress as:

1) Change in knowledge

2) Substitution of factors of production.

Change in knowledge is technical progress. Substitution is changing the bundle of inputs and may include an addition to the total bundle. The substitution of the less expensive resource for the more expensive resource denotes progress.

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[1] Ibid.

[2] Heady, Earl O., Economics of Agricultural Production and Resource Use, Prentice Hall, 1952, New York, p. 794.

Others have looked at the causes and effects of technological advances primarily in aggregate. Rather than studying the changes in the production function for an individual firm they have studied the aggregate supply function.

Schultz in considering economic progress hypothesizes that technological changes occur sporadically.[1] Change, he believes, is not constant, but comes in varying surges and lapses. Each surge and/or lapse has an intensity which is unpredictable, and this recurrent phenomenon is not understood. The result of this uneven flow of technical progress, he states, causes the aggregate supply function for agricultural products to shift to the right by jumps.

Also Schultz finds that changes in the bundle of resources are not all quantitative. Input changes may be qualitative, and he states that it is these improvements that account primarily for the increases in the input-output ratio. Hybrid seed is a qualitative change. The quality of the human factor, labor and management, also changes.

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[1]Schultz, T. W., Reflection on Agricultural Production, Output and Supply, Journal of Farm Economics, August, 1956.

Also see: Schultz, T. W., The United States Farm Problem in Relation to the Growth and Development of the United States Economy, Report of the Joint Committee on Policy for Commercial Agriculture, Its Relation to Economic Growth and Stability, November, 1957, and The Emerging Economic Scene and Its Relation to High-School Education, (reprinted from The High School in a New Era, Chase and Anderson), University of Chicago Press, 1958.

Johnson[1] adds that the changes in input-output ratios may also be attributed to increasing returns to scale resulting from greater division of labor and specialization as the economy has increased in size.

Technological Change

For the purposes of this study economic progress will be considered to be a general concept made up of two parts, technical improvement and resource substitution. This study is primarily concerned with the first portion, technical improvement in wheat production.

Technology has not had a precise meaning. Several recent writers have attempted to make technological changes more meaningful. Among these have been T. W. Schultz of Chicago University, Earl O. Heady of Iowa State College, and Vernon W. Ruttan of Purdue University. Heady has given considerable insight into the concept of technology, particularly as it affects the production function of an individual firm. Ruttan has given careful study to the problems of measurement of technological change. Schultz has concerned himself with the effects on the aggregate supply function and with qualitative changes in the factors.

Classification. Classification is a simplifying process used in scientific inquiry. An attempt to meaningfully classify technological progress by types has been attempted by a number of writers. Heady

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[1]Johnson, Glenn L., Agriculture's Technological Revolution, published in the Final Report of the Seventh American Assembly, Arden House, Harriman Campus of Columbia University, 1955.

classifies technology into two physical categories, biological and mechanical.[1] Another classification used by Heady emphasizes effects on output, on total costs, and on receipts through price elasticity of demand.[2] Ruttan discusses labor-saving, land-saving, and capital-saving innovations.[3]

The purpose of classification is to simplify analysis, therefore different classifications of technological advance have been made depending on the purposes of the particular analysis.

The most general classification is the physical one. It seems that all new techniques can be grouped as to whether their effect is (1) biological, (2) mechanical, (3) mechanical-biological or (4) cultural. Heady did not consider the cultural category.

The biological category includes all innovations resulting from new knowledge about the biological processes of plants and animals which result in increasing output per animal or yield per acre. New varieties and breeds resulting from discoveries in genetics have been perhaps the most noticeable of this type of innovation. Others include disease, insect, pest and weed control through discoveries in the physiology of plants and animals and chemistry which result in increased yields.

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[1] Heady, Earl O., Farm Technological Advance, Journal of Farm Economics, May, 1949.

[2] Ibid.

[3] Ruttan, Vernon W., Agricultural and Non-Agricultural Growth in Output per Unit of Input.

The mechanical category refers to innovations that do not change the physiological output or makeup of plants and animals to which they are applied. Usually this category takes the form of substituting some type of capital for labor, land, or any other type of capital. Examples include the whole range of mechanization that has taken place in agriculture.

The biological-mechanical category includes those innovations that are not truly biological or mechanical. Elements of both may exist. For example, application of fertilizer has a physiological effect on plants yet has elements of substitution or addition of capital. Mechanical innovations that increase timeliness of operations which in turn affect yields are other examples. The use of the fast milking technique in dairying is an example in the livestock industry.

A category largely ignored by the economists[1], who have considered the nature of technology, has been one that will be referred to as cultural. This category will include that new knowledge which has improved the quality of the human factor. Examples are: (1) the managerial process has been improved and certainly must account for part of the increased productivity of agriculture, (2) new knowledge has made labor more effective, (3) new knowledge has made possible legal institutions that affect productivity. This category consists of intangible concepts that are not easily handled by presently known analytical and measurement techniques.

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[1]An exception to this has been T. W. Schultz and his students.

The analytical and measurement problems involved in the first three categories arise not because of lack of techniques, but because of scarcity of data collected in a form that is readily usable for analysis. Analysis of the fourth category not only is hindered by the scarcity of data, but also by the lack of techniques of measurement of changes in quality of the human factor.

Other classifications will be discussed under the headings, effects on the firm and effects on the industry.

Effects on the firm. Technical advance is manifested in such things as new crop varieties, new animal breeds, and new practices. These advances, as related to the firm, have two general properties.

First, the adoption of a technical improvement results in a new production function. New knowledge permits the production of a greater output with the same quantity of inputs. Although the quantity of each input may remain constant, a new method of application may change the effectiveness of an input. For example, time of seeding or different placing of fertilizer may affect output with no change of inputs. The change in quality of the factor such as a new variety may mean no change in the quantity of the factor. In these cases there has been a change in technical efficiency. Economic efficiency is increased if the costs of the input remain constant or decrease while price of the product remains constant or decreases less than the cost decreases or if costs increase, then the value of the additional output must exceed the increased costs.

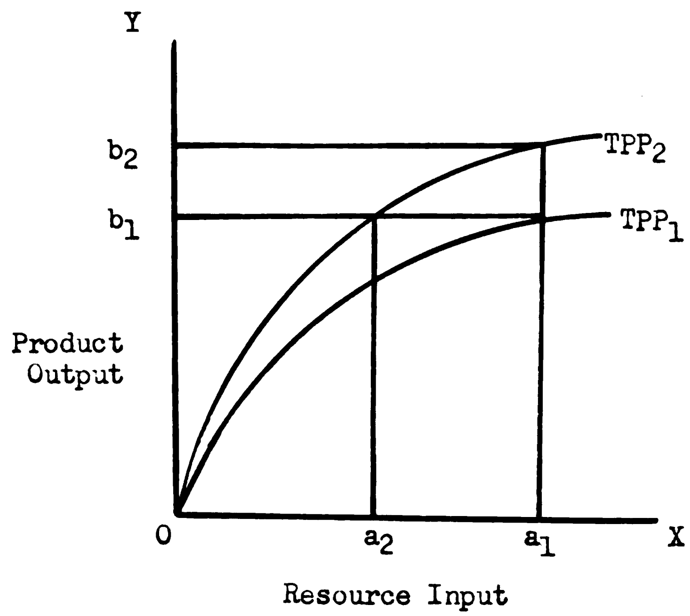

Fig. 1. The effect of technological improvement on a production function.

Figure 1 results from a general function such as:

$$Y = f\ (x_1 \ldots x_n)$$

Conceptually, the function must include all possible inputs, including knowledge. The inputs $x_1 \ldots x_n$ can only represent the known factors and techniques. In order to provide for the knowledge (or inputs) presently undetermined, which exist and at least potentially affect the function, a function must include these. By using a function of this form, $Y = f\ (x_1 \ldots x_n,\ u_t)$ when u represents the knowledge and inputs not yet determined, this can be accomplished. In order to construct Figure 1, only one factor (or bundle of factors) can be variable and all others are fixed; therefore a more specific function of this nature must be considered:

$$Y = f\ (x_1\ /\ x_2,\ u_t)$$

or

$$Y = f\ (x_1 \ldots x_g\ /\ x_g + 1 \ldots x_n,\ u_t)$$

where:

$x_1 \ldots x_g$ are the known variable factors

$x_g + 1 \ldots x_n$ are the known fixed factors

u_t represents the unknown factors (fixed as long as known)

The production function TPP_1 (Figure 1) represents the old method of production where Oa_1 units of input results in Ob_1 units of output. With adoption of the new technique, the production function shifts upward to TPP_2 where the input of Oa_1 units of factors results in the output of Ob_2 units of product. This represents the case where with a given set of resources technological change makes possible the production of more units of output. The converse of this is also illustrated in the diagram. With a reduction of factor X from Oa_1 to Oa_2 the production of output Ob_1 remains unchanged.

In the model used, a shift to TPP_2 results from a discovery of knowledge presently unknown (u_t). If this new knowledge pertained to the variable factor it could have increased the effectiveness of $x_1 \ldots x_g$. However, the new knowledge could also affect the fixed factors so that the productivity of the variable factors would be increased. Also, there remains the question of the relation of the unknown to the known portions of the function and the interaction that arises between the two and within each as the knowledge conditions change.

Since u is assumed to be unknown conceptually it is not possible to say whether u is changed or unchanged.[1]

Glenn L. Johnson and Curtis F. Lard in an unpublished manuscript prepared as a part of the Interstate Managerial Study have attacked the problem of defining technology.

> "Because of the apparent inadequacy of the definition of new developments (new technology) followed in the IMS, a revised definition has been proposed which includes the degree of knowledge involved in converting a new technology to an old technology. The new definition can be stated as follows: a new technology is the discovery of a new input (which did not exist before), where inputs are defined to include ideas; an input will be considered a new technology to an individual farmer until he makes either a positive or negative risk action decision concerning the input, after which, the input is an old technology to him. If afterwards he adopts the input, it would be an economic adjustment and not a technological advance."

In Figure 1 in either case the effect on the cost curves would be to reduce per unit costs, as in the first instance greater product resulted from given resources, in the second less resources were used to produce a given quantity of product. Technological improvement must at least momentarily increase profits (or decrease losses) to be adopted by the firm. An exception to this is the case of a firm maximizing some satisfaction function other than a profit function. Two

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[1]For example, before plant breeders developed Pawnee wheat, its potential existed within u. After development, u lost this potential. The symbol of the unknown, u, was diminished. Whether an indeterminate quantity or quality is changed when a portion of the indeterminate becomes known is a metaphysical question that need not necessarily be solved for the purpose of this study.

examples are: (1) conspicuous consumption and (2) reduction of uncertainty. Innovations may have prestige value even though profits are decreased by the adoption. The ownership of expensive equipment to harvest small acreages may enhance the status of a farmer, but may also reduce profits. An innovation may decrease profits in the long run, but may reduce uncertainty.[1] That is, a rotation of constant wheat may maximize profits over a long period, but is made up of a series of yields as follows: 20, 10, 18, 2, 40, 11, 8, 15, 0. Introducing fallow into the rotation may actually reduce profits, but be adopted because of the effect on yield uncertainty. Under the new rotation yields (using total acres rather than harvested acres to be comparable to no fallow and assuming total costs remain constant) would be 12, 16, 13, 11, 14, 9, 12, 15, 13. In the first case the average yield was 14 bushels per acre, in the second only 13. However, the zero and near zero yields have been eliminated. The wheat farmer has increased his certainty and may therefore sacrifice profits for certainty. In Figure 1 this could be illustrated by going from TPP_2 to TPP_1, assuming the technique of summer fallow was previously unknown.

Not all individual farms may have improved their economic position after all or a large number of farms have adopted the improvement. All could even be worse off, however; failure to adopt the improvement could diminish individual profits even more. The early innovators may

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[1]Heady, Earl O., _op. cit._

have temporarily gained by the innovation, but as more producers adopt the cost-reducing innovation, prices of the product are forced to a lower level. Prices fall due to two influences, lower cost of production and/or higher level of output. The price decline will be proportionally greater than the increased output due to the inelastic demand for farm products. Profits for each producer will be reduced; however, if individual producers were to retain the old methods, costs would be greater and profits even smaller. Also, there may be gains to the producer as a consumer. As members of a technologically advancing society they may be the beneficiaries of lower prices of commodities purchased.

Technological developments not only affect the firm's output and resource use, but they also affect the combination of resources and factor prices.

The second general property of technological progress is that the marginal physical rates of substitution are always altered in favor of one factor by specific innovations.[1] The production coefficients do not remain constant nor do the coefficients retain their relative positions. That is, as a new technique is discovered all coefficients are not equally affected. This change in marginal rates of substitution can be illustrated by using a factor-factor diagram.

Before the new technique is applied, production is on the Y_1 surface of Figure 2. If we let Y_1 be bushels of wheat produced with inputs OA of capital and OP of labor, the marginal rate of substitution

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[1] Heady, Earl O., _op. cit._ p. 13.

of the capital factor for the labor factor is AB substitutes for PN. After the new technique is used the same bushels of wheat are produced, as represented by Y_2. The marginal rate of substitution of capital for labor is now AB capital for LM labor. The change in capital (x_2) has remained constant both under the old and new method, but the change in labor (x_1) has increased (PN to ML). Therefore, marginal productivity of capital relative to labor has increased with the use of the new technique.

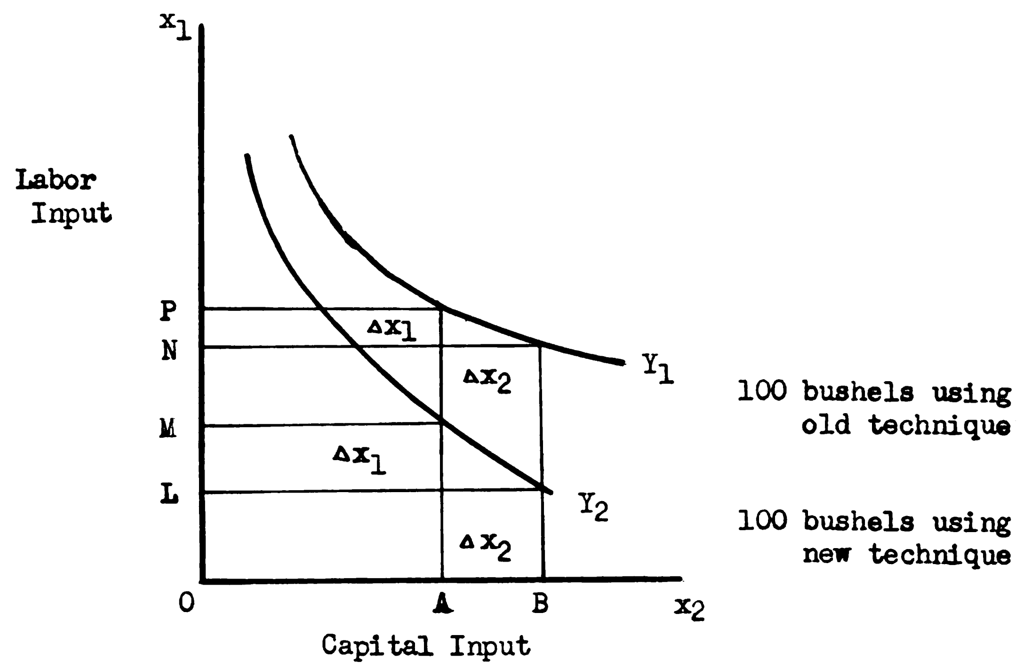

Fig. 2. The effect of technological improvement on the iso-product curve.

Changes in the coefficients within the production function result in a shift from one production function to another. Also, a new bundle of resources may be used which results in movement along the new function, using either a greater total quantity of resources or a smaller total quantity of resources.

Although the quantitative value of the inputs remains constant this does not imply that the qualitative value is constant. For example, quantitatively a bushel of Turkey Red seed wheat is equal to a bushel of Pawnee seed wheat. However, their qualitative value in regard to yielding potential is quite different. This can be demonstrated. When the quantitative value of all inputs was held constant on experimental plots and the qualitative value of all inputs except the seed wheat was held constant there was a change in output.[1] The qualitative value of labor, management, and capital can change while the quantitative value of these inputs remains constant. Thus for changes in input-output relationships the researcher is faced with the problem of measuring qualitative values of inputs. He is also faced with the problem of considering the cost of quality improvement as one of the inputs. For example, experiment station expenditures for variety improvement rightly are an input for wheat production. There has been no method of determining appropriate distribution of these costs.[2]

Function TPP_1 in Figure 3 represents production under the old technique. By using the new technique on the same quantity of

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[1]See Kansas Experiment Station Circular 366, 1958 Experiment Station Results With Fall Seeded Wheat, Barley, Oats, Rye.

[2]For a discussion of this problem see T. W. Schultz's article in the August, 1956, Journal of Farm Economics, "Reflections on Agricultural Production, Output and Supply."

Also see the Schultz paper presented before the Joint Economic Committee considering Policy for Commercial Agriculture, November 22, 1957.

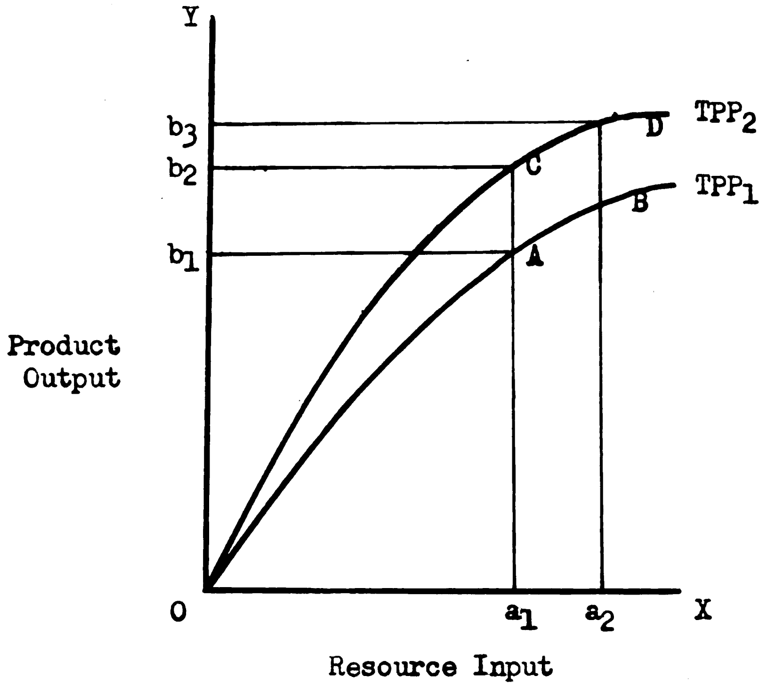

Fig. 3. The nature of the substitution effect resulting from technological improvement.

resources Oa_1, production moves to the new function TPP_2 and Ob_2 is the output. The increase of output from Ob_1 to Ob_2 was due to the new knowledge. However, because of the new knowledge, there is a change in the marginal rates of substitution which makes it desirable to change the bundle of resources, using more total resources. Substitution and/or expansion effect causes the shift from C to D on the TPP_2 curve when the new technology makes profitable uses of more inputs. The relative prices of factors and prices of products have been assumed to be not affected by innovations. When this is not the case, the change along the TPP_2 curve may be caused by the change in prices rather than (or along with) the substitution and expansion effect. It seems entirely reasonable that if the price effect on the product (falls) relatively more than price of factors and that this price change more than offsets the substitution and expansion effects (to use more resources) that fewer resources may be used than previously. In this case the movement would be to the left along TPP_2.

The effects of technology on the individual firm as discussed in this chapter assume unlimited access to capital by the firm. In the case where the firm is limited in capital, the manager cannot adopt all new practices even though all may increase the firm's profits. The manager, in order to maximize his net returns must adopt those new techniques that add most to his profits. He will continue to make expenditures on that technique until another new technique will return more. Then he will add that one. He will continue to push each new technique to the point where there are equi-marginal returns, to the limit of the available resources.

Effects on an industry. This study is primarily concerned with the effects of technology on the wheat industry. Therefore, not only the nature of effects of innovations on the individual farm, but the effects on the entire industry are of importance. Agriculture has greatly increased its total output since 1900. During this period agricultural output has increased more rapidly than has the increased employment of resources in agriculture.

Public sponsored research has as one of its purposes the increasing of farm income. Research agencies are charged with the responsibility of finding new knowledge which permits technological progress. But technological improvements may affect an industry in different ways. The effect on income will depend on the price elasticity of demand for the specific product and the effect of innovation on the total output and on the total cost of production.[1,2]

Technological progress can affect an industry as follows. When demand is elastic (1) total output and total cost may increase, (2) total output may remain constant and total cost decrease, (3) total output may increase and total cost may decrease. When demand is inelastic the same possibilities exist.

The above propositions can be illustrated by Figures 4 and 5.[3]

The TR curve represents total revenue for various levels of output. The curve represents different degrees of price elasticity of demand. The rising portion of the TR curve results from a demand curve with an elasticity greater than one. The declining portion results from a demand curve with an elasticity of less than one or is relatively inelastic.

The TC_1 and TC_2 curves represent total costs for the industry producing various outputs under the old technique and the new technique, respectively.

Innovations made under conditions of elastic demand which in-

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[1]Heady, Earl O., op. cit., p. 16.

[2]Wilcox, Walter W. and Cochrane, Willard W., Economics of American Agriculture, Chapter 23, Prentice-Hall, Englewood Cliff, New Jersey, 1951.

[3]These diagrams were used by Professor Heady in his article Farm Technological Advance in the May, 1949 issue of the Journal of Farm Economics. However, it was necessary to change the diagram to illustrate the loss in net revenue due to an innovation. Professor Heady did not shift from the original cost curve after adoption of innovation.

Two nearly identical diagrams were used in this study because the points could be illustrated more clearly than on a single diagram. The slope of the TC curve in Figure 5 was changed from Figure 4 for purposes of clarity.

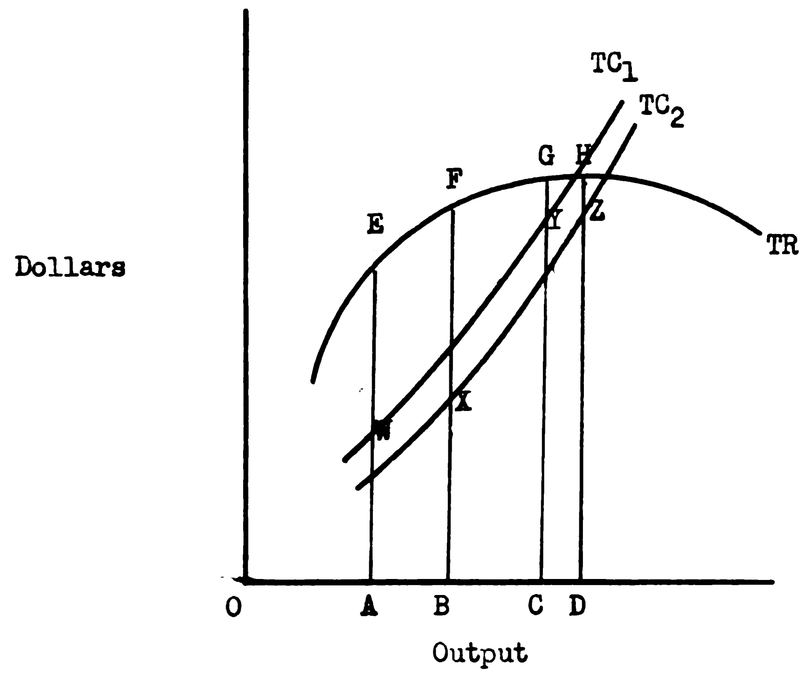

Fig. 4. The effect of technological progress on industry returns.

creases total output through using a new technique which increases total costs can be illustrated by Figure 4.[1] Prior to the innovation (TC_1) total output was OA, total cost AW, and total revenue AE. After the innovation (TC_2) total output was OB, total cost BX, total revenue BF. The net returns need not always be increased even though total revenue increases. When total revenue is increased by a smaller amount than are total costs, net income is smaller. For example, in Figure 4, if under the old technique total output is OA, total cost AW, and total revenue AE, and with the introduction of the new technique total output is OC, total cost CY and total revenue CG, then net revenue fell from EW to GY (AE - AW = EW and CG - CY = GY).

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[1]While total costs may have increased the per unit costs have decreased.

If an innovation causes total costs to decrease and output to remain constant when demand is elastic, net revenue will always increase.

If an innovation causes total costs to decrease and total revenue to increase when demand is elastic the effect must always be to increase net revenue. This situation is illustrated in Figure 5. Using the old technique the net return will be LF, when output is OA, whereas with the new technique, if output is OB, the net return will be MG.

The effect on net returns in an industry producing a product which has a relatively inelastic demand will be somewhat different.[1]

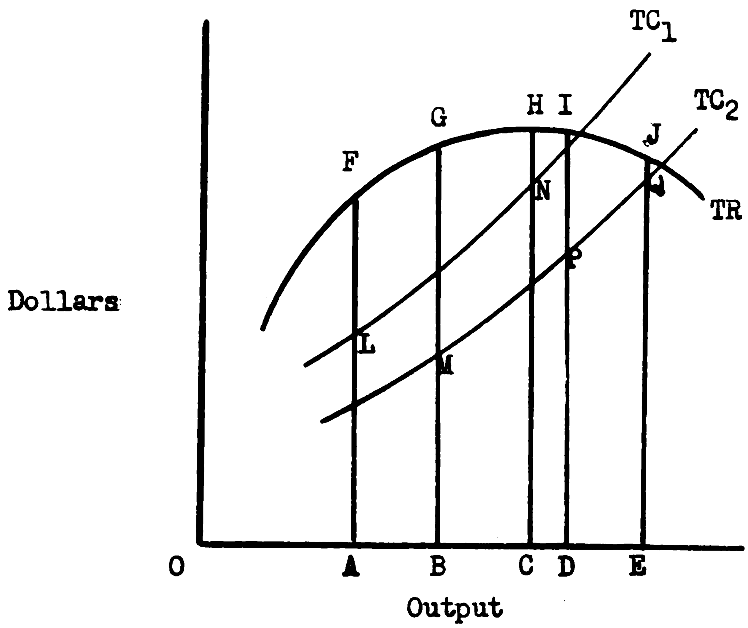

Figure 5. The effect of technological progress on industry returns.

[1]Agricultural products generally have elasticities of less than one. T. W. Schultz in "The Economic Organization of Agriculture" has brought together the work of Henry Schultz, Karl Fox, George Mehren, and Gerhard Tintner to establish this conclusion.

If demand is inelastic, net revenue to an industry must decline when the innovation is of a type that increases both total production and total cost. In Figure 4 under the old method, OC output gives a total revenue of CG and total cost of CY, leaving a net revenue of GY. If total output is OD when the new method is used, the total return will be DH and the total cost DZ, leaving a net return of HZ. HZ is less than GY.

If demand is inelastic, net revenue must always increase for the industry when the innovation reduces total costs and leaves output unchanged.

If demand is inelastic, net revenue may decrease or increase for the industry where the innovation causes output to increase and total costs to decrease. Total revenue must be less. If the decrease in total revenue is greater than the reduction in total cost the net revenue must also decline. In Figure 5 with output OC under the old method (TC_1) the net return is HN. By moving to the new method (TC_2) the net return is JQ, which is less than HN and with the new method, output is OD and net return is PI, then net return must increase.

Effect on the supply function. United States agriculture has had two forces at work that have acted as supply shifters. Up to the last years of the nineteenth century most of the great increase in agricultural production was due to an ever expanding agricultural land area. The western movement of settlers annually added thousands of acres on which to produce food. By 1900 this supply shifter had largely disappeared. Most of the land was in use.

At this point the second great supply shifter began to become a dominant force. New knowledge was being applied to agriculture. The technological revolution that had swept transportation and manufacturing was now taking place in agriculture. Cochrane states that agricultural production increased 90 percent in the period 1914-1956 and that almost all of this increase was attributable to technology.[1]

Figure 6 shows the nature of the effects of technology on the supply function for agriculture. S_1 represents the amount of output that will be produced at varying price levels under old technology. (Price OP_2 will bring forth OQ output.) Given time for adjustment after the adoption of new technology the supply function is shifted to the right, S_2. After the change, OQ output is forthcoming at a price OP_1. This is possible because of the effect of technology on the cost curves. Innovations to be adopted will always reduce per unit costs, except for the prestige and uncertainty cases, even though total costs increase. The supply function is derived from the rising portion of the average total cost curve as illustrated in Figure 7.

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[1]Cochrane, Willard W., Farm Prices, Myth and Reality, University of Minnesota Press, Minneapolis, 1958. Cochrane does not indicate whether substitution and expansion effect are included as a part of technological progress.

See also Johnson, Glenn L., Agriculture's Technological Revolution, Chapter 2 of the Final Report of the Seventh American Assembly, Arden House, Harriman Campus of Columbia University, 1955.

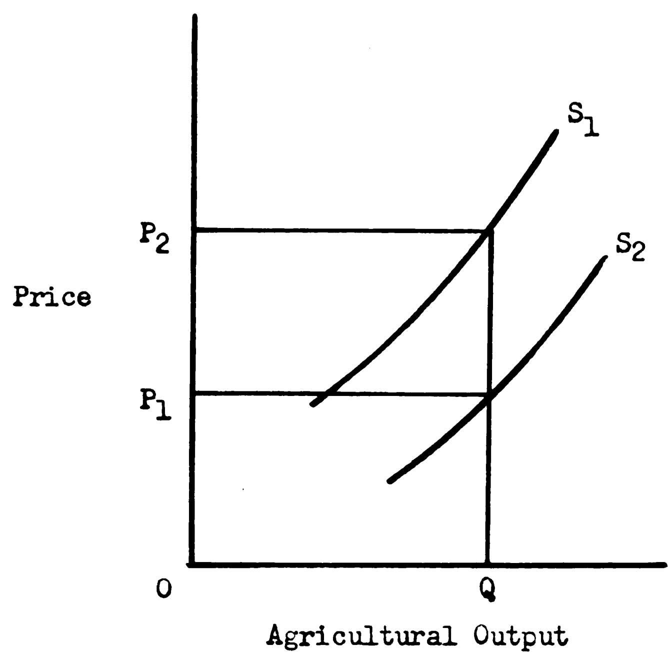

Fig. 6. **Effect of technology on the aggregate supply function for agriculture.**

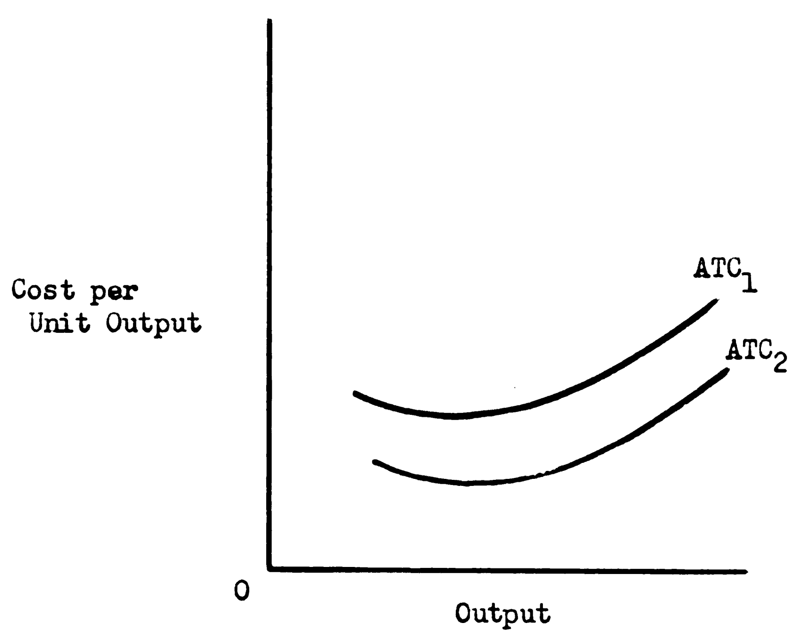

Fig. 7. **Effect of technology on cost per unit of output.**

<u>Welfare aspects</u>. Bushrod W. Allin stated that belief in technology is part of the American creed.[1] In a lecture before the Graduate School of the Department of Agriculture he listed three principal dynamics of an American creed:

1) Belief in enterprise
2) Belief in democracy
3) Belief in technology

The American people expect and demand technological advance in all segments of the economy. Within their system of values increasing efficiency is desirable. It is so desirable that if some sector of the economy lags, the public is willing to invest public funds seeking new knowledge for that segment of the economy. Agriculture has been the recipient of large amounts of public money for research and development. Society has generously invested in agricultural development, therefore it must have expectations of increased welfare to society.

What is the nature of what can be expected?

If aggregate demand for agricultural products were relatively elastic then agriculture or any segment of agriculture would benefit from technology when adopted. The expanding supply would cause only slightly reduced prices and total revenue in the aggregate and individually would increase. Technology always reduces per unit costs and may decrease total costs, therefore technology would increase farm

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[1] Allin, Bushrod W., <u>Rural Influences on the American Politics - Economic System</u>, lecture before the United States Department of Agriculture Graduate School, April, 1957.

incomes. Society in general would benefit because of lower prices for farm commodities and from the release of resources from agricultural production to production of goods which add to the standard of living.

However, aggregate demand for agricultural products as shown by Henry Schultz and others is not elastic, but is relatively inelastic. When supply is shifted to the right, prices fall sufficiently to give a smaller total revenue. Under these conditions farmers are forced to adopt new techniques which will reduce costs. The new techniques continue to push the supply function to the right and lower prices again result. Cochrane characterizes this phenomena by calling it the agricultural treadmill.[1]

Under these conditions the question arises, why encourage technological development in agriculture?

The answer is in the effect that technology has on the economy as a whole. Highly developed and wealthy societies are characterized by having few resources employed in primary industries, such as agriculture and mining. The fewer resources employed to produce basic raw materials the more resources that are available for secondary and tertiary industries which fashion the basic materials into consumer items. On this basis, new methods which increase the $\frac{\text{output}}{\text{input}}$ ratio (the definition of economic progress) are desirable from the viewpoint of the society as a whole.

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[1]Cochrane, Willard W., op. cit., p. 32.

Although technology may decrease total returns to agriculture it may be desirable because of the resources released from food production. Even though total returns to farmers may be lower it does not indicate that individual farmers are worse off. If the resources (usually manpower) not needed in agriculture are diverted to other portions of the economy the reduced returns are divided among fewer producers. Should this happen, all remaining farmers could conceivably have larger incomes than in the pre-innovation period. In the case where income would be smaller for all remaining farmers, their incomes would be even smaller if the individuals had not adopted the new technology. Or some remaining farmers may end up with larger incomes while aggregate returns fall, as do the returns to most operators. In the case where aggregate and all individual returns decline, the few farmers who were the innovation leaders enjoyed increasing incomes until sufficient numbers adopted to cause prices to fall.

Although it is easy to conclude that technological advances are not to the interest of the farmer when he is faced with a consumer who has an inelastic demand function for agricultural products, the conclusion that agricultural research ought to be curtailed or stopped does not follow. Agricultural efficiency is necessary if the economy as a whole is to expand. Farmers, even if their incomes are adversely affected by increased efficiency (through more than offsetting falls in prices), are benefited when the economy is growing.[1] Or one sector of

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[1]Witt, Lawrence W., Welfare Implications of Efficiency and Technological Improvements in Marketing Research and Extension, Journal of Farm Economics, December, 1955.

agriculture may benefit, the producers of products with elastic demand functions, while other sectors are not benefitting.[1]

In reviewing the concept of technological development, one phase of economic development, and the consequences of technology on the industry a foundation has been laid for the investigation of the effects of technology on wheat production.

[1]See Glenn L. Johnson in the Arden House report.

CHAPTER III

METHODOLOGICAL APPROACHES TO AN ANALYSIS OF TECHNOLOGICAL DEVELOPMENT

One of the aspects of dynamic economic theory is technological progress. The investigation of technological progress within an industry, in this case wheat, necessitates an inquiry into data needed and methods of analysis of these data. Previous work in analyzing technological change in agriculture has been rather limited. Ruttan of Purdue[1] and Griliches of Chicago[2] have recently considered the problems of analyzing the effects of technology on agricultural production.

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[1]Ruttan, Vernon W., Technological Progress in the Meat Packing Industry, 1919-1947, Marketing Research Report No. 59, United States Department of Agriculture, 1954.

_____, Agricultural and Non-agricultural Growth in Output per Unit of Input, Journal of Farm Economics, December, 1957.

_____, and Stout, Thomas T., Regional Patterns of Technological Change in American Agriculture, Journal of Farm Economics, May, 1958.

[2]Griliches, Hybrid Corn: An Exploration in the Economics of Technological Change, Econometrica, October, 1957.

_____, Demand for Fertilizer: An Economic Interpretation of A Technical Change, Journal of Farm Economics, August, 1958.

_____, The Demand for Fertilizer in 1954--An Interstate Study, Journal of the American Statistical Association, June, 1959.

_____, Specification Bias in Estimation of Production Functions, Journal of Farm Economics, February, 1957.

_____, and Grunfeld, Yehuda, Is Aggregation Necessarily Bad? The Review of Economics and Statistics, February, 1960.

Much of the analysis of technology has been concerned with measurement. Historical observation alone can point to the changes that have taken place in agriculture, but does not tell the degree of the change. Nor can observation measure the effects of the change that occurred. Measurement can be accomplished only after suitable data and methods of analysis are available.

It is the purpose in this chapter to discuss problems and techniques associated with analysis of technological change.

The Data

A major difficulty encountered in measuring the contribution of technological progress to changes in output is the problem of the inter-relatedness of technology to other changes. Much of the data has not been recorded in such a way to facilitate the untangling of this interrelationship. Output data reflect changes in scale, price relationships, substitution, and shift toward equilibrium as well as technological changes. Input data are quantitative, whereas the quality of inputs is important in studying technology. For example, bushels of wheat seeded are not a true reflection of the contribution of seed to production. Data show that the quantity seeded per acre has decreased over time, but production per acre has increased. Part of the increased productivity resulted from technology, innovations in weed control, insect control, cultivation and fertilization, but part was due to qualitative improvements in seed wheat. A 1920 bushel of seed wheat is not equal to a 1954 bushel of seed wheat. Quantitative statistics are not adjusted for qualitative changes.

Schultz argues that the quality of the human factor has been upgraded. Data do not show this qualitative change, yet improvement in quality of factors affects a technological development.

Two aggregation problems exist. In the first case, to measure total output or total input the separate outputs and inputs must be reduced to common units of measure so they may be aggregated. The data are in the form of number of tractors, horses, acres, or men. In the second case, data are in an aggregated form and the analysis demands the data in separate components. This is particularly the case of inputs. Joint costs are not allocated to enterprises. For example, to get the inputs used in wheat production the researcher must estimate what portion of the total labor, tractor, or gasoline cost should be assigned to wheat. This problem shall be called the disaggregation problem.

To measure technological change precisely data are necessary that separate out the effects of the other changes or the effects of related changes must be negligible.

The Measurement

As discussed under the theoretical aspects of technology other phenomena are closely associated with technical progress. They are: (1) changing marginal rates of substitution, (2) expansion or contraction of output (benefits of increasing returns to scale), (3) benefits or disbenefits of movement toward equilibrium position, (4) changes in relative prices.

Accurate measurement is possible only if the changes in the associated conditions can be measured separately or their effect is zero.

According to Ruttan, changes in input savings or output gains due to technological changes could be measured precisely by several methods if:[1]

> "First, resource and product combinations must be identical to the combinations that would be employed under conditions of competitive equilibrium in both periods."
>
> "Second, the production function must be homogeneous of degree one, that is, constant returns to scale must hold."
>
> "Third, technological progress must be neutral, that is, the marginal rate of substitution among factors must be the same in both periods."
>
> "Fourth, the prices of factors of production relative to each other and the prices of the products of the firm (industry) relative to each other must remain unchanged."

These four conditions are rarely, if ever, exactly met. Nor can the researcher determine the extent to which the conditions are met. There are no known objective methods of testing the degree of equilibrium, homogeneity, neutrality and price relationship or interrelationship among them. However, recognition of this weakness need not nullify work towards measurement of the effect of technology. Selection of methods and data that will minimize the bias introduced by the four conditions not being met will provide indicators of the magnitude of effects of technological change.

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[1]Ruttan, Vernon W., Agricultural and Non-agricultural Growth in Output per Unit of Input, Journal of Farm Economics, December, 1957. See also Ruttan, Vernon W., Technological Progress in the Meat Packing Industry, 1919-1947, U.S.D.A., M.R.S. Report No. 59; May, Kenneth, Technological Changes and Aggregation, Econometrica, January, 1947; Stigler, George J., Trends in Output and Employment, New York, National Bureau of Economic Research, 1947.

If the four conditions were met perfectly then any one of the following three methods of measurement would precisely measure technological progress: (1) labor productivity approach, (2) input-output approach, (3) production-function approach.

Labor productivity approach. The labor productivity approach was long the most popular means of measuring technological change.[1] Output per man hour was considered to measure progress. It did and would yet if the four conditions are met. Even though the four conditions are not met, so long as labor is relatively more expensive than the other factors employed, the index of average labor productivity is an indicator of economic progress. When other factors become relatively expensive, for example land, progress could be measured by the productivity of land. European and Asiatic agriculturalists are more concerned with yield per acre than with output per man hour.

Boulding states that the ultimate product of production is human utility and the ultimate input is human time. If this be the case then $\frac{\text{units of output}}{\text{units of labor}}$ may be considered an adequate measure of technological progress.

However, if the four conditions are not met, average labor productivity is not a true measure of technological advance. This measure may include bias as a result of the effect of movement toward equilibrium, expansion, substitution or changes in relative prices. Price change bias can be demonstrated in Figure 8.

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[1]Examples of the labor productivity approach are the work of Sherman Johnson, S. H. McCrory, R. F. Hendrickson, Reuben W. Hecht and Glen T. Barton in the Department of Agriculture.

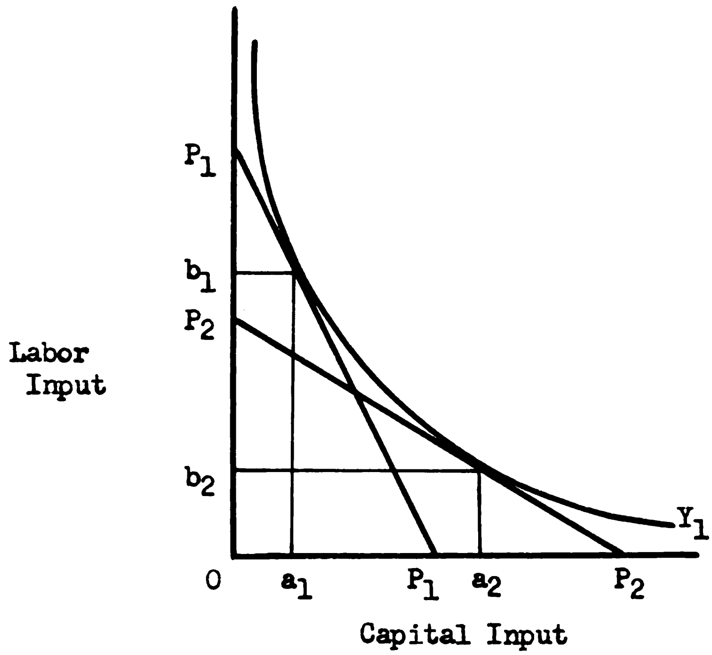

Fig. 8. Price change bias in labor productivity.

Let us assume technology remains constant. Y_1 represents an iso-product surface, P_1 represents the outlay necessary to produce Y_1 at prices existing in the first time period. P_2 represents the outlay in a second time period after prices have changed. As the price of capital fell relative to the price of labor there was a shift from using Oa_1 capital and Ob_1 labor to using Oa_2 capital and Ob_2 labor. Less labor and more capital was used to produce the same product. Average labor productivity increased while technology remained constant.

Bias introduced by movement toward or away from equilibrium can be illustrated in Figure 9.

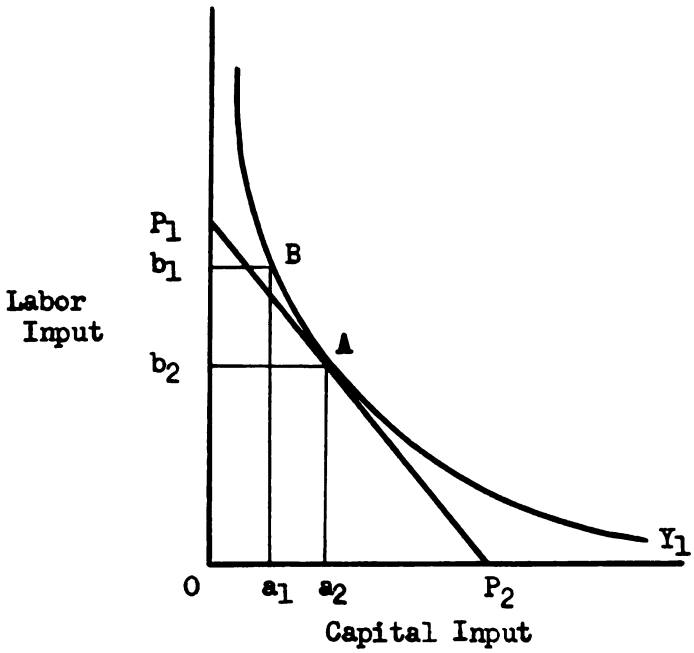

Fig. 9. Movement toward equilibrium bias in labor productivity.

If it is assumed that technology remains constant it can be demonstrated in Figure 9 that a movement toward equilibrium increases labor productivity. To produce Y_1 with the price ratios represented by P_1P_2, a firm is in equilibrium with an outlay of Oa_2 capital and Ob_1 labor. However, if the firm, or the industry, is producing at B using Oa_1 capital and Ob_2 labor, less labor and more capital can be used as the producer moves along Y_1 from B towards A. The productivity of labor has been increased, not due to technology, but due to a move toward equilibrium.

Bias introduced by expansion effect is illustrated in Figure 10.

If it is assumed that technology remains constant it can be demonstrated in Figure 10 that increase in scale can affect the productivity of labor relative to capital. To produce Y_1 required Oa_1 units of

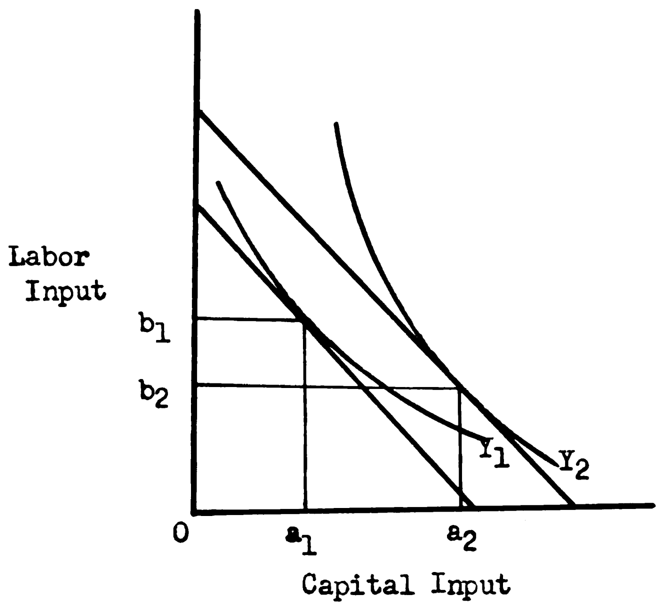

Fig. 10. Expansion effect bias in labor productivity.

capital and Ob_1 units of labor. If scale of operation expands to produce Y_2, Oa_2 units of capital and Ob_2 units of labor are required. As size of operation increases economies of scale may occur which results in increased labor productivity.

However, the opportunity to increase labor productivity through increases in scale alone is rather limited. Labor can only be added in units of one man, except for part-time help, which requires a nearly duplicate unit of land and capital to that required by the first man. The view that the addition of a second man does not greatly affect the productivity of the first man has been widely accepted.

Input-output approach. The input-output method of measuring technological change aggregates total inputs and outputs (if more than one product is produced) from which the $\frac{\text{output}}{\text{input}}$ ratio is calculated.

The change in the ratio measures changes due to technology if the four conditions hold. If the conditions do not hold, bias will be introduced resulting from other changes as discussed under the labor productivity approach. This method does have the advantage of considering changes in productivity of all resources and not just one. An additional problem connected with this method is the problem of aggregation which will be discussed under a separate heading.

Production function approach. The production function approach consists of constructing a production function for some base period and then substituting the inputs of a selected period into the function. The contribution of technology can be measured by calculating the difference between the actual production and the production estimated by the base period production function. If the four conditions hold, this would be an accurate measure of technological change. As the four conditions are relaxed, bias will enter the measurement.

Aggregation. If factors are aggregated, again the researcher is faced with the problem of aggregation.

In studying wheat one is not faced with the problems that one would be faced with in a study of agriculture as a whole. In agriculture as a whole many farm products are consumed in further production. For example, grains and forage are fed to livestock; if both the crops produced and the livestock produced are counted the researcher has erred in total output by the quantity fed.

The recorded data are inputs for total agricultural production, not by enterprises. For the purposes of this study, inputs must be separated by uses. Conceptually a portion of tractor costs, truck costs, labor costs, etc. is incurred in the production of several products. No satisfactory accounting system has been devised to allocate joint costs among enterprises. A method often used is to allocate costs on the basis of the portion of total income contributed by the enterprise. Such an allocation is arbitrary and may not reflect the actual costs incurred in producing the product. However, if the productivity of the input is the same for all uses, then such an allocation would approximate the actual costs.

Generally, researchers have shown that small grain production has been affected by technological advances more than have other phases of agricultural production. If this is the case, an allocation of joint costs based on the portion of income contributed by wheat will overestimate costs of producing wheat.

The series of man hours of farmwork published annually by ARS divided the labor input among various enterprises. This data, available by geographical regions and for the United States, may be useful in verifying the estimates made by counties in this study. Also, ARS published a farm labor productivity index by groups of enterprises, i.e. food grains. These seem to be the sole attempts to allocate inputs to enterprises.[1]

In inter-industry comparisons of rate of change in output per unit of input, the weighted average of the segments must equal the rate of

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[1]See Agricultural Handbook No. 118, Major Statistical Series of the U.S. Department of Agriculture, Vol. 2, prepared by Agricultural Research Service and Agricultural Marketing Service, 1957.

change of the total. This would also be the case where several segments of one industry are compared, one against another, and also to the whole. This requirement can be met if change is measured by the value added, that is the net increase in the value of the intermediate products used in production.[1]

In constructing input and output indexes a base period must be selected. If the beginning period is used, the effect is to bias downward the effect of technology. To use the end period causes an upward bias.[2]

Methodology Applicable to This Study

The wheat input-output time series data available were a limiting factor in the selection of appropriate statistical procedures. Production function analysis would have necessitated the use of multiple correlation. The value of multiple correlation results depends upon the number of degrees of freedom. The small number of observations and the large number of variables reduced the degrees of freedom to nearly zero. Production economists counseled that the results would have little meaning.[3]

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[1]Ruttan, Vernon W., Agricultural and Non-agricultural Growth in Output per Unit of Input, Journal of Farm Economics, December, 1957.

[2]Ladd, George W., Biases in Certain Production Indexes, Journal of Farm Economics, February, 1957.
See also: Ruttan, Vernon, W., Technological Progress in the Meat Packing Industry, 1919-1947, U.S.D.A., Marketing Research Report No. 59.

[3]Knight, Dale and Orazem, Frank, associate and assistant agricultural economists, respectively, at the Kansas Experiment Station.

Statistical analysis, chapters V and VI in this study was the labor productivity and input-output approaches. Chapter IV will be devoted to an historical analysis of the technological developments in wheat production.

CHAPTER IV

AN HISTORICAL INQUIRY INTO THE TECHNOLOGICAL DEVELOPMENTS IN WHEAT PRODUCTION IN THE UNITED STATES AND IN FOUR SELECTED REGIONS

Wheat, it is believed, originated in the Eastern Mediterranean region. From there it spread to Phoenicia and Egypt and eventually throughout the world. The cultivation of wheat by man antedates historical records. Neolithic man in Switzerland knew wheat. The Chinese cultivated wheat in 3000 B.C. Wheat has long been an important source of food. Cultivated wheat differs greatly from the wild wheats. Nothing is known of the methods used by early man to improve wild wheat, but undoubtedly over the centuries he must have saved the seeds of the most desirable plants. Without knowledge of what the results would be, early man in selecting and cultivating the original wild wheat laid the basis for the technological advances to be made centuries later.

The Basis for Technological Development

In the pre-historic period the technological advances made were: (1) learning to cultivate wheat, (2) selecting seed that improved the quality, and (3) spreading wheat culture to many new geographical areas.

Throughout the historical period little technological advancement was made in wheat production until the beginning of the nineteenth century. For centuries the ground was prepared with a wooden plow drawn by men or cattle, seed was sown by hand, harvest was with the sickle and threshing with a flail or animal hooves. It was under these conditions of production that wheat was brought to the United States.

The first introduction was made in 1602 by Gosnold on the Elizabeth Islands off the southern coast of Massachusetts. Wheat was first grown in Virginia in 1611 and in New York in 1622.[1]

This historical study shall be limited to the technological improvements which occurred in the United States after this introduction of wheat. Late in the nineteenth century the principles of science were first applied to the growing of wheat. Prior to this a number of improvements in machinery occurred which had an effect upon the production of wheat.

The interest of the government in encouraging technological development in agriculture provided the basis for wheat improvement work. In 1839 the first appropriation by Congress, one thousand dollars, was made for agricultural purposes. Prior to this President Washington had suggested in 1796 the establishment of a national board of agriculture, but it was not until 1862 that Congress created the National Department of Agriculture. In 1889 the department was elevated to the status of an executive department with a cabinet member as Secretary of Agriculture.

Another institution to apply scientific principles to agricultural problems was the experiment station of the land grant colleges, the first being established in 1875 at Middletown, Connecticut. By 1887, when the Hatch Act was passed, seventeen stations were in operation. This gave federal support to the experiment stations and greatly stimulated their expansion. By 1894 there were 55 stations in the United States.

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[1]Dondlinger, Peter Tracy, The Book of Wheat, Orange Judd Company, New York, 1910.

Biological Developments and Introduction of New Varieties From Foreign Countries

The Improvement of Wheat. The improvement of wheat consists chiefly of increasing the desirable qualities of the wheat plant. Man is now able to speed up the processes of natural selection and hybridization in the quest of wheat characterized by qualities deemed desirable through purposive selection, scientific breeding, and introduction of new seed from abroad.

Dondlinger a half century ago recognized the value of wheat improvement work when he wrote:

> "A century ago wheat was wheat, but now thousands of varieties have been bred which thrive best under the local conditions for which they were bred, and often they satisfy conditions, uses and tastes not in existence a century ago. The entire wheat harvest of the world is being improved. The value of this work in proportion to its cost must appeal to everyone, and indicates its permanency.
>
> The conclusions of scientists seem to be that varieties will not wear out or materially change if the same conditions which made them excellent are kept up. If special care was exercised to produce an artificial variety, this care must be continued, or it will deteriorate. The improvement of wheat by breeding is no longer theory as in the time of Darwin, but an established fact."[1]

Conscious selection is a modern process in wheat improvement. The plant breeder attempts to intensify a particular characteristic by selecting seed from only those plants which have this characteristic more markedly than other plants. One of the first experiments in wheat selection began in 1857 in England by Hallet.[2]

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[1]Ibid.

[2]Ingersoll, C. L. and Bessey, Charles E., Wheat and Some of Its Products, Nebraska Agricultural Experiment Station Bulletin No. 32, 1894.

He selected for size of head, number of heads per plant, and number of kernels per head. He proved that it was possible to change the characteristics of wheat by selection. He began with a head four and three-eights inches long which had 47 grains. In 1858 the best head raised from the seed of the original head was six and one-fourth inches long with 79 grains and the plant with the most heads on a single plant was ten. After four annual selections, in 1861 the largest head was eight and three-fourths inches, the greatest number of grains per head was 123, and the plant with the most heads had 52. By purposive selection the characteristics desired had been intensified.

Such experiments were not begun in the United States until late in the century. The most extensive and successful of the early selection experiments were at the Minnesota Experiment Station under the direction of Professor N. M. Hays.[1] According to Webber and Bessey, in 1899, little attention had been given to the systematic growing of wheat for selection until recently. They also credit Hays as the most important of the early workers in wheat selection. From 1888 to 1889 he tested 552 different wheats from which he selected eight for further testing.[2]

As early as 1882 Blount of the Colorado Experiment Station reported the results of the variety field tests that he had run.[3] The Kansas station conducted selection experiments beginning in 1891.[4]

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[1]Dondlinger, Peter Tracy, op. cit., p. 51.

[2]Webber, Herbert I. and Bessey, Ernest A., Progress of Plant Breeding in the United States, Yearbook of Agriculture, 1899.

[3]Department of Agriculture Report, 1881 and 1882.

[4]Kansas Bulletins, 20, 33, 40, and 59.

Webber and Bessey in 1899 wrote in the Yearbook of Agriculture:

> "In selecting wheat to improve the strain early attempts were mainly confined to simply taking the largest grains . . . . Many experiments in this country have worked on the improvement of wheat by selection, but in general with rather indifferent success. Recently, however, Professor Hays of the Minnesota Agricultural Experiment Station has used a very careful method of selecting wheat, grown in nursery form, which has given valuable results."

> "The early cases of wheat grown in this country were, as was the case with almost all our cultivated plants, of foreign origin and even now a great many sorts are being imported, especially from Russia. A large number, however, have had their origin in America; the first of these being mainly, such as originated in fields of wheat or from chance--sown seeds, which, owing to their differences from other wheat, were preserved and perpetuated. Such, for example, were the Tappahannock, found in Virginia in 1854, and the famous Fultz wheat found in a field of Lancaster Red Wheat in Pennsylvania in 1862 by a Mr. Abraham Fultz."[1]

The first recorded new variety developed through selection was at the Minnesota station. Variety No. 169 in yield experiments from 1895 to 1898 outyielded its parent variety by an average of 5.8 bushels per acre.

Introduction of new varieties of wheats was one of the important means by which improvement has been made. Mark Alfred Carleton, cerealist with the Department of Agriculture, was an early proponent of seeking varieties and cultural practices in foreign countries that would be useful in the United States. He made the following observations for the Great Plains area:

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[1]Webber, Herbert I. and Bessey, Ernest A., op. cit., p. 53.

> "It may be noted by any careful observer that occasionally there are farmers in these four districts who seem always to have a good crop of wheat whatever the season, even when there may be failures of the crop all about them. As other farmers in the vicinity have the same climate, and approximately the same kind of soil, such differences in results cannot be due to differences in these conditions. They are simply due to certain methods of agriculture adopted by these farmers by which they are able to overcome unfavorable conditions of weather."[1]

He noted that with the Great Plains area the Russian immigrants were particularly successful as wheat farmers because they:

1) came from an area of Russia of great weather extremes so they knew how best to handle crops under these conditions

2) brought varieties of wheat from Russia that were superior to the varieties being grown on the plains.

He urged all wheat farmers to adopt the Russian varieties and the cultural methods used by the newly arrived immigrants. In 1914 he reported that these wheats, hard red wheats, were best for the Great Plains area. With the development of the steel rolling process of milling and the wheat-flour purifier the millers no longer discriminated against the hard red wheats.

Hard red spring wheat was introduced about 1850, but did not become established as a profitable crop until 1870. The varieties that became important, Fife and Bluestem, were selections from wheat imported in 1842 from the northern Volga regions of Russia.

The hard red winter wheats were carried to Kansas by the Russian Mennonite immigrants from the Crimean region of Russia. The two varieties resulting from this importation were Turkey Red and Kharkof.

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[1] Carleton, Mark Alfred, Successful Wheat Growing in Semiarid Districts, Yearbook of Agriculture, United States Department of Agriculture, 1900.

However, it was not until 1897 that the Kansas Experiment Station recognized the superiority of the hard red winter wheats. Not until after 1900 did these varieties become important in the southern Great Plains.[1]

Durum wheat was also introduced from eastern Europe into the northern Great Plains because of its drought resistance and ability to outyield the spring wheats. The two varieties imported were Arnantka and Kubanka.[2]

From Australia two new wheats were introduced, Early Baart and Federation.[3]

Interest in the possibilities of finding new foreign wheats superior to domestic wheats culminated in sending Carleton to Russia to find strains of wheat grown for generations in an isolated locality so that the strain would be pure and well adapted to environmental conditions.[4]

Hybridization is the process of cross-fertilization of different strains, varieties, or types of plants. Hybridization occurs in nature and has had its effects upon altering wheat. Purposive hybridization by man was begun about 1800 in England by the plant physiologist

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[1]Carleton, Mark Alfred, Hard Wheats Winning Their Way, Yearbook of Agriculture, United States Department of Agriculture, 1914.

[2]Galloway, B. T., Immigrant Plants Hold Large Place Among U.S. Crops, Yearbook of Agriculture, United States Department of Agriculture, 1928.

[3]Ibid.

[4]Woods, A. F., Wheat Output Grows Through Survival of the Fittest Strain, Yearbook of Agriculture, United States Department of Agriculture, 1927.

Thomas Andrew Knight.[1] It is believed that the first hybrid produced scientifically in the United States was a pear in 1806.

In the United States C. G. Pringle of Charlotte, Vermont, was the pioneer hybridizer of wheat. He began his work in 1877 and developed several varieties which were widely produced. Another early wheat breeder was A. E. Blount of the Colorado Experiment Station who successfully developed Amethyst, Improved Fife, Hornblende, Gypsum, Blount's No. 10, Felspar, Ruby, and Granite.

Blount contributed an article to the 1885 Report of the Commissioner of Agriculture in which he discussed the production of new varieties by what he called cross-fecundation.[2] Interest in the new method of plant improvement continued. In 1897 Swingle and Webber wrote in the Yearbook of the Department of Agriculture an article which emphasized the use of hybrids in wheat improvement work.[3]

Webber, with Bessey, in 1899, again gave attention to the value of hybridization work. He states that interest in developing hybrid wheat began only in 1890.[4] The characteristics the plant breeders were attempting to establish in new varieties were earlier maturity, higher yields, and winter hardiness. In this work many of the crosses were between American and Russian varieties.

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[1]Dondlinger, Peter Tracy, op. cit., p. 51.

[2]Report of the Commissioner of Agriculture, 1885.

[3]Swingle, Walter T. and Webber, Herbert J., Hybrids and Their Utilization in Plant Breeding, Yearbook, Department of Agriculture, 1897.

[4]Webber, Herbert J. and Bessey, Ernest A., Progress of Plant Breeding in the United States, Yearbook of Agriculture, 1899.

In 1910 Dondlinger concluded no valuable results had been achieved through the hybridization work of the experimenters. He noted that plant breeding experiments in wheat were being carried out in Texas, Kansas, South Dakota, Minnesota, and Maryland. In these experiments the scientists were seeking earlier maturity so that by sowing two varieties the harvest period could be lengthened to avoid too green cutting and shattering. He perceived later developments when he stated:

> "Experience has taught that the most successful and practical way to fight disease is to aid natural selection in producing disease-resistant or immune plants, rather than to attempt to cure the disease."[1]

Mechanization of Wheat Production

Mechanization of wheat production was an outgrowth of the westward expansion of the nation. Each farmer's production west of the Mississippi was limited largely by the supply of labor. The cheap abundant labor of the eastern seaboard was not available. Because the farmer had a ready market for his grain in Europe, he was anxious to expand production. In mechanization the farmer of the Trans-Mississippi region recognized the solution of his problem.

Without mechanization westward expansion would have been much slower. Development of the frontier and mechanization were interdependent. The conditions of the frontier were favorable to adoption of labor saving equipment and in turn mechanization made possible development of the new lands.

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[1]Dondlinger, Peter Tracy, op. cit., p. 51.

An example of this was in the experience of McCormick with his reaper. He made no progress in promoting the reaper in the eastern states; but when he moved to Chicago, his reaper quickly spread.

This period, 1800 to 1900, was the period in which the concept of substituting capital for labor became firmly established as desirable in agriculture. It was not suddenly recognized nor sought. It was forced upon the farmer by a set of circumstances, available market, abundant supply of land and a shortage of labor.

This portion of the study will trace briefly the historical development of the mechanization of wheat production in the United States.

Power. The United States farmer has progressed through many stages in relation to power. The first source of power was human energy. During the colonial period a large portion of the power needed was provided by the farmer, his family, hired labor, or slaves. For example, the seeding was done by hand broadcasting, harvest was with the sickle, the scythe, or the cradle, and threshing was by flail. Oxen were the source of power for plowing and soil cultivation, such as harrowing. With the advent of the steel plow, horses replaced oxen as a source of power. Horses dominated the farm power picture roughly from 1850 to 1920.

Mechanical power was first possible after the invention of the steam engine. In 1861 the first attempts were made to use steam power for plowing. Because of the cumbersomeness of the steam engine, little headway was made in substituting mechanical power for horsepower on wheat farms. In the Pacific coast area steam power made the most headway. Dry land, large scale operation, big flat fields were factors that encouraged the use of steam power in California.

The first use of mechanical power was for threshing. For this purpose stationary engines could be used.

Rogin reports that in 1900 the gas tractor had begun to supplant the steam tractor and found immediate popularity, especially among farmers needing small outfits.[1]

Tillage implements. The plow has been the basic tool for cultivation of the soil, so that it was to be expected that it would be one of the first implements to undergo improvement. However, the wooden plow of antiquity underwent little change until the nineteenth century when the cast iron plow was introduced. Early cast iron plows were cast all in one piece and never were accepted by farmers. In 1814, Jethro Woods patented a plow with interchangeable parts.[2] Manufacture of Woods' plow on a commercial scale began in 1817 and the census of 1880 reports that the cast iron plow was in universal use by 1825, an apparent overstatement.

Cast iron plows tended to wear out very quickly due to the softness of the metal. For this reason the moldboard, share, and landside were later made of cast steel. By 1840 John Deere and others were commercially producing steel plows.

The walking one bottom plow continued to dominate until after the Civil War. The riding wheel plow with several bottoms gradually came into use, particularly in the Pacific coast area. According to Rogin, 1864 marks the time of introduction of the gang plow.

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[1]Rogin, Leo, The Introduction of Farm Machinery, University of California Press, Berkeley, 1931.

[2] Ibid.

Improvement in design and in quality of material and adaption to tractor power are the principal changes in the plow made in the last century.

Harrowing was first accomplished by dragging branches or brush over the plowed land to cover the seed. First, wooden beams with spikes and eventually iron frames with teeth were the evolutionary path of the harrow.

In the dry western lands wheat farmers experimented with implements that would speed the process of soil tillage. In the late nineteenth century the development of the disk fulfilled this need. The principle of the disk has been used in the one-way and the disk plow. Elwood, Arnold, Schmutz, and McKibben concluded that the development of the vertical disk and its use as a one-way has been the most important development affecting the labor needed to prepare land for small grain production.[1]

Present day tillage equipment is primarily improvements on and adaptations of the implements discussed. These include duck-foots, spring tooth harrows, rod-weeders, and sub-soilers.

Seeding implements. Until about 1850, all planting of wheat was by hand, commonly called broadcasting. After scattering the seed the ground was dragged with a harrow to cover the seed. The principle of the drill was to place the seed evenly beneath the surface of the ground. After the mechanical seeder was developed in the last half of the nine-

[1]Elwood, Robert B., Arnold, Lloyd E., Schmutz, D. C., and McKibben, Eugene G., Changes in Technology and Labor Requirements in Crop Production, Wheat and Oats, Works Progress Administration, National Research Project, Report No. A-10, Philadelphia, 1939.

teenth century, changes have been primarily in the improvement of this basic implement.

Harvesting. Tillage and seeding equipment were quite well developed before the advent of the tractor. However, the need for large units of power to run the present day harvesting equipment slowed the adoption of mechanical harvesting.

The sickle used in early America gave way to the scythe and the scythe to the cradle. Treading and flailing gave way to the thresher. Until tractor power became available the two steps of harvesting, cutting and threshing, were not combined into one.

The cradle, a short-lived intermediary harvesting implement, came into general use during the first half of the nineteenth century.

In 1834 McCormick patented his first reaper and made his first sale in 1840. Little progress was made in spreading its use for the next decade.

> "Realizing the difficulty of trying to introduce harvesting machinery in a section of the country where farms were comparatively small and labor cheap and plentiful, McCormick undertook the task of personally demonstrating his reaper during 1844 in western New York, Ohio, Illinois, Wisconsin, and Missouri.[1]

After moving his factory to Chicago in 1847, McCormick was hard pressed to produce sufficient reapers to meet the needs of the farmers. From this time on the reaper was well established.

In the next 75 years many improvements were made in the reaper. Two general types developed, the binder and the header.

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[1]Rogin, Leo, op. cit., p. 60.

Threshing by mechanical means was first attempted about 1800. Horses and water wheels provided the power. The first adaptation of the steam engine to farming was as a source of power for threshing. Originally stationary engines were used. As the mobile steam engine was developed greater flexibility of threshing was possible. The gasoline engine, of course, made possible even greater flexibility.

The tractor, the header, and the mechanical thresher, at first separate units, provided the basis for the modern combined harvester-thresher. The dry flat lands of California provided the experimental environment needed to develop the combine. As early as 1828 a patent was granted for what was claimed to be a combine but was never developed. In 1835 a patent was granted for a machine that was to cut, thresh, clean, and bag the grain. It seems that the development of combines in California sprang from this patent. A machine was built in the East in 1843, but did not successfully operate until 1853. In 1859 a machine was taken to California where it cut 600 acres of wheat. However, it was not used again. In 1884 only about 50,000 acres of wheat were cut by combines in California. In the East, cheap labor and small size of farms further retarded the use of the combine long after the principles of its use were understood. The successful development of the combine was delayed until after the gasoline tractor was in fairly general use.

Technological Changes and the Effect of the Changes Since 1900

The scientific basis for the twentieth century technological evolution in wheat production was well advanced by the turn of the century. The mechanical principles that underlie mechanization were known. Many of the principles of plant breeding useful in plant improvement were ready for application. Scientists were aware that there were functional relationships between cultural practices and successful crop production.

Yet in 1900 wheat production was very different than it was in the 1950's. In 1900 farmers were not applying scientific principles to wheat production. The nineteenth century was an era of scientific discovery. The application of this new knowledge to agriculture was in the process of being worked out. During the twentieth century the new technology passed from the experimental stage into wide dissemination and use.

It is simple to conclude that the most significant changes in wheat production in the last fifty years have been the application of science to the problems of production. This does not imply that this period has been devoid of the development of new principles which in the future can be applied. On the contrary, scientists today are experimenting with climate control, radiation in plant development, automation of operational procedures, and electronic computational procedures for solving organizational problems, all of which hold the potential of further revolution in farm production.

This section will be concerned with the adoption of the nineteenth century discoveries in wheat production in the 1900-1954 period. During this period the agricultural scientists were also interested in improving and perfecting their knowledge of principles and methodology.

The tractor, the combine, the multiple bottom plow, the drill, and the cultivation implements were all in use in 1900. New wheat varieties had been developed by scientists both through hybridization and selection. The biological nature of most diseases and insects attacking wheat was fairly well understood. Yet wheat production was not too different from what it was in 1800. The great production changes were yet to come.

Mechanization. An indicator of mechanization is the number of tractors on farms. A study of the replacement of horse power by mechanical power is a crude measure of the rate of mechanization. Therefore the rate at which tractors displaced horses was calculated for each of the four areas in order to determine if there were regional differences in the rates of mechanization.[1]

Simple regression analysis was used to determine the functional relationship between tractors and horses.[2] The results of this analysis are shown in Figures 11 and 12.

In interpreting the diagram it is necessary to be cognizant of the reason for the relative positions of each of the curves. The hard red spring wheat curve is furthest to the right and highest because a greater geographical area was considered than was considered in the other three areas. There were just more horses and tractors under consideration.

Secondly, this cannot be interpreted as being a true factor-factor relationship inasmuch as the curves do not represent a constant product.

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[1]See pp. 89, 90, and 91 of Chapter V for the areas of the hard red winter, hard red spring, white, and soft red wheat included in this study.

[2]See Tables 26 to 33 of Appendix A.

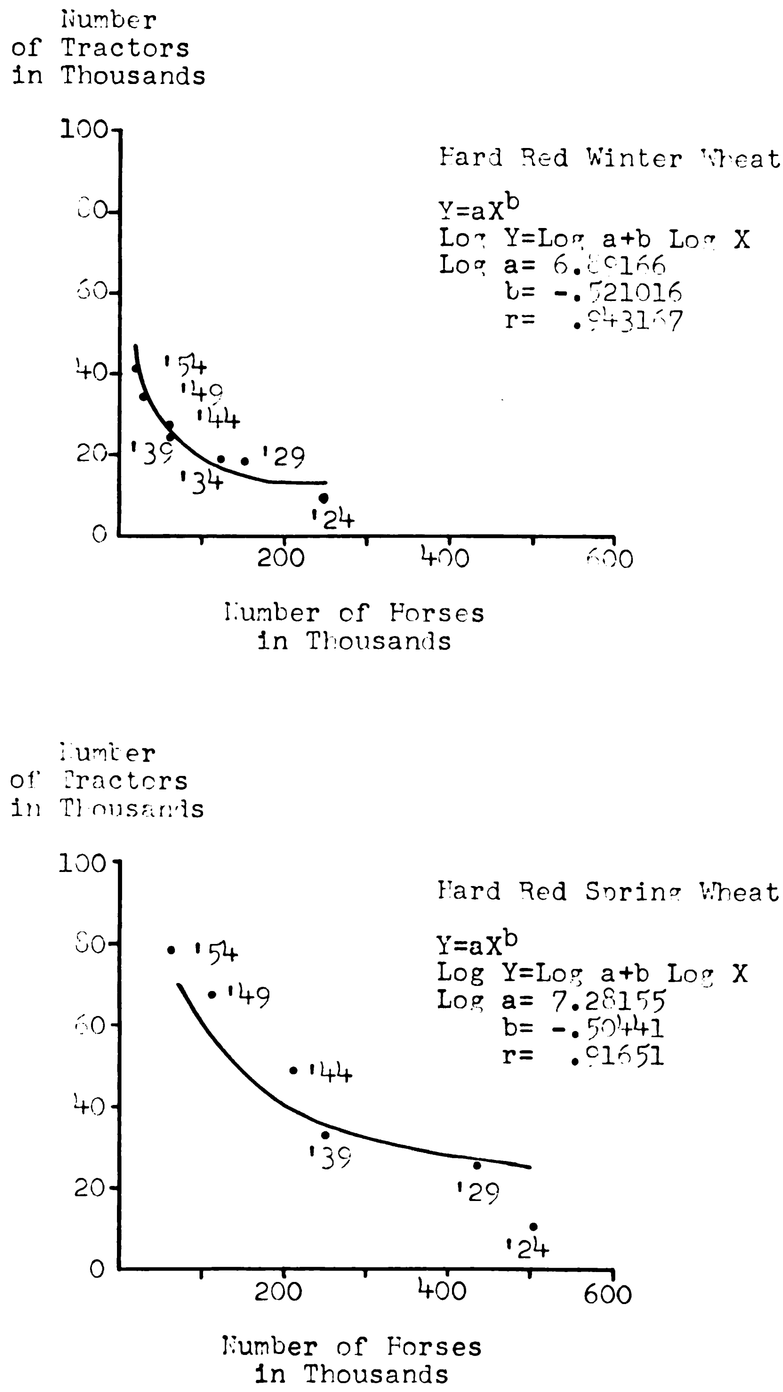
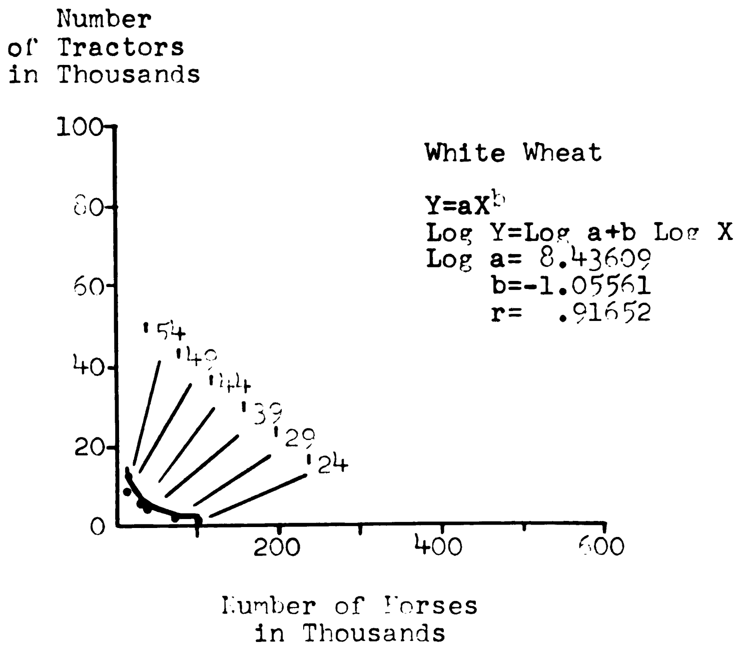


Fig. 11. The relationship between number of tractors on farms and number of horses on farms for the specialized wheat regions of the hard red winter wheat area and the hard red spring wheat area, 1924 to 1954.



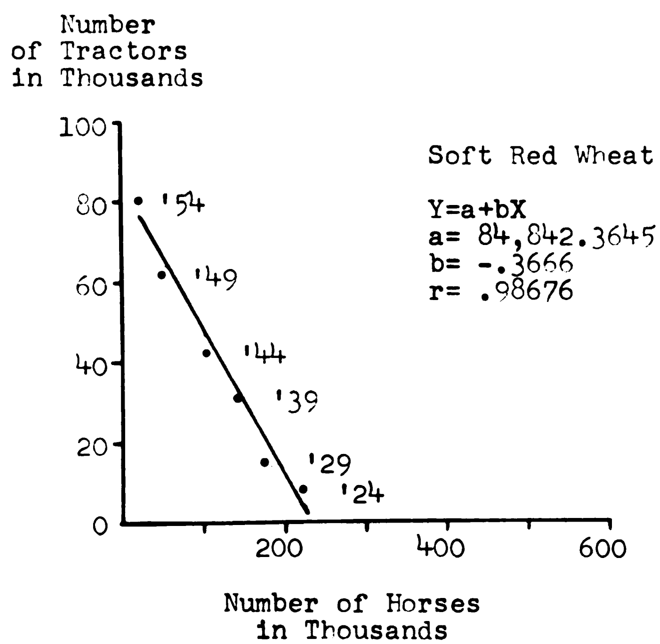
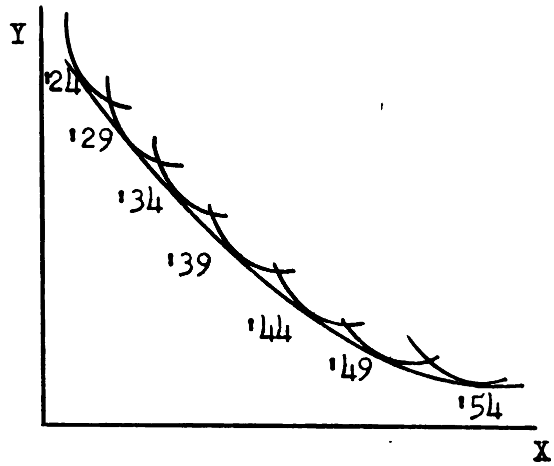


Fig. 12. The relationship between number of tractors on farms and number of horses on farms for the specialized wheat regions of the white wheat area and the soft red wheat area, 1924 to 1954.

Each point on the curve represents one point on a separate iso-product curve as follows:



Therefore, in speaking of the number of horses that were replaced by each tractor it must be remembered that this is not a true marginal rate of substitution. With the available data it was impossible to determine the marginal rate of substitution because only one point was known on each iso-product curve. However, by connecting each of these points an average rate of substitution over time can be calculated which gives a crude measure of the rate of mechanization, and provides the basis for inter-regional comparisons.

Thirdly, the data does not differentiate size of tractors, therefore, the more rapid rate of substitution in the western areas is partially due to the larger size of tractor used there. A larger tractor provided more power, consequently each tractor replaced more horses than the smaller tractors used in the eastern states.

By inspection of the data plotted in Figures 11 and 12 it was determined that a curvilinear relationship existed between tractors and horses in the hard red winter, hard red spring, and white wheat areas. The functional relationship $Y = aX^b$ was chosen to measure the relationship between the decreasing number of horses and increasing number of tractors for these three areas. In the soft red area the relationship appeared to be linear and $Y = a + bX$ was used to measure the relationship. The computation of the b values gave a measure of the rate at which tractors substituted for horses. The b value represented the average percent decline in number of horses associated with a one percent increase in the number of tractors. By areas, an increase in tractors by one percent was accompanied by an average decrease in horses as follows: white, 1.05561; hard red winter, .521016; hard red spring, .50441; and soft red, .3666.[1]

The rate of mechanization as measured by the relationship in changes of numbers of horses and tractors was much more rapid in the white wheat area than for any of the other areas. The hard red winter and hard red spring areas mechanized at about the same rate, whereas the soft red area has lagged behind. The rate of change has been relatively constant in the soft red area as represented by the linear relationship. Since 1924, although the absolute number of tractors that has replaced horses has increased, there has been little change in the rate. Each of the other areas experienced a particularly high rate of substitution of tractors for horses in the early years as indicated by the flatness of the right side of the curve. After 1939 the curves became much steeper which represented a slowing of the rate of substitution. Between 1924 and 1939 a small increase in tractors was accompanied by a large decline in number of horses. In the years

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[1]See Tables 26 to 33 for the computational procedures and Figures 11 and 12 for geometric presentation. The r values show that the functional relationships used, $Y = aX^b$ and $Y = a + bX$ gave a good approximation of the relationship.

1939 to 1954 the larger increases in number of tractors was accompanied by decreasing declines in number of horses, which indicates that the substitution was largely accomplished by 1939. On the average it can be concluded that the rate of mechanization was most rapid in the Pacific Northwest, followed by the southern Great Plains, northern Great Plains, and the eastern Cornbelt. Furthermore, the mechanization, as measured by substitution of tractors for horses has been at a declining rate since 1939 for all areas except the soft red area.

There are other measures of mechanization, all dependent upon the use of the tractor. An analysis of the relationship of substitution of machinery for labor would represent a measure of mechanization. If number of tractors were considered a crude measure of the degree of mechanization then the rate at which tractors were substituted for labor would be an indicator of the rate of mechanization. Number of combines, trucks, grain drills also indicate the trends in mechanization. Because the replacement of the horse by the tractor was basic to mechanization in 1924 to 1954, the rate at which tractors substituted for horses was selected as the measure of rate of mechanization.

Factors that may explain the differential rates of mechanization. A number of factors may have influenced the rates of mechanization. Small grain production had only a few relatively simple operations, soil preparation, seeding, and harvesting. The character of these operations favored mechanization. From this it could be concluded that the areas having the larger portion of the land in small grains would mechanize most rapidly. In testing this it was found that the hard red winter and hard red spring areas had the greatest specialization in small grains as well as in wheat.

Table 1. The percent of farm land in wheat and the percent of farm land in small grains for four wheat producing areas.[1]

Year	Hard red winter: Wheat	Hard red winter: Small grains	Hard red spring: Wheat	Hard red spring: Small grains	White: Wheat	White: Small grains	Soft: Wheat	Soft: Small grains
1954	21.2	29.5	18.4	38.7	16.6	21.7	7.2	14.5
1944	25.5	31.6	23.6	39.0	18.9	19.5	7.1	14.3
1934	19.4	20.8	6.0	8.5	17.0	17.5	8.2	15.2
1924	25.8	30.2	25.0	45.3	17.4	18.0	7.4	15.3
Avg.	22.9	28.0	18.2	32.9	17.5	19.2	7.5	14.8

[1]Computed from census data.

The soft red areas had the lowest percent of farm land in small grains. The relation between degree of specialization and rate of mechanization in each case was consistent with the hypothesis.

Table 2. The relation of rate of mechanization and degree of crop specialization.[2]

Area	Degree of specialization % land in small grains 1924-54 average	Rate of mechanization
White	19.2	1.05561
Hard Red Winter	28.0	.521016
Hard Red Spring	32.9	.50441
Soft Red	14.8	.3666

[2]Computed from census data.

The larger the size of the farm the more rapid the farm may be expected to mechanize. Mechanization represents a large fixed cost and for the small farm the per unit cost discourages mechanization.

Table 3. The relation of size of farm and the rate of mechanization.[1]

Area	Average size of farm 1934	Average size of farm 1954	Percent of farms over 500 acres 1934	Percent of farms over 500 acres 1954	Rate of mechanization
White	894	1,246	49.8	46.8	1.0556
Hard Red Winter	523	724	44.3	49.5	.5210
Hard Red Spring	365	705	47.9	57.5	.5044
Soft Red	93	128	1.0	1.5	.3666

[1]Source: United States Census.

In Table 3 the relationship between size of farm and rate of mechanization is substantiated in each case, except in the soft wheat area. The larger the average size of farm the more rapid mechanization occurred. The portion of the farms that were over 500 acres was closely associated with the rate of mechanization. The white, the hard red winter, and the hard red spring all had nearly one-half the farms in the largest size group, over 500 acres.

The character of the fields themselves can be expected to influence the rate of mechanization. Large fields of relatively level land encourages the use of large equipment.

Labor supply may be an influencing factor in rate of mechanization. In a comparison of the four areas it could be concluded that the scarcer the supply of labor the more rapid the rate of mechanization.

Table 4. The relation of rate of mechanization and the labor supply.

Area	Number of farm workers per farm[1] 1934	1944	1954	Rate of mechanization
White	1.7	1.8	1.5	1.05561
Hard Red Winter	1.7	1.6	1.8	.521016
Hard Red Spring	1.6	1.5	2.1	.50441
Soft	1.5	1.4	1.3	.3666

[1]Source: United States Census.

The tabular analysis reveals that within a region there is a relationship between labor supply and rate of mechanization.

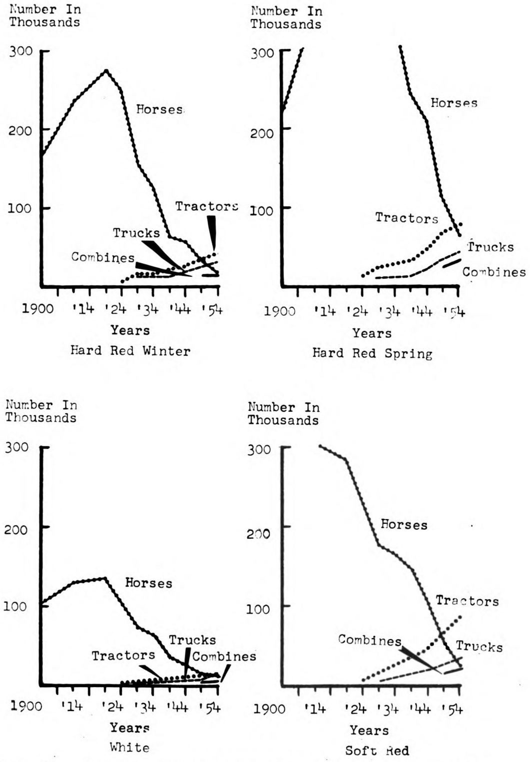

Fig. 1[illegible]. An inter-regional comparison of tractors, combines, trucks, and horses, 1900-1954.

Control of diseases and pests. An identifying characteristic of the work of the United States Department of Agriculture and the state experiment stations has been the concern for plant disease and pest control. It is a rare year that none of the publications of either deal with problems associated with diseases and pests attacking wheat.

Two general approaches to solving these problems has dominated research activity in the area. Most emphasis, judged by the number of publications, was placed upon developing resistant strains of wheat. This was discussed under the section of wheat improvement in this chapter. A second approach was to find specific treatments and cultural practices which would control the disease or pest.

One of the problems, the Hessian fly, has been largely controlled by a combination of both. A study of the life cycle of the fly showed the dates at which it hatched and if wheat were planted after this date it was not attacked. The plant breeders also have built into some varieties a resistance to the Hessian fly.

Stem rust of wheat was subjected to the same two-pronged attack beginning in 1902. Seed treatment before planting gives control. Also, when the relationship between barberry, stem rust, and cereal grains was understood stem rust could be controlled if one or other of the hosts were destroyed. Therefore, concerted efforts to destroy barberry were made.

The early search for resistant varieties was carried out at the Minnesota, Kansas, and Tennessee experiment stations both through selection and plant breeding work. In Kansas, selection led to the development of Kanred, a strain resistant to rust.

Timeliness of operations. In 1910 Dondlinger recommended fall plowing for spring wheat and as early plowing after harvest as possible for winter wheat. Better control of weeds, moisture conservation, and time for settling of the seed bed, all of which increased yields, were the reasons given for the recommendation. Experiment station publications to the present have echoed and re-echoed the recommendations of Dondlinger.

With the newly gained knowledge of the relationship between seeding dates and infestation by Hessian fly, the plant scientists of the early twentieth century advocated the sowing of wheat after the fly free date.

The development of the tractor made possible the improvements made in timeliness of operations. The tractor provided a high speed, constant and dependable power unit that made possible the accomplishment of soil preparation, seeding, and harvesting activities within the narrow time limits demanded, in order to optimize wheat yields and quality.

Tenure of farm operators. Tenure patterns in each of the four areas have been very similar. From 1900 to 1934 there was a general increase in the proportion of tenancy. In the two Great Plains areas the increase continued until 1939, whereas in the other two areas the peak was reached by 1934. Throughout the period under consideration the proportion of tenancy has been greatest in the hard red winter wheat area and lowest in the soft red wheat area.

Table 5. Changes in the tenure position of farm operators in four wheat producing areas, 1900, 1934, and 1954.[1]

Area	Percent tenancy			Percent full owners			Percent part-owners		
	1900	1934	1954	1900	1934	1954	1900	1934	1954
Hard Red Winter	20.0	46.2	33.6	39.0	25.6	24.5	41.0	28.2	41.9
Hard Red Spring	6.2	42.2	21.6	72.9	26.9	34.4	20.9	30.9	23.4
White	11.2	31.9	20.5	73.3	45.1	46.9	15.5	23.0	32.6
Soft Red	23.8	25.0	11.6	61.9	58.6	67.9	14.3	16.4	20.5

[1]Source: United States Census.

In considering the percent of operators who were full owners the same pattern by geographical areas prevailed. A higher portion of the operators in the soft red wheat area were full owners than in any other area. The hard red winter areas of Kansas and Nebraska consistently have had the lowest proportion of full owners.

A unique feature of the Kansas-Nebraska counties is the domination of the part-owner type tenure situation. This indicates that many operators own land for a base of operation and secure additional land through rental agreements. This organization has provided a means of expanding the size of the farm business without confronting the problems of capital limitations.

Average size of farm. Farms in all regions of the United States have been increasing in area of land farmed. Each of the four wheat producing areas under consideration have shown a relatively constant increase in acreage since 1900 with the exception of the Great Depression years.[1] The corn belt area has shown the steadiest growth, although at the slowest rate of all the areas. In the 54 year period the soft wheat farms had an average annual growth in land area of but .68 percent. The white wheat area in the Northwest showed the most rapid growth. The average farm has added 13.49 acres each year since 1900 which was a 2.6 percent annual rate of growth. Except for the 1929-34 and 1949-54 periods, when farms slightly decreased in acreage the growth has been steady. The size of farm in the two hard red wheat areas has followed similar patterns. The slower rate of growth in the winter wheat area is explained primarily by the decline in size of farms in the 1900 to 1909 period. During this period the spring wheat area was making a relatively rapid rate of growth in size of farms. After 1910 the rate of growth of the two areas has been nearly equal.

Table 6. A comparison of average size of farms in acres for selected wheat producing areas, 1900-1954.[2]

Area	Average size of farm in acres		Total increase in size		Average annual growth	
	1900	1954	Acres	Percent	Acres	Percent
Hard Red Winter	522.94	723.71	200.77	38.39	3.72	.71
Hard Red Spring	365.62	704.68	339.06	92.74	6.28	1.71
White	518.17	1246.82	728.65	140.62	13.49	2.60
Soft	93.32	127.79	34.47	36.93	.64	.68

[2]Source: United States Census.

Three of the areas, hard red winter, hard red spring and white have shown a tendency to follow the classical growth pattern whereby

[1]See Figure 14.

early rate of growth is rapid, followed by a slower growth rate, another growth spurt, and finally a leveling out.

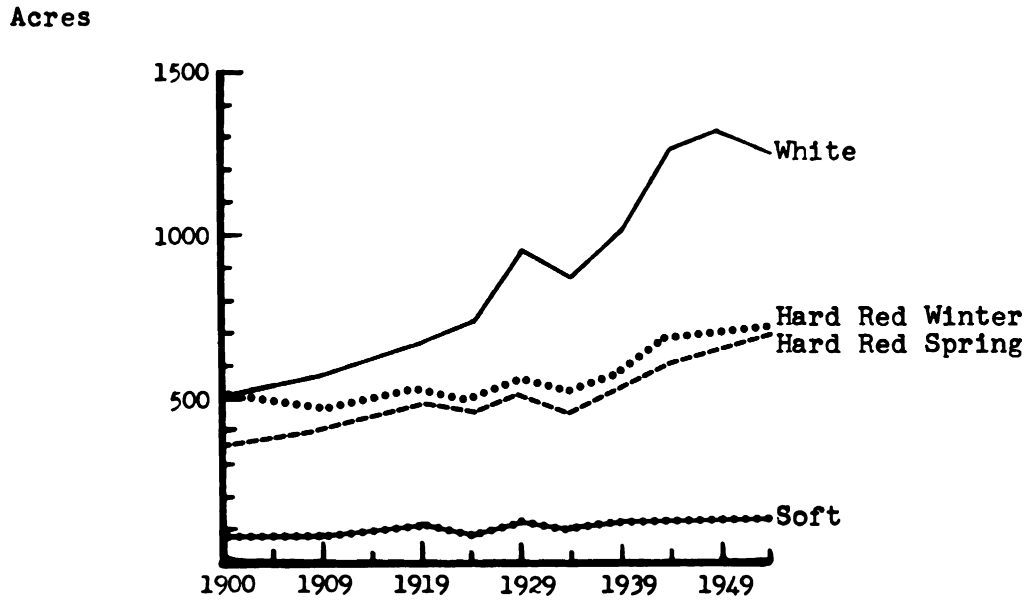

Fig. 14. The average size of farm in acres for selected regions of each of the principal wheat producing areas, 1900 to 1954.

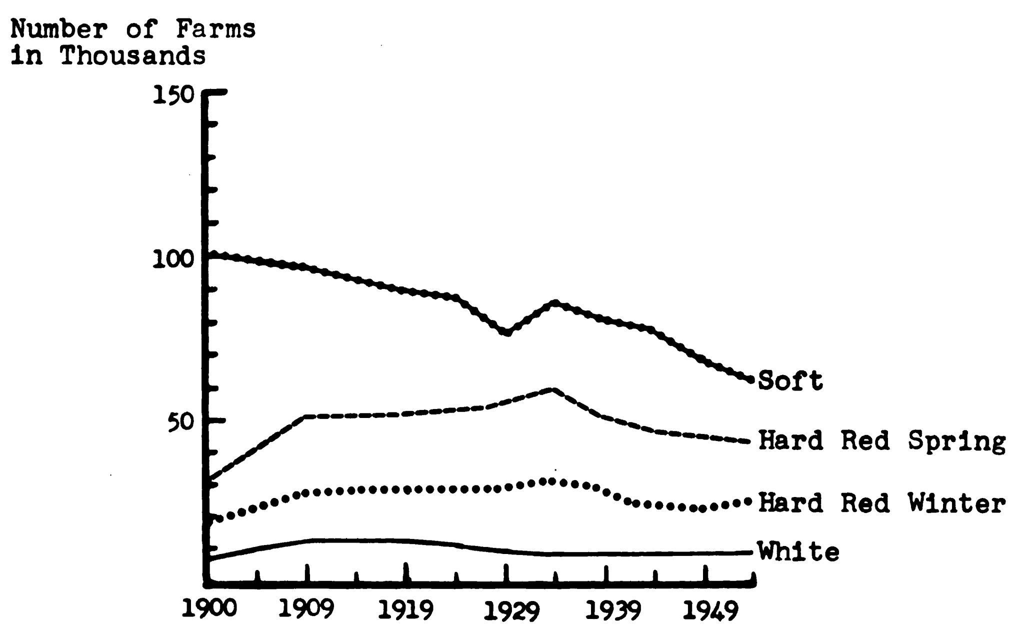

Fig. 15. The number of farms for selected regions of each of the principal wheat producing areas, 1900 to 1954.

Number of farms.[1] The change in number of total farms is somewhat less than could be expected when the rapid rate of increase in acreage per farm is considered. Only in the case of the soft wheat area has the decrease been significant. The Great Plains had a steady increase in number of farms until 1934 after which time the number has declined at a fairly constant rate. The soft wheat area has had a decline in the number of farms, except in the great depression period, throughout the period. The white wheat area has had very little change since 1934 in the number of farms. Table 7 summarizes changes in number of farms in each area in the period 1934 to 1954.

Table 7. A comparison in number of farms and the annual rate of change in number of farms for four wheat producing areas.[2]

Area	Total number of farms		Change in number of farms		Annual rate of change
	1934	1954	Number	Percent	Percent
Hard red winter	30,963	23,854	- 7,109	-22.9	-1.1
Hard red spring	59,458	42,949	-16,509	-27.8	-1.4
White	9,861	7,813	- 2,048	-20.8	-1.1
Soft	86,592	62,889	-23,703	-27.4	-1.4

[2]Source: United States Census.

Adjustments in resource use. Data on the county basis for number of people living and working on farms were not available prior to 1934. Not until the 1925 census was the farm population enumerated separately. Again in the 1955 census the number of people on farms was not enumer-

[1]See Figure 15.

ated. This shortcoming of the data was a serious handicap in attempting to measure changes in resource productivity.[1] The data available, however, provided sufficient information for crude estimates of the trends in resource use. In all areas the generally accepted conclusion that the labor input relative to other resources has continuously declined was verified.

On the per farm basis all inputs have been increased during the 1924 to 1954 period. The greatest input increase on the average farm was the capital input. Capital input (see Table 8) increased 111.7 percent in the hard red winter, 155.1 percent in the soft red, 163.7 percent in the hard red spring, and 271.3 percent in the white wheat area. The increased size of the farm was also reflected in the increase in the acres per farm as discussed on pages 77 and 78 of this chapter. A more recent period, 1924 to 1954, was given consideration in Tables 8 and 9. The land area per farm increased most in the hard red spring area, 51.7 percent, in the white area, 39.4 percent, in the hard red winter, 36.3 percent and in the soft red by 27.6 percent. In every area the average labor input per farm has increased, but at a much slower rate than the other inputs, 31.2 percent in the hard red winter, 17.6 percent in the white wheat, 6.2 percent in the soft red, and 5.9 percent in the hard red spring wheat.

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[1]In order to correct this data gap the Bureau of the Census, Washington, D. C. and each of the state Crop and Livestock Reporting Services were contacted directly. State Board of Agriculture Reports in the Kansas State University Library for each state were carefully studied. In each case no additional data was available.

Table 8. Percent changes in the land, labor, and capital inputs in four wheat producing areas, 1934, 1939, 1944, 1949, and 1954, average per farm.[1]

Area	Percent change from 1934											
	Land[2]				Labor[3]				Capital[4]			
	1939	1944	1949	1954	1939	1944	1949	1954	1939	1944	1949	1954
Hard red winter	11.3	28.5	34.1	36.3	-17.6	-5.9	-5.9	5.9	-46.2	33.4	87.1	111.1
Hard red spring	15.0	31.5	40.9	51.7	0.0	-6.2	6.2	31.2	14.1	112.0	230.6	163.7
White	17.5	42.9	47.5	39.4	0.0	5.9	11.8	17.6	-27.5	61.6	251.8	271.3
Soft red	2.0	10.4	17.6	27.6	-12.5	-12.5	-6.2	6.2	-24.8	11.0	81.7	155.1

[1]Computed from census data.
[2]Based on number of acres of land in wheat.
[3]Based on number of laborers in wheat production.
[4]Based on dollar investment (1910-14 dollars = 100).

Table 9. Percent changes in the total land, labor, and capital inputs used in four wheat producing areas, 1934, 1939, 1944, 1949, and 1954.[5]

Area	Percent change from 1934											
	Land[6]				Labor[7]				Capital[8]			
	1939	1944	1949	1954	1939	1944	1949	1954	1939	1944	1949	1954
Hard red winter	2.1	2.4	2.8	5.0	-23.8	-21.2	-25.7	-16.1	-50.7	6.3	43.4	62.7
Hard red spring	0.0	7.6	8.2	9.6	-12.3	-23.2	-20.0	-8.1	-0.9	73.3	153.8	90.5
White	2.7	12.3	12.4	10.4	-9.8	-14.0	-13.4	-6.3	-36.6	27.0	168.2	194.2
Soft red	-4.2	-1.9	-5.1	-7.3	-16.8	-21.8	-24.4	-19.1	-29.5	-1.2	46.4	85.1

[5]Computed from census data.
[6]Based on number of acres of land in wheat.
[7]Based on number of laborers in wheat production.
[8]Based on dollar investment (1910-14 dollars = 100).

The average labor input per farm and the total labor input in each area decreases were probably underestimated, particularly for the decreases since 1950. The basis for counting farm labor was changed in the 1954 Census.[1] No adjustment factor was available to apply to the 1954 data to make them comparable to the previous years. Therefore the decrease in labor was more pronounced than indicated by the data used.

Table 10. The average number of acres per unit of farm labor for four wheat producing areas, 1934 to 1954.[2]

Year	Hard red winter	Hard red spring	White	Soft red
1934	318.9	286.3	540.4	64.3
1939	427.4	326.4	615.6	74.0
1944	414.5	401.0	705.9	80.7
1949	440.9	387.2	701.8	80.7
1954	399.2	341.5	637.2	73.6

[2] Source: Computed from census data.

A measure of the change in the labor input was illustrated by the change in total acres in farms per unit of man labor, (Table 10). In this instance the increase in acres was underestimated due to concomparability of data. From 1934 to 1949 there was the following increases in acres of land per man unit:

[1] The 1954 Census of Agriculture states, "data shown for earlier censuses are not fully comparable with those of 1954, primarily because of differences in the period to which the data relate. The data for 1954 were purposely related to a period of peak employment."

Area	Percent Increase	Acres Increase
Hard Red Winter	38	132.0
Hard Red Spring	35	100.9
White	30	161.4
Soft Red	26	9.3

Had the 1954 farm labor data been comparable it could be expected that the increase would have continued.

The average farm in each area would have had inputs used in wheat production for the different time periods, illustrated in Table 11.

Table 11. The inputs used for wheat production on the average farm for four wheat producing areas, 1924, 1934, 1944, and 1954.[1]

Year and type of input	Hard red winter	Hard red spring	White	Soft red
1924				
Acres of land	133.2	115.4	129.3	7.3
Number of men	n.a.	n.a.	n.a.	n.a.
Capital (1910-14 dollars)	$1,423	$1,141	$1,192	$121
1934				
Acres of land	103.2	27.7	152.2	8.2
Number of men	.6	.2	.8	.2
Capital (1910-14 dollars)	$920	$601	$1,343	$109
1944				
Acres of land	173.7	144.2	241.3	7.9
Number of men	.9	1.0	1.3	.2
Capital (1910-14 dollars)	$1,227	$1,274	$2,170	$121
1954				
Acres of land	155.4	129.7	207.1	9.2
Number of men	.9	.8	1.2	.2
Capital (1910-14 dollars)	$1,942	$1,585	$4,986	$278

[1]Computed from census data.

The aggregate changes are somewhat different than the individual farm changes. For example, the labor input on the average has increased on the individual farm, but in the aggregate the number of laborers employed in the production of wheat has continuously fallen since 1924. The acreage planted to wheat has remained almost constant in the aggregate but on the individual farm basis has increased much more rapidly.

Summary of historical review. The historical review has shown technological advances have been made in several ways: new varieties, mechanization, control of disease and pests, and improved practices. These changes have made possible several developments summarized below.

New varieties, control of disease and pests, and improved practices have made possible a steady increase in wheat yields. Mechanization has provided the basis for increasing labor productivity, consequently, the labor input and the number of farms have steadily declined and the size of farm has steadily increased. Changes in the relative productivity of the inputs has caused shifts in resource use. Substitution of capital for labor and for land has occurred, thus, the portion of total inputs made up of labor and land has dwindled and the portion made up of capital has increased.

In Chapter V the procedures for a statistical analysis are to be discussed, to be followed by Chapter VI, in which the statistical procedures are applied to data related to technological progress in wheat production.

CHAPTER V

METHODOLOGICAL PROCEDURES AND THE SELECTION OF HYPOTHESES TO BE TESTED

Data collectional agencies such as the United States Department of Agriculture, Bureau of the Census, and state experiment stations have not recorded data in a form most useful in technological studies. Two reasons for the lack of appropriate data were (a) procedures for collection and recording data in the most useful form have not been worked out, and (b) since methodological procedures in technological studies are not well developed, it is not known what data are needed. This study can help point up the type of data necessary to study a single sub-industry of an industry characterized by many widely scattered small firms producing a number of products.

Formulation and testing of hypotheses is limited by data. For example, it may be hypothesized that there was a lagged response between technological advance in wheat production and funds spent on wheat research. However, experiment station accounts are not kept in such a manner as to identify expenditures for wheat research. It can be only estimated as some portion of the total.[1]

This chapter will be devoted to a presentation of the methodological procedures used and an exposition as to the appropriateness of the methods of analysis selected.

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[1]This was verified by Glenn H. Beck, Director of the Kansas Experiment Station, and the directors of eight other state experiment stations.

Selection of the Areas Studied

In order to handle the problem in this study it was necessary to look only at a portion of the wheat producing areas of the United States. Wheat is produced in four general areas in the United States, each identified by a particular type of wheat. (See Figure 16). To make an inter-regional comparison of technological advances in wheat production, it seemed most reasonable to select counties for each region based on type of wheat. The inclusion of counties was based on a stratified purposive selection.

Selecting those counties in which a large portion of the resources were devoted to wheat production reduced the probable error due to the disaggregation problem.[1] It was necessary to estimate the portion of total inputs devoted to wheat production on the basis of source of income from various enterprises. In those counties where wheat was the principal source of income it is known that most of the combine, tractor, petroleum, machine hire, and labor costs are incurred in the production of wheat. In those counties where only a small portion of the income is from wheat the difficulty in making a reasonable disaggregation estimate of joint costs increases. Therefore, in those regions containing counties classed as wheat specialty counties,[2] only those counties were included in the sample. It was possible to make this

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[1]See page 101 for a discussion of the disaggregation problem.

[2]According to the 1954 Census of Agriculture, a wheat specialty county was defined as a county that is typed as a cash grain county (50 percent or more of the total value of products sold consisted of cash grain crops) in which the principal cash grain was wheat.

selection for the hard red winter wheat area, hard red spring wheat area, and the white wheat area. In the soft red wheat area, which lies within the corn belt, there were no wheat specialty areas. However, the principle of selecting those counties deriving the largest portion of the farm income from wheat was followed. Since the soft red wheat area was much less homogeneous than the other three areas it seemed desirable to select counties more widely distributed which would reflect the heterogeneity. Counties from three states were selected. Southwestern Indiana is a general farming area where wheat is an important source of income. Southern Michigan has been a livestock and dairy region which has gradually shifted to cash grain. These counties also are on the borderline between winter and spring wheat areas. Pennsylvania once was the leading wheat producing area of the United States and is the oldest farming region studied.

By selecting counties in which a large portion of the farm income was from wheat, it was possible to minimize the problem of disaggregating joint costs because (a) in these counties there are fewer joint costs, and (b) of the existing joint costs a smaller portion is devoted to production of crops other than wheat.

Based upon the 1954 Agricultural Census the stratified purposive selection of counties was made as follows:

Hard Red Winter Wheat

Kansas, Economic Area 2a

Barton	Gove	Ness	Sheridan
Cheyenne	Graham	Pawnee	Sherman
Decatur	Hodgeman	Pratt	Stafford
Edwards	Kiowa	Rawlins	Thomas
Finney	Lane	Rush	Trego

Nebraska, Economic Area 2

Banner	Keith
Chase	Kimball
Box Butte	Morrill
Cheyenne	Perkins
Deuel	Scotts Bluff

Hard Red Spring Wheat

South Dakota, Economic Area 2a

Campbell	Hyde
Edmunds	McPherson
Faulk	Potter
Hand	Sully
Hughes	Walworth

North Dakota, Economic Areas 2a, 2b, 3a, 3b[1]

Burke	Sheridan	Towner
Divide	Benson	Ward
McLean	Bottineau	Barnes
Mountrail	Cavalier	Eddg
Williams	McHenry	Foster
Burleigh	Nelson	Griggs
Emmons	Pierce	La Moure
Kidder	Ramsey	Steele
Logan	Renville	Stutsman
McIntosh	Rolette	Wells

White Wheat

Washington, Economic Area 72

Adams	Grant
Douglas	Lincoln
Franklin	

Oregon, Economic Area 3

Gillman	Umatilla
Morrow	Wasco
Sherman	

[1]Data for North Dakota combines hard red spring and durum wheat.

Soft Red Wheat

Indiana, Economic Area 2b

Clay	Pike
Daviess	Posey
Gibson	Spencer
Greene	Sullivan
Knox	Vigo
Morgan	Warrick
Owen	

Michigan, Economic Areas 5a, 7[1]

Bay	Montcalm	Jackson
Gratiot	Clinton	Lapeer
Isabella	Eaton	Livingston
Midland	Ionia	Shiawasee

Pennsylvania, Economic Area 5

Bedford	Huntington	Perry
Center	Juniatia	Union
Fulton	Mefflin	Snyder

Source of Data

Time series data are a prerequisite for studying technological changes. Input-output data by enterprises were non-existent. Therefore, a source which provided data for estimating fairly accurate enterprise input figures was necessary. Since specialized wheat production is limited to geographical areas of less than state size, it was necessary to rely upon a county breakdown. The five-year Census of Agriculture provided the best source of data that fulfilled these two requirements. Also, the Census data were readily available at the

[1]Considerable spring wheat is grown in these counties. See Salmon, S. C. and Reitz, L. P., Distributor of Varieties and Classes of Wheat in the United States in 1954, Agriculture Handbook No. 108, United States Department of Agriculture, 1957.

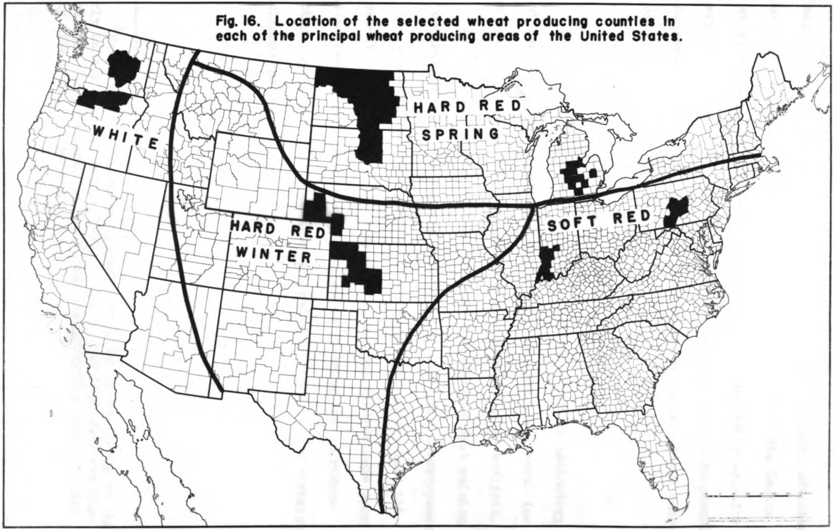

Fig. 16. Location of the selected wheat producing counties in each of the principal wheat producing areas of the United States.

Kansas Experiment Station. Although Census data have these advantages over other sources of data, there were disadvantages in the Census statistics: (a) aggregation of joint costs, (b) available only for every fifth year, (c) the time series data were not always comparable from census to census,[1] and (d) lack of data for certain input categories.

Selection of the Measurement Techniques

To meet the measurement problems, the researcher in technology must improvise ways to adjust data so that they are more useful for the specific problem and to experiment with procedures of analysis.

In the early stages of this study it was believed that gaining an understanding of the factors associated with and the consequences of the technological developments in wheat production provided the greatest challenge. As the study progressed, the demands made upon the researcher's ingenuity and imagination to solve the intricate methodological problems encountered, gradually replaced the envisioned challenge in importance.

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[1]For example, investment in machinery data was available in the early census reports, but in 1949, collection of this data was discontinued. Expenditures on fertilizer and petroleum were included only after the 1949 census.

Problems of Measuring Output

Wheat production is measured in constant terms, bushels.[1] This quantitative measure can be easily converted into terms of value by multiplying production times price. Because only one product was considered in this study, there was no problem of aggregation.

Wheat production was influenced by factors other than the usually considered inputs. Climate conditions explained a portion of the variations in production. This was particularly true in the western Great Plains areas. The principal climatic factor affecting yields was rainfall. The hard red winter and hard red spring wheat areas were characterized by great variability in yields. Hoover has found that the coefficient of variability for wheat yields in economic area 2a in Kansas range from 34 in Stafford County to 77 in Lane County.[2] The aggregate yield data for each producing area selected for this study show considerable yield variability as shown in Table 12.

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[1]The constant measure of bushels is accurate only so long as all bushels of wheat are identical. However, this is not always the case. Each class of wheat and the same class of wheat over time have individual qualitative characteristics which differentiate a particular sample from all other wheat. A bushel of hard red winter wheat, hard red spring wheat, white wheat or soft wheat are not identical products. Each has properties which cause it to have special uses. Weather conditions may cause qualitative differences within classes from year to year and from county to county. Replacement of old varieties with new have made qualitative changes in wheat. These quality changes in wheat have not been reflected in the bushel measurement. Therefore, productivity measures on the basis of bushels unadjusted for quality changes may be biased downward when quality has been improved.

[2]Hoover, Leo M., Kansas Agriculture After 100 Years, Bulletin 392, Kansas Experiment Station, Manhattan, 1957.

Table 12. Wheat yield variability for each of the principal wheat producing areas, 1900 to 1954.[1]

Year	Yield by geographical areas, bushels per acre of harvested wheat								
	Hard red winter		Hard red spring		White		Soft red		
	Kans. Econ. Area 2a	Nebr. Econ. Area 2	S.Dak. Econ. Area 2a	N.Dak Econ. Area 2a	Wash. Econ. Area 7a	Ore. Econ. Area 3	Ind. Econ Area 2b	Mich. Econ. Area 7	Penn. Econ. Area 5
1900	7.1	9.8	10.5	12.9	19.5	16.6	8.4	12.0	11.6
1909	11.3	17.9	14.6	13.6	19.3	16.3	18.3	19.6	14.5
1919	11.2	13.5	8.0	5.8	16.8	18.1	16.7	20.6	14.3
1924	n.a.	n.a.	n.a.	n.a.	14.2	n.a.	19.5	26.4	15.6
1929	12.4	14.6	9.6	10.1	18.6	20.0	20.5	18.8	13.8
1935	7.4	7.8	4.7	2.9	19.2	11.7	16.8	13.5	12.4
1939	8.3	11.0	8.4	8.5	22.4	21.3	19.3		17.9
1944	17.2	12.6	12.1	18.1	26.8	26.4	22.6	24.7	18.6
1949	10.1	13.5	7.8	11.4	21.8	21.2	24.0	25.0	21.8
1954	14.8	19.1	9.7	8.6	32.0	29.2	33.1	28.8	25.0

[1]Source of data: Bureau of Census.

Wearden and Orazem[1] at the Kansas Station concluded that rainfall accounted for 50 percent of the variability in wheat yield for western Kansas. In order to study the effects of technology on production, it would be desirable to remove the influence of weather on yield variability. Since it was believed that rainfall was the principal climatic factor affecting wheat yields in most areas, it was believed to be appropriate to adjust production data by a rainfall factor.[2]

In order to calculate a rainfall factor, consideration was given to the period of rainfall that has the greatest effect upon wheat yields. According to crop scientists, the rainfall in the months preceding harvest has the greatest effect on yields.[3] Therefore, county rainfall data were collected for the years 1900-1958. County wheat production was then adjusted by the index of rainfall. Had a more sophisticated method of estimating yields unaffected by weather, for example multiple correlation analysis, been used it is possible that better estimates could have been achieved. However, lack of data of other climatic factors, humidity, temperature, wind, light intensity,

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[1]Orazem, Frank and Wearden, Stanley, Yield Variability of Different Crops and Its Estimated Sources, unpublished manuscript.

[2]Other weather factors which affected yields were distribution of rainfall, evaporation rates, temperatures, humidity, wind, and sunshine. Technological factors other than weather which have not been considered are damage by insects, diseases, and weeds. Insufficient data were available to correct yield data for these factors.

[3]Nauheim, Bailey, and Merrick used this procedure in work in the U.S.D.A. See Nauheim, Charles W., Bailey, Warren R., and Merrick, Della E., Wheat Production, Agricultural Research Service, Agricultural Information Bulletin No. 179, U.S.D.A., Washington D. C., 1958.

and evaporation rate, made it impossible to include all factors in an equation. Exclusion may be a greater contributor to inaccuracy than the inaccuracies of the simple method adjustment used. The advantages of simplicity outweighed the disadvantages of a more complex analysis. The rainfall index was calculated as follows:

$$I = \frac{R}{\overline{R}/n}$$

Where I = Index of rainfall
R = Rainfall for six months prior to harvest
n = number of years

Production was adjusted as follows:

$$Y = y/I$$

Y = Production adjusted for rainfall
y = Actual production
I = Index of rainfall

The assumption underlying the use of this method was that rainfall is very closely related to yields and that variation in rainfall accounts for most of the variation in yields. The assumption was fairly valid for the Great Plains and white wheat regions.[1] However, in the Cornbelt moisture usually was not a limiting factor for wheat. Excessive moisture may be more detrimental than lack of moisture; therefore yield data for the soft wheat area could not be adjusted satisfactorily for moisture variability. An additional problem, particularly related to the Great Plains area, arose in making adjustment in yield for variations in rainfall when the yields fluctuated more

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[1]Also see Clawson, Marion, Reflections on Gross Farm Output, Journal of Farm Economics, May 1959, and Stalling, James, Indexes of the Influence of Weather on Agricultural Output, unpublished thesis, Department of Agricultural Economics, Michigan State University.

than did rainfall. For example, when rainfall dropped below ten inches in the western Great Plains, which was 50-75 percent of the normal rainfall, the wheat yields were near zero. Adjusting yields by a rainfall factor of .50 when yield was two bushels, resulted in a yield of four bushels, which was still below normal yields. In the analysis of yield trends all years were considered and the adjustment of all areas except the soft red area proved to be satisfactory. In the analysis where only the census years were used this adjustment gave results less satisfactory than the raw data. Production, adjusted for rainfall, was used only when the adjusted data reduced variability, in the hard red winter, hard red spring, and white wheat areas.

Problems of Measuring Inputs

Problems of measuring inputs arose from gaps in time series data, inappropriate breakdown or lack of breakdown of input data, multiple enterprise firms employing the inputs to produce more than one product, and aggregation of non-homogeneous inputs.

The measurement problems have not been perfectly solved for farm input-output studies. The most tedious and complex methodological problem of this study was the identification and quantification of the inputs used in the production of wheat.

Gaps in time series data. As production techniques changed data collectional agencies did not immediately include the new data. Although tractors, combines, and trucks were in general use in the 1930's in most of the wheat producing areas the first count made by the census was in 1949. For the years prior to 1949 county estimates were made based upon the state total, which were made available for this study by

O. J. Scoville, Director, Farm Efficiency Section, F.E.R.D., A.R.S. of the U.S.D.A. The census series on value of farm machinery which began before 1900 would have been very useful had it not been dropped from the Census of 1950.

While horses were the principal source of farm power, one of the important inputs was the grain and roughage fed the horses. No data were available for this input. However, construction of feed inputs was not difficult. In the 1929 U.S.D.A. study of Reynoldson's the average ration for a horse was reported.[1] From this it was possible to estimate the total feed input by counties.

During the 1920 and 1930's the feed input was rapidly being displaced by the petroleum input. However, it was not until 1949 that the Census reported farm expenditures for gasoline and oil.

Fertilizer data by counties were not available until 1949. Lacking this data in prior years was not a serious handicap since very little commercial fertilizer was used in the Great Plains and Northwest prior to this data. In Indiana, Michigan, and Pennsylvania this gap was more serious.

The problem of what was the average price of all tractors on farms in 1949 is a complex problem that was not solved entirely satisfactorily. In consultation with agricultural engineers an estimate was made of the average size of tractor used. Assuming that at any

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[1]See Morrison, Frank B., Feeds and Feeding, The Morrison Publishing Company, Ithaca, New York, 1956.

given moment the total tractors on farms were 50 percent depreciated it was possible to take 50 percent of the selling price of this average tractor to be used in constructing the input statistic.[1]

A substantial annual input was the expenditure of public and private funds to improve production techniques, to develop new varieties, and to develop new machinery. No record has been kept by the various public agencies as to the amount spent on specific developments. The state experiment stations were unable to separate expenditures on wheat from expenditures on other crops.[2] Not only did this problem exist for private expenditures, but also there was the problem of identifying who made the expenditures.

Inappropriate form of data. Data have not been collected for the purpose of measuring rate of technological change, therefore many data were in a form not appropriate for a study such as this.

The number of farm machines was not broken down into size groups. For example a tractor was listed as one tractor regardless of size. Data on number of horsepower or investment in tractors would have been more useful. Also, this type of enumeration assumed no qualitative change in tractors over time.

No appropriate means of handling the qualitative changes that occurred in farm machinery was found. Tractors in 1954 were different

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[1]Fairbanks, G., Department of Agricultural Engineering, Kansas State University, private consultation with the author.

[2]This is verified by the response of directors of experiment stations to a request for this data.

inputs qualitatively than the 1920 tractor. This was also true for harvesting, soil preparation, and planting machinery.

The use of prices adjusted for inflation should have reflected qualitative changes in machinery. If the price of machinery in constant dollars has shown a rising trend over time this should reflect the qualitative changes. However, efficiency gains in manufacturing techniques may actually cause prices of farm machinery to fall, thus not reflecting qualitative changes.

Disaggregation of joint costs. Farms were usually multiple enterprise firms. Data were available only for the entire farm unit. The farm uses most types of inputs on more than one enterprise, therefore, the researcher attempting to make an enterprise analysis is faced with the problem of disaggregating the joint costs. This study attempted to minimize the bias that would be introduced by erroneous disaggregation procedures by selecting only those areas specializing in wheat production. For the hard red winter, hard red spring, and white wheat areas this was particularly appropriate. For the soft wheat area there were no wheat specialty areas, but there were areas that derived a substantial portion of the farm income from wheat. These areas were selected.

In no county in the United States was wheat the sole product, thus in every case it was necessary to select some method to estimate the portion of the resources used in wheat production. The techniques employed in cost accounting were considered.[1] The most appropriate method of allocating joint costs, from the standpoint of data available, was the distribution of inputs on the basis of the contribution of the enterprise to the farm income. This arbitrarily allocates the inputs, perhaps at times incorrectly, but according to Hopkins and Heady there is no method that will guarantee correct apportionment.

Non-homogeneity of inputs. The inputs for wheat production were in the form of number of tractors, number of horses, number of acres, and dollars of petroleum products purchased which could not be aggregated directly. This necessitated selection of a method of constructing a total input index. The Laspeyre method,[2] which has been used by Ruttan[3] in his technology studies, was considered and tried. However, there were so many gaps in quantity data that it was impossible to aggregate on this basis. For example, only dollar input figures were available for machinery, equipment, and petroleum. Consequently, it was determined that the most appropriate means of aggregation was to express all inputs in a constant dollar figure.

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[1]See Hopkins, John A., and Heady, Earl O., Farm Records, Third Edition, Iowa State College Press, Ames, Iowa.

[2]Frederick Cecil Mills, Statistical Methods Applied to Economics and Business, Henry Holt and Company, New York, 1938.

[3]Vernon W. Ruttan, Technological Progress in the Meat Packing Industry, 1919-1947, U.S.D.A. Marketing Research Report No. 59.
See also George W. Ladd, Biases in Certain Production Indexes, Journal of Farm Economics, February, 1957.

Problems of Measuring the Changes in Input-Output Relationships

A measure of rate of technological change, input-output ratios, was computed for the various factors of production. Output per unit of land, labor, current expenditure, and capital investment was computed in an attempt to compare the changes in productivity for each of the factors of production. By using the value of total production and the value of total inputs it was possible to calculate total input-output ratios which measured the aggregate change in productivity.

Most studies related to technology have been concerned with changes in yield per unit of land and the changes in the productivity of labor. Recently Ruttan and others have concerned themselves with the whole bundle of resources. In this study it was attempted to measure the productivity of each factor separately and then collectively over time and for each of the selected wheat producing areas.

Four Hypotheses

After the completion of the measurement of the changes in productivity, in order to relate these findings to the individual farm decision-making problems and to the problems of public policy for the wheat industry, it was necessary to analyze the changes that occurred.

Four hypotheses were formulated for testing.

1) The rate of technological change in wheat production has been sporadic.

2) The higher the degree of specialization in wheat production the more rapid the rate of technological change.

3) The larger the size of business the more rapid will be the rate of technological change.

4) The rate of technological change is positively associated with the level of income of the wheat producers and with the level of income in the general economy.

The empirical testing of these hypotheses is presented in the next chapter, together with the data developed using the procedures discussed in this chapter.

CHAPTER VI

STATISTICAL ANALYSIS OF THE INPUT-OUTPUT DATA

Chapter VI is devoted to an exposition of the procedure used and the application of these procedures to data in order to measure technological change and to test the four hypotheses listed in Chapter V. Five measurements of the technological change that have taken place in wheat production were made. These measurements were land productivity, labor productivity, capital productivity, current expenditure productivity, and total input-output relationships.

If all increases in productivity measured for each type of input could be attributed to that class of input the sum total ought to equal the rate of changes in the aggregate input-output ratio. The sum of the change of the individual inputs exceeded the total change, which indicated the limitations in measuring technological change by measuring the change in the returns to the individual factors.

Computation of the Input-Output Data

In order to add the annual services rendered by each of the input categories, it was necessary to express the data in a commom unit of measure.

The construction of index numbers was found to be impractical because of insufficient data. Items such as equipment, fertilizer, petroleum, and machine hire were given only in dollars. To construct a weighted index of total annual inputs quantity data would have been necessary. In all cases where only quantity data was given value of the inputs could be calculated by multiplying the quantity times price. After studying the data and aggregation possibilities it was concluded to express all inputs and outputs in terms of 1910-14 dollars. Inputs were divided into four categories: land, capital investment, current expenditures, and labor. The aggregate input of each category was computed for the selected regions of each of the principal wheat producing areas. The summary of these computations is included in Tables 34, 35, 36, and 37 of appendix B. Changes in the aggregate input-output ratio theoretically measures the change in the productivity of resources in production. This change can be attributed to technology.[1] However, in the application of the theoretical model there are complexities which complicate the measurement of technology. Some of the complexities include:

1) Even though there is no change or even a decrease in the ratio it may be erroneous to conclude there has been no change in technology. This is particularly the case when aggregation must be accomplished on a dollar basis inasmuch as the benefits of technology may have been absorbed in greater price changes for the product and factors than in the general price level used as a deflator.

Secondly, production of a product may be done only at continuingly higher costs. A new technology may slow this per unit increasing cost trend, but not reverse it. In such a case there would be no improve-

[1]See page 41 for a discussion of other factors that may influence the aggregate input-output ratio.

ment in the input-output ratio even though there had been the introduction of new knowledge that slowed the rate of per unit increasing costs.

2) The problems of measurement of the inputs were very great. Changes in aggregate productivity may have resulted from failure to correctly measure, or even failure to recognize, all inputs or outputs.[1] Qualitative changes in inputs or products were particularly difficult to measure. However, when a constant price level is used and a persistent upward price trend continues for a particular input it can be argued that this upward trend represents the change in quality. In this study this was particularly the case for the labor input. The quantity of labor measured in number of man units declined throughout the period under consideration while the price of the labor input after deflation continued to rise. The higher price of labor at least crudely represents the qualitative change in the labor input, if the price of labor was not leading the price rises. The result, when measuring the labor productivity based on the deflated price of labor, was a smaller change in labor productivity than when the output per man unit was used.[2]

3) Failure to account adequately for all inputs influences the change in productivity. In this study the change in the managerial

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[1]See the Schultz-Heady discussion over this point in the Journal of Farm Economics, August, 1956, May, 1958, November, 1958, and February, 1959.

[2]See Table 23.

capacity of the producers was included in the residual, which was spoken of as a change in technology. This technological change did not occur without cost, yet it was impossible to allocate a cost to this qualitative change. Some portion of the cost of elementary, secondary and university education, extension service, public and private research, and public information programs of radio, television, press, and other private sources should have been added to the input side of the ledger.

It was necessary to assume that all research and developmental costs that have been incurred in making possible the great capital-labor substitution was accounted for in the value of the capital input. It is entirely possible that these costs were not included.

4) The productivity of separate inputs does not change at the same rates. Consequently, the bundle of resources used changed over time so that even if there were not improvement in the input-output ratio there could be technological advances, even if the ratio were a constant 1-1 as Schultz argued was conceptually the case.[1] Labor efficiency in wheat production in all areas has increased at a more rapid rate than has the aggregate input efficiency. This means that capital and land efficiency has not increased as rapidly. Even had there been a decrease in capital and land efficiency[2] that more than offset the gains

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[1]See Schultz's article in the Journal of Farm Economics, August, 1956.

[2]There may well have been a decrease in the productivity of land despite the contrary evidence in Table 12. In this data the increases in yields were primarily due to improved varieties (a capital investment) and use of fertilizer (another capital investment).

in labor efficiency it would be difficult to argue there had been no technological change or benefits from technology.

If the Boulding thesis that labor is the ultimate input is accepted, then any change in resource use that reduces the labor input necessary to produce a given product is a benefit to society.

Changes in Total Resources Invested in Wheat Production

In three of the four areas, the hard red winter, hard red spring, and soft red, the total resources invested annually in the production of wheat have declined in the period under consideration, 1924-1954. In the fourth area, the white, there has been a general increase in the total resources used in wheat production. When the areas are considered separately it was found that the greatest decline in inputs was in the hard red spring wheat area where there was a 34.4 percent drop; followed by a 28.4 percent drop in the hard red winter wheat area; a 13.2 percent drop in the soft red wheat area; and a 56.1 percent increase in the white wheat area. The individual categories of inputs showed both increases and decreases. Generally the labor input declined. Land input remained about constant and the two types of capital inputs increased. The significant shift in the bundle of resources was in the substitution of capital for labor as illustrated by the following diagrams.[1] It should be noted that prior to 1944 there was little substi-

[1]See Figure 17. It should be noted that because of the small number of observations a simple free hand fit was made. With the limited number of observations, little advantage would result from a statistical fit. Also, the purpose of these diagrams was to illustrate the change rather than to measure the rate of the change.

tution of capital for labor. The two inputs appeared to move in the same direction. Since 1944 the substitution of capital for labor has been significant.

Table 13. Changes in the capital and labor inputs used in the production of wheat in four areas of the United States expressed as a percent of 1944.[1]

	Hard red winter		Hard red spring		White		Soft red	
	Capital	Labor	Capital	Labor	Capital	Labor	Capital	Labor
1944	100	100	100	100	100	100	100	100
1949	142	75	162	88	250	66	161	98
1954	175	69	128	52	278	64	190	85
Percent change since 1944	+75	-31	+28	-48	+178	-36	+90	-15

[1]Calculated from Tables 34, 35, 36, and 37 of appendix B.

The most rapid rate of increase in capital investment and the most rapid rate of decline of labor input was not in the same area. The white wheat area of the Pacific Northwest has shown the most rapid rate of mechanization if increasing capital investment represents mechanization, followed by the Cornbelt area, the southern Great Plains and lastly the northern Great Plains. Almost the converse was true of the labor input. The greatest decrease was in the northern Great Plains followed by the Pacific Northwest, the southern Great Plains and lastly the Cornbelt. This does not, however, represent the changes in the quantity of capital employed per unit of labor or the capital-labor ratios.

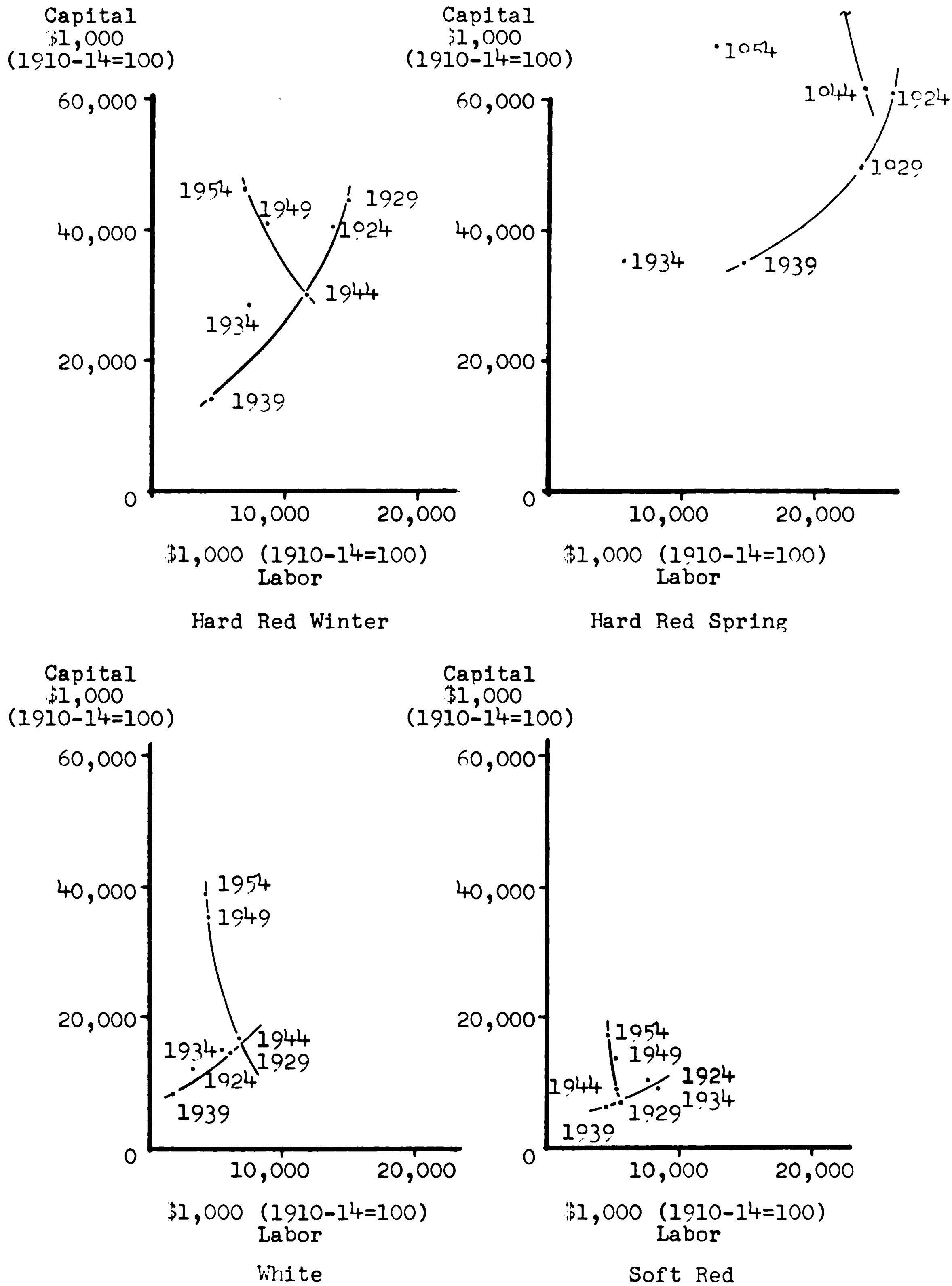

Fig. 17. A comparison of labor-capital input used to produce wheat in four areas of the United States.

Annual Resource Use

The proportional changes in the relationship of four categories of resources used annually in the production of wheat in the four areas were calculated.[1] In each of the areas the percent of total annual services rendered by labor decreased from 1924 to 1954. Most of the decrease in the proportion of the resources consisting of labor occurred in and after the World War II period. From 1944 to 1954 labor continuously made up a smaller portion of the annual resources used in wheat production. The white area had the greatest decrease in portion of labor, 41.3 percent; soft red, 29.8 percent; hard red spring, 26.6 percent; and hard red winter, 25.7 percent.

Table 14. The percent of the annual resources used in the production of wheat made up of labor.

	Hard red winter		Hard red spring		White		Soft red	
	1944	1954	1944	1954	1944	1954	1944	1954
Labor	40.0	29.7	46.6	34.2	46.7	27.4	52.3	36.7
Percent decrease		25.7		26.6		41.3		29.8

At the time the proportion of the services rendered by labor was declining the proportion rendered by capital investments was increasing in all areas and the proportion contributed by current expenditures was increasing in all areas except the white wheat area.

The land input remained relatively stable throughout the period.

[1]See Table 42 of Appendix D

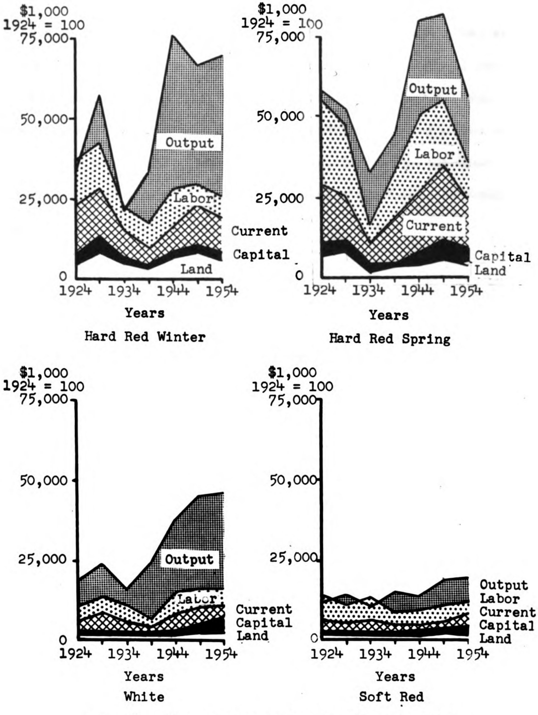

Fig. 18. The annual services rendered by four classes of inputs in the production of wheat in four selected areas, 1924 to 1954.

Changes in Resource Productivity

The changes in resource productivity were measured in two separate approaches. The first approach was to apply the traditional measures of efficiency, such as yield per acre and bushel output per man unit. The second approach was to compute input-output ratios for the aggregate and for each of separate inputs. From the ratios an index of productivity was constructed which gave an estimation of technological change.

Changes in Land Productivity

Yield per acre. One of the first indicators observed and most easily computed measure was the yield per acre of land. Figures 17, 18, 19, and 20 show the actual yield per harvested acre and the adjusted yield per harvested acre.[1] A trend line was computed by the least squares method. From this it was estimated that yields have increased at the rates listed in Table 13.[2]

Table 15. The average annual increase in wheat yields for four wheat producing areas, 1919 to 1954 and 1939 to 1954.

Area	Average annual increase in bushels	
	1919 to 1954	1939 to 1954
Soft red	.31277	.52720
White	n.a.	.33603
Hard red winter	.24322	.28191
Hard red spring	.18010	.04912

[1]See pages 94 to 98 for discussion of the weather adjustment problem.

[2]Calculated from annual Crop Reporting Service data.

Technological change measured in terms of yield per acre indicates that the greatest average increase was in the soft red wheat region of the eastern Cornbelt for the period 1939 to 1954. Unfortunately, no county annual production was available prior to 1939 except in the census years for Washington and Oregon, therefore, it was not possible to compare the four regions for a longer time period.

Table 16. The average yield of wheat over two time periods, 1919 to 1954 and 1939 to 1954, for four wheat producing areas of the United States.[1]

Area	Average yield in bushels per acre	
	1919 to 1954	1939 to 1954
White	n.a.	24.7
Soft red	18.6	21.8
Hard red winter	13.4	16.4
Hard red spring	10.7	13.2

[1]Calculated from Crop Reporting data.

Value of wheat per acre of land. The gross value of wheat produced on an acre of land has shown a more or less constant increase since 1924. The hard red spring area seems to be an exception. In this area the value of wheat per acre has varied considerably from one time period to another but there is no apparent trend.

Land cost to produce one bushel of wheat. Prior to 1939 the general movement of the value of land input in terms of the value of wheat produced on that land was upward. From 1929 to the present this trend has been downward reflecting the increased yields. The hard red spring area, in which there has been less change in the per acre yields, has shown little change in the per bushel land cost since 1939.

Changes in Labor Productivity

The second measure, labor productivity, has been a widely used measure of technology. In this study not only the output per man unit was given consideration but also the labor cost in dollars per unit of output, gross return per unit of labor, acres harvested per man unit, investment per man unit,[1] and labor cost to produce one acre.

Bushels output per man unit. Throughout the historical period covered by the study the white wheat area continuously had a higher output per man unit input than any of the other areas. The white wheat area was followed in this order by the hard red winter, hard red spring, and the soft red wheat areas.[2] With exceptions only in 1934 and 1944 there was a continuous increase in labor productivity in each of the areas. However, the rate of increase and the total increase varied from one area to another. The most rapid increase in labor productivity was an average annual increase of 182 bushels in the white wheat area for the 30 years since 1924. The hard red winter wheat area increased labor productivity by 116 bushels per year, the hard red spring wheat area by 45 bushels, and the soft red wheat area by 43 bushels. On a percentage basis the areas had the changes in labor productivity given in Table 17.

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[1]Includes annual capital, current expenditures, and land investment.

[2]See Table Table 40 in appendix C.

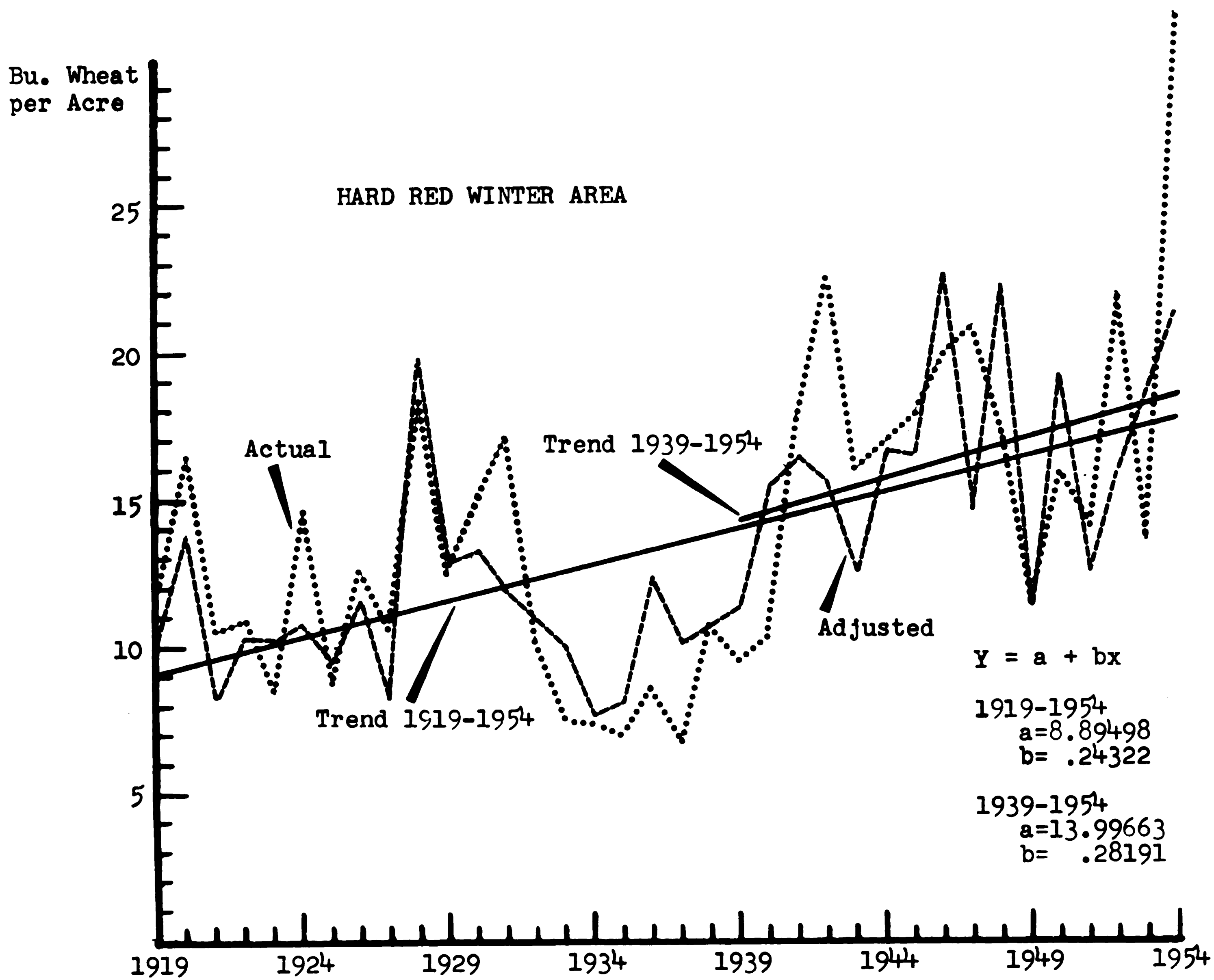

Fig. 19. Changes in wheat yields per harvested acre showing actual yields, yields adjusted for precipitation, and trend of yields for selected region of the hard red winter area, 1919-1954.

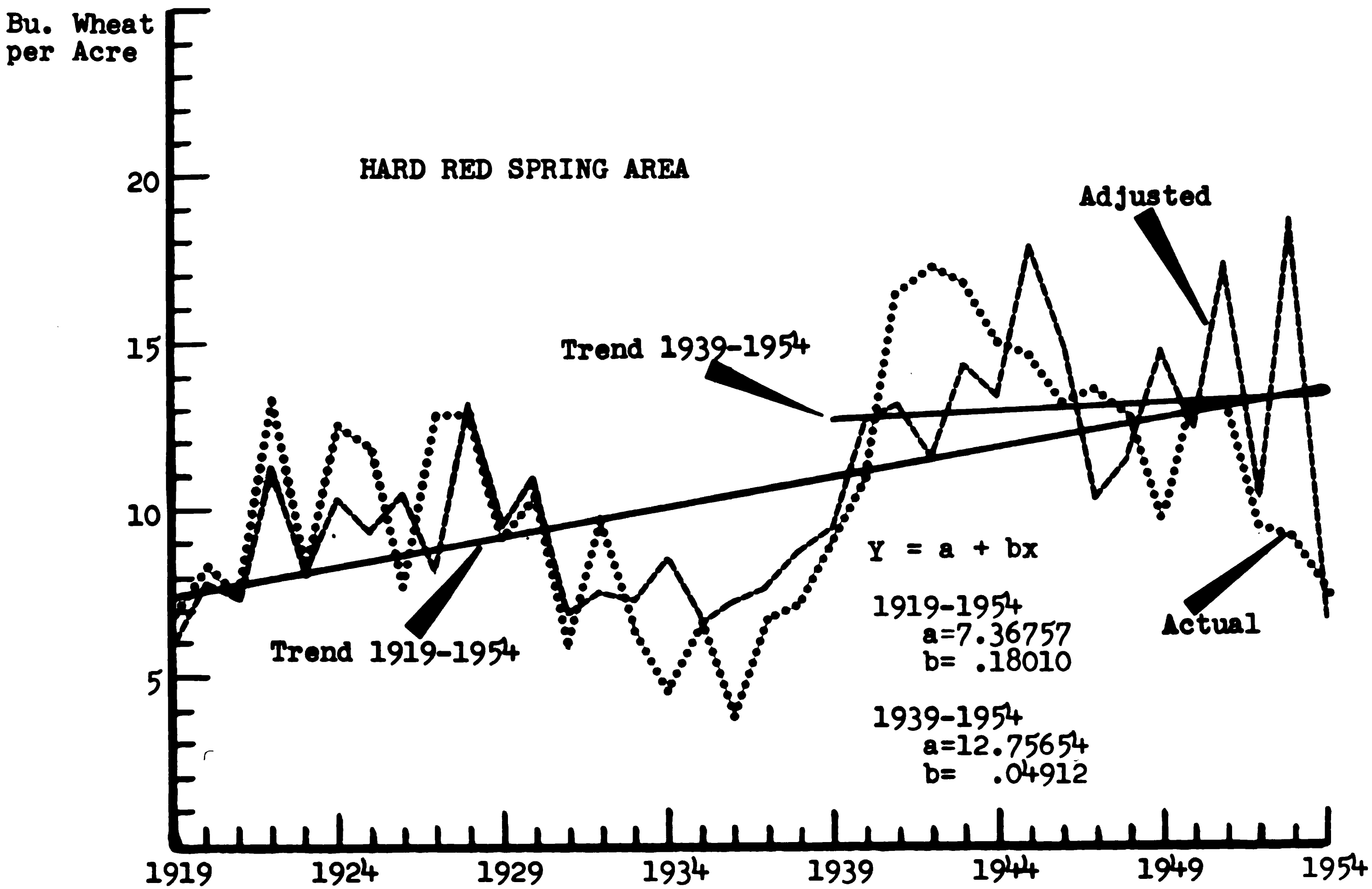

Fig. 20. Changes in wheat yields per harvested acre showing actual yields, yields adjusted for precipitation, and trend of yields for selected region of the hard red spring area 1919-1954.

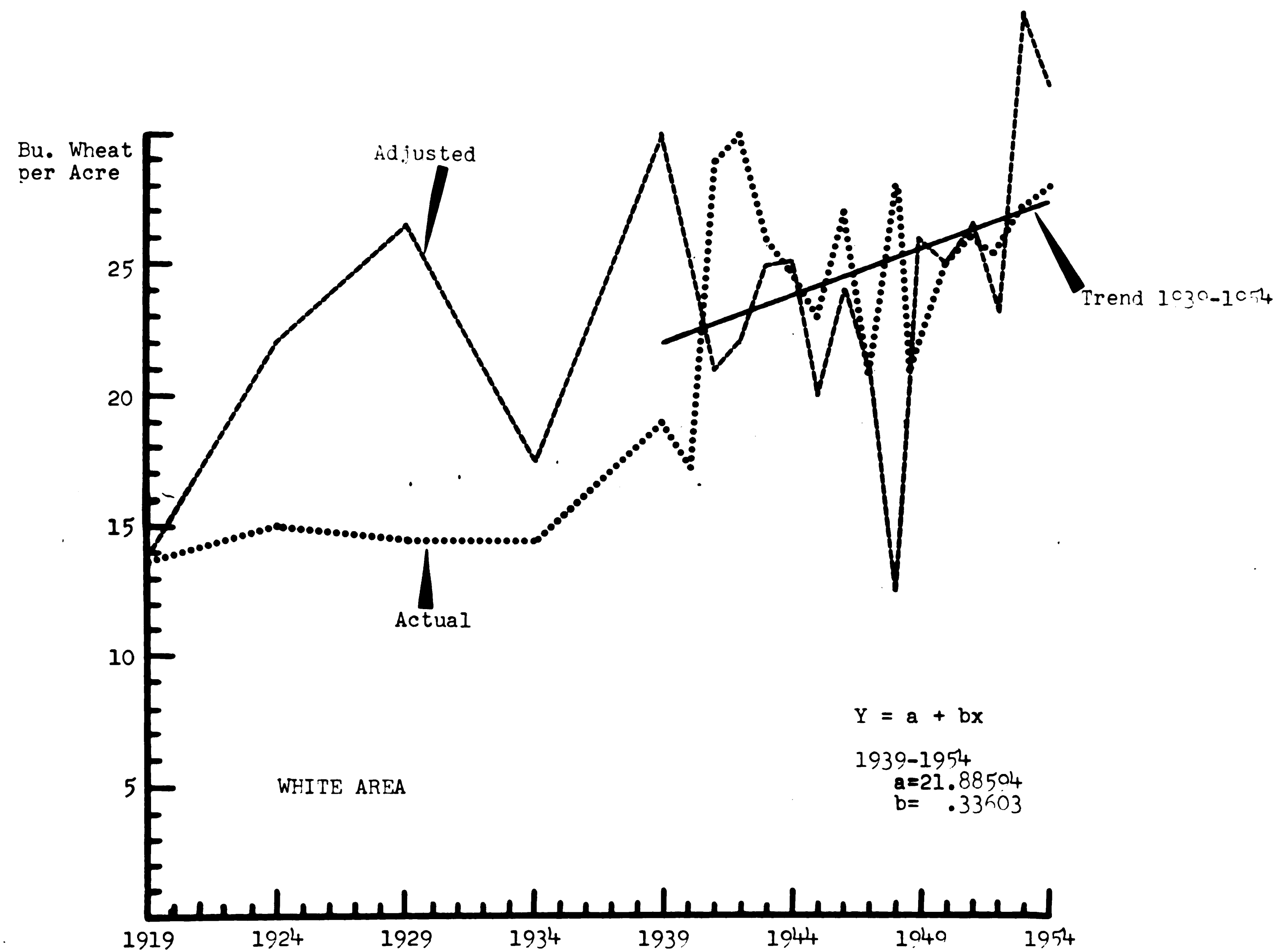

Fig. 21. Changes in wheat yields per harvested acre showing actual yields, yields adjusted for precipitation, and trend of yields for selected region of white area, 1919-1954.

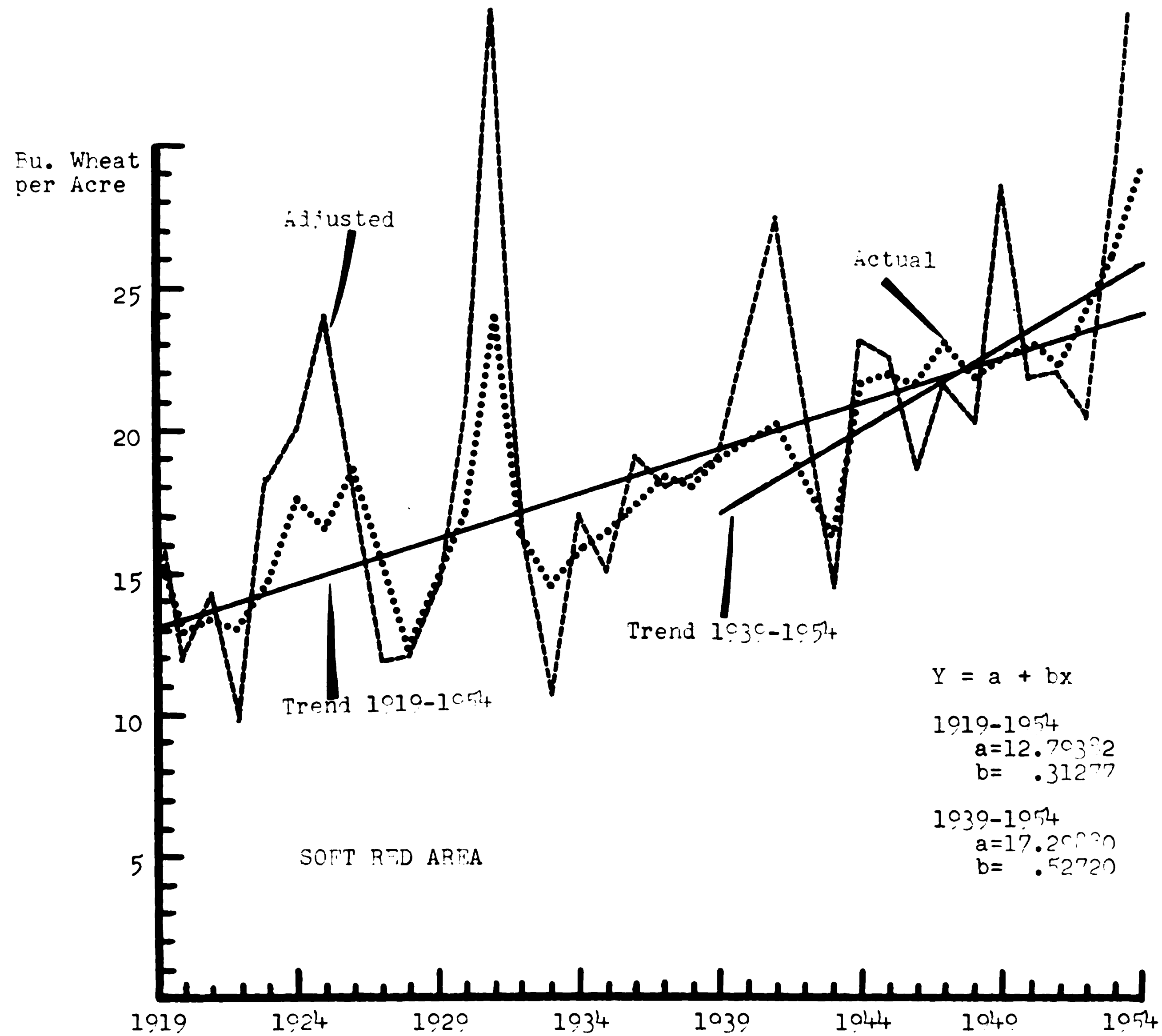

Fig. 22. Changes in wheat yields per harvested acre showing actual yields, yields adjusted for precipitation, and trend of yields for selected region of soft red area, 1919-1954.

Table 17. Changes in labor productivity as measured by bushels produced per man unit and percentage change, 1924 to 1954.[1]

Measure of change	White	Soft red	Hard red winter	Hard red spring
Total percentage increase 1924-1954	333.9	318.0	413.9	242.3
Average annual percentage increases	11.1	10.6	13.7	8.1
Total increase in bushels produced per man unit 1924-1954	5,452	1,282	3,486	1,355
Annual average increase in bushels produced per man unit	182	43	116	45

[1]Calculated from census data.

The most rapid growth in labor productivity whether on an absolute or percentage basis was in the southern Great Plains and in the Pacific Northwest. This was consistent with the rate of increase in capital investment, as these two areas have increased capital investment per man unit more rapidly than have the other two areas.

Acres harvested per man unit. There has been a fairly constant increase in all areas in the number of acres harvested per man unit. The only striking difference among areas is the much lower number of acres handled per man unit in the soft red area as compared to all other areas. Also, the rate of increase was significantly less in that area than the other areas.

Investment per man unit.[1] Labor efficiency increases, usually, when capital replaces labor in the organizational structure of the farm

[1]Investment = total investment in land, capital, and current expenditures.

business. On a per man unit basis investment in wheat production increased more rapidly in the white wheat area and most slowly in the hard red spring area as shown in Table 18.

Table 18. Average annual rate of increase in investment per man unit for four wheat producing areas in the United States, 1924 to 1954.[1]

Average annual rate of increase	White	Soft red	Hard red winter	Hard red spring
Dollars (1910-14 dollars = 100)	$256	$91	$187	$86
Percent	9.0	8.1	7.9	6.2

[1]See Table 40 of appendix C.

Labor cost to produce one bushel. The value of the labor input per bushel of wheat produced in each of the areas has diminished by one-half or more in the last thirty years. In the hard red winter area the per unit labor cost has been lowered the most, 69.7 percent or from 33 cents per bushel in 1924 to 10 cents per bushel in 1954. The least reduction was in the hard red spring area 48.7 percent or from 39 cents per bushel in 1924 to 20 cents per bushel in 1954.

In all areas the greatest reduction in labor costs were in the period of 1924 to 1939. From 1939 to 1954 the labor cost to produce a bushel of wheat has remained remarkably constant.

Labor cost to produce one acre. From the data it could be generalized that per acre labor costs have declined since 1934. However, in the white wheat area the labor cost per acre has remained relatively constant and may have actually increased slightly.

<u>Gross return per man unit</u>. Another measure of labor productivity, closely associated with bushel output per man unit, is the gross return per man unit. In constant 1910-14 dollar terms the areas have increased as shown in the following table.

Table 19. Gross return in 1910-14 dollars per man unit for four wheat producing areas of the United States, 1924 to 1954.

Years	Hard red winter		Soft red		Hard red spring		White	
	Dollars[1]	Percent	Dollars	Percent	Dollars	Percent	Dollars	Percent
1924-54	3,119	420.2	1,312	323.1	1,295	255.5	4,616	223.4
1924-39	1,580	262.2	663	212.8	260	131.2	1,892	189.3
1939-54	1,539	160.2	649	151.9	1,035	194.0	2,724	160.2

[1]1910-14 = 100.

In all cases, except the hard red spring wheat area, the gross return per man unit increased at a more rapid rate in the 1924 to 1939 period than in the 1939 to 1954 period.

Changes in the Productivity of Capital Resources

The annual services rendered by the capital investment has shown growth in the post-depression years. In this period there has been a rapid substitution of capital for land and labor. The early substitution resulted in a substantial diminution of the capital services used to produce a bushel of wheat in each of the areas decreased as shown in Table 20.

Table 20. The average capital services used to produce a bushel of wheat in four wheat producing areas of the United States, 1934 and 1939.[1]

Year	Dollar (1910-14 = 100) value of services per bushel			
	White	Hard red winter	Soft red	Hard red spring
1934	.04	.07	.04	.08
1939	.02	.02	.03	.04

[1]See Table 41 in appendix C.

In every area since 1939 there has been a gradual increase in the capital services used to produce wheat. By 1954 the per bushel capital cost was five cents in the hard red winter, nine cents in the hard red spring, six cents in the white, and seven cents in the soft red. This evidence indicates that as capital in the form of power and equipment was first substituted for labor, the returns to the capital were higher than after this substitution continued for 15 years. The technological change associated with this, first, increasing productivity of capital, followed by a decreasing productivity, was the development of and improvement of the gasoline internal combustion tractor and the harvesting, planting, and cultural equipment used with it. The initial returns to this substitution made possible by new technology diminished as the substitution was carried further so that by 1954 the returns to capital had been pushed to the pre-tractor period. A new burst of technology was necessary if the returns to capital were to be increased.

Changes in the Productivity of Current Expenditures

Current expenditures included such items of cost as horse feed, petroleum products, fertilizer, and seed. Items not included, which ought to have been included had the data been available, were repairs, irrigation, insecticides, weed sprays, seed treatment, and storage.

Most horse feed was produced on the farm. The cost of production of this feed was not available. Therefore, based upon Morrison's maintenance ration for a draft animal the quantity of feed necessary for horses was estimated, then multiplied by the price of the feed to give the value of feed fed horses. Undoubtedly, this resulted in an overestimation of the value of feed fed horses. It did not appear that this overestimation had an effect upon the conclusions drawn.

The significant change in current expenditures is not in the total quantity incurred, which remained relatively constant, but in the make-up of the bundle of expenditures. As the value of horse feed fed dropped the value of petroleum purchases shot upward. Fertilizers, very little used in any area in 1924, became important inputs by 1954, particularly in the areas of higher rainfall. Seed was a function of acres of wheat and followed the acreage fluctuations.

Although there was no great change in the total current expenditures from 1924 to 1954, the two areas in the Great Plains showed a slight decline, the white wheat area and the soft red wheat area each showed a tendency to have an increasing current expenditure.[1]

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[1]See Tables 34, 35, 36, and 37 of appendix B.

The gains in yields over time have had a considerable influence in decreasing the per bushel current expenditures. The total current expenditure was slightly less in the hard red spring wheat area in 1954 than in 1924, but yields had increased only slightly, so that the per unit costs showed only a slight decline. The soft red wheat area had both increasing current expenditures and yields, at about the same rates. As a result there was little change in the per bushel expenditure. The greatest reduction in per unit expenses was in the hard red winter wheat area, closely followed by the white wheat area.

Table 21. Changes in the productivity of the current expenses incurred to produce wheat, 1924 to 1954.[1]

Year	Dollar (1910-14 = 100) expenditures to produce one bushel			
	Hard red winter	Hard red spring	White	Soft red
1924	.42	.28	.25	.32
1929	.25	.21	.22	.30
1934	.37	.20	.19	.34
1939	.14	.25	.10	.19
1944	.10	.20	.10	.22
1949	.14	.25	.12	.19
1954	.12	.24	.11	.25

[1]Calculated from data in Tables 34, 35, 36, and 37 of appendix B.

In making an analysis of the relationship of time and rate of change it was found that the greatest decrease in per unit current expenditure was from 1934 to 1939. In fact, after 1939 that level has remained nearly constant with a tendency toward turning upward.

The change in the bundle of inputs making up the current expenditure has produced one of the most significant social and economic changes of technology. In the horse power era the farm remained a more or less self contained unit. When the farmer shifted his dependence for a source of energy from his own acres to the petroleum producers, he entered upon an era characterized by the dependence of the farmer on other sectors of the economy.

Construction of Indexes of Changes in the Productivity of Resources Used in Wheat Production

Indexes of productivity for total resources and each of three classes of resources land, labor, and capital were constructed. The computational procedure began with input-output data summarized in Tables 34, 35, 36, and 37 in the appendix. The common denominator used in the aggregation was dollar value of inputs based on the 1910-14 price level.

From the aggregated inputs and output a ratio $(\frac{\text{output}}{\text{input}})$ was computed which represented the return per unit of input. The next step involved the conversion of the ratios to an index where 1924 input-output ratio equaled 100 percent. Such an index was computed for each of the years studied, each of the areas, and for the land, labor, and capital inputs, in addition to the aggregate input. The results are recorded in Table 38 of appendix C and portrayed graphically in Figure 23.

The hard red winter wheat area has shown the greatest increase in productivity of the total resources employed in the production of wheat. The increase for the thirty year period was 174 percent as compared to 80 percent in the soft red area, 66 percent in the white area and 48 percent increase in the hard red spring area. The average

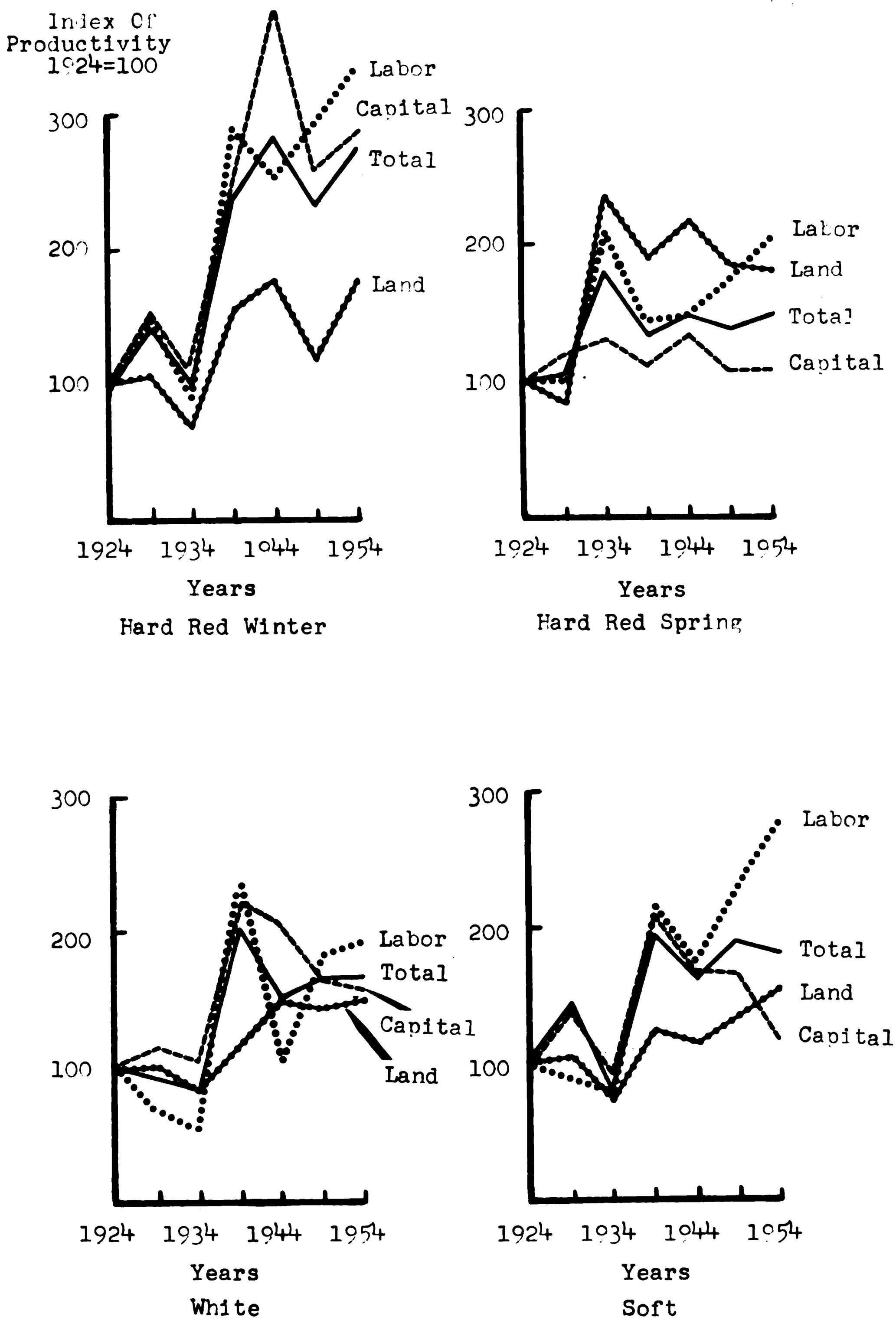

Fig. 23. A comparison of the productivity of each type of input for four selected wheat producing areas.

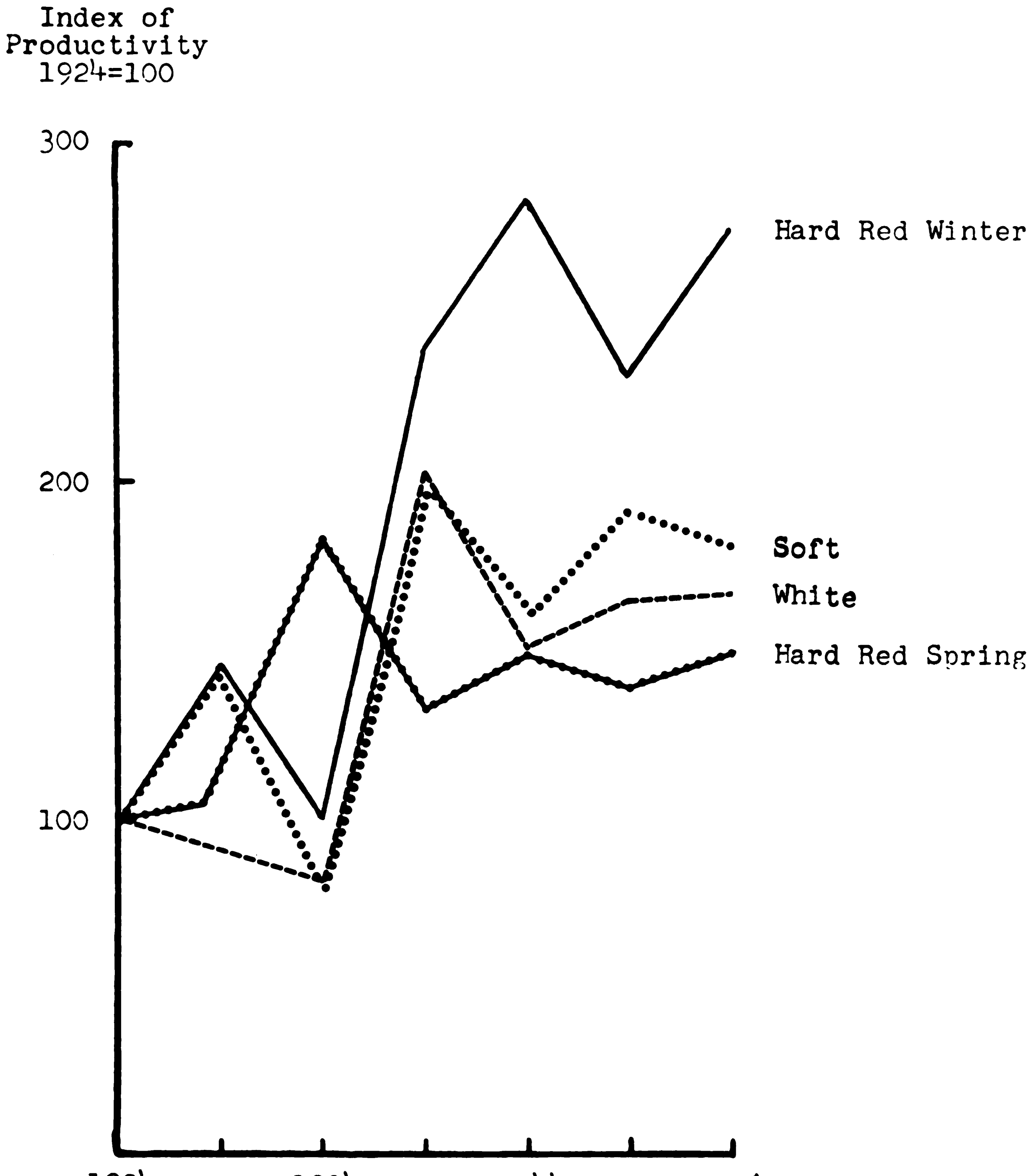

Fig. 24. Changes in the productivity of the aggregate resources used in the production of wheat in four selected wheat producing areas.

annual rate of increase was 5.8 percent, hard red winter; 2.7 percent, soft red; 2.2 percent, white; and 1.6 percent, hard red spring. Although on the average there has been this rate of increase in productivity the change has not been in a continuous flow. Rather the increases have come in bursts. From 1934 to 1939 was the greatest period of increased productivity. In the hard red winter area 138 percent of the 174 percent increase occurred in this one five year span. If the 1934 to 1939 increase in the input-output ratio were dropped from the calculation of the productivity index the gains would have been more modest and steady. From 1924 to 1954 the hard red winter area gained 36 percent or 1.2 percent annually; hard red spring, 16 percent or .5 percent annually; soft red, -5 percent or -.1 percent annually; and white, -34 percent or -1.1 percent annually. This emphasizes the significance of the one short surge in productivity. Gains since 1939 have been much less rapid and after 1944 there has even been a slight decline in productivity. The white and soft red areas also experienced a burst of changing productivity in the 1934 to 1939 period and a gradual decline in productivity since then. The hard red spring area follows a pattern of slower and steadier growth, if the atypical situation of 1934 is discounted. In all other areas the productivity of resources showed a sharp drop in this depression and drouth year. In the northern Great Plains in using the same aggregation and disaggregation procedures as in other areas the results do not follow the pattern expected. <u>A priori</u> it could be anticipated that the productivity would decline. The increase shown in Table 38 of appendix C was due to the nature of the original data. Almost no resources were allocated to wheat production by this procedure because the harvested acres were so near zero and the portion of the farm income from wheat was abnormally low. Had planted acreage data been available and used as a basis, the bias due to high abandonment would have been reduced. The high level of productivity shown in Table 38 is due to procedural bias and must not be accepted as the true situation. When 1934 is discounted then the hard red spring area would follow the pattern of the other areas. There was a much milder productivity burst after 1934 and a gradual upward movement in the later years.

When considering the productivity of the land input on a value basis rather than a bushel per acre basis a somewhat different picture developed. Generally the increases in yield per acre were greater than the change in value of the output produced from the value of land input.

Table 22. A comparison of two methods of calculating changes in land productivity, bushels per acre, and value of wheat produced per dollar land input for four wheat producing areas, 1924 to 1954.

Basis	Percent changes in land productivity, 1924 to 1954 (1910-14 dollar = 100)			
	Hard red winter	Hard red spring	White	Soft red
Bushels per acre	108	0	121	70
Value of wheat per dollar land input	78	81	49	54

The greatest increase in the productivity of the land input on a value basis was in the hard red spring area followed by hard red winter, soft red, and white.

The measurement of changes in labor productivity varies with the methodology used. As with land productivity, labor productivity was measured first by the bushels output per man unit and on a value output per unit value input.

Table 23. A comparison of two methods of calculating changes in labor productivity, bushels produced per man unit and value of wheat produced per dollar labor input for four wheat producing areas, 1924 to 1954.

Basis	Percent changes in labor productivity, 1924 to 1954 (1910-14 dollar = 100)			
	Hard red winter	Hard red spring	White	Soft red
Bushels per man unit	312.9	142.3	233.9	218.0
Value of wheat per dollar labor input	232	102	90	77

In either case the greatest increase in labor productivity was in the Kansas-Nebraska specialized wheat areas. However, on the bushels produced per man unit the increase was more rapid than if the value of the labor and the value of the wheat is considered.

As was the case with total resources used, the change in labor productivity occurred in a relatively short period of time. The greater portion of the increased labor productivity occurred between 1934 and 1939. Even if the effects of the depression and drought are considered, the evidence points this era up as the one of great advances in increasing labor productivity. This ties into the rapid rate of mechanization of wheat farming in this period of time.[1]

[1]See pages 58 to 69.

The productivity of the capital input has changed less than has the productivity of the other classes of inputs. In all cases the rate of increase in capital productivity was greatest in the 1920's and early 1930's. The peak was reached by 1939 and since that time there has been a gentle decline in the productivity of capital. Over time as more and more units of capital were substituted for labor the marginal productivity of capital has declined.

The greatest increase in capital productivity occurred in the hard red wheat area and the least in the hard red spring area.

Changes in the Cost of Production

Cost of production information has been eagerly sought by the researchers, the agricultural program administrators, politicians, and farmers. Despite the strong need for this type of information, little has been accomplished, primarily because of the difficulty of identifying and correctly measuring all cost items. Another weakness of cost of production information is the difficulty incurred when trying to make application of the data to public and private policy decisions. If cost data were on an aggregative basis, it may have little validity for individual cases. When on an individual producer basis, there may be little usefulness in the data for industry-wide planning.

The computation of the input-output relationship necessitated the gathering of all the data necessary to calculate cost of production figures on both a bushel and an acre basis for each area. The input data, within the restriction discussed on pages 106, 107, 108, and 109, was perhaps more accurate, complete, and detailed than has previously been recorded. Since the data was gathered for a purpose other than a cost of production calculation the author believes there is a minimum of *a priori* bias.

For the above three reasons it was determined that the time spent working up the cost of production figures would be worthwhile. The results are tabulated in Tables 43 and 44 of appendix D.

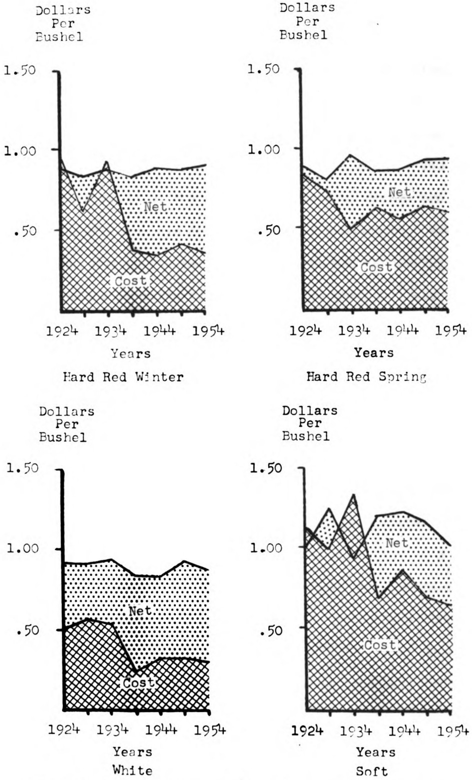

Fig. 25. A comparison of the cost to produce a bushel of wheat and the price of wheat, 1924 to 1954. (1910-1914 Dollar = 100)

The cost to produce a bushel of wheat, except for the depression and drouth years of the 1930's, has been reduced at a relatively constant rate when expressed in constant dollar values, 1910-14 = 100. During the depression years the downward trend was reversed and pushed sharply upward in the hard red winter and soft red areas. The white area was not as affected by the combined effects of drouth and economic conditions, thus did not have the sharply increased costs. The northern Great Plains, due to the nature of the data and methodology, showed its sharpest decline in costs in the depression period. This decline was due not to actual reductions, but to the very little wheat produced and the very small amount of resources allocated in this study to the production of wheat.

The white wheat area has consistently been able to produce wheat at lower cost per bushel than any other area. High yields and size of the wheat producing firm were important contributions to this efficiency. The hard red winter area produced wheat at a higher cost per bushel throughout the period but reduced costs at a slightly more rapid rate than did the white wheat area. In 1954 wheat was produced at the following per bushel costs: white, 29.6 cents; hard red winter, 34.4 cents; hard red spring, 59.6 cents; and the soft red, 63.5 cents.

It should be emphasized these are cost calculations adjusted to the 1910-14 price level and include charges for annual land use, labor, depreciation and repair charge for machinery, fuel and oil (oats, corn and hay for horses), fertilizer, machine hire, and seed. Expenditures not included were taxes and interest on loans. Converted to the 1954 price level the cost to produce a bushel of wheat was: white, 74.6 cents; hard red winter, 86.7 cents; hard red spring, $1.50; and soft red, $1.60.

In Figure 25 a comparison of the average per bushel costs and the price of wheat for each area are compared. The dotted area represents the average profit margins.

Each area has since 1924 reduced the average cost of production on a bushel basis. The hard red winter per bushel costs have been decreased since 1924 by 63.1 percent or by 2.1 percent annually, the white by 57.7 percent or 1.9 percent annually, the soft red by 56.5 percent or 1.89 percent annually, and the hard red spring by 28.6 percent or .95 percent annually.

Whereas the cost[1] to produce the average bushel of wheat was lower in 1954 than in 1924, it does not assure that the per acre costs were reduced. Lower 1954 per acre labor costs had been largely offset by the increased per acre capital inputs, such as fertilizer, higher quality seed, and machine costs.

The two Great Plains areas were able to reduce the average per acre costs of production slightly in the thirty year period, the hard red spring by 27.9 percent and the hard red winter by 25.6 percent. The soft red area experienced only a 3.9 percent decrease and the white area had a 28 percent increase in per acre cost of producing wheat.[2]

Over the thirty year span there has been two per acre cost trends. From 1924 through 1939 the cost to produce an acre of wheat was sharply reduced. In the last half of the span the costs have generally been upward.

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[1]Costs are in the term of a constant dollar, 1910-14 = 100.

[2]See Table 44 of appendix D.

The Rate of Technological Change Over Time

Technology and the economic progress associated with its application is not a continuous and evenly occurring phenomenon according to Schultz.[1] One of the purposes of this study was to seek evidence in regard to rate of economic growth in four segments of the wheat industry and to determine whether or not there were changes in the rate of growth. Each of the measures of productivity: land, labor, capital, and aggregate resources lend credence to the Schultz hypothesis.

An area by area and resource by resource analysis of the data was made.[2]

Hard Red Winter

Changes in total resource productivity was sporadic. Increasing productivity to aggregate resources had begun by 1924 and a sharp increase was experienced in the following five years. However, this economic growth was curtailed by the double pressures of drouth and depression the first five years of the 1930's. By 1939 the increasing returns to inputs was in full evidence again. By 1944 a productivity peak was reached and in the following ten years there was only a maintenance of this level. Almost all of the increase in total resource

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[1] Schultz, T. W., Reflections on Agricultural Production, Output, and Supply, Journal of Farm Economics, August, 1956.

[2] See Figure 23.

productivity of the 1924 to 1954 period occurred in ten years, 1934 to 1944. As compared to the other three areas, the hard red winter area has shown a more rapid rate of technological change.

Output per unit of land had a steadier and more consistent increase, particularly when the bushels per acre were used as a measure.[1] The ratio of the deflated value of inputs to the deflated value of output also showed a rather consistent growth. The sharp rise after 1934 should not be attributed as much to change in land productivity as to a change in economic and climatic influences which could not be entirely removed in the analysis.

Labor productivity has risen at a fairly steady rate since 1924, except for the severe depression period. There has been perhaps a tendency for the rate of increase to slow in the last decade. On the basis of bushels produced per man unit the average annual increase was 116 bushels. The average annual increase by five year periods was as follows:

1924 to 1929	178 bushels
1929 to 1934	excluded because of abnormal conditions
1934 to 1939	excluded because of abnormal conditions
1939 to 1944	147 bushels
1944 to 1949	72 bushels
1949 to 1954	90 bushels

Labor productivity measured as the value of output per unit of value of input showed a similar pattern, as shown in Figure 23.

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[1]See Table 12.

Changes in capital productivity follow almost an identical pattern as did changes in the aggregate productivity. There was little change from 1924 through 1934. However, in the 1934 to 1939 and 1939 to 1944 periods there was a surge in capital productivity of 163 percent or 16.3 percent annually as compared to the 232 percent total or 7.7 percent annual increase from 1934 to 1954.

In the southern Great Plains productivity has not increased at a steady rate in the thirty years prior to 1954. Technological developments responsible for changes in productivity apparently were adopted in bursts that were closely associated with the prosperity of the producers. The fastest rate of growth was in the recovery period after the 1930's depression and drouth and in the early war boom years.

Hard Red Spring

If the abnormal years of the depression and drouth are dropped there has been a rather steady gain in productivity to aggregate and individual resources in the hard red spring wheat area. Throughout the historical period studied technological progress as represented by the indices of productivity, Figure 24, show this area to lag behind all other areas in rate of increase. In the post-depression period the northern Great Plains have not only lagged in rate of increase, but have lagged in absolute terms, Table 38 of appendix C. Only labor productivity has shown a significant increase since 1939. Land and capital productivity has shown little change since 1939. Total productivity increased slightly, due to the rising labor productivity.

White

The abnormalities of the depression and drouth period of the 1930's did not produce as marked an interruption in the productivity changes of the white wheat areas as was experienced in each of the other areas. Throughout the thirty years studied the Pacific Northwest has had a higher level of return to resources than the other areas. The hard red winter and soft red areas have each increased productivity at a more rapid rate than the white area. However, technological advances, particularly mechanization, were introduced in this area at an earlier date than in the other areas, so that despite the differential rates of change in productivity, the white area has remained the most productive. Labor productivity has increased more rapidly than has capital and land productivity; as a result the total productivity has increased more rapidly than the productivity of capital and land.

Soft Red

Although the soft red area was the least efficient in wheat production in 1924, its productivity has increased more rapidly than the other areas, except the hard red winter area, and in 1954 had surpassed the hard red spring area in productivity. The changes in productivity had largely occurred prior to 1944. Since that time labor productivity has been increasing very rapidly, land less rapidly, and capital productivity has dropped rather rapidly. Consequently, total productivity has remained fairly constant since 1944.

This chapter has been devoted to identifying and measuring the changes in the productivity of resources used in wheat production in the four selected regions of the United States. The changes in productivity were indicators of the technological changes that have affected the industry and the individual producers. Chapter VII, the final chapter, will summarize the conclusions, point out limitations, and relate the findings to the problems of the wheat industry.

CHAPTER VII

THE CONCLUSIONS AND THE IMPLICATIONS OF THE CONCLUSIONS

The conclusions of this study do not always confirm generally held notions concerning technological development. Agriculturalists have for the last several decades marvelled at the constant flow of technology into farming. The increased productivity of agriculture has been legendary. Article after article by the scientist, the journalist, or the layman has heaped praise upon the economic accomplishments in agriculture. Seldom has there been any dissent from this conclusion. Schultz's and Cochrane's recent arguments concerning the uneven flow of technology have not been widely accepted. Schultz's argument that output-input ratios remain a constant 1:1 except when there is failure to account for all of the inputs, especially the qualitative changes of the inputs, has been received with skepticism.

Limitations

The conclusions of a scientific investigation may be at least partially drawn as a result of limitations of the methodology or the data. Recognition of these limitations, this author believes, strengthens the validity of the findings. Three factors influencing this study may have had an effect upon the conclusions that are to be outlined in this chapter.

First, for the purpose of this study a more restrictive definition of technology was used than has been the case in many of the technology studies. What has often been considered technology, such as mechanization, did not fall within the definition of technological progress. Such changes were considered as changing the bundle of resources, that is, substitution of one input for another. Only the act of gaining the knowledge that made possible the substitution was considered to be technological advance. One of the weaknesses of studies of technology has been the lack of precision in defining technology. The development of a refined concept of technology may have influenced the conclusions, but was a positive contribution to the development of framework for technology studies.

Secondly, when only a portion of agriculture was considered, the conclusions may be different from those drawn had the whole agricultural industry been considered. Technology applicable to different types of production occurs at different times, therefore the flow of technology may have been rather steady for the whole, but very erratic for the parts.

Third, empirical analysis was made difficult by the insufficient data in appropriate form for technology studies. Error in judgment used to solve the many and intricate methodological problems, of course, may be reflected in the results of the analysis and in the conclusions drawn. However, there was no reason to conclude that the error of judgment in this study was more or less than in the studies of other technological researchers.

The Hypotheses

Four general hypotheses were formulated for empirical testing. The statistical analysis of Chapter VI and the historical analysis of Chapter IV were directed toward finding clues in support of or not in support of the following: (1) technological change in wheat production has been sporadic, (2) the degree of specialization affected the rate of technological advancement, (3) size of the farm in acres affected the rate of technological change, (4) technological change was associated with the level of income of the farmers.

Sporadic Economic Development

Wheat production in the four regions studied has not been characterized by a steady increase in the productivity of the aggregate resources. The 1934 to 1944 period was a period of rapid increase in productivity as a result of technology and substitution of the more productive resource, capital, for the less productive resource, labor. The initial marginal rate of substitution quickly diminished. There had not been accumulated a new backlog of technology, such as knowledge concerning mechanical power, new varieties, and cultural practices ready for adoption in immediate post depression years. Conditions of recovery in the general economy increased employment opportunities off the farms. Consequently, a steady migration from farm employment to industrial employment occurred as farm labor sought higher returns from its labor. The loss of labor on the farm coupled with the increased productivity of capital resulted in a rapid substitution of capital for labor. The outbreak of World War II intensified the labor shortage, thus continuing the conditions that encouraged resource substitution. Improving economic conditions affected farm incomes favorably. Improved income position of farmers offset the inadequate credit facilities available, by giving them profits to invest or the collateral to mortgage for increasing capital inputs.

The conditions that stimulated the burst of increased productivity diminished after 1944. The subsequent period has been characterized by little change in productivity of the resources in aggregate. The accumulation of new knowledge that would change the relative marginal productivity of the resources has not recurred. The same general conclusion can be drawn for each of the types of inputs used in wheat production as could be made for the aggregate input.

Based upon these conclusions, a generalization explaining economic growth resulting from technological change in wheat production can be made. Had the change been in a steady flow a model for change in resource productivity could have been constructed that showed a continuous shift to a higher production plane. As technology affected the production coefficients, each shift to a higher production plane would be accompanied by a continuous recombination of resources. Unless the price-cost ratios became less favorable the pressure would be to use more resources. The following is a geometric presentation of this concept. In the initial time period (t) the production would be on the plane represented by Ot using Ox_1 resources to produce Oy_1 product. At this combination of resources the industry approximates equilibrium. The inflow of new knowledge increases the productivity of the resources so that in period $t + 1$ the productive process will be on Ot_1 plane when using Ox_1 resources. Technology affected the technical coefficients so that at Oy_2 production disequilibrium condition exists and a resource adjustment is made to use Ox_2 resources to produce Oy_3 product, the new equilibrium condition. In each new production period this process would be repeated.

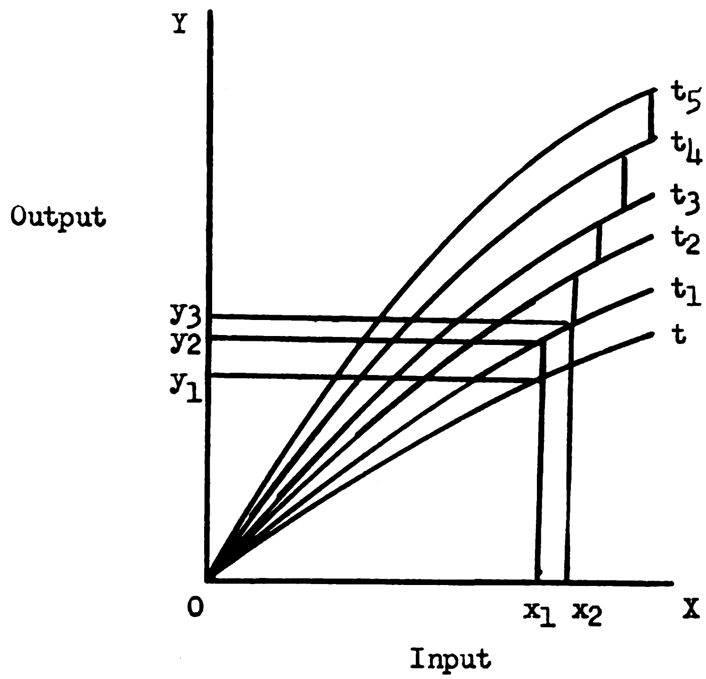

Fig. 26. The effect of technology and resource substitution on an industry.

In this study of four segments of the wheat industry, evidence indicates changes in resource productivity which have encouraged resource recombination. The technology that caused the disequilibrium conditions to arise has not entered the wheat industry in a steady flow. In most of the thirty year period the shifts from one production plane to another have been imperceptible for any one production period. The shift to a higher production plane appears to have occurred in a very short time period, 1935-1944. There was a quick rise in the index of productivity[1] in the immediate post depression period. Economic change in wheat production has come in spurts followed by periods of resource adjustment, which can be explained by a model such as Figure 27.

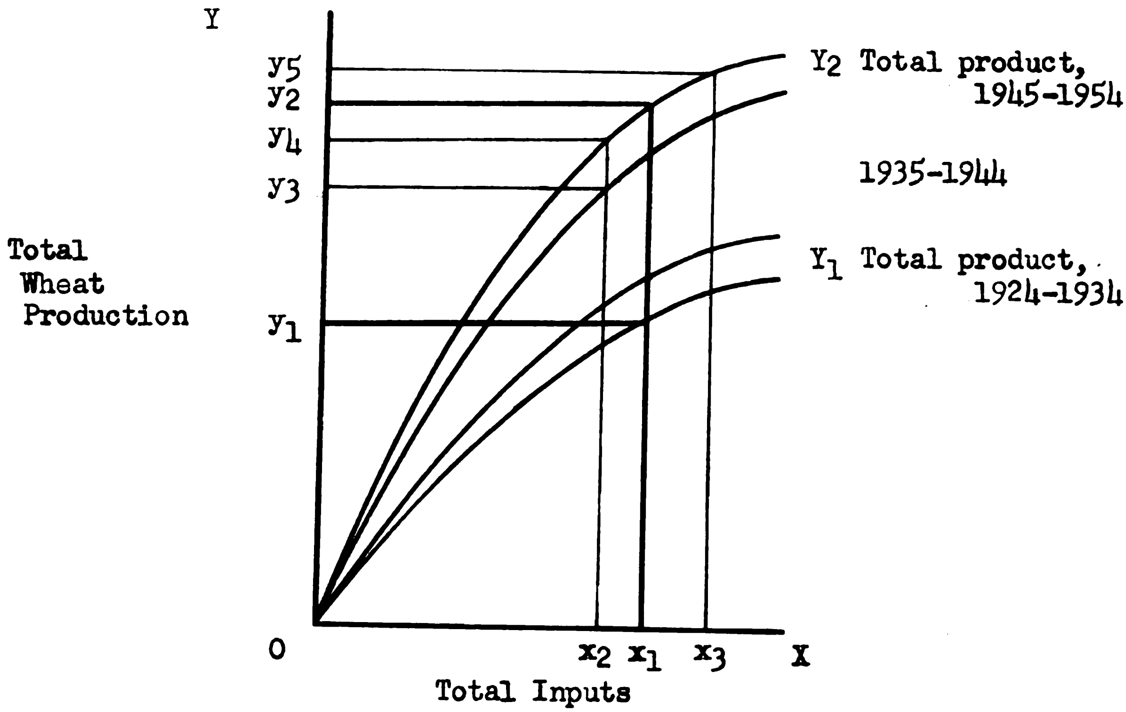

Fig. 27. A model of the changes in the productivity of resources used in wheat production.

Wheat production in 1924 was at Oy_1 level, Figure 27, when Ox_2 resources were employed. The process of mechanization had just begun. As a result the next decade was characterized primarily by resource recombination with perhaps a slight movement to higher production planes.[2] The principal adjustment was the introduction of new capital with little change in land and labor.

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[1]See Figure 24.

[2]The small bands represent the narrow range of the production planes in 1924-34 and 1945-54.

Following the depression each of the wheat areas had a burst in productivity. This sudden increase in productivity appears to have resulted primarily from new knowledge[1] which had increased the efficiency of resources. Simultaneously and immediately following the innovations resource adjustments were made possible by the off-farm opportunities for employment. As labor was pulled from the farms by these opportunities a recombination of the capital-labor resources were possible and necessary. Wheat production in a very few years, 1934-44, moved from the Y_1 plane of production to the Y_2 plane. Still using Ox_1 inputs the wheat industry would have produced Oy_2 wheat. The gain in total product was y_1y_2. The increased efficiency of resources should have resulted in the use of more factors Ox_3 producing Oy_5 wheat. Farmers responded in just this manner, which resulted in surplus production, causing government to intervene with acreage restriction programs, thus forcing a decrease in resources used for wheat production. Rather than increasing to Ox_3 units of input, there was a decline to Ox_2 units. The increased productivity of resources permitted an increased output from Oy_1 to Oy_3.

The hard red winter, soft red, and the white areas follow the pattern of Figure 27. The hard red spring area has not shown the same surge in productivity, such as characterized the other areas, nor has it had a very significant steady incline. Thus it more closely

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[1]Examples: introduction of new varieties, time of plowing and planting, disease and insect control.

conforms to Figure 26. The development of new yield increasing varieties such as Tenmarq and Pawnee in the southern Great Plains has not taken place in the hard red spring wheat area.[1] The biological and climatological hazards were much greater in the northern Great Plains. These factors complicated the breeding of yield increasing wheats.

The evidence substantiates the lumpiness of technological advances. Varietal and cultural innovations in wheat production were ready for wide adoption by 1940. The importance of yield increasing varieties was demonstrated in the differences among the four areas, particularly the most rapid rate of increase in the hard red winter wheat area. Early results of genetic knowledge applied to wheat breeding problems came in varieties grown in the southern Great Plains. Prior to 1929, Turkey Red, or some of its selections, was the dominant wheat variety. Tenmarq, the result of scientific crossbreeding, was released for farm production at this time. By the late 1930's a second new variety, Pawnee, began the rapid replacement of Tenmarq. The productivity surge followed these varietal innovations. In other areas, new variety development lagged and the yield effect of the released varieties was less pronounced. Improved soft red varieties were developed at a later date; however the hard red winter varieties began the replacement of standard old varieties in the soft red area prior to the development of Thorne, Fairfield, and Vigo. White wheat

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[1]Salmon, S. C. and Reitz, L. P., Distribution of the Varieties and Classes of Wheat in the United States in 1954, Agriculture Handbook No. 108, United States Department of Agriculture, 1957.

had two popular varieties, Golden and Federation, prior to 1939 and no other important change until Elmar was released in the early 1950's. The hard red spring area had no new varieties comparable to the winter wheat area. Figure 28 illustrates the changes in productivity as related to variety improvements for each of the areas for the 1924 to 1954 period. Across the top, the dates new varieties became important are indicated by the series of x's. It should be noted that the hard winter wheat increased productivity more rapidly than the other areas. Also, in this area varietal improvement preceded the varietal improvement of the other areas. The development of Tenmarq and Pawnee wheat seemed to explain the increase in productivity in the hard red winter area.

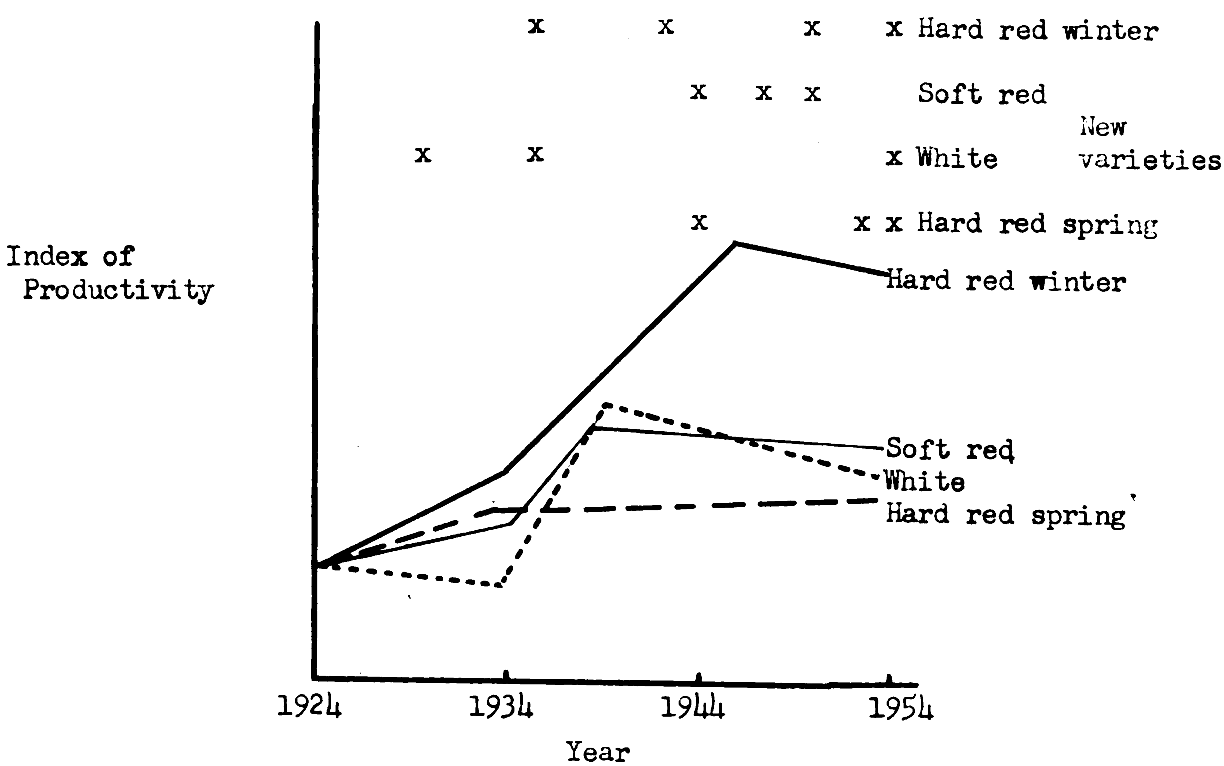

Fig. 28. The time relationship between new varieties and changes in productivity in four wheat producing areas, 1924 to 1954.

Specialization and Economic Development

If all other factors had been equal among acres then the significance of the degree of specialization on economic development could have been more accurately determined. The importance of specialization would be greater in a study comparing regions within one of the types of wheat areas. Between areas the level of income, varietal development differences, and degree of hazard overshadowed the importance of specialization on rate of technological development. All innovations were not equally applicable among areas.

The northern Great Plains had the highest degree of specialization of the four areas studied. The southern Great Plains the second highest, followed by the Pacific Northwest and eastern Cornbelt. In no case did increase in productivity follow the order of specialization. The southern Great Plains were not nearly as specialized in small grains as the northern Great Plains but had a faster rate of economic development. The other two areas fairly closely fit the expected pattern.

If the hard red spring area is considered an exceptional case, then it could be generalized that specialization affects economic growth.[1] The evidence certainly does not conclusively support such a generalization.

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[1]The author thinks that to make specialization the cause and the rate of innovation the effect may be inappropriate. Perhaps the case is really the reverse. Providing there exist adapted innovations for the area, the area may be stimulated to specialize as a result of innovation. The innovation must be cost reducing to be adopted. The comparative advantage position in producing wheat of the area becomes more favorable vis-a-vis other areas to which the innovation was unsuited and more favorable for wheat relative to other crops presently grown. Therefore an area such as the hard red winter specialized as wheat became more profitable for the producer. In the hard red spring area even though the rate of growth was slowest of all areas the small improvement may have been sufficient to encourage specialization due to the relative position of wheat to alternatives in the area.

Size of Operation and Economic Development

The average acres in farms and the average investment in wheat production were used as indicators of size of operation. It was not possible to explain productivity differences among areas by size of operation.

By either indicator of size the areas were ranked, first, white; second, hard red winter; third, hard red spring; and fourth, soft red. In no case did the ranking of size of operation coincide with a ranking of increases in productivity.

A study comparing increased productivity and size of operation among individual farms within one area may provide greater evidence to support the hypothesis that size influences the rate of technological advance.

Size of operation was closely associated with level of productivity. The most favorable $\frac{\text{output}}{\text{input}}$ ratios[1] were in those areas with the largest farms. The white wheat area had a higher level of productivity at the beginning of the period studied and despite a slower rate of increase than the hard red winter and soft red still had the highest level of productivity in 1954.

Level of Income and Economic Development

Level of income and level of productivity were closely associated. The areas with the highest incomes had the highest level of productivity. The exception was the soft red area where income per farm was

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[1]See Table 38 of appendix C.

lowest, but the productivity ratio was higher than the hard red spring ratio. There was not a similar relationship between income and rate of change in productivity.

Table 24. A comparison of average level of income per farm, input-output ratio, and the average rate of increase in productivity in four wheat regions, 1954.

	Average level of income per farm, 1954	$\frac{\text{Output}}{\text{Input}}$, 1954	Average rate of increase in productivity
White	$20,146	2.928	2.2
Hard red winter	9,796	2.587	5.8
Hard red spring	5,693	1.549	1.6
Soft red	4,343	1.601	2.7

Cost of Production

The cost of production analysis demonstrated the cost reducing nature of the technological developments in wheat production. In every area studied there has been almost a continuous decline in the real cost of producing a bushel of wheat, 1924 to 1954.[1] In the subsequent period there was doubt that per unit costs have declined.

Depsite the shortcomings of cost of production work the figures calculated in Table 43 provide some insight into the nature of costs by areas. Size of operation is necessary to reduce the per unit costs. As technology was adopted the unit costs dropped. The 1935-1944 technological surge was accompanied by a sharp drop in unit costs. After the 1935-1944 low there were even slight per unit increases.

[1]All input data was expressed in terms of the 1910-14 price level.

The Policy Implications of Technological Advances in Wheat Production

Discoveries of knowledge have not been predictable. Nor has the application of scientific discoveries been predictable. One of the greatest strides in improving the output-input relationships in wheat production has been the development of new varieties through application of genetic principles. The basic genetic discoveries were made in 1865 by Mendel. The results of this work were not applied to the wheat industry for nearly 50 years and success in application took fully 75 years after his work was completed. Scientific discoveries of this century may have great potential, yet may not be applied for long periods of time. There is evidence that the gap between discovery and innovation may be narrowing.[1] Regardless of the time necessary for innovations to affect the productive process, the policy consequences both for the individual and for the public are considerable.

Had the technological surge of the late 1930's and the early 1940's not coincided with World War II and the following economic aid programs to Europe and Asia, the economic consequences would have been much different. Prior to the war, the wheat industry faced a demand curve such as D_1D_1, characterized by its relative inelasticity. Innovations were pushing the supply function rapidly upward. As a result prices had dropped without a proportionally great increase in sales. Farm incomes sagged. Government programs had not successfully solved the problem.

[1]Two years after hybrid grain sorghum was available for planting, almost all Kansas grain sorghum producers had switched to hybrid seed.

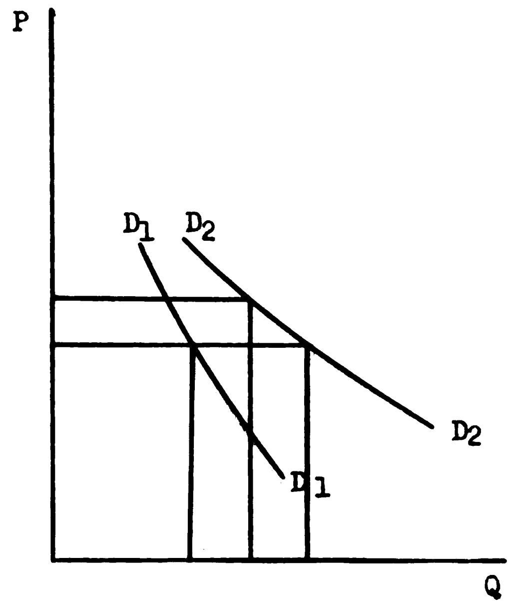

Fig. 29. The nature of the demand curve for wheat in two time periods, 1930 to 1940 and 1945 to 1950.

After the termination of the war the rebuilding of war torn Europe and Asia not only increased the quantity saleable at higher prices, but pushed the demand curve to the right. Increased demand temporarily solved the problem, but also provided the basis for a more serious supply problem in the 1950's. Technology made possible the reduction of per unit costs. Coupling this with higher prices and the public urging to produce more as a patriotic duty provided the wheat farmer a triple incentive to increase wheat production. So long as these conditions, increasing demand and falling costs, continued both the industry and the individual improved economically by increasing production through further innovation and employment of more resources.

Cessation of aid programs to Europe returned the wheat industry to prewar demand conditions. Without price supports, price would have fallen to very low levels. With price supports, supply exceeded demand and surpluses resulted. Production controls were ineffective, because policy makers did not fully understand the power of adoption of technology or the extent it would pay farmers to reorganize resources due to the result of the changes in the production coefficients after the adoption.

So long as sufficient innovation takes place to make it advantageous to substitute capital for labor and land, simple acreage retirement at present levels will not affect total supply. With present price relationships and substitution relationships wheat farmers will continue to make the resource substitution that will maintain production.

Continuation of such a program can be justified only if:

1) Technological advances in the future will be at a slower pace than in the past.

2) Demand shifters will be successful.

Even if there may be no immediate prospect for a surge in technology comparable to the 1935 to 1944 period there is evidence that there will be continuous small gains. New varieties are being released almost annually, which have at least slight yield advantages over the old varieties. Cultural practices, such as timeliness, weed, insect, and disease control, methods of soil preparation and fertilization also provide the basis for increased productivity of resources. Dramatic technological advances, comparable or exceeding those of the

1920's and 1930's, appear to be just around the corner. If plant breeders are successful in producing hybrid wheat the yield increases may be by fifty or one hundred percent. Producers will be eager to plant the new variety, as demonstrated by the grain sorghum producers.[1] The surge in wheat productivity, such as the 1935 to 1944 surge, may occur in a one or two year period.

The Kansas experiment station staff point out the technical possibility of the change in the molecular structure of other sources of protein to duplicate the highly special protein, gluten, of wheat. Such a technological advance would have greatly different effects than one intended to increase productivity of resources used in wheat production.

Cochrane has concluded that agriculture, in general, is in its earliest phases of the technological revolution. There appears to be no reason his conclusion does not apply to the wheat industry. The expectation of important technical advances further complicates the wheat supply-demand situation by destroying the national reliance upon a hope that technology would soon move ahead at a slower pace than the growing population. Nor are there important indicators to justify the second national hope—the possibility of changing demand for wheat.

Per unit costs can be expected to fall even further, perhaps very rapidly if an important innovation takes place. In the absence of

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[1]It should be noted that it is largely the same group of farmers who raise wheat in the southern Great Plains who also raise grain sorghum.

price supports, the price of wheat would fall even more than costs. Price supports without effective production control will continue the surplus problem.

In conclusion, technical progress in wheat production seems inevitable and necessary for increasing the economic welfare of the society in general. As the productivity of the resources change, resource adjustment problems will intensify. Vigorous public policies will be necessary to facilitate the changes.

Productivity in wheat production has increased annually on the average by 5.8 percent for hard red winter, 2.7 percent for soft red, 2.2 percent for white, and 1.6 percent for hard red spring. Assuming a constant level of inputs, predictions can be made as to level of production in future years.

Production in 1970 and 1980 was estimated at three levels of technological advance. First, assuming that there will be a new burst of technology comparable to the 1930's, the average rate of technological progress since 1924 was used as a basis for estimation. Second, it was assumed that some new scientific breakthrough would greatly affect productivity and estimation was made on the basis of double the 1924 to 1954 rate of increase in productivity. Third, it was assumed there would be no new surge in productivity, but a steady slow growth similar to the period since 1940. The surge years were dropped and estimation was made based on the changes since 1940. The results of these estimations are recorded in Table 25.

Table 25. The predicted wheat production in the United States, by classes, assuming three rates of technological progress, 1970 and 1980.

Area	Millions of bushels of wheat produced with three levels of technological progress						
		1970			1980		
	Average 1953-54 production	Average 1924-54 rate	Double average 1924-54 rate	Average 1924-54 dropping 1934-39 period	Average 1924-54 rate	Double average 1924-54 rate	Average 1924-54 dropping 1934-39 period
Hard red winter	496	930	1,480	590	1,210	1,952	650
Hard red spring	180	210	275	195	250	350	205
White	183	240	403	153	280	380	133
Soft red	202	250	298	200	282	360	195

Schnittker estimates a slight increase, one percent per year, in total wheat utilization, based upon the leveling off of the drop in per capita consumption in recent years.

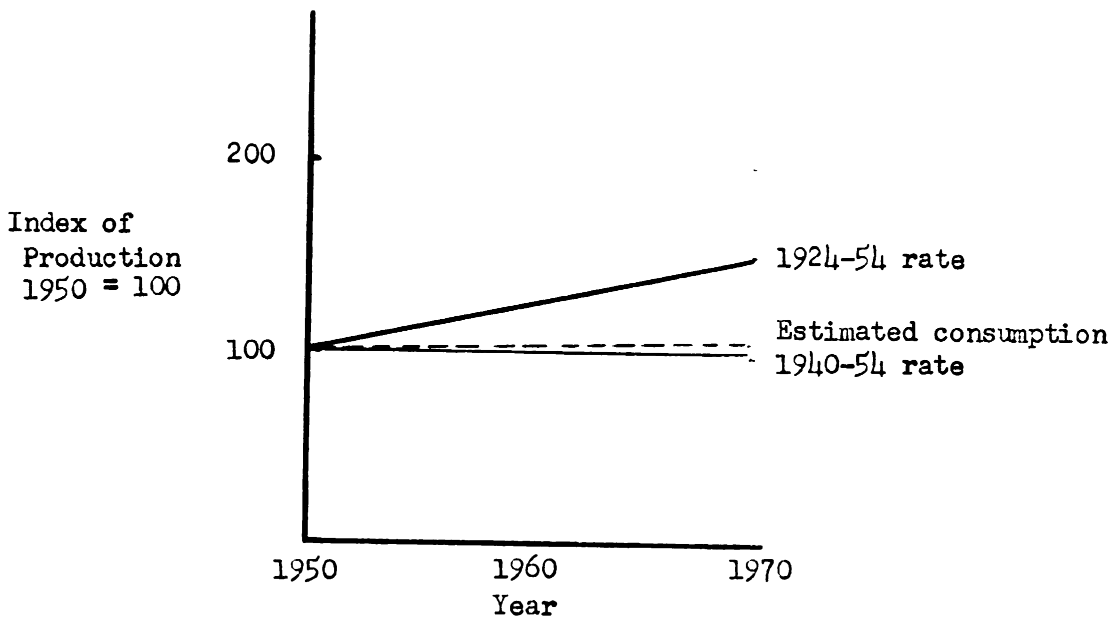

Fig. 30. The estimated rate of increase in productivity and rate change in utilization of wheat, 1950 to 1970. Source: Table 25.

If the increase in productivity of resources used in wheat production were to continue for the next two decades at the average rate of the last thirty years, the surplus problem will continue. The thirty year average was most affected by the post depression surge in productivity. Were the future not to have such a surge in productivity, then the prospects are excellent that the wheat surplus is only a temporary problem. This author, after some rather intensive study of wheat production, concludes that an increasing rate of technological change is more probable than a continuation of the post 1940 rate. The optimism of scientists in the areas of plant breeding, disease and insect control, and radiation, along with the evaluation of leading agriculturalists, support this conclusion.

The implications for the individual farmer, for the wheat industry, and for society as a whole are clear. Individual producers will not only be forced by economic pressures to adopt innovations but will be eager to adopt. The innovations will increase the productivity of the aggregate resources, thus, increasing the production of wheat. Increased productivity of the resources will encourage employment of more inputs, which also will result in increased production. Under a free price system the increased supply will cause the price of wheat to fall without a comparable increase in consumption. The gross return to the wheat industry will be less after innovation. On the average each producer will have a lower income unless there is a movement of producers out that more than offsets the total income decline. The individual who does not adopt the innovation will have even a lower income, inasmuch, as he will have the old higher cost schedule and the new lower price schedule. The producer in the wheat industry is caught on the Cochrane treadmill. He has no alternative but to make the decision to adopt which sets in motion the forces that will lower his income.

The society as a whole benefits in terms of higher quality wheat in abundant supply and produced at low cost. Consumer welfare depends on increased productivity in agricultural production.

Public programs to assist the wheat industry can be based upon policies to regulate the supply of wheat through control of the rate of technological innovation or through limitation of resources devoted to wheat production. The regulation of technology, thus slowing economic progress in the wheat industry, does not appear justifiable. If the disruption to cultural and social institutions has undesirable effects which more than offset the economic benefits, then an argument can be made to slow the rate of increasing productivity. Such a policy would be a reversal of the historic policy of publicly stimulating technological development. Continued technological innovations in wheat production will necessitate the continuation of programs that aid the industry and the individual producers in determining and making the necessary resource adjustments.

BIBLIOGRAPHY

Allin, Bushrod W., Rural Influence on the American Politico-Economic System, lecture before the United States Department of Agriculture Graduate School, April, 1957.

Anderson, James R., Wooten, Hugh H., Cooper, Martin R., and Burkhead, Charles E., Major Statistical Series of the U. S. Department of Agriculture, How They Are Constructed and Used, Agricultural Handbook No. 118, U.S.D.A., 1957.

Baumol, William J., Economic Dynamics, The Macmillan Company, New York, 1952.

Boulding, Kenneth E., Economic Analysis, 3rd edition, Harper and Brothers, New York, 1955, p. 716.

Brewster, John M., Effects of Scientific Progress on the Family Farm, Journal of Farm Economics, December, 1958.

Brinegar, George K., Backman, Kenneth L., and Southworth, Herman H., Reorientation in Research in Agricultural Economics, Social Science Research Council Items, March, 1959.

Bureau of the Census, United States Census of Agriculture, 1954, 1949 1944, 1939, 1934, 1929, and 1924.

Carleton, Mark Alfred, Hard Wheats Winning Their Way, Yearbook of Agriculture, United States Department of Agriculture, 1914.

Carleton, Mark Alfred, Successful Wheat Growing in Semi-arid Districts, Yearbook of Agriculture, United States Department of Agriculture, 1900.

Carter, Harold O., and Heady, Earl O., An Input-Output Analysis Emphasizing Regional and Commodity Sectors of Agriculture, Research Bulletin 469, Iowa State University, Ames, September, 1959.

Clark, Colin, The Conditions for Economic Progress, 2nd edition, Macmillan and Company, London, 1951.

Clawson, Marion, Reflections on Gross Farm Output, Journal of Farm Economics, May, 1959.

Cochrane, Willard W., Conceptualizing the Supply Relation in Agriculture, Journal of Farm Economics, December, 1955.

Cochrane, Willard W., Farm Prices, Myth and Reality, University of Minnesota Press, Minneapolis, 1958, Chapter V, pp. 85-107.

Commissioner of Agriculture, Department of Agriculture Report, 1881 and 1882.

Commissioner of Agriculture, Report of the Commissioner of Agriculture, 1885.

Dondlinger, Peter Tracy, The Book of Wheat, Orange Judd Company, New York, 1910.

Ellickson, John P. and John M. Brewster, Technological Advance and the Structure of American Agriculture, Journal of Farm Economics, November, 1947.

Elwood, Robert B., Arnold, Lloyd E., Schmutz, D. C., and McKibben, Eugene G., Changes in Technology and Labor Requirements in Crop Production, Wheat and Oats, Works Progress Administration, National Research Project, Report No. A-10, Philadelphia, 1939.

Galloway, B. T., Immigrant Plants Hold Large Place Among U. S. Crops, Yearbook of Agriculture, United States Department of Agriculture, 1928.

Griliches, Zvi, Demand for Fertilizer: An Economic Interpretation of a Technical Change, Journal of Farm Economics, August, 1958.

Griliches, Zvi, Hybrid Corn: An Exploration in the Economics of Technological Change, Econometrica, October, 1957.

Griliches, Zvi, The Demand for Fertilizer in 1954--An Interstate Study, Journal of the American Statistical Association, June, 1959.

Griliches, Zvi, Specification Bias in Estimation of Production Functions, Journal of Farm Economics, February, 1957.

Griliches, Zvi, and Grunfeld, Yehuda, Is Aggregation Necessarily Bad?, The Review of Economics and Statistics, February, 1960.

Heady, Earl O., Basic Economic and Welfare Aspects of Farm Technological Advance, Journal of Farm Economics, Vol. XXI, No. 2, pp. 293-316, May, 1949.

Heady, Earl O., Economics of Agricultural Production and Resource Use, Prentice-Hall, Inc., New York, 1952, Chapter 27, pp. 794-829.

Heady, Earl O., Farm Technological Advance, Journal of Farm Economics, May, 1949.

Hecht, Reuben W., and Barton, Glen T., Gains in Productivity of Farm Labor, Technical Bulletin No. 1020, Bureau of Agricultural Economics, United States Department of Agriculture, Washington, D. C., December, 1950.

Hoover, Leo M., Kansas Agriculture After 100 Years, Bulletin 392, Kansas Experiment Station, Manhattan, 1957.

Hopkins, John A., and Heady, Earl O., Farm Records, 3rd edition, Iowa State College Press, Ames, 1949.

Ingersoll, C. L., and Bessey, Charles E., Wheat and Some of Its Products, Nebraska Agricultural Experiment Station Bulletin No. 32, 1894.

John, M. E., The Impact of Technology on Rural Values, Journal of Farm Economics, December, 1958.

Johnson, Glenn L., Agriculture's Technological Revolution, United States Agriculture: Perspectives and Prospects, The American Assembly, Columbia University, 1955.

Johnson, Sherman E., Changes in American Farming, Miscellaneous Publication No. 707, United States Department of Agriculture, December, 1949.

Kendrick, John W., Productivity Trends in Agriculture and Industry, Journal of Farm Economics, December, 1958.

Ladd, George W., Biases in Certain Production Indexes, Journal of Farm Economics, February, 1957.

May, Kenneth, Technological Changes and Aggregation, Econometrica, January, 1947.

MacGregor, M. A., Implications of Changing Technology for Prices and Incomes in Agriculture, Journal of Farm Economics, December, 1958.

McCrory, S. H., Hendrickson, R. F., and Committee, Technological Trends in Relation to Agriculture, Report of the Subcommittee on Technology to the National Resources Committee, United States Department of Agriculture, Washington, D. C., 1937.

Mill, John Stuart, Principles of Political Economy, Vol. II, D. Appleton and Company, New York, 1881, Book IV.

Mills, Frederick Cecil, Statistical Methods Applied to Economics and Business, Henry Holt and Company, New York, 1938.

Morrison, Frank B., Feeds and Feeding, The Morrison Publishing Company, Ithaca, 1956.

Nauheim, Charles W., Bailey, Warren R., and Merrick, Della E., Wheat Production, Agricultural Research Service, Agricultural Information Bulletin No. 179, United States Department of Agriculture, Washington, D. C., 1958.

Orazem, Frank, and Wearden, Stanley, Yield Variability of Different Crops and Its Estimated Sources, unpublished manuscript.

Pearson, Frank A., and Bennet, Kenneth R., Statistical Methods Applied to Agricultural Economics, John Wiley and Sons, Inc., New York, 1942.

Report of a Subcommittee of the Committee on Technological Developments of the American Farm Economics Association, Economic Implications of Technological Developments in Agricultural Production, Journal of Farm Economics, February, 1947.

Rogin, Leo, The Introduction of Farm Machinery, University of California Press, Berkeley, 1931.

Ruttan, Vernon W., Agricultural and Non-Agricultural Growth in Output per Unit of Input, Journal of Farm Economics, December, 1957.

Ruttan, Vernon W., Technological Progress in the Meat Packing Industry, 1919-1947, Marketing Research Report No. 59, United States Department of Agriculture, 1954.

Ruttan, Vernon W., The Contribution of Technological Progress to Farm Output: 1950-75, The Review of Economics and Statistics, February, 1956.

Salmon, S. C., and Reitz, L. P., Distribution of Varieties and Classes of Wheat in the United States in 1954, Agricultural Handbook No. 108, United States Department of Agriculture, 1957.

Schultz, T. W., Economic Efficiency: Its Meaning, Measurement and Application to Agricultural Problems, Note, Journal of Farm Economics, February, 1951.

Schultz, Theodore W., The Economic Organization of Agriculture, McGraw-Hill Book Company, Inc., New York, 1953.

Schultz, Theodore W., Reflections on Agricultural Production, Output, and Supply, Journal of Farm Economics, Vol. XXXVIII, No. 3, pp. 248-762, August, 1956.

Schultz, Theodore W., The United States Farm Problem in Relation to the Growth and Development of the United States Economy, Report of the Joint Committee on Policy for Commercial Agriculture, Its Relation to Economic Growth and Stability, United States Government Printing Office, Washington, D. C., 1957, pp. 3-14.

Schumpeter, Joseph A., The Theory of Economic Development, Harvard University Press, Cambridge, 1949.

Smith, Adam, An Inquiry into the Nature and Causes of the Wealth of Nations, 1776.

Solow, Robert M., Technical Change and the Aggregate Production Function, The Review of Economics and Statistics, August, 1957.

Stigler, George J., Trends in Output and Employment, National Bureau of Economic Research, New York, 1947.

Stout, Thomas T., and Ruttan, Vernon W., Regional Patterns of Technological Change in American Agriculture, Journal of Farm Economics, May, 1958.

Swingle, Walter T., and Webber, Herbert J., Hybrids and Their Utilization in Plant Breeding, Yearbook of Agriculture, United States Department of Agriculture, 1897.

United States Department of Agriculture, Major Statistical Series of the United States Department of Agriculture, Vol. 2, 1957.

Webber, Herbert I., and Bessey, Ernest A., Progress of Plant Breeding in the United States, Yearbook of Agriculture, 1899.

Wilcox, Walter W., A Mistake in Problem Formulation and Its Impact on Farm Policy, Journal of Farm Economics, May, 1959.

Wilcox, Walter W., and Cochrane, Willard W., Economics of American Agriculture, Chapter 23, Prentice-Hall, Inc., Englewood Cliffs, 1951.

Witt, Lawrence W., Welfare Implications of Efficiency and Technological Improvements in Marketing Research and Extension, Journal of Farm Economics, Vol. XXXVII, No. 5, pp. 912-923, December, 1955.

Woods, A. T., Wheat Output Grows Through Survival of the Fittest Strain, Yearbook of Agriculture, United States Department of Agriculture, 1927.

APPENDIX A

Computation of the Rate of Substitution of Tractors for Horses

Table 26. The relationship between number of tractors on farms and number of horses on farms for a specialized wheat region of the hard red winter wheat area, 1924 to 1954.

Year	Number of horses X	Number of tractors Y	Log X	Log Y	Log X Log Y	Log X^2	Estimated $\hat{Y}$
1924	248,809	8,762	5.39586	3.94260	21.2737	29.1153	12,310
1929	156,017	19,183	5.19318	4.28291	22.2419	26.9691	15,340
1934	125,691	19,389	5.09930	4.28751	21.8633	26.0028	17,170
1939	65,511	24,652	4.81631	4.39185	21.1525	23.1968	24,110
1944	59,121	28,587	4.77173	4.45616	21.2635	22.7694	25,440
1949	31,471	35,890	4.49791	4.55618	20.4932	20.2311	35,330
1954	17,737	41,488	4.24885	4.61792	19.6208	18.0527	47,640
Sums			34.02314	30.53513	147.9091	166.3374	

$$Y = aX^b$$
$$\text{Log } \hat{Y} = \text{Log } a + b \text{ Log } X$$

$$Na + b\Sigma(X) - \Sigma(Y) = 0$$
$$a\Sigma X + b\Sigma(X^2) - \Sigma XY = 0$$

$$7a + 34.02314b - 30.53513 = 0$$
$$34.02314a + 166.337453b - 147.909181 = 0$$

$$.205742a + b - .897481 = 0$$
$$\underline{.204542a + b - .889211 = 0}$$
$$.001200a - .008270 = 0$$
$$.0012a = .00827$$
$$\text{Log } a = 6.89166$$

$$a + 4.860448b - 4.362161 = 0$$
$$\underline{a + 4.888950b - 4.347311 = 0}$$
$$-.028502b - .014850 = 0$$
$$-.028502b = .014850$$
$$b = -.521016$$

Table 27. Calculation of the correlation coefficient for the relationship between tractors and horses for a specialized hard red winter wheat area, 1924 to 1954.

	Calculation of $\sigma^2 Y$			Calculation of $S^2 Y$		
Year	Tractors Y	Deviation from mean $Y-\bar{Y} = y$	Deviation from mean^2 y^2	Estimated tractors $\hat{Y}$	$Y-Y = \hat{y}$	$\hat{y}^2$
1924	8,762	-16,660	277,555,600	12,310	-3,548	12,588,304
1929	19,183	- 6,239	38,925,121	15,340	3,843	14,768,649
1934	19,389	- 6,033	36,397,089	17,170	2,219	4,903,961
1939	24,652	- 770	592,900	24,110	542	293,764
1944	28,587	3,165	10,017,225	25,440	3,147	9,903,609
1949	35,890	10,468	109,579,024	35,330	560	313,600
1954	41,488	16,066	258,116,356	47,640	-6,152	37,847,104
Sums	177,951	0	731,183,315			80,638,991
Mean	25,422					

$$\sigma^2 Y = \frac{y^2}{N} \qquad S^2 Y = \frac{(\hat{y})^2}{N}$$

$$\sigma^2 Y = \frac{731,183,315}{7} \qquad S^2 Y = \frac{80,638,991}{7}$$

$$\sigma^2 Y = 104,311,902 \qquad S^2 Y = 11,519,856$$

$$r = \sqrt{1 - \frac{S^2 Y}{\sigma^2 Y}}$$

$$r = \sqrt{1 - \frac{11,519,856}{104,311,302}}$$

$$r = \sqrt{1 - .110436}$$

$$r = \sqrt{.889564}$$

$$r = .943167$$

Table 28. The relationship between number of tractors on farms and number of horses on farms for a specialized wheat region of the hard red spring wheat area, 1924 to 1959.

Year	Number of horses X	Number of tractors Y	Log X	Log Y	Log X Log Y	Log X^2	Estimated $\hat{Y}$
1924	503,292	11,799	5.70182	4.06151	23.1580	32.5017	25,440
1929	435,215	27,060	5.63870	4.43233	24.9925	31.7949	27,370
1934	342,815	n.a.					30,880
1939	247,239	33,092	5.39294	4.51971	24.3745	29.0838	36,420
1944	210,409	48,068	5.32286	4.68185	24.9208	28.3328	39,550
1949	112,032	67,164	5.04932	4.82714	24.3737	25.4956	54,280
1954	65,690	78,413	4.81750	4.89439	23.5787	23.5787	71,050
Sums			31.92314	27.41693	145.3984	170.7876	

$$Y = aX^b$$
$$\text{Log } \hat{Y} = \text{Log a} + \text{b Log X}$$

$$Na + b\Sigma(X) - \Sigma(Y) = 0$$
$$a\Sigma X + b\Sigma(X^2) - \Sigma XY = 0$$

$$6a + 31.92314b - 27.41693 = 0$$
$$31.92314a + 170.78768b - 145.39842 = 0$$

$$.18795a + b - .85884 = 0$$
$$\underline{.18692a + b - .85134 = 0}$$
$$.00103a - .00750 = 0$$
$$.00103a = .00750$$
$$a = 7.28155$$

$$a + 5.32052b - 4.56949 = 0$$
$$\underline{a + 5.34996b - 4.55464 = 0}$$
$$-.02944b - .01485 = 0$$
$$-.02944b = .01485$$
$$b = -.50441$$

Table 29. Calculation of the correlation coefficient for the relationship between tractors and horses for a specialized hard red spring wheat area, 1924 to 1954.

Year	Calculation of $\sigma^2 Y$			Calculation of $S^2 Y$		
	Tractors Y	Deviation from mean $Y-\bar{Y} = y$	Deviation from mean^2 y^2	Estimated tractors $\hat{Y}$	$Y-\hat{Y} = \hat{y}$	$\hat{y}^2$
1924	11,799	32,467	1,054,106,089	25,440	13,641	186,076,881
1929	27,060	17,206	296,046,436	27,370	310	96,100
1934	N.A.			30,880		
1939	33,092	11,174	124,255,607	36,420	3,328	11,075,584
1944	48,068	3,802	14,455,204	39,550	8,518	72,556,324
1949	67,164	22,898	524,318,404	54,280	12,884	165,997,456
1954	78,415	34,147	1,166,017,609	71,050	7,363	54,213,769
Sums	265,596		3,179,199,351			490,016,123
Mean	44,266					

$$\sigma^2 Y = \frac{y^2}{N} \qquad S^2 Y = \frac{(\hat{y})^2}{N}$$

$$\sigma^2 Y = \frac{3{,}179{,}199{,}351}{6} \qquad S^2 Y = \frac{490{,}016{,}123}{6}$$

$$\sigma^2 Y = 529{,}866{,}558 \qquad S^2 Y = 81{,}669{,}354$$

$$r = \sqrt{1 - \frac{S^2 Y}{\sigma^2 Y}}$$

$$r = \sqrt{1 - \frac{81{,}669{,}354}{529{,}866{,}558}}$$

$$r = \sqrt{1 - .154132}$$

$$r = \sqrt{.845868}$$

$$r = .91651$$

Table 30. The relationship between number of tractors on farms and number of horses on farms for a specialized wheat region of the white wheat area, 1924 to 1954.

Year	Number of horses X	Number of tractors Y	Log X	Log Y	Log X Log Y	Log X^2	Estimated $\hat{Y}$
1924	102,728	1,017	5.00170	3.00732	15.0417	25.0170	1,433
1929	73,099	2,030	4.86391	3.30750	16.0873	23.6576	2,003
1934	62,817	n.a.					2,351
1939	35,527	4,161	4.55056	3.61920	16.4693	20.7076	4,290
1944	28,607	5,637	4.45648	3.77105	16.8056	19.8602	5,390
1949	14,584	9,075	4.16388	3.95785	16.4800	17.3379	11,080
1954	10,277	12,653	4.01186	4.10875	16.4837	16.0950	15,990
Sums			27.04839	21.77167	97.3678	122.6753	

$Y = aX^b$

$\text{Log } \hat{Y} = \text{Log } a + b \text{ Log } X$

$Na + b\Sigma(X) - \Sigma(Y) = 0$

$a\Sigma X + b\Sigma(X^2) - \Sigma XY = 0$

$6a + 27.048396 - 21.77167 = 0$

$27.04839a + 122.675356 - 97.36783 = 0$

$.22182 + b - .80492 = 0$

$\underline{.22049 + b - .79370 = 0}$

$.00133a = .01122$

$a = 8.43609$

$a + 4.50807b - 3.62861 = 0$

$\underline{a + 4.53540b - 3.59976 = 0}$

$- .02733b - .02885 = 0$

$- .02733b = .02885$

$b = -1.05561$

Table 31. Calculation of the correlation coefficient for the relationship between tractors and horses for a specialized white wheat area, 1924 to 1954.

	Calculation of $\sigma^2 Y$			Calculation of $S^2 Y$		
Year	Tractors Y	Deviation from mean $Y-\overline{Y}=y$	Deviation from mean^2 y^2	Estimated tractors $\hat{Y}$	$Y-Y=\hat{y}$	$\hat{y}^2$
1924	1,017	-4,745	22,515,025	1,433	416	173,056
1929	2,030	-3,732	13,927,824	2,003	27	729
1934	N.A.			2,351		
1939	4,161	-1,601	2,563,201	4,290	129	16,641
1944	5,637	- 125	15,625	5,390	247	61,009
1949	9,075	3,313	10,975,969	11,080	2,005	4,020,569
1954	12,655	6,891	47,485,881	15,990	3,337	11,135,569
Sums	34,573	0	97,483,525			15,407,029
Mean	5,762					

$$\sigma^2 Y = \frac{y^2}{N} \qquad S^2 Y = \frac{(\hat{y})^2}{N}$$

$$\sigma^2 Y = \frac{97,483,525}{6} \qquad S^2 Y = \frac{15,407,029}{6}$$

$$\sigma^2 Y = 16,247,254 \qquad S^2 Y = 2,567,838$$

$$r = \sqrt{1 - \frac{S^2 Y}{\sigma^2 Y}}$$

$$r = \sqrt{1 - \frac{2,567,838}{16,247,254}}$$

$$r = \sqrt{1 - .1580475}$$

$$r = \sqrt{.8419525}$$

$$r = .91652$$

Table 32. The relationship between number of tractors on farms and number of horses on farms for a general farming region with a wheat specialty of the soft red wheat area, 1924 to 1954.

Year	Number of horses X	Number of tractors Y	XY	X^2	Estimated $\hat{Y}$
1924	225,085	7,948	1,788,975,580	50,663,257,225	2,326
1929	173,269	15,931	2,760,348,439	30,022,146,361	21,322
1934		n.a.			24,765
1939	146,357	31,729	4,643,761,253	21,420,371,449	31,188
1944	102,723	43,066	4,423,868,718	10,552,014,729	47,184
1949	54,494	63,481	3,459,333,614	2,969,596,036	64,865
1954	23,262	81,160	1,887,943,920	541,120,644	76,315
Sums	725,190	243,315	18,964,231,524	116,141,506,444	

$$Y = a + bX$$
$$Na + b\Sigma(X) - \Sigma(Y) = 0$$
$$a\Sigma X + b\Sigma(X^2) - \Sigma(XY) = 0$$

$$6a + 725{,}190b - 243{,}315 = 0$$
$$725{,}190a + 116{,}141{,}506{,}444b - 18{,}964{,}231{,}524 = 0$$

$$.00000827a + b - .33552 = 0$$
$$\underline{.00000624a + b - .16329 = 0}$$
$$.00000203a = + .17223$$
$$a = 84{,}842.3645$$

$$a + 120{,}865b - 40{,}552.50 = 0$$
$$\underline{a + 160{,}151b - 26{,}150.3468 = 0}$$
$$-39{,}286b = 14{,}402.1532$$
$$b = -.36660$$

Table 33. Calculation of the correlation coefficient for the relationship between tractors and horses for a specialized soft red wheat area, 1924 to 1954.

	Calculation of $\sigma^2 Y$			Calculation of $S^2 Y$		
Year	Tractors Y	Deviation from mean $Y-\bar{Y}=y$	Deviation from mean² y^2	Estimated tractors $\hat{Y}$	$Y-\hat{Y}=\hat{y}$	$\hat{y}^2$
1924	7,948	-32,604	1,063,020,816	2,326	5,622	31,606,884
1929	15,931	-24,622	606,242,884	21,332	-5,391	29,062,881
1934	N.A.			24,765		
1939	31,729	- 8,824	77,862,976	31,188	541	292,681
1944	43,066	2,514	6,320,196	47,184	-4,118	16,957,924
1949	63,481	22,928	525,693,184	64,865	-1,384	1,915,456
1954	81,160	40,608	1,649,009,664	76,315	4,845	23,474,025
Sums	243,315	0	3,928,149,720			103,309,851
Mean	40,552.5					

$$\sigma^2 Y = \frac{y^2}{N} \qquad S^2 Y = \frac{(\hat{y})^2}{N}$$

$$\sigma^2 Y = \frac{3,928,149,720}{6} \qquad S^2 Y = \frac{103,309,851}{6}$$

$$\sigma^2 Y = 654,691,620 \qquad S^2 Y = 17,218,308$$

$$r = \sqrt{1 - \frac{S^2 Y}{\sigma^2 Y}}$$

$$r = \sqrt{1 - \frac{17,218,308}{654,691,620}}$$

$$r = \sqrt{1 - .0262998}$$

$$r = \sqrt{.9737002}$$

$$r = .98676248$$

APPENDIX B

The Annual Services Rendered in the Production of Wheat

Table 34. Annual services rendered by each of the factors of production in the production of wheat in the selected regions of the hard red winter wheat area.

Year	Value of wheat produced[1] $1,000 (1910-14=100)	Land[2]	Capital investment: Equipment[3]	Capital investment: Horses[4]	Capital investment: Total	Current expenditures: Fertilizer	Current expenditures: Petroleum[5]	Current expenditures: Machine hire	Current expenditures: Seed	Current expenditures: Horse-feed	Current expenditures: Total	Labor	Total services rendered
		$1,000 Services rendered in constant dollars (1910-14=100)											
1924	34,927	5,138	1,390	659	2,049	NA	989	NA	7,067	8,610	16,666	13,353	37,206
1929	58,295	8,088	2,286	261	2,547	NA	1,880	NA	11,169	4,591	17,640	14,613	42,888
1934	21,541	4,798	1,530	274	1,804	NA	NA	NA	5,765	3,324	9,089	7,266	22,957
1939	33,697	3,352	692	89	781	NA	1,253	NA	3,570	972	5,795	4,489	14,417
1944	76,301	6,390	2,023	87	2,110	NA	2,474	NA	4,670	1,603	8,747	11,494	28,741
1949	66,102	8,135	2,973	15	2,988	NA	3,049	1,748	5,290	806	10,893	8,636	30,652
1954	68,909	5,686	3,687	10	3,697	507	3,298	1,696	3,352	476	9,329	7,921	26,633

1 Five-year moving average of bushels of wheat produced was used.

2 Annual land use was computed on the basis of annual cost of using land which was considered to be the interest rate on long-term mortgages.

3 Annual equipment use was computed on the basis of annual depreciation, using a straight line method with an estimated life of 10 years. Ten years may be a somewhat low average expectation for the life of equipment, but will have the effect of compensating for repair expenses which were not accounted for elsewhere.

4 Annual horse use was computed on the basis of annual depreciation with an estimated life of 15 years. Source: Vaughan, Henry W., Types and Market Classes of Livestock, Long's College Book Company, Columbus, Ohio, 1948.

5 Petroleum products purchased were estimated for 1924, 1929, 1939, and 1944.

Table 35 Annual services rendered by each of the factors of production in the production of wheat in the selected regions of the hard red spring wheat area.

		$1,000 Services rendered in constant dollars (1910-14=100)											
			Capital investment			Current expenditures							
Year	Value of wheat produced[1] $1,000 (1910-14=100)	Land[2]	Equipment[3]	Horses[4]	Total	Fertilizer	Petroleum[5]	Machine hire	Seed	Horse-feed	Total	Labor	Total services rendered
1924	57,719	7,394	2,330	1,317	3,647		1,168		2,613	14,485	18,266	25,821	55,128
1929	52,899	8,226	2,740	573	3,313		2,017		3,344	8,305	13,666	23,445	48,650
1934	32,573	1,771	2,420	312	2,732		NA		3,163	3,699	6,862	5,684	17,049
1939	45,211	3,048	1,454	489	1,943		2,335		6,905	4,319	13,559	14,074	32,624
1944	79,045	4,618	3,824	350	4,174		4,447		8,871	5,146	18,464	23,752	51,008
1949	81,889	5,662	6,706	66	6,772		7,224	1,994	9,859	3,583	22,660	20,946	56,040
1954	56,029	3,973	5,318	29	5,347	710	4,491	1,141	7,047	1,084	14,473	12,388	36,181

1 Five-year moving average of bushels of wheat produced was used.

2 Annual land use was computed on the basis of annual cost of using land which was considered to be the interest rate on long-term mortgages.

3 Annual equipment use was computed on the basis of annual depreciation, using a straight line method with an estimated life of 10 years. Ten years may be a somewhat low average expectation for the life of equipment, but will have the effect of compensating for repair expenses which were not accounted for elsewhere.

4 Annual horse use was computed on the basis of annual depreciation with an estimated life of 15 years. Source: Vaughan, Henry W., Types and Market Classes of Livestock, Long's College Book Company, Columbus, Ohio, 1948.

5 Petroleum products purchased were estimated for 1924, 1929, 1939, and 1944.

Table 36. Annual services rendered by each of the factors of production in the production of wheat in the selected regions of the white wheat area.

Year	Value of wheat produced[1] $1,000 (1910-14=100)	Land[2]	Capital investment: Equipment[3]	Capital investment: Horses[4]	Capital investment: Total	Current expenditures: Fertilizer	Current expenditures: Petroleum[5]	Current expenditures: Machine hire	Current expenditures: Seed	Current expenditures: Horse-feed	Current expenditures: Total	Labor	Total services rendered
		$1,000 Services rendered in constant dollars (1910-14=100)											
1924	18,159	1,325	439	184	623		95		1,756	3,222	5,073	3,220	10,241
1929	23,402	1,707	718	122	840		270		2,404	2,982	5,656	6,125	14,329
1934	16,644	1,432	620	195	815		NA		2,343	1,768	4,111	5,213	11,571
1939	23,616	1,482	472	58	530		349		1,717	736	2,802	1,780	6,594
1944	38,599	1,809	1,130	52	1,182		809		2,670	1,261	4,740	6,772	14,503
1949	45,166	2,318	2,948	11	2,959		1,617	516	2,919	808	5,860	4,446	15,583
1954	46,793	2,294	3,283	7	3,290	1,356	1,588	506	2,218	357	6,025	4,373	15,982

1 Five-year moving average of bushels of wheat produced was used.

2 Annual land use was computed on the basis of annual cost of using land which was considered to be the interest rate on long-term mortgages.

3 Annual equipment use was computed on the basis of annual depreciation, using a straight line method with an estimated life of 10 years. Ten years may be a somewhat low average expectation for the life of equipment, but will have the effect of compensating for repair expenses which were not accounted for elsewhere.

4 Annual horse use was computed on the basis of annual depreciation with an estimated life of 15 years. Source: Vaughan, Henry W., Types and Market Classes of Livestock, Long's College Book Company, Columbus, Ohio, 1948.

5 Petroleum products purchased were estimated for 1924, 1929, 1939, and 1944.

Table 37. Annual services rendered by each of the factors of production in the production of wheat in the selected regions of the soft red wheat area.

Year	Value of wheat produced[1] $1,000 (1910-14=100)	$1,000 Services rendered in constant dollars (1910-14=100)											Total services rendered
			Capital investment			Current expenditures							
		Land[2]	Equipment[3]	Horses[4]	Total	Fertilizer	Petroleum[5]	Machine hire	Seed	Horse-feed	Total	Labor	
1924	12,359	1,540	449	142	591		106		1,533	2,297	3,936	7,825	13,892
1929	13,830	1,604	326	50	376		138		2,176	986	3,300	5,732	11,012
1934	9,933	1,751	350	154	404		NA		1,919	1,701	3,620	8,468	14,243
1939	15,022	1,544	347	63	410		277		1,174	784	2,235	4,424	8,613
1944	14,166	1,563	631	33	664		432		1,286	807	2,525	5,218	9,970
1949	18,607	1,762	1,064	7	1,071		752	393	1,516	412	3,073	5,161	11,067
1954	19,295	1,561	1,260	3	1,263	2,373	816	364	1,095	163	4,811	4,420	12,055

[1] Five-year moving average of bushels of wheat produced was used.

[2] Annual land use was computed on the basis of annual cost of using land which was considered to be the interest rate on long-term mortgages.

[3] Annual equipment use was computed on the basis of annual depreciation, using a straight line method with an estimated life of 10 years. Ten years may be a somewhat low average expectation for the life of equipment, but will have the effect of compensating for repair expenses which were not accounted for elsewhere.

[4] Annual horse use was computed on the basis of annual depreciation with an estimated life of 15 years. Source: Vaughan, Henry W., Types and Market Classes of Livestock, Long's College Book Company, Columbus, Ohio, 1948.

[5] Petroleum products purchased were estimated for 1924, 1929, 1939, and 1944.

APPENDIX C

Input-Output Ratios

Table 38. Changes in productivity of the resources used in the production of wheat in the selected regions of the four principal wheat producing areas of the United States, 1924 to 1954.[1]

Year	Hard red winter: Ratio	Hard red winter: Index 1924=100	Hard red spring: Ratio	Hard red spring: Index 1924=100	White: Ratio	White: Index 1924=100	Soft red: Ratio	Soft red: Index 1924=100
	Total output/total input							
1924	.939	100	1.047	100	1.773	100	.890	100
1929	1.359	145	1.087	104	1.633	92	1.256	142
1934	.938	100	1.910	182	1.438	81	.697	79
1939	2.337	238	1.386	132	3.581	202	1.744	195
1944	2.655	283	1.550	148	2.661	150	1.421	160
1949	2.157	250	1.461	139	2.898	164	1.681	189
1954	2.587	274	1.549	148	2.928	166	1.601	180
	Total output/land input							
1924	6.80	100	7.81	100	13.70	100	8.02	100
1929	7.21	106	6.43	82	13.71	100	8.62	107
1934	4.49	66	18.39	235	11.48	84	5.67	71
1939	10.05	154	14.83	190	15.94	116	9.73	121
1944	11.94	176	17.12	219	20.23	148	9.06	113
1949	8.13	119	14.46	185	19.48	142	10.56	132
1954	12.12	178	14.10	181	20.40	149	12.36	154

Table 38 (concl.).

Year	Hard red winter: Ratio	Hard red winter: Index 1924=100	Hard red spring: Ratio	Hard red spring: Index 1924=100	White: Ratio	White: Index 1924=100	Soft red: Ratio	Soft red: Index 1924=100
	Total output/labor input							
1924	2.62	100	2.24	100	5.64	100	1.58	100
1929	3.99	152	2.26	101	3.82	68	2.41	89
1934	2.37	90	4.75	212	3.19	57	1.17	94
1939	7.51	287	3.21	143	13.27	235	3.40	215
1944	6.64	253	3.33	149	5.70	101	2.71	172
1949	7.65	292	3.91	175	10.16	180	3.61	228
1954	8.70	332	4.52	202	10.70	190	4.37	277
	Total output/capital input							
1924	1.87	100	2.63	100	3.19	100	2.73	100
1929	2.89	155	3.12	119	3.60	113	3.76	138
1934	1.98	106	3.40	129	3.38	106	2.47	90
1939	5.12	274	2.92	111	7.09	222	5.68	208
1944	7.03	376	3.49	133	6.52	204	4.44	163
1949	4.76	256	2.78	106	5.12	161	4.49	164
1954	5.29	283	2.83	108	5.02	157	3.18	116

[1] Computed from the data in Table 34. The ratio represents the return for each one dollar spent on the aggregate or particular input for the production of wheat.

Table 39. Changes in the productivity of the land resources used annually in the production of wheat in the selected regions of the four principal wheat producing areas of the United States, 1924 to 1954.

Year	Bushels per acre				Value of wheat per acre land (1910-14 dollar = 100)				Land cost to produce one bushel (1910-14 dollar = 100)			
	Hard red winter	Hard red spring	White	Soft red	Hard red winter	Hard red spring	White	Soft red	Hard red winter	Hard red spring	White	Soft red
1924	10.5	10.6	15.1	19.3	9.22	9.31	13.70	19.34	.13	.11	.07	.12
1929	13.5	8.7	14.6	16.9	11.38	6.94	13.38	20.99	.12	.12	.07	.14
1934	7.8	20.8	14.5	15.0	6.74	19.80	11.09	13.95	.19	.05	.07	.16
1939	15.4	11.0	19.0	21.6	12.83	9.34	15.85	26.03	.08	.06	.05	.12
1944	20.3	13.2	24.7	19.4	17.80	11.27	20.65	23.41	.07	.05	.04	.13
1949	15.9	11.6	24.9	22.8	13.67	10.56	22.58	26.25	.11	.06	.05	.11
1954	21.8	10.9	33.4	32.9	19.40	10.06	28.92	33.45	.07	.07	.04	.08

Table 40. Changes in the productivity of the labor resources used in the production of wheat in the selected regions of the four principal wheat producing areas of the United States, 1924 to 1954.

Year	Bushels output per man unit				Acres harvested per man unit				Investment per man unit (1910-14 dollar = 100)			
	Hard red winter	Hard red spring	White	Soft red	Hard red winter	Hard red spring	White	Soft red	Hard red winter	Hard red spring	White	Soft red
1924	1,114	952	2,331	588	106	89	154	30	3,996	3,018	4,518	1,969
1929	2,003	1,193	2,214	819	148	137	152	49	5,955	3,856	4,228	2,899
1934	1,411	2,490	2,740	536	181	119	188	36	7,060	5,015	5,259	2,227
1939	3,057	1,288	4,801	1,040	199	117	253	48	6,146	2,330	6,460	3,127
1944	3,790	1,955	4,743	904	187	148	191	46	6,890	3,255	5,434	3,130
1949	4,152	2,003	4,658	1,288	262	173	187	57	11,013	4,551	7,945	3,912
1954	4,600	2,307	7,783	1,870	211	212	233	57	9,509	5,604	12,209	4,795

Year	Labor cost to produce one bushel (1910-14 dollar = 100)				Labor cost to produce one acre (1910-14 dollar = 100)				Gross return per man unit (1910-14 dollar = 100)			
1924	.33	.39	.16	.63	3.52	4.16	2.43	12.25	974	833	2,119	588
1929	.21	.35	.24	.52	2.85	3.08	3.50	8.70	1,683	953	2,027	1,018
1934	.29	.17	.24	.79	2.27	3.46	3.47	11.89	1,221	2,362	2,089	498
1939	.11	.26	.06	.35	1.71	2.91	1.19	7.67	2,554	1,093	4,011	1,251
1944	.13	.26	.15	.45	2.68	3.38	3.62	7.96	3,325	1,667	3,958	1,093
1949	.11	.23	.09	.32	1.79	2.70	2.22	6.37	3,578	1,828	4,229	1,484
1954	.10	.20	.08	.23	2.23	2.22	2.70	7.66	4,093	2,128	6,735	1,900

Table 41. Changes in the productivity of the capital resources used annually in the production of wheat in the selected regions of the four principal wheat producing areas of the United States, 1924 to 1954.

Year	Capital service to produce one bushel (1910-14 dollar = 100)				Capital service to produce one acre (1910-14 dollar = 100)			
	Hard red winter	Hard red spring	White	Soft red	Hard red winter	Hard red spring	White	Soft red
1924	.05	.06	.03	.05	.54	.59	.47	.92
1929	.04	.05	.03	.03	.50	.43	.48	.57
1934	.07	.08	.04	.04	.56	1.66	.54	.57
1939	.02	.04	.02	.03	.30	.40	.36	.71
1944	.02	.05	.03	.06	.49	.60	.63	1.10
1949	.04	.08	.06	.06	.62	.87	1.48	1.51
1954	.05	.09	.06	.07	1.04	.96	2.03	2.19

APPENDIX D

Cost of Production

Table 42. The distribution of total costs incurred in producing wheat in the selected regions of the four principal wheat producing areas of the United States, 1924 to 1954.[1]

	Percent of total annual cost[2]															
	Land				Labor				Investment				Current expense			
Year	Hard red winter	Hard red spring	White	Soft red	Hard red winter	Hard red spring	White	Soft red	Hard red winter	Hard red spring	White	Soft red	Hard red winter	Hard red spring	White	Soft red
1924	13.8	13.4	12.9	11.1	35.9	46.8	31.4	56.3	5.5	6.6	6.1	4.3	44.8	33.1	49.5	28.3
1929	18.9	16.9	11.9	14.6	34.1	48.2	42.7	52.1	5.9	6.8	5.9	3.4	41.1	28.1	39.5	30.0
1934	20.9	10.4	12.4	12.3	31.6	33.3	45.1	59.5	7.9	16.0	7.0	2.8	39.6	40.2	35.5	25.4
1939	23.2	9.3	22.5	17.9	31.1	43.1	27.0	51.4	5.4	6.0	8.0	4.8	40.2	41.6	42.5	25.9
1944	22.2	9.1	12.5	15.7	40.0	46.6	46.7	52.3	7.3	8.2	8.2	6.7	30.4	36.2	32.7	25.3
1949	26.5	10.1	14.9	15.9	28.2	37.4	28.5	46.6	9.7	12.1	19.0	9.7	35.5	40.4	37.6	27.8
1954	21.3	11.0	14.4	12.9	29.7	34.2	27.4	36.7	13.9	14.8	20.6	10.5	35.0	40.0	37.7	39.9

1 Calculated, based upon data in Tables 34, 35, 36, and 37.

2 1910-14 dollars = 100.

Table 43. The cost to produce one bushel of wheat in each of the selected regions of the four principal wheat producing areas of the United States, 1924 to 1954.[1]

Year	Cost per busnel (1910-14 dollars = 100) Hard red winter	Hard red spring	White	Soft red
1924	.931	.835	.513	1.124
1929	.618	.734	.561	.992
1934	.923	.496	.530	1.330
1939	.357	.612	.233	.689
1944	.330	.550	.313	.851
1949	.400	.624	.313	.685
1954	.344	.596	.296	.635

[1] Calculated, based upon the data in Tables 34, 35, 36, and 37.

Table 44. The cost to produce one acre of wheat in each of the selected regions of the four principal wheat producing areas of the United States, 1924 to 1954.[1]

Year	Cost per acre (1910-14 dollars = 100) Hard red winter	Hard red spring	White	Soft red
1924	9.82	8.89	7.72	21.74
1929	8.37	6.39	8.19	16.71
1934	7.18	10.36	7.71	20.00
1939	5.49	6.74	4.43	14.93
1944	6.70	7.27	7.76	16.48
1949	6.34	7.22	7.79	15.61
1954	7.50	6.50	9.88	20.89

[1] Calculated, based upon data in Tables 34, 35, 36, and 37.