SOURCES OF PRODUCTIVITY CHANGE IN UNITED STATES AGRICULTURE

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PREFACE

The purpose of this study was to develop and utilize an econometric model to explain productivity growth in the United States agricultural sector over the 1939 to 1972 period. In addition, an attempt was made to explain the observed differential rates of productivity growth among ten farm production regions of the United States. Particular emphasis was placed on examining the role of the public sector in stimulating productivity change in agriculture and evaluating the form of the time lag between public investment in agricultural research and extension activities and the ensuing contribution to agricultural production.

The author wishes to express his appreciation to his major adviser, Dr. Gerald M. Lage, for his guidance and assistance throughout this study. A special debt of gratitude is owed Dr. Yao-chi Lu, for without his support the study would have suffered greatly. Appreciation is also expressed to the other committee members, Dr. Joseph M. Jadlow, Jr. and Dr. Ansel M. Sharp, for their valuable assistance in the preparation of the final manuscript. Also, my thanks go to Dr. Leroy Quance of the National Economic Analysis Division, Economic Research Service, United States Department of Agriculture for his assistance in assembling data used in this study.

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My special appreciation is extended to my parents and those of my wife for their encouragement. Finally, to my wife, Julie, our son, Benjamin, and our daughter, Susan, let's go fishing!

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CHAPTER I

INTRODUCTION

The Role of Technological Change

Prior to 1960, the economics of technological change - its sources, diffusion, and application - occupied a relatively small corner of the main body of economic thought. Since that time, however, the proliferation of literature on this subject has occurred at a rather fantastic rate.

Why the sudden interest? There is probably no single answer to this question. Possible candidates run the gamut from a relatively uncrowded outlet for publications to a genuine recognition of the crucial role technological change plays in economic growth and development, competition, factor markets, and nearly every other aspect of economics.

As an explanation for the growing interest in this topic as it relates to the agricultural sector of the economy, one can point to three recent developments. The first is the fact that at the present time nearly half a billion people are suffering from some sort of hunger. Some 10,000 of them die each week in Latin America, Asia, and Africa (94, p. 66). The major causes of this crisis are well-known and need not be discussed here. What is important for the present discussion is that the export of agricultural technology by the U. S. and other developed countries to the developing nations is being tauted as a primary long-run solution to the problem. It is natural that this has resulted in an increasing awareness of and interest in the nature of specific agricultural technologies: their potential rates of adoption by the developing countries, the means by which they can best be diffused, and their ultimate contributions to the supply of food.

The second explanation concerns the behavior of agricultural productivity in the last decade. The performance of the aggregate productivity index for the U. S. agricultural sector - a measure of total agricultural output per unit of all inputs used in production or charged to the farming industry - was not nearly as satisfying during the decade of the 1960's as in the two previous decades (see Figure 1). In 1940-50, this measure of efficiency rose 18 percent; in 1950-60 the productivity index rose 26 percent; however, in 1960-70, the increase was only 3 percent (16, p. 4).

The erosion of the rate of increase in productivity is in part due to structural changes in the agricultural sector which have occurred since 1960. In the period 1940-1973, the number of farms decreased about 54 percent from 6,096,799 to 2,831,290. Meanwhile, the average size of a farm increased 121 percent from 174 acres to 385 acres (67, 68).

This process of growth in the size of individual farms apparently moved the agricultural sector nearer to the minimum point on its long-run average cost curve. As the optimum scale of plant was approached, the marginal gains in efficiency from capturing additional economies of size became less. The result was a dampening of the rate of growth of output per unit of aggregate input, i.e., productivity in agriculture. In order to enhance productivity growth in the future, favorable shifts of the long-run average cost curve through technical change must

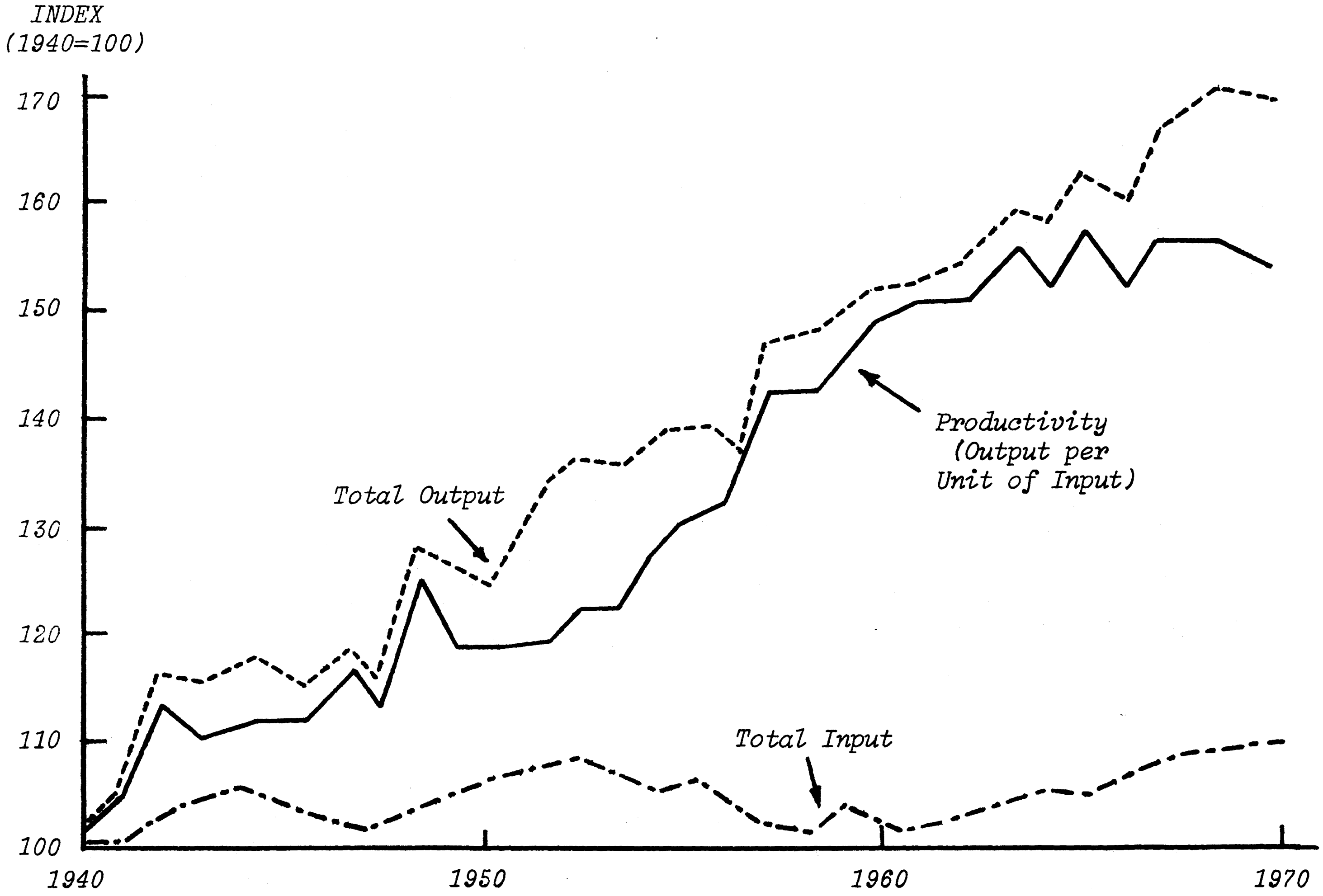

Figure 1. Productivity: The 30-Year Record

continue to occur.

The final explanation for the growing interest in the economics of technological change in agriculture is a result of the recent upsurge in public and private concern for assessing the costs as well as the benefits of existing and emerging technologies. For example, the productivity gains brought about by increased utilization of certain pesticides and herbicides were not an unmixed blessing. The energy inputs required to produce these chemicals and their attendant environmental hazards have led to stepped-up research efforts in the areas of breeding of insect-resistant plants and pheromones. Experiences such as this led in 1973 to the preparation of a report for the National Science Foundation (6) which presented the results of a poll intended to derive a list of technologies which, in the judgment of respondents from the academic community, industry, and all levels of government, had impacts so uncertain or large that they were prime candidates for technology assessments. From 278 given technologies, the respondents were asked to select the 30 "most important." Among these top 30, technologies relating to food production accounted for 30 percent.

Objectives

The three concerns described in the above section suggest three broad areas of inquiry. The present study focuses on the second of these concerns; the behavior of agricultural productivity over time. In general terms, this study is designed to identify and analytically examine sources of productivity change in the U. S. agricultural sector for the period 1939-1972. The specific objectives are to:

1. Develop a theoretical framework in which the contributions

to agricultural production of identified sources of productivity change can be conceptualized and confront this framework with data;

2. Examine the role of the public sector in stimulating technical change in agriculture, with particular emphasis on evaluating the form of the time lag between public investment in research and extension activities and the ensuing contribution to agricultural production;

3. Examine the regional impact of public sector research and extension expenditures with an eye toward explaining the differential rates of return to these public sector investments, the differential levels of productivity, and the differential time forms of the research and extension-output relationships between the ten farm production regions of the U. S. defined by the U. S. Department of Agriculture (USDA);

4. Evaluate the rate of return to public sector agricultural research and extension expenditures;

5. Formulate, based upon empirical results of this study, public policy implications regarding investments in agricultural research and extension.

It is hoped that by better understanding the historical sources of productivity change, some insight into methods to control its behavior in the future may be gained.

Definitions and Limitations

As pointed out above, the economics of technological change is a relatively new area of interest. One consequence of this is that there still remains considerable misuse of several quite similar, but theoretically distinct terms. To minimize confusion, these terms as they are used in the present study are discussed below.

Productivity is a measure of the efficiency with which resources are transformed into goods and services that satisfy human wants (36, p. 3). The ratio of output to all inputs combined is called "total factor productivity."[1] An increase in this ratio, i.e., positive productivity change, implies that more output can be produced with the same quantity of inputs. To facilitate comparison over time, these total factor productivity ratios are normally converted to a productivity index which expresses the value of the current ratio as a percent of the base year ratio.

Conceptually it is convenient to categorize the sources of productivity changes in the U. S. agricultural sector into two major groups: sources whose impacts on productivity are made by increasing the stock of knowledge regarding the industrial arts, and sources whose impacts on productivity are made by altering the physical and/or economic environment in which production takes place.

The type of productivity change brought about by sources in the former group is called "technical change." Technical change measures the increase in output which has occurred as a result of some of the potential users adopting a new technology (2, p. 2). Technical change consists of two acts: the discovery of new technology and the diffusion of that information to potential users. Since the public only benefits from those improved techniques which are adopted by the agricultural industry, these two acts are complementary in the function explaining productivity.

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[1] Unlike quantities of inputs--hours of work, acres of land, etc.--are combined into a single aggregate input by using their monetary values.

The type of productivity change brought about by sources in the latter group is distinct from technical change in that these sources do not emit new knowledge of the industrial arts. Instead, they cause the aggregate agricultural production function to shift by altering the state of one or more of the variables which are assumed constant in estimating the production function. Examples of these *ceteris paribus* variables include the weather, the level of demand for farm output, and agricultural price support programs.

While this categorization of the sources of productivity change is handy from a conceptual standpoint, it is quite awkward to maintain this distinction in an empirical study. To date, economists have been unable to isolate the effects of pure technical change except when dealing with individual processes (43, p. 31). Therefore, this aggregate study is concerned with analyzing all shifts in the production function, whether they are caused by technical change or by changes in any of the *ceteris paribus* variables.

The second major limitation of this study is that reliable data on production-oriented private sector expenditures on research and extension are not available. As a result of their omission, the estimated contribution of corresponding public sector activities will be biased. Steps to alleviate this bias problem will be taken.

Organization of the Study

In Chapter II the methodologies and conclusions of previous efforts to determine the contribution of public sector research and extension activities to agricultural productivity are discussed and critically evaluated. Having gleaned as much as possible from these earlier works, a theoretical framework is developed in Chapter III to guide the empirical measurement of the contributions of identified sources of productivity change, particularly research and extension activities. In Chapter IV, the empirical model and the techniques to be used are presented. The following two chapters, Chapters V and VI, consist of the empirical results and implications for the U. S. and the ten farm production regions respectively. In Chapter VII, conclusions are drawn.

CHAPTER II

MODELS OF PRODUCTIVITY CHANGE IN AGRICULTURE

A Conceptual Framework

In order to adequately appraise previous theoretical and empirical contributions to the area of productivity change in agriculture, it is first desirable to develop a clear concept of the process in question. Such is the intent of this section.

To expedite the discussion, assume that production in the agricultural sector of the U. S. can be described by a Cobb-Douglas function where productivity change is time related. Then an aggregate production function for agriculture may be written as

$$V_t = A_t L_t^{\alpha} K_t^{\beta} \qquad (2.1)$$

where:

V_t is agricultural output in time t,

L_t is aggregate labor in agriculture in time t,

K_t is aggregate capital in agriculture in time t,

A_t measures the cumulative effect of productivity over time.

The log linear form of equation (2.1) is

$$\ln V_t = \ln A_t + \alpha \ln L_t + \beta \ln K_t. \qquad (2.2)$$

Equation (2.2) can be expressed in terms of rates of change by differentiating with respect to time. This manipulation yields

$$\frac{\frac{dV_t}{dt}}{V_t} = \alpha \frac{\frac{dL_t}{dt}}{L_t} + \beta \frac{\frac{dK_t}{dt}}{K_t} + \frac{\frac{dA_t}{dt}}{A_t} \qquad (2.3)$$

or, using the standard convention of placing a dot over a variable to represent the derivative of that variable with respect to time, Equation (2.3) becomes

$$\frac{\dot{V}_t}{V_t} = \alpha \frac{\dot{L}_t}{L_t} + \beta \frac{\dot{K}_t}{K_t} + \frac{\dot{A}_t}{A_t} . \qquad (2.4)$$

Rearranging terms, it becomes clear that the rate of productivity change can be viewed as a residual:

$$\frac{\dot{A}_t}{A_t} = \frac{\dot{V}_t}{V_t} - \left[\alpha \frac{\dot{L}_t}{L_t} + \beta \frac{\dot{K}_t}{K_t}\right] . \qquad (2.5)$$

Equation (2.5) can be interpreted as meaning that the rate of productivity change in agriculture, $\dot{A}_t/A_t$, is equal to the difference between the rate of growth of agricultural output and the weighted sum of the rates of growth of agricultural inputs, where the weights represent the partial production elasticity of each input. In other words, $\dot{A}_t/A_t$ is a "shifter" of the production function which resolves the physical relationship between output and inputs at a given point in time. If the physical relationship changes over time, the value of $\dot{A}_t/A_t$ changes to reflect this.

$\dot{A}_t/A_t$ can be more precisely specified as a function of n specific sources of productivity change:

$$\frac{\dot{A}_t}{A_t} = f[x_{1t}, x_{2t}, \ldots, x_{nt}]. \qquad (2.6)$$

It follows that Equation (2.1) can then be rewritten as

$$V_t = L_t^{\alpha} K_t^{\beta} g[x_{1t}, x_{2t}, \ldots, x_{nt}]. \qquad (2.7)$$

The x_i's may therefore be considered to be "nonconventional" inputs in the aggregate agricultural production function. The major thrust of the present effort and the earlier studies discussed in the next section is to identify the x_i's in Equation (2.6) and, where possible, measure their contributions to agricultural output.

Models developed to date which directly or indirectly seek to examine the sources of agricultural productivity have identified the following explanatory variables: research expenditures (2, 17, 22, 23, 47, 53, 65), espenditures on extension of the improved techniques (2, 17, 23, 47, 65), education (17, 23, 24, 65), and weather (17). Edwin Mansfield (44, p. 35), in discussing technological change in general rather than with regard to the agricultural sector, expands this list to also include betterment of worker health and nutrition, economies of scale, changes in product mix, and improved allocation of resources. Still other factors which are likely determinants of agricultural productivity are the expectations of farmers, particularly with regard to output prices, and the various farm programs of the federal government.

This list of nonconventional inputs in the production function describing agriculture is hardly complete, nor is it meant to be. There are benefits and costs associated with the inclusion of any given factor in the list of x_i's which comprises Equation (2.6). Inclusion of a very large number of factors may lead to a more complete specification of the production process over the time period in question, however it may do so with an attendant complexity that is difficult to grasp and may render meaningful conclusions impossible to draw. Therefore, even though studies of productivity change in agriculture do extend the list of variable resources to include certain nonconventional inputs, they do not pretend nor do they desire to perfectly specify the production function. In lieu of this, the investigator includes only those x_i's which can be varied over the time period being considered and which in his judgment are most important in determining output per unit of time.

Taken as a body of literature, previous studies have focused upon the role of research expenditures and the return to agricultural research. There would seem to be two major reasons for this relatively intense interest in the contribution of research: intuitively, technological change in agriculture is closely associated with the amount of research effort (as represented by research expenditures) forthcoming, and the growth record of agricultural research expenditures has been quite imposing (see Table I).

This growth record warrants further comment. Over the 1939-1972 period, total annual public sector expenditures on agricultural research and extension work have grown from some $105 million to $1,235 million, a nominal increase of about 1,100 percent or a real increase of about 245 percent.[1] However, these total expenditure figures are somewhat misleading. Not all public sector research is oriented toward increasing agricultural output per unit of aggregate input at the farm level. As shown in Table I, these "production-oriented" expenditures comprise only a fraction of the total. The residual expenditures are "nonproduction-oriented" and include expenditures on such research activities as enhancement of the efficiency of the marketing system and product utilization research. The same holds true for expenditures on

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[1] Price deflators used in this study are explained in the Appendix.

TABLE I

PRODUCTION-ORIENTED, NONPRODUCTION-ORIENTED, AND TOTAL PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES, 1939-1972 (CURRENT DOLLARS 000)

Year	Production-Oriented Expenditures	Nonproduction-Oriented Expenditures	Total Public Sector Expenditures
1939	64128	41364	105492
1940	65651	43408	109059
1941	62869	42639	105508
1942	64967	46361	111328
1943	66340	40159	106499
1944	68321	41859	110180
1945	76430	43072	119502
1946	91353	45947	137300
1947	113466	72227	185693
1948	120321	90007	210328
1949	137945	68284	206229
1950	157254	121469	278723
1951	162491	84108	246599
1952	173587	88919	262506
1953	179962	98233	278195
1954	190273	100842	291115
1955	201666	104421	306087
1956	223547	137215	360762
1957	249829	145633	395462
1958	281854	184401	466255
1959	296162	188629	484791
1960	312374	190589	502963
1961	333978	203585	537563
1962	361325	206366	567691
1963	380695	227832	608527
1964	413009	245491	658500
1965	456447	254796	711243
1966	497629	248241	745870
1967	520007	267354	787361
1968	565669	283441	849100
1969	597340	299113	896453
1970	644513	354111	998624
1971	710457	371814	1082271
1972	779013	455776	1234789

Source: See the Appendix.

the extension of the research results to farmers. Extension activities of the public sector which are nonproduction-oriented account for a significant portion of total extension expenditures and include activities designed to improve community services and environment, enhance consumer health, nutrition, and well-being, and raise the standard of living in rural areas.

This distinction between production-oriented research and extension activities and nonproduction-oriented activities is a most important one. It is a distinction which will be maintained throughout this study. As conceived of herein, production-oriented research and extension activities include those activities which have as their ultimate aim the improvement of agricultural productivity by enhancing the state of the industrial arts and the application of these arts. Thus, production-oriented activities are conducted in an effort to bring about technical change in agriculture. Nonproduction-oriented activities, on the other hand, are those research and extension activities which seek to improve agricultural productivity by favorably altering the physical and/or economic environment in which agricultural production takes place, as well as to enhance consumer welfare.

Using this conceptual framework, selected previous works are reviewed and evaluated in the next section. This discussion is confined to the more quantitative, analytical approaches rather than the qualitative, public relations approaches. As pointed out above, most of these works focus on the return to agricultural research. Some of the techniques which measure the benefits resulting from research in terms of the value of inputs saved are first examined. A consumer surplus approach which heralds the more recent production function approach is then presented, followed by an evaluation of these recent efforts.

Review of Selected Previous Works[2]

Value of Inputs Saved Approach

Estimating the benefits received from public sector research and extension expenditures is not a simple task. One technique which has emerged is to calculate the value of inputs saved by new and better techniques. Two different approaches which utilize this basic idea have been applied by Schultz (53), and Tweeten and Hines (65).

Schultz determines how many more resources would have been required to produce the 1950 level of agricultural output if 1910 techniques had been employed. As an upper limit, Schultz estimates that expenditures on total inputs of $30,000 million at 1946-1948 prices were 14 percent larger in 1950 than in 1910. The dollar value of output, however, was 75 percent larger in 1950 than in 1910. Output per unit of aggregate input, therefore, was 54 percent larger in 1950. Schultz reasons from this that to produce the 1950 level of output with 1910 techniques would have required $16,200 million ($30,000 million x .54) of additional inputs. Since these additional inputs were saved, $16,200 million represents the benefits in 1950 alone from improved, more efficient production techniques obtained through research and extension activities.

Using this same approach, only valuing inputs at 1910-1914 prices, yields a lower limit in inputs saved in 1950 of $9,600 million. The obvious question is, at what costs were these benefits obtained? In an

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[2] Portions of this section draw substantially upon an article by Willis L. Peterson (48).

effort to present a very conservative estimate of benefits over costs, Schultz assumes that the 1950 level of agricultural research and extension expenditures prevails throughout the 1910-1950 period. This implies that total expenditures over the entire 40 year period were $7,000 million ($175 million x 40), which is substantially less than the lower limit savings in agricultural inputs of $9,600 million in the single year 1950.

Schultz (53) closes his discussion of the contribution of research and extension to agricultural production with some very appropriate warnings. First, he points out the fact that

> . . . while it has been convenient to treat all the expenditures for agricultural research and extension as if they were used wholly to advance agricultural techniques, some activities for other purposes are financed by these expenditures. (p. 121)

As noted in the preceeding section (see Table I), these nonproduction-oriented expenditures represent a significant portion of the total. Failure to distinguish between production-oriented and nonproduction-oriented expenditures tends to bias the return to production-oriented agricultural research and extension.

Schultz's second warning has to do with the lack of reliable information on the research and extension expenditures of firms and individuals in the private sector.

> It would be a mistake to ascribe all the gains from new and better production techniques to the work of the agricultural experiment stations, the agricultural extension services, and to the many agencies of the U. S. Department of Agriculture engaged in research and its dissemination. (53, p. 121)

Neglecting the expenditures of the private sector tends to overstate the return to public sector research and extension. Finally, Schultz acknowledges that this technique ignores the contribution of education over time.

Schultz's technique and warnings can be used to examine the contribution of research and extension to agricultural production over time. In Table II are presented estimates of total resources employed in agriculture in the final year of each of three recent periods, the proportionate increases in productivity over each period, the value of inputs saved in only the final year of the period, and estimated total (public plus private) production-oriented research and extension expenditures for the entire period.

The means by which these final figures were obtained deserves further explanation. Although there is little reliable information on private sector production-oriented research and extension expenditures, a 1966 study by the USDA (82) estimates industrial research and development related to agriculture as being 53.9 percent of total research and development in agriculture in 1965. Thus, in order to approximate total expenditures, it is assumed that public sector and private sector production-oriented research and extension expenditures are equal.

The results obtained from this more recent data are not quite as favorable for agricultural research as those obtained by Schultz for the 1910-1950 period. The research bill from 1950-1959 is $4,234 million whereas the value of inputs saved in 1959 alone is $10,762 million; more than twice the total production-oriented research and extension expenditures for the entire decade. In the decade of the 1960's, however, the research bill is more than twice as great as the value of inputs saved in 1969. Some improvement occurred over the 1970-1972 period, however the research bill still exceeded the value of inputs saved in 1972.

TABLE II

VALUE OF INPUTS EMPLOYED IN AGRICULTURE IN FINAL YEAR OF PERIOD, PROPORTIONATE INCREASE IN PRODUCTIVITY OVER PERIOD, VALUE OF INPUTS SAVED IN FINAL YEAR OF PERIOD, AND TOTAL (PUBLIC PLUS PRIVATE) PRODUCTION-ORIENTED RESEARCH AND EXTENSION EXPENDITURES OVER PERIOD FOR SELECTED YEARS (MILLIONS OF 1957-1959 DOLLARS)

Period	Value of Inputs in Final Year of Period[a]	Proportionate Increase in Productivity Over Period[b]	Value of Saved Inputs in Final Year of Period[c]	Total Research and Extension Expenditures for Period[d]
1950-59	$46,791	0.23	$10,762	$4,234
1960-69	46,632	0.08	3,731	8,876
1970-72	47,053	0.08	3,764	4,268

[a] Source: Unpublished data obtained from USDA sources. These are the same data used by the USDA in computing the productivity index published in Changes in Farm Production and Efficiency (76).

[b] Calculated by subtracting the value of the official USDA productivity index for the beginning year of the period from the value in the final year of the period and dividing by the index value for the beginning year of the period. For example, the 1940-49 figures (see Appendix, Table XVIII) are (73-62)/62 = 0.17

[c] Calculated by multiplying the proportionate increase in productivity by the value of inputs employed in agriculture in the final year of the period.

[d] Source: See Appendix.

These figures should not be construed to mean that agricultural research and extension is no longer a sound investment. If we view these figures in another way, it becomes quite apparent that the return to these investments is still realatively high: the production-oriented research bill from 1970 through 1972 is $4,268 million, while the total value of inputs saved over the entire period is about $7,074 million. The major conclusion to be drawn from Table II is that the return to agricultural research and extension has apparently fallen over the 1950-1972 period. This conclusion is strengthened by the fact that the technique used to construct Table II ignores the contribution to productivity increases of an exponentially rising level of educational attainment among farm workers.

The basic idea underlying the technique utilized by Tweeten and Hines (65) also stems from a notion that increased agricultural productivity has released resources which would otherwise have been engaged in the production of food and fiber. Specifically, Tweeten and Hines suggest that the release of human resources from agricultural production has freed them to take positions in other sectors of the economy where the values of their marginal products are higher. As a result, national income has risen more than it would have had increases in agricultural productivity not occurred.

As an example of the means by which Tweeten and Hines estimate the returns to increased agricultural productivity, consider the 1910 to 1963 period.[3] Per capita income in the farm sector was $1,302 in 1963

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[3] These figures are taken from an article by Willis L. Peterson (48). All the figures necessary to complete the calculations were not presented in the Tweeten and Hines article (65) and therefore the secondary source was consulted.

as compared to $2,639 in the nonagricultural sector of the economy. National income in 1963 would therefore have been $247 billion if everyone had received the per capita income prevailing in the farm sector. Had everyone received the per capita income of the nonagricultural sector, national income in 1963 would have been about $500 billion. Weighting these two figures by the proportion of the population in each sector and summing, an estimate of actual national income in 1963 is obtained: 0.071 ($247 billion) + 0.929 ($500 billion) = $482 billion. Performing this same calculation using as weights the proportions of the population in each sector which existed in 1910 yields an estimate of what the 1963 level of national income would have been had not human resources been freed by productivity increases to move to more productive jobs: 0.347 ($247 billion) + 0.653 ($500 billion) = $411 billion. Thus, national income in 1963 was $71 billion higher as a result of the impacts of increased agricultural productivity realized since 1910.

Based upon similar lines of reasoning, the authors estimate that in the early 1960's the changes stemming from greater farm productivity increased national income by about $1 billion annually (see Table 1 of the Tweeten and Hines article). If these yearly increments occur into perpetuity, the present value of accumulated future benefits from each annual increase in productivity is $20 billion when discounted at five percent.

The list of costs which Tweeten and Hines suggest are incurred to realize this $20 billion annual return is quite extensive. Included are the annual public costs of agricultural research, extension, and vocational training; private investment in agricultural research and development; the estimated annual expense for rural farm primary and secondary education; Federal outlays to support farm prices and control or dispose of excess production; the cost of education in the nonfarm sector that contributes to agricultural productivity; and other miscellaneous items. These annual costs sum to about $10 billion in 1963, yielding a benefit-cost ratio of 2.0.

There are several problems inherent in this approach to estimating ✓ the returns to agricultural education and research. First, the incremental returns approach zero as the distribution of the population between farm and nonagricultural sectors approaches equilibrium. That is, if no migration from the farm sector to the nonagricultural sector occurs between times t and t + 1, national income as calculated by this technique does not increase. This is a consequence of the authors' assumption that per capita incomes in the farm and nonagricultural sectors are the same for both the base year and the current year.

The incremental returns also approach zero as the differential between farm and nonagricultural per capita incomes approaches zero. The larger this differential and the greater the rate of migration to the nonagricultural sector, the greater the imputed returns to agricultural education and research.

Finally, the assumption that per capita incomes in the two sectors do not change over time is not entirely consistent with the basic idea behind the approach; namely, that migration contributes to the growth of national income. Presumably, both farm and nonagricultural per capita incomes should be lower in the base year than in the current year.

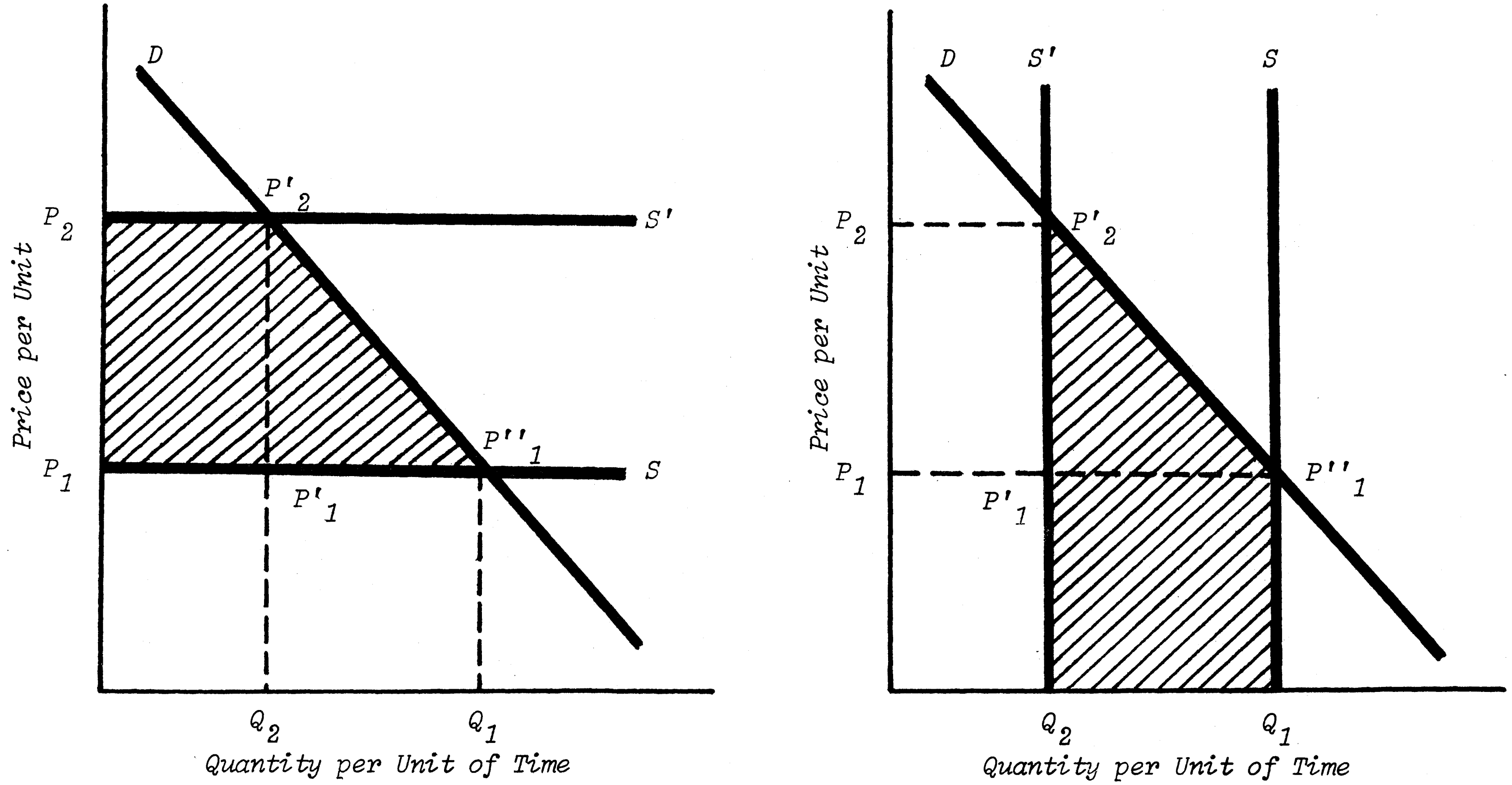
Consumer Surplus Approach

The value of inputs saved approaches discussed above shed considerable light on the general relationship between the returns and the costs of agricultural research. However, Griliches (22) in his study of hybrid corn research brings somewhat more specificity to the problem by computing a rate of return to research. The vehicle by which he estimates the returns to research involves calculating the loss in consumer surplus to society which would occur had hybrid corn seed never been developed and adopted.

As depicted in Figure 2, the disappearance of a new technology such as hybrid corn seed causes the supply curve of the affected commodity to shift upward and/or to the left: from S to S'. This shift results in a loss in consumer surplus equal to the total area under the demand curve between the old and new supply curves. In portion a.) of Figure 2 the supply curve is assumed to be perfectly elastic and the resulting welfare loss is represented by the hatched area $P_2\ P'_2\ P''_1\ P_1$.

The reason for presenting two extreme assumptions about the elasticity of the supply curve is that, given prior knowledge about the demand elasticity of the product in question, a perfectly elastic supply curve yields a lower limit of the estimated returns while assuming a perfectly inelastic supply results in an upper limit.

The formulas employed by Griliches to calculate the losses are, for Figure 2a.) Loss 1 = $kP_1Q_1\ (1 - 1/2\ kn)$ and for b.) Loss 2 = $kP_1Q_1\ (1 + 1/2\ k/n)$, where k is the percentage change in yield brought about by hybrid corn seed, P_1 and Q_1 are the original equilibrium price



a.) Perfectly Elastic Supply

b.) Perfectly Inelastic Supply

Source: Zvi Griliches (22, p. 422).

Figure 2. Losses in Consumer Surplus Resulting from the Disappearance of a Technology

and quantity of corn produced respectively, and n is the absolute value of the price elasticity of demand for corn.[4] The formula for the lower limit of the returns (Loss 1) has one important advantage over that formula used in computing the upper limit; the former is much less sensitive to changes in n than the latter when n is small. That is, a small error in the estimated value of n results in a much greater error in the estimated returns yielded by the Loss 2 formula than that error yielded by the Loss 1 formula.

Having estimated the returns to hybrid corn research, Griliches next concerns himself with calculation of a rate of return. There are at least two different rates of return that can be computed: the "external" rate of return and the "internal" rate of return.

The procedure for calculating an external rate of return makes use of a rate of interest which, in the investigator's opinion, reflects the opportunity cost of capital in the economy. This external rate of interest is used to accumulate the flows of costs and returns to that point in time at which development of the technology in question is closed. The costs are then expressed as a capital sum. The returns are accumulated to the same point in time and expressed as an annual flow. To this annual flow of past returns is added an annual future return which is assumed to equal the level of net returns (returns minus costs) existing in the year in which development is closed. This flow of future returns is assumed to continue into perpetuity. Division of total annual returns by cumulated past costs yields the estimate of the perpetual external rate of return.

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[4] The formula in the original article is Loss 2 = kP_1Q_1 (1 + 1/2 kn). This error is corrected in a reprint of the article by Rosenberg (50).

As an example of the calculation of an external rate of return, consider Griliches's summary figures on hybrid corn research as shown in Table III. Given that the opportunity cost of capital, r, equals .05, the 743 percent external rate of return can be interpreted as follows: the average dollar invested in hybrid corn research has returned 5 percent annually to society from the date of investment to 1955 and from 1955 into perpetuity it pays off at the rate of 743 percent per year. If the rate of discount were higher, say 10 percent, the annual past return of each dollar invested would be higher but the annual future return would be lower.

Griliches goes on to point out that this external rate of return is not really different from a benefit-cost ratio (B/C). The external rate of return can be defined as follows:

$$k = 100\,(PR \cdot r + AFR)/RC$$

where

k = external rate of return,

PR = cumulated past returns,

r = the rate of interest used to cumulate or discount returns,

AFR = annual future returns,

RC = cumulated research costs.

The relationship for a benefit-cost ratio (B/C) can be written as $B/C = (PR + AFR/r)/RC$. Therefore, $k = 100r\,(B/C)$. A benefit-cost ratio of about 149 means that the average dollar spent on hybrid corn research yields a perpetual external rate of return of 743 percent if $r = .05$.

The internal rate of return is somewhat different concept from

TABLE III

EXTERNAL RATE OF RETURN ON HYBRID CORN RESEARCH EXPENDITURES AS OF 1955 (MILLIONS OF DOLLARS)

	r = .05	r = .10
1. Cumulated past returns	$4,405	$6,542
2. Past returns as an annual flow	$ 220	$ 654
3. Annual future returns	$ 248	$ 248
4. Total annual returns (2 + 3)	$ 468	$ 902
5. Cumulated past costs	$ 63	$ 131
6. External rate of return (100 x 4/5). .	743%	689%

Source: Zvi Griliches (22, p. 426).

either the external rate of return or the B/C ratio. The procedure used to calculate an internal rate of return does not make use of an interest rate determined by some opportunity cost notion. Rather, the internal rate of return is defined as that rate of interest which will equate the accumulated present value of the flow of costs with the discounted present value of the flow of returns at a point in time. It can be calculated through an iterative process as that value of R which forces the following condition to hold:

$$\sum_{t=0}^{n} F_t/(1 + R)^t = 0 \qquad (2.1)$$

where F_t if the net return in year t.

The internal rate of return in the Griliches hybrid corn study is between 35 and 40 percent. This can be interpreted as meaning that on the average each dollar invested in research on hybrid corn returns about 37 percent annually into perpetuity from the time it was invested. Even though the two methods of calculating a rate of return yield significantly different answers, it should be kept in mind that they are really explaining the same thing. The important point to be made is that one must recognize which rate of return is being put forth.

Production Function Approach

Both the value of inputs saved approach and the consumer surplus approach as discussed above result in estimates of average returns to past investment in agricultural research. Decisions to invest in research, however, are made at the margin. It would therefore be desirable to have knowledge of the marginal rate of return to additional investment. As explained below, the production function approach is one method to obtain estimates of the marginal return to agricultural research.

Yet another advantage of the production function approach is that, through various distributed lag techniques, one can come to grips with the lag between the time an investment in research is made and the time this investment actually results in increased output. This is a problem of timing which the other approaches do not consider. A detailed consideration of the problem and its implications is taken up in Chapter III. For the purposes of the present discussion, it is sufficient to be aware that the lag exists and that it should be taken into account when estimating the returns to agricultural research.

One of the very early efforts to introduce research and extension expenditures directly into an aggregate agricultural production function was made by Griliches (23). In this specification of the production function, education is also included as an explanatory variable. Both these variables were found to have a significant impact on the level of agricultural output.

Griliches's measure of the variable which reflects the contribution of public expenditures on agricultural research and extension is the sum of the expenditures of the state agricultural experiment stations and the extension services. To allow for a lag in the effect of the expenditures, the author constructs the observations on this variable by averaging the flow of expenditures in the previous year and the level six years previously. For example, the average of 1958 and 1953 expenditures is used as the observation for 1959. While this measure is admittedly crude and largely based on intuition, it is at least a step in the right direction.

The Griliches study, which fits a Cobb-Douglas production function to cross-section data for 1949, 1954, and 1959, finds that the marginal product of public research and extension is about $13. To allow for the effect of private expenditures, Griliches assumes that private investment is roughly equal to public investment and divides the marginal product in half, thereby obtaining an adjusted marginal product of $6.50. Assuming a six-year lag between the expenditure and the beginning of a return, Peterson (48, p. 152) converts this estimate to an internal rate of return. He finds that if the return is assumed to continue into perpetuity, the internal rate of return is about 53 percent. It is about 36 percent if the return is fully realized in the sixth year.

Using a slightly different approach, Evenson (17) fits a linear regression model to time series data for the 1935-1963 period. A productivity index is employed as the dependent variable and the model explains its behavior by current values of public research and extension expenditures, weather, and an index of educational attainment. Evenson finds that the marginal product of research and extension is about $10.80, the equivalent of about a 57 percent marginal internal rate of return. Adjusting the coefficient for private research reduces this rate of return to 48 percent.

The attribute that makes the Evenson study of particular interest, however, is the manner in which this increase is distributed through time. Evenson hypothesizes that the returns to research are distributed over time in such a way that the flow of returns resembles an inverted V; first increasing as the technology is adopted by more and more farmers, reaching a maximum, and then declining as the knowledge depreciates. To support this theory (which will be more fully developed in Chapter III), the author imposes weights on the research and extension expenditure data which are constrained to obey the inverted V time form. Given that the flow of returns is forced to substantiate the time form implied by the theory, alternative lengths (n) of the lag are tried in an iterative fashion to estimate the parameter n/2, the mean length of lag. The maximum R^2 criterion is then used to determine the "best" estimate of n/2. The study concludes that the mean lag for state supported research is about five and one-half years and eight and one-half years for federally supported research.

Evenson's theoretical analysis of the time form of the contribution of research and extension expenditures to agricultural productivity represents a great step forward. However, his empirical estimation of the lag leaves room for improvement. In Evenson's words (17), ". . . the inverted V approach is inelegant and difficult to treat statistically" (p. 34) . By its use, one is in effect put in the position of limiting the set of possible lags from which the "best" lag is to be selected to only those which substantiate the theory. It would be preferable to let the data determine the form of the lag.

Allen and Howitt (2) employ in a recent paper a more flexible lag technique to estimate the returns to research for California agriculture over the 1949-1969 period conditional on a normalized extension expenditure. In their model, output in the current period is specified as a logarithmic function of labor and capital in the current period, a given level of extension expenditures, and lagged values of research expenditures. The research and extension expenditures are those made by the California Agricultural Experiment Station and Cooperative

Extension Service through which University of California agricultural research and extension is performed. Allen and Howitt do not include the contributions of USDA research, private research and development, weather, and education in the model.

A composite lag consisting of a polynomial lag and an exponential decay term is used by the authors to estimate the impact of research on agricultural output in California. Use of the exponential tail requires them to adopt a search technique for the decay term, however the technique is considerably more flexible than the inverted V technique in which all weights are prespecified. The empirical time forms yielded by the Allen and Howitt model are not entirely consistent with the form which available theory indicates should occur. This difference is not explained in the paper.

General Evaluation of Selected Previous Works

The results presented in the above section represent a process of continual refinement in both techniques and data as well as theory. These refinements have led to the point where it is now possible to suggest that further studies on the nature of agricultural productivity should incorporate the following features: first, estimates of marginal returns should be made; second, allowance for the contribution of education and weather as well as research and extension should be made; third, techniques which allow the impacts of research and extension to be distributed over time in some flexible manner should be employed; and finally, the research and extension variable should be defined in such a way that production-oriented expenditures and nonproduction-oriented expenditures are kept distinct and an adjustment for private sector activities can be made. An attempt is made to capture all of these features in the empirical model adopted in the present study. The theory underlying this model is developed in Chapter III.

CHAPTER III

A THEORETICAL FRAMEWORK

The purpose of this chapter is to develop a theoretical model for explaining the behavior of aggregate agricultural productivity over time.

Productivity and the Aggregate Agricultural Production Function

To define explicitly the relationship between agricultural productivity and the aggregate agricultural production function, recall the conceptual framework developed in Chapter II and once again assume production in the agricultural sector can be described by the following Cobb-Douglas production function:

$$V_t = A_t \, L_t^{\alpha} \, K_t^{\beta} \, . \qquad (3.1)$$

As explained in Chapter I, productivity is a comparison of the output of a production process to one or more of its inputs. The ratio of output to a single input is called the partial productivity of that input. Since measures of partial productivity do not consider the level of use of other inputs and the possibility of factor substitution, they are not particularly good measures of the overall efficiency of the production process. A preferable measure of overall efficiency is one that compares output with the combined use of all inputs, i.e., total factor productivity. For the production function described by Equation

(1), total factor productivity (y) is given by

$$y_t = \frac{V_t}{L_t^{\alpha} K_t^{\beta}} = A_t. \tag{3.2}$$

Usually, the major difficulty in computing total factor productivity lies in constructing an aggregate input to serve as a divisor.[1] This difficulty has two sources. First, unlike quantities - hours of work, number of tractors, etc. - must be combined. Second, within a given class of inputs, e.g., labor, there are normally several grades of quality represented.

To overcome the problem of combining unlike quantities, the conventional inputs - L and K in the equations above - are normally converted to their monetary values, as is V. This procedure would be perfectly acceptable if input prices accurately reflected the contributions of each class of inputs. However, in estimating aggregate production functions, more often than not it is necessary to ignore certain quality differences within a given class of inputs. This in turn can give rise to changes in output per unit of time that cannot be accounted for by changes in the levels of inputs per unit of time. For instance, suppose the labor input in Equation (3.2) is measured as hours worked and then converted to a monetary value by means of an "average" wage rate, i.e., a wage rate reflecting the wage per hour for each skill level category weighted by the number of workers in each category. In practice, it is not economically feasible to identify each and every

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[1] A parallel problem exists on the output side. However, quality changes in agricultural output have not been nearly as significant as those which have occurred on the input side over the period in question.

skill level category and its corresponding wage rate. Therefore, some changes in the proportion of workers in each skill level category will not be detected. If these changes result in an upgrading of the overall skill level of labor, the average wate rate will fail to reflect this and cause the illusion of an increase in output with no corresponding increase in inputs. Such unexplained changes in output - which are caused by ignoring quality differences that are not reflected in input prices - are called technical changes. They are captured by the A_t term of Equation (3.2), along with changes in ceteris paribus variables such as weather.

Having defined total factor productivity, it is a short step to defining a productivity index in terms of the aggregate agricultural production function. In the base period (t = 0), Equation (3.2) reduces to

$$y_o = \frac{V_o}{L_o^{\alpha} K_o^{\beta}} = A_o. \tag{3.3}$$

Again from Equation (3.2), total factor productivity in time t is

$$y_t = \frac{V_t}{L_t^{\alpha} K_t^{\beta}} = A_t. \tag{3.4}$$

By definition, the value of an aggregate productivity index (P) at a particular time, say t, is given by the ratio of total factor productivity in the current period to total factor productivity in the base period:

$$P_t = \frac{y_t}{y_o} = \frac{A_t}{A_o}. \tag{3.5}$$

It follows from Equation (3.5) that the rate of change of productivity per unit of time is equal to $\dot{A}_t/A_t$. That is,

$$\ln P_t = \ln A_t - \ln A_o$$

and

$$\frac{d(\ln P_t)}{dt} = \frac{\frac{dA_t}{dt}}{A_t} = \frac{\dot{A}_t}{A_t}. \qquad (3.6)$$

A linear approximation[2] of $\frac{d(\ln P_t)}{dt}$ in discrete time is $\ln P_t - \ln P_{t-1}$. Thus, as was the case with the rate of change of output, an explanation of the behavior of productivity in agriculture comes to an examination of the determinants of $\dot{A}_t/A_t$. This task is addressed in the next section.

Sources of Productivity Change in Agriculture

Sources of Technological Change

Evenson (17, pp. 12-16) identifies and discusses several sources of improvements in the quality of inputs used in agriculture. In the

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[2] A linear approximation of $\frac{d(\ln P_t)}{dt}$ in discrete time is $\ln P_t$ - $\ln P_{t-1}$. That this is the case can be seen by considering the function $P_t = P_o e^{rt}$. Taking the log of this function and differentiating with respect to time yields:

$$\ln P_t = \ln P_o + rt \ln e = \ln P_o + rt \quad (P_o \text{ constant})$$

$$\frac{d \ln P_t}{dt} = 0 + \frac{d}{dt} rt = r.$$

In discrete time, if $P_t = P_o e^{rt}$, then $P_{t-1} = P_o e^{r(t-1)}$
It follows that

$$\ln P_t = \ln P_o + rt$$

and

$$\ln P_{t-1} = \ln P_o + r(t-1).$$

Taking first differences yields

$$\ln P_t - \ln P_{t-1} = \ln P_o + rt - (\ln P_o + r(t-1))$$

or

$\ln P_t - \ln P_{t-1} = r$, the same result obtained by differentiating the original function with respect to time.

context of the present study, such improvements can be thought of as resulting in technical change if they are adopted by some or all of the potential users.

First, the quality of an input used by a farmer will increase if there is an increase in the quantity of resources used to produce the input. For instance, a combine large enough to harvest twice as much wheat in one pass as a smaller combine can be considered to be of superior quality to the former. To the extent that prices of inputs purchased by farmers reflect the resource costs of producing those inputs, this source of input quality change will be captured by the conventional method of measuring inputs referred to in the previous section.

Another source of improvements in the quality of inputs directly used by farmers is an increase in the quality of resources used to produce those inputs. An improved method of producing nitrogen fertilizer which results in decreased cost per unit to the farmer with no change in the physical characteristics of the fertilizer has the same effect as an increase in the quality of the fertilizer itself, given normal methods of measuring inputs. In this study, changes in the quality of resources used to produce agricultural inputs will not be kept distinct from changes in the quality of inputs directly used in agricultural production.

According to Evenson (17, p. 12) research effort undertaken by private firms will eventually show up as quality changes in inputs. (Expenditures for research effort of this type have been labeled production-oriented research expenditures in the present study.) These quality changes are partially captured by conventional measures of inputs in that the private firm can command a higher price for its superior input for some length of time. The length of this time period depends upon the speed with which competing firms react in the face of legal (e.g., patents), technological, and economic constraints. Quality changes emitted by this source are not fully captured by increased prices simply because if the firm were to pass along the full value of the improved input, the farmer would no longer have any economic incentive to adopt the new technology. Also, it is quite likely that the improved input developed by the private firm is the end product of both private research and basic research conducted by the public sector. If this is the case, part of the pay-off to the research activity could include some return to public research.

A third source of quality change in inputs is production-oriented research effort undertaken by public institutions. A role for the public sector in agricultural research is not difficult to justify. By the orthodox definition, a public good or service is in varying degrees equally available to all members of the community. This jointness and nonexcludability on the production side gives rise to spillovers or externalities which in turn imply efficiency reasons for publicly managed supply. In agriculture, many of the important technological changes are typified by plant varietal and other biological changes which can be easily reproduced or techniques which can be easily copied and marketed by other firms (17, p. 1). This ease of reproducibility does not allow a sufficiently high return to research by small farm firms or their suppliers to encourage the socially optimal amount of inventive activity. Perhaps this can be most clearly seen in the case of public research of an economic nature aimed at improving cultural practices. In short, there exists a divergence between the private benefits of much agricultural research and the social benefits of that research. In the absence of public sector activity, technology in agriculture would be underproduced.

If the fruits of public research are incorporated by a private firm in some patentable input improvement, an increase in the price of the input will occur. This price increase will be picked up by the conventional method of measuring the input and therefore at least part of the quality improvement will be captured in the calculation of the productivity index. If, however, competition among suppliers of inputs directly used by farmers brings about the embodiment of public sector findings which are not patentable, no increase in input prices will occur and the quality improvement will be lost to the conventional method of input estimation.

Public and private extension activities also have the effect of improving the quality of inputs. This effect can be realized in either one of two ways. If the information imparted by the extension activity is input-specific, the effect will be to increase the rate of adoption of the improved input or improve the efficiency with which the new input is combined with other inputs. If, on the other hand, the information imparted is not input-specific but rather involves an improvement in the efficiency with which existing inputs are combined, the extension activity can be thought of as increasing the quality of the flow of labor and management, i.e., the human capital input.

If private firms behave as profit maximizers, the costs of extension activity related to the sales and services of their products will be reflected in the prices of these purchased inputs. Thus, the conventional method of measuring inputs will capture this activity. The same cannot be said for public extension efforts since they are not likely to affect input prices (17, p. 16).

According to Evenson (17, p. 18), the work to date by economists such as Schultz (54) in the field of human capital lends support for including the effects of education as a source of quality change in inputs used in agriculture. The level of educational attainment of farmers has an important impact on their ability to assimilate information into the decision-making process and translate this information into gains in efficiency. Therefore, an index of educational attainment such as that used by Griliches (24) should be included in the framework to control for the contribution of formal education to the quality of the labor and management input.

There is one final source of quality change in inputs identified by Evenson (17, p. 16) which, over a very long period of time, could become important. This source is an aglomeration of several factors which indirectly determine the present level of input qualities and includes such factors as general communication and transportation. Over the time period considered in this study, the contribution of this source to agricultural productivity is assumed constant.

Summary of Sources of Technological Change

Before proceeding with the discussion of sources of productivity change, it is appropriate at this point to stop and take stock of those activities which bring about technical change in agriculture. They include:

1. Technical change brought about by changes in resources used

to produce direct inputs into the agricultural production process.

2. Technical change brought about by production-oriented private research activities.
3. Technical change brought about by production-oriented public research activities.
4. Technical change brought about by production-oriented private extension activities.
5. Technical change brought about by production-oriented public extension activities.
6. Technical change brought about by changes in the level of educational attainment of farmers.
7. Technical change brought about by long-run improvements in transportation, communication, and other factors which indirectly influence the quality of agricultural inputs.

A primary concern of this study is to measure the contributions to agricultural productivity of those sources whose effects are not captured by the conventional method of measuring agricultural inputs. From the above discussion of the list of sources set forth by Evenson, it would appear that technical change brought about by changes in resources used to produce direct inputs into the agricultural production process and those brought about by private extension activities are reasonably well captured by changing input prices. Technical change that is the result of public extension activity and changes in the level of educational attainment of farmers are not captured and therefore are determinants of the rate of growth of productivity change ($\mathring{A}_t/A_t$ in Equation (3.5)). Indirect determinants of the quality of inputs that are not likely to significantly affect productivity over the time horizon of this study are assumed constant.

Public and private production-oriented research activities cannot be so neatly characterized. As pointed out above, there is a possibility that the affect of some public research may be partially reflected in input prices. This would be the case if a private firm succeeded in combining the fruits of that research with its own findings to produce a patentable product. Given the biological and fundamental nature of much public research, however, the extent to which conventional measures actually capture the effects of production-oriented public research is likely to be quite small. The contributions of private sector research activities are somewhat more readily reflected by input prices, although it is not precisely known to what degree. The only conclusion that can be drawn with some certainty is that the full value of private research findings will not be fully reflected by input prices.

Other Sources of Productivity Change

In Chapter I a distinction was drawn between productivity change that occurs as the result of technical change and productivity change that is the result of an alteration of the physical and/or economic environment in which agricultural production takes place. The sources of productivity change discussed thus far all belong in the category of technical change in the sense that input quality improvements are tangible results of improvements in the body of knowledge regarding the industrial arts in agriculture. Attention will now be directed to those sources of productivity change that do not alter the state of the arts but that nevertheless have an impact on the efficiency of production.

Certainly one primary determinant of the environment in which production takes place is weather. As early as 1914, Smith (57) reported in a statistical study that rainfall was a critical factor in corn yields in Ohio. Thompson (61), in 1966, performed a multiple regression analysis of corn and soybean yields and weather variables and concluded that recent high yields per acre (a measure of partial productivity) "have resulted primarily from the direct effects of favorable weather on plant growth..." (p. 80).

"Normal" weather is rarely experienced. The usual experience is some deviation from the normal. The weather variables of greatest significance in agriculture are precipitation and temperature; variables which are subject to wide fluctuations and which occur to a great extent in a random fashion (46).

Not only does weather directly affect productivity in agriculture in a physical sense, it is also probable that weather variability has an impact on the rate of adoption of new technologies. That is, it may be hypothesized that a farmer producing in a geographic area that is subject to a relatively high degree of randomness in precipitation and temperature would be expected to fully employ a new technique more cautiously than a farmer operating with stable weather conditions since the latter can more readily assign costs and benefits to the new technique. (This hypothesis will be tested in Chapter V.)

A second group of activities that affects agricultural productivity through the environment in which production takes place is somewhat akin to transportation and communication improvements that bring about technical change over the very long run. Like the latter, this second group is important in indirectly determining the level of productivity at a given time, but its affect on productivity changes in the short-run is not likely to be significant. This group has been labeled nonproduction-oriented research and extension expenditures in the present study. It includes the following types of activities:

1. Utilization research and development aimed at expanding the demand for farm products.
2. Nutrition and consumer use research aimed at determining nutrient requirements and how foods can best supply these requirements.
3. Marketing research that seeks to reduce costs and maintain product quality in moving products from farm to consumer.
4. Plant and animal disease and pest control programs designed to keep out of this country, by means of inspection at ports of entry, harmful diseases and pests.[3]
5. Extension activities related to items such as child development, community development, health, food preparation and selection, home furnishings, and marketing and utilization of farm output.

Based on the above observations, it is hypothesized that the observed productivity change in U. S. agriculture depends upon production-oriented research and extension, the level of educational attainment of farmers, weather, and nonproduction-oriented research and extension. As explained in Chapter II, this list is not meant to be complete. Unquestionably, there are many other factors which influence

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[3] It should be made clear that investigations conducted to improve methods to control plant and animal diseases and pests and to develop safe chemical, biological, and other methods for control of harmful pests are included under production-oriented research and extension expenditures.

productivity. It would be appropriate at this time to mention a few of the most important of these "left-out" variables.

Omitted Variables

Several recent studies have suggested that one determinant of productivity change is demand. Quinn (49) goes so far as to state that "... clearly perceived demand...tends to be the primary force stimulating technological change" (p. 91). During much of the period under consideration in this study, one of the major problems confronting the agricultural sector was excess supply of aggregate farm output at market prices. For this reason, productivity change over the period that occurred as a result of demand forces is not likely to have been significant. Almost without question, this will not continue to be the case in the future.

If excess demand was not a significant determinant of agricultural productivity over the relevant period, it is fair to ask if excess supply in some way had an impact. It is entirely possible that it did. Without considerations of efficiency, the U. S. has had for more than thirty years a policy of protecting farmers from falling prices, whatever the cause of the price decline. This policy has in turn dampened one of the elements of risk facing farmers; that is, it has tended to stabilize the prices received by farmers for their output at a higher level than would otherwise have been the case. The economic rewards expected by farmers who adopted new technologies and thereby increased their production were therefore greater than they would have been in the absence of this policy. In short, it would appear that public sector reaction to the situation of excess supply could have speeded the adoption of new technology over the period under consideration. Also, farm programs aimed at controlling production through acreage restrictions may have had the effect of bringing about the retirement of marginal land from cultivation. This would tend to make aggregate yield per acre higher than if all arable land were employed.

Evenson (17, pp. 20-23) lists several other factors which might contribute to the unexplained residual productivity change in most empirical studies. Briefly, the list includes output change unexplained by input changes due to realized economies of scale,[4] disequilibrium in the factor markets, capital measurement problems, and capitalization of research-induced and extension-induced output change into the value of fixed inputs as a "rent".

This concludes the discussion of sources of productivity change in U. S. agriculture. In the following section, time is explicitly introduced into the framework; particular emphasis is placed upon the time lags associated with production-oriented research and extension activities.

Time and the Sources of Productivity Change

Based upon the observations of the preceeding section, it is

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[4] According to Evenson (17),

> . . . the existence of measured economies of scale implies a disequilibrium with respect to firm size. This disequilibrium is likely to have been generated in the first place by changes in input qualities.
>
> From the point of view of the contribution of research and extension, these realized scale economies result from research-and-extension-induced quality changes in the conventional inputs. (p. 21)

hypothesized that the behavior of the agricultural productivity index, P, can be described by the following general function:

$$P = f(R, E, W, O) \tag{3.7}$$

where:

R represents production-oriented research and extension expenditures,

E represents the level of educational attainment of farmers,

W represents the effect of weather,

O represents nonproduction-oriented research and extension expenditures.

In order to proceed to an actual estimation procedure, it is necessary to introduce time into the theoretical framework. With regard to the E and W variables, this does not present a problem. Weather in the current time period, t, affects productivity in the same time period. Also, the level of formal education of farmers in time t determines their ability to assimilate and utilize information in the decision-making processes of period t. Therefore, productivity in the current period is in part determined by educational attainment in the same time period.

The timing of the effect of the O variable is not as obvious. As explained above, the activities comprising the nonproduction-oriented research and extension variable probably have a good deal to do with the level of productivity in the long run, but are not likely to significantly influence efficiency over the short run. In other words, if these activities suddenly ceased to be undertaken, it is doubtful that the level of productivity would be immediately and strongly impacted.[5] Rather, other things equal, one would expect to see a somewhat gradual deterioration of efficiency over an extended period of time. Given this line of reasoning and the fact that the purpose of the study is to explain variations in productivity, nonproduction-oriented research and extension activities enter the theoretical framework contemporaneously as a "bouyancy" factor, i.e., a factor whose influence assists in sustaining the level of agricultural productivity over the long run rather than bringing about period-to-period changes in efficiency.

The final determinant of productivity to be considered is production-oriented research and extension activities, R. There are two important questions which must be answered with regard to the R variable: first, what is the expected time form of the contribution of R to productivity and second, how should observations on R be constructed? These two questions can be answered using Figure 3.

Consider a single production-oriented research activity initiated in time t. According to Griliches (21, p. 20) and Evenson (17, p. 25), this research activity will not immediately bear fruit in terms of improvements in the techniques of agricultural production. There is a time lag between the initiation of the research activity and its ensuing impact on productivity. As shown in Figure 3, from time t to time t + m research is being conducted, but no new technology is yet

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[5] It can be argued that the sudden absence of animal and plant disease and pest control activities would cause productivity to decline in relatively short order. This could quite likely be the case if one's major concern was with a specific crop or animal. However, since the present study is concerned with aggregate agricultural output, the effect of a decline in productivity for any given product would be dampened in the aggregation process.

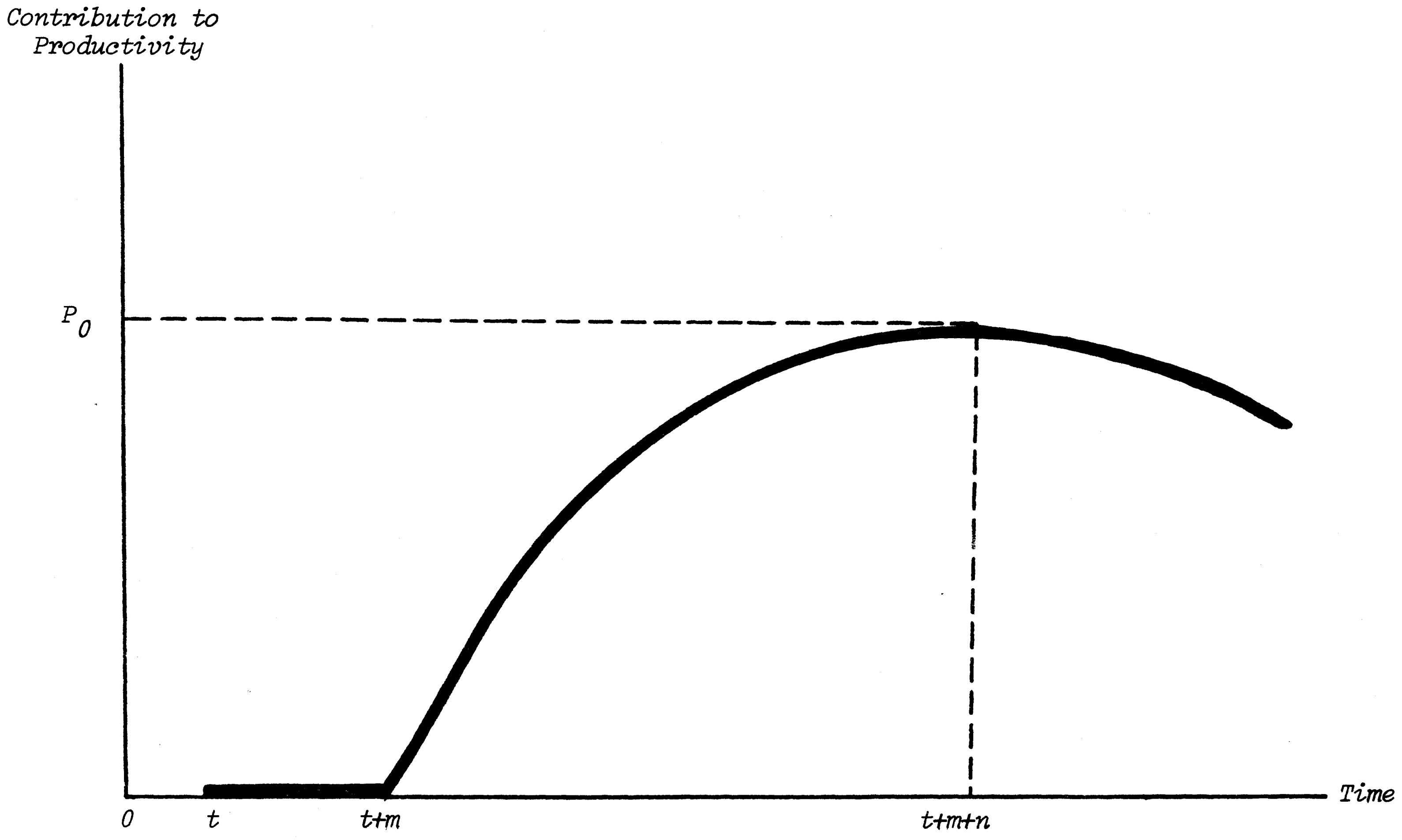

Figure 3. The Effect of Production-Oriented Research and Extension Activities on Productivity

forthcoming from this research. In Marschak's (45) terminology, this is the "inquiry" or "data gathering" phase of the decision relevant approach to information value. The period t to t + m is normally composed of two lags: the lag between the time funds are invested in research and the time inventions actually begin to appear, and the lag between the invention of an idea or device and its development into a commercially applicable stage (21, p. 20). At time t + m, the research is effectively completed and its end product is an "extendable" technique. At this time, the extension of this new knowledge begins and decisions upon actions on the basis of messages received are made at the farm level (45, p. 2). As the new technology is adopted by farmers, technical change occurs and the contribution of R to productivity increases. The contribution to productivity will continue to increase as a result of the new technology as more and more farmers adopt it, and as early adopters extend their use of the effected inputs and gain experience in its application (time t + m to t + m + n). At some point t + m + n, the contribution of this past research and extension will reach a maximum, P_o. Then the value of the information will depreciate, according to Evenson (17, p. 25) and Allen and Howitt (2, p. 5), for any one of several reasons. First, it may become irrelevant. For example, the technology used in producing mule harnesses is still available; however, it no longer has any significant relevance to agricultural productivity. Second, the information may become obsolete as old inputs are replaced by superior or improved inputs. Third, the value of the technology may depreciate after some point in time due to biological decay. An example of this is the case of insects building up resistance to certain insecticides over time. Finally, changes in the prices of other inputs may make the information economically obsolete. These types of phenomena are represented by the downward sloping portion of the curve in Figure 3. The form of the total lag between production-oriented research and extension activities and its contribution to agricultural productivity is given by the convolution[6] of these individual lags (21, p. 20).

The above points give some indication of how observations on the R variable should be constructed. Production-oriented research and extension are complementary inputs into the production of technical change. Without extension activity, the information generated by research will not be communicated to potential adopters and, as a result, productivity will not be affected. On the other hand, extension activity is only beneficial if there are research results to be transmitted. According to Marschak (45) the selection of an optimal combination of the inquiry (research) service and the communication (extension) service requires that these services be chosen simultaneously; "just as a manufacturer cannot choose between rail and road as a means of bringing him fuel without making up his mind, at the same time, whether the fuel should be coal or oil" (p. 2). Therefore, production-oriented research and extension should theoretically be combined. But these two activities are somewhat unique complements since they do not enter into the production of technical change at the same time. As shown in Figure 3, extension activities lag research by the length of the inquiry lag, m. This imples that an observation on R (a "dose" of production-oriented research and extension activity) can be written as

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[6] The term convolution refers to the combination of two or more distributed lag functions into one.

$$R_t = (\text{Research Activity})_t + (\text{Extension Activity})_{t+m}. \quad (3.8)$$

With these thoughts in mind, the total contribution to productivity of all relevant research can be examined by rewritting Equation (3.7) as

$$P = f[g(L)\ R, \bar{E}, \bar{W}, \bar{O}] \quad (3.9)$$

where:

$g(L)R$ is the convoluted distributed lag function of a dose of of production-oriented research and extension activities,

and all other variables are defined as before and assumed constant.

In considering the overall effects of a stream of production-oriented research and extension activities on the productivity of U. S. agriculture, the process can be viewed as one of continuous, relatively small improvements in the quality of inputs. If a snapshot were taken of this stream of contributions, it would be found that a given investment in research and extension affects productivity over time in a manner such as shown in Figure 3. To measure the total contribution at a given point in time of all relevant production-oriented research and extension, it becomes necessary to expand the analysis to include many periodic injections of R; this is depicted in Figure 4 (the inquiry phase has been eliminated from the diagram to simplify the analysis).[7]

As shown, the effects of each periodic dose of R on productivity are assumed to be distributed over six periods. It is further assumed that a dose of R in any period is equally productive per unit of expenditure on research and extension. Thus, the varying heights and shapes of the curves imply different investment outlays.

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[7] The remainder of this chapter benefits in part from an analysis by P. G. Allen and R. E. Howitt (2, pp. 2-6).

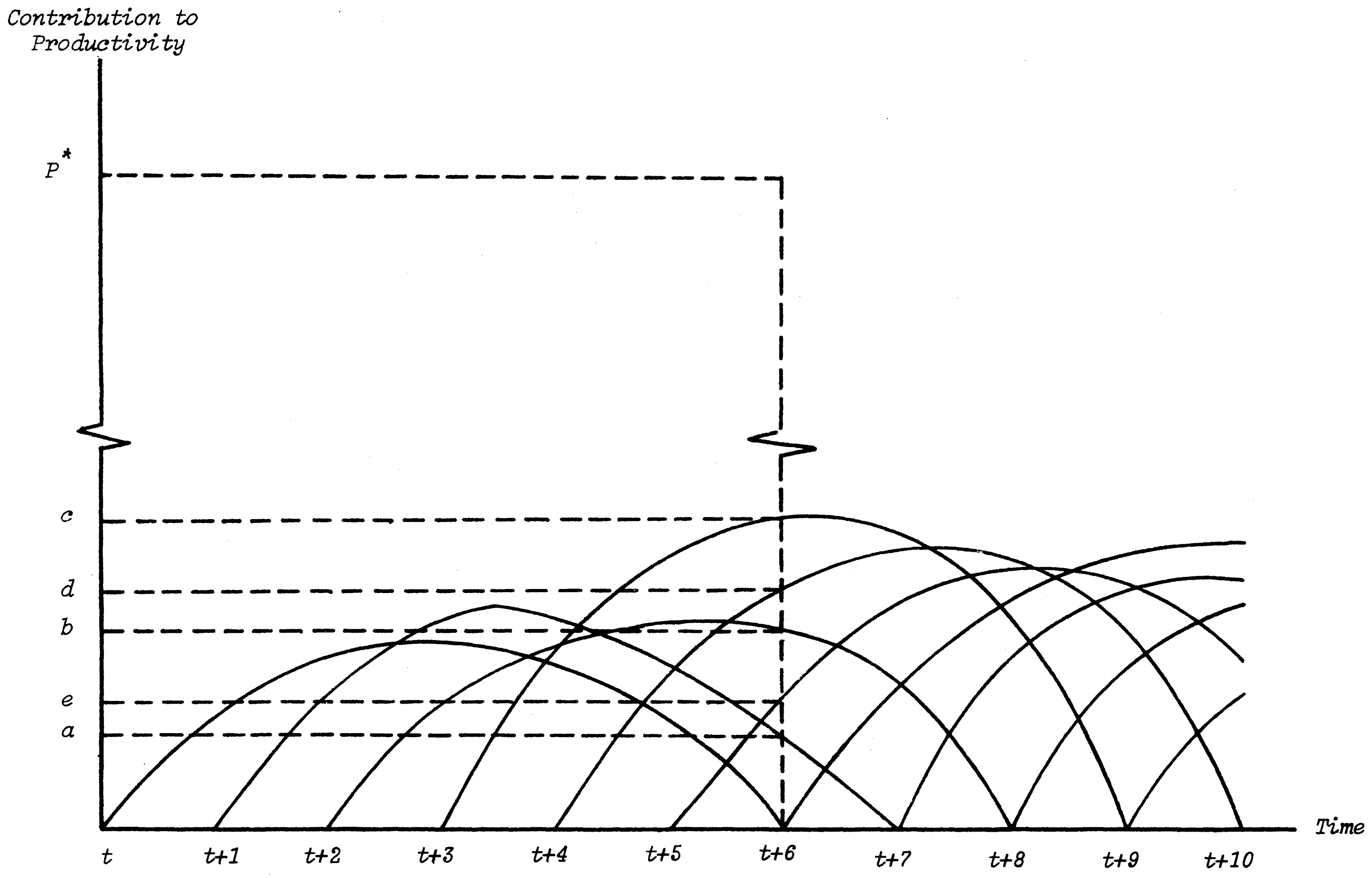

Figure 4. The Time Forms of Several Periodic Doses of Production-Oriented Research and Extension Activities

Define the rate of technological change per dollar of expenditure resulting from a dose of R as b, a constant for all time periods. Then, from Equations (3.6) and (3.9), the contribution of the dose of R injected in time t to the rate of productivity change from time t + 5 to t + 6 is given by

$$\ln P_{t+6} - \ln P_{t+5} = bR_t \, \Pi_o \tag{3.10}$$

where Π is the proportion of total agricultural output actually affected by the new technology generated in time t. This quantity is directly related to the relevance to users in time t + 6 of the information from the dose of R in time t. In terms of Figure 4, the contribution of R_t to productivity in time t + 6 is zero since the information generated by R_t is depicted as having no value to users in time t + 6.

Consider next the contribution of a dose of R injected in time t + 1 to the same time interval. The effect of this production-oriented research and extension activity is

$$\ln P_{t+6} - \ln P_{t+5} = bR_{t+1} \, \Pi_1 \tag{3.11}$$

where Π is defined as above and the subscript 1 refers to activity undertaken in time t + 1. This contribution is shown as 0a in Figure 4.

Proceeding in this manner, it becomes apparent that the total contribution of all relevant production-oriented research and extension activity to the rate of growth of productivity is

$$\ln P_{t+6} - \ln P_{t+5} = \sum_{i=0}^{k} bR_{t+i} \, \Pi_i \tag{3.12}$$

where k is the length of the relevant period to users of the information. In other words, the total contribution to productivity at any given time t + σ is the cumulative effect of investments in R made in times t,

$t + 1, \ldots, t + \sigma$; that is,

$$\ln P_{t+\sigma} - \ln P_{t+\sigma-1} = \sum_{i=0}^{k} bR_{t+\sigma-i}\, \Pi_{\sigma-i}. \qquad (3.13)$$

For instance, at time t + 6 in Figure 4, the contribution to productivity, OP*, is composed of the vertically summed contributions to productivity of doses of R made in times t(zero), t + 1 (0a), t + 2 (0b), t + 3 (0c), t + 4 (0d), t + 5 (0e), and time t + 6 (zero).

The increase in the rate of growth of productivity brought about by a one dollar additional expenditure on R in time $t + \sigma$ is determined at the margin as

$$\frac{\partial(\ln P_{t+\sigma} - \ln P_{t+\sigma-1})}{\partial R_{t+\sigma}} = b\Pi_{\sigma}. \qquad (3.14)$$

Recalling Figure 4, if the individual effects which comprise OP* are plotted against time as in Figure 5, an estimate of the time form for a particular injection of R over the relevant periods of use is obtained. If it is assumed that the periodic doses of production-oriented research and extension activity are constant and therefore have identical distributed effects on productivity, then the estimated curve shown in Figure 5 will exactly reflect each of the individual time forms of Figure 4. Using this assumption and Equation (3.13), the discounted value, PV, (in terms of increases in the rate of growth of productivity) of a dose of R initiated in time t can be expressed as

$$PV = \sum_{i=0}^{k} b\bar{R}\, \Pi_{\sigma-i} \frac{1}{(1+r)^{k}} \qquad (3.15)$$

where r is the social discount rate and $\bar{R}$ is the constant dose of production-oriented research and extension activity.

Much of the remainder of this study is concerned with empirical

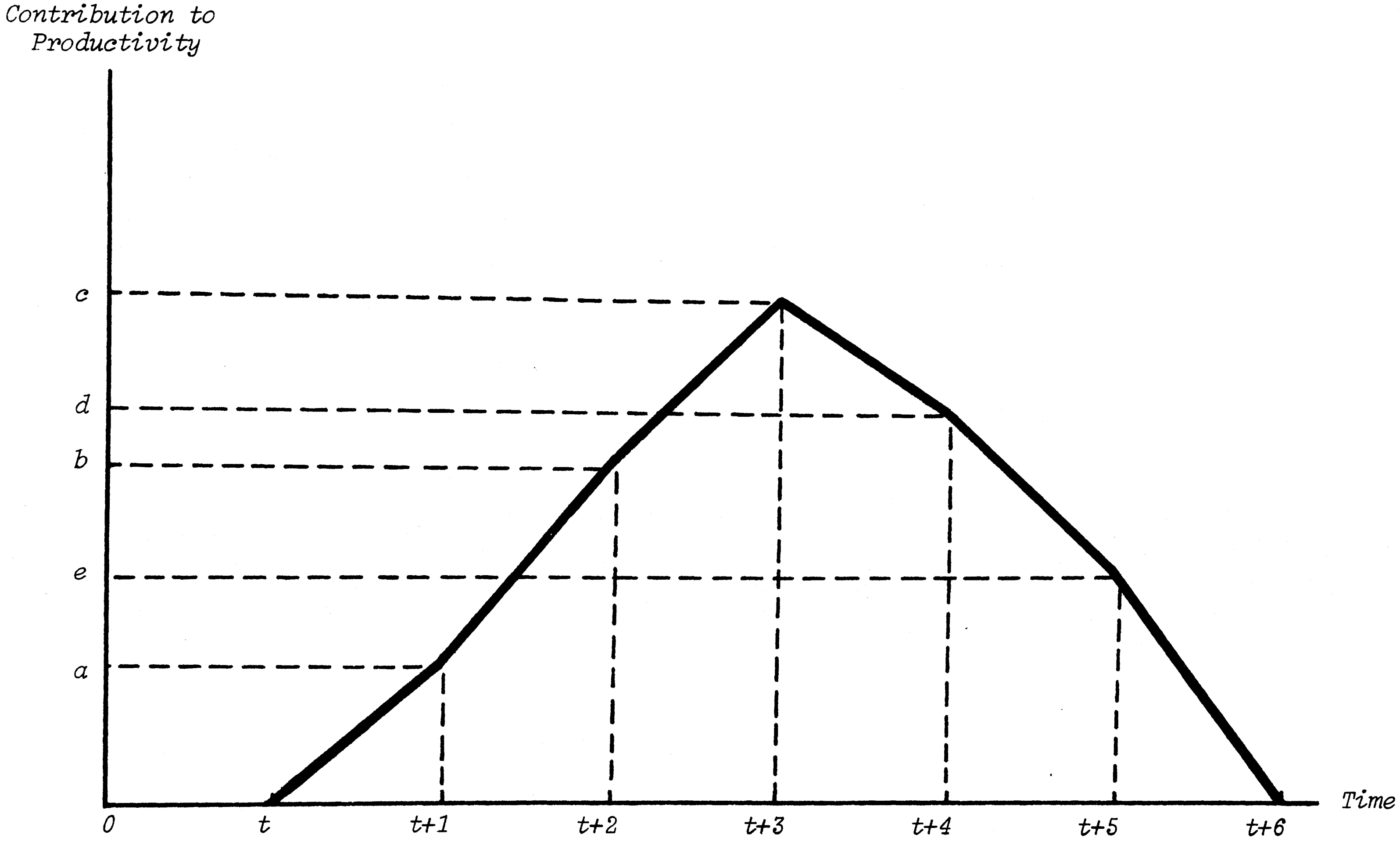

Figure 5. Estimated Time Form of One Injection of Production-Oriented Research and Extension Activity

estimation of the time form for a particular dose of R over the relevant periods of use and its discounted value. In Chapter IV, the estimation techniques to be employed are discussed.

CHAPTER IV

AN EMPIRICAL FRAMEWORK

In Chapter III, a theoretical model of the sources of productivity change in agriculture was developed. These sources were examined with an eye toward explaining the nature of their impacts on productivity and the timing of those impacts. The purpose of the present chapter is to explain the techniques employed to confront the theoretical model with data in order to measure the contributions of the sources to productivity change.

The Productivity Change Model

Based on the observations of Chapter III, the productivity change model is specified as

$$P_t = \prod_{i=0}^{n} R_{t-i}^{\beta_i} \, O_t^{\beta_{n+1}} \, E_t^{\beta_{n+2}} \, e^{\beta_{n+3} W_t}. \tag{4.1}$$

A detailed description of each time series variable is reserved for the Appendix. They can be briefly described as follows:

P_t is the value of the official USDA aggregate productivity index for agriculture in time t,

R_{t-i} is a distributed lag function of public sector production-oriented research and extension expenditures in the current period and n preceding periods,

O_t is public sector nonproduction-oriented research and extension expenditures in the current time period,

E_t is the value in the current period of an index of educational attainment of farmers and farm laborers,

W_t is the value in the current period of a weather index.

The research and extension variables were deflated and expressed in constant 1958 dollars in order to reflect real changes in the variables over time. Since researcher salaries are the major item in the research bill, that portion of total expenditures spent on scientific personnel was deflated by an index of average salaries of college and university teachers. The residual portion was deflated by the implicit price deflator for government purchases of goods and services.

Construction of Observations on R

It was pointed out in the preceeding chapter that even though production-oriented extension activity lags research activity, they should theoretically be combined when measuring their effect on productivity in a manner such as Equation (4.2).

$$R_t = (\text{Research Activity})_t + (\text{Extension Activity})_{t+m} \qquad (4.2)$$

The best available data for measuring the contribution of public sector production-oriented research and extension activity are expenditures on those activities. It must now be determined how public sector expenditures on these activities are related in time to the actual undertaking of the activities. One possible assumption employed at various times by Griliches (23) and Evenson (17) is that the public sector officials charged with determining the level of expenditures in any given year are aware of the lag between research activity and extension activity and build it into their decision-making process. In other words, the assumption is that

$$R_t = (\text{Research Expenditures})_t + (\text{Extension Expenditures})_t. \quad (4.3)$$

The appropriateness of this assumption can be questioned.

As explained in Chapter III, there are, according to Marschak (45), three successive links in the sequence of "symbol-manipulating" services: inquiry, or data gathering; communication of messages; and deciding upon actions on the basis of messages received. In terms of the problem at hand, the inquiry service can be thought of as being carried out by those public sector agencies performing production-oriented agricultural research. The communication of messages is undertaken by public sector agencies performing production-oriented agricultural extension activities. Finally, decisions for action are made by the farmers themselves.

Before the farmer can make a decision on the basis of messages received, however, a higher-order decision must have been made. "Someone representing the interests of the economic unit considered . . . must have chosen a particular combination of these three services . . ." (45, p. 2). The maker of this higher-order decision -- the "meta-decider" -- is in the case at hand, that public institution charged with determining how funds will be appropriated among research, extension, and all other public sector activities. It will not harm the analysis to assume that executive apportionment reflects Congressional appropriations; Congress can then be viewed as filling the role of the meta-decider. In order for the combination of production-oriented research and extension services to be optimal and efficient in an economic sense, Congress must choose these components simultaneously. Ideally, then, Congress would have full information about the length of the lag between each research expenditure and the ensuing extension expenditure (the inquiry lag) and act according to the assumption embodied in Equation (4.3).

However, economic considerations are not always dominant in the budgetary process; instead, according to Singer (56) "the budget is a political document that may be influenced by economic analysis" (p. 194). In the absence of full information and faced with very real time constraints, participants in the budgetary process rely on strategies, rules-of-thumb, and past experience at least as much as upon economic considerations. Once a program is approved as part of an agency's base, continued funding is nearly automatic. "Congressional attention is focused at the budget margin, on new programs and on those that are being expanded greatly or that are changing in character" (56, p. 200). Singer (28, p. 201) estimates that some 90 percent of an agency's appropriations escapes scrutiny.

What conclusions can be drawn from an attempt to reconcile Marschak's explanation of the optimal situation and the realities of the budgetary process? Clearly, the optimal situation is not attained. Rather, it is quite likely that Congress does not attempt to identify the lag between research activity and extension activity in the preponderance of cases. Congressional determination of the level of extension expenditures in any given year does not presuppose consideration of or even knowledge of the level of research activity in some earlier year. It does not seem unreasonable to conclude that Marschak's meta-decider in this instance fails to recognize the jointness of demand for the symbol-manipulating services. The assumption that economic considerations of the length of the lag between production-oriented research and extension activities are built into public sector expenditures on these activities in any given year must be considered tenuous at best.

It can therefore be argued that extension expenditures lag research expenditures just as extension activities lag research activities. The problem is that the length of this lag is unknown unless one is dealing with a specific research activity. However, instead of thinking in terms of an expenditure on a specific research activity and the time form of its life, consider that total public sector expenditures on research in any given year finance a wide variety of specific activities. Some of these activities will be at an early stage in the inquiry lag. Some will be quite mature. Still others will be somewhere in between. In this case, the inquiry lag is not a fixed lag but some distribution. This move to the aggregate enables one to view the process of technological change as one of continuous, small improvements in the state of the industrial arts as they relate to agriculture. It follows that aggregate research activity in a given period will yield extendable information in the following period. Therefore, it is assumed in this study that a dose of R in time t can be constructed by combining research expenditures in the previous year with extension expenditures in the current year:[1]

$$R_t = (\text{Research Expenditures})_{t-1} + (\text{Extension Expenditures})_t. \qquad (4.4)$$

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[1] It is doubtful that this formulation of an observation on R will appreciably alter the results obtained by assuming that Equation (4.3) holds. The aggregate nature of this study and others like it makes the construction of observations on R under any assumption a candidate for measurement errors in the variable. As long as the flow of expenditures over time exhibits relatively narrow variations, however, the consequences of such an error will not be too severe.

Specification of the Weather Variable

The weather variable enters Equation (4.1) in exponential form. Since this specification is somewhat out of the ordinary, an explanation of the thinking behind it is in order.

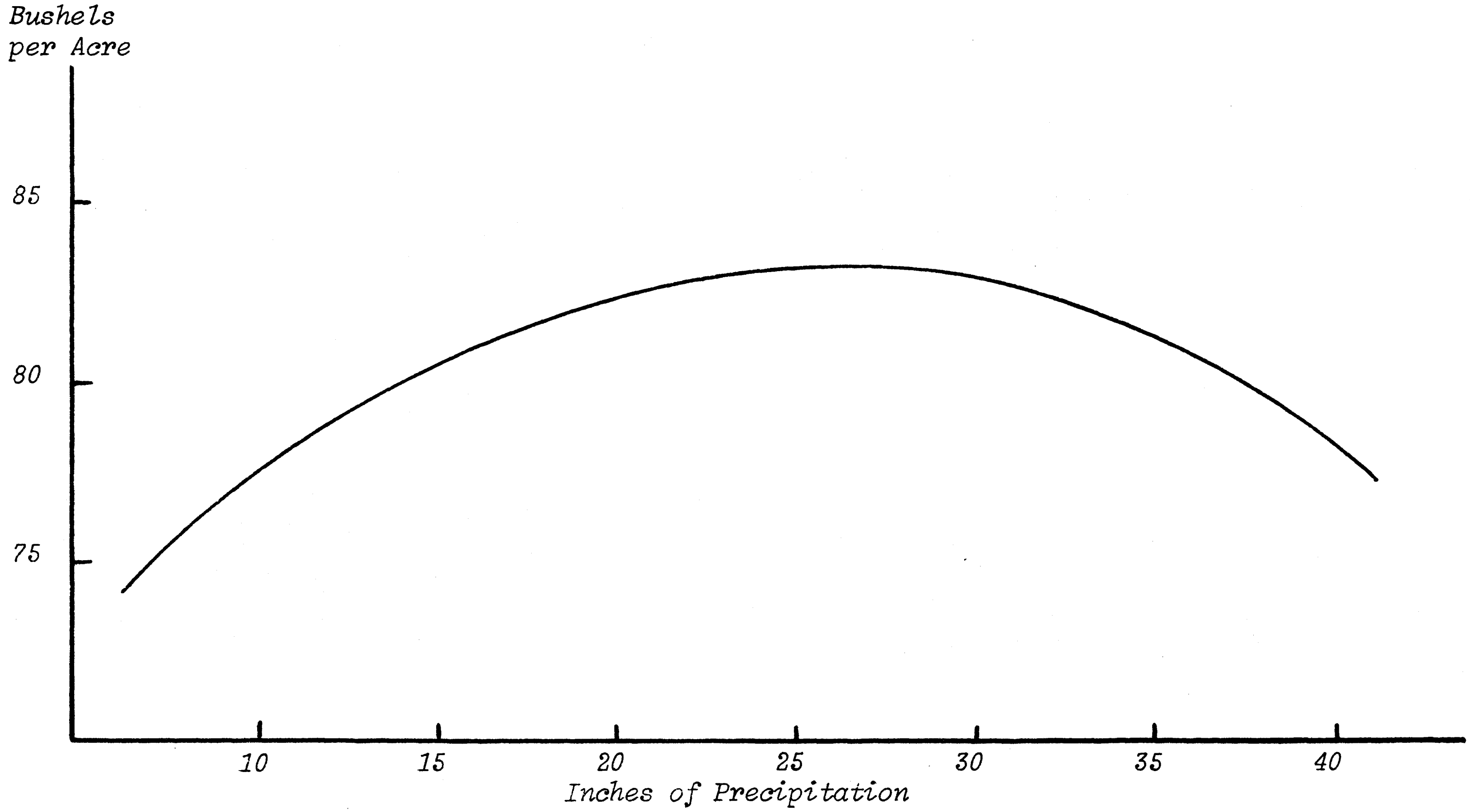
In a study of the response of grain yeilds to weather variables, Thompson (61) found that the relationship is a curvilinear one. As an example of this relationship, consider Figure 6 in which is shown an adaptation of Thompson's findings on the response of corn to preseason precipitation in the U. S. Corn Belt. The relationship is such that rainfall in any given period may be too high or low for optimum growth of corn. The same can be said for temperature.

The approximate quantities associated with Figure 6 are reproduced in the first two columns of Table IV. Inches of precipitation is converted to a weather index and shown in the third column in order to reflect the weather variable used in the present study; the highest value of the weather index occurs at the optimum level of precipitation. From this information, one can derive the elasticity of yield with respect to the weather index. As shown in column four, the value of this elasticity is not constant.

This nonconstancy of the elasticity of productivity with respect to changes in the weather index has important implications for the manner in which the weather index is specified in the productivity change model. Suppose the relationship is specified as

$$Y = x^{\beta} \text{ where } \beta \text{ is a constant.} \tag{4.5}$$

The elasticity of y with respect to x is defined as (x/y) (dy/dx). For Equation (4.5), this calculation yields an elasticity $(x/x^{\beta})\ \beta x^{\beta-1} = \beta$.



Source: Louis Thompson (61, p. 13).

Figure 6. The Average Response of Corn to Preseason Rainfall in Five Corn Belt States

Since β is a constant, a specification such as that of Equation (4.5) implies a constant elasticity between y and x.

TABLE IV

THE ELASTICITY OF CORN YIELD WITH RESPECT TO WEATHER

Bushels Per Acre	Inches of Precipitation	Weather Index[a]	Elasticity[b]
77.5	15	105	
79.0	20	120	.1354
81.1	25	125	.6380
80.9	30	120	.0616
79.0	35	105	.1879

[a] Calculated by assuming the weather index and inches of precipitation obey the following relationship: $WI = 10I - .2I^2$, where WI is the value of the weather index and I is the value of inches of precipitation.

[b] Elasticity equals the percentage change in bushels per acre divided by the percentage change in the weather index. For instance, the the elasticity in going from 15 to 20 inches of precipitation is calculated as [(79.0 - 77.5)/77.5]/[(120-105)/105].

Suppose, on the other hand, the relationship is specified as

$$y = e^{\beta x}. \tag{4.6}$$

Then the elasticity of y with respect to x is $(x/e^{\beta x})\beta e^{\beta x} = \beta x$. That is, the elasticity varies with the value of x. Since this behavior is consistent with Thompson's findings regarding the relationship between weather variables and yield, the weather variable in the present study is specified in the form of Equation (4.6).

The Estimating Equation

To estimate the parameters of Equation (4.1), a logarithmic transformation is performed:

$$\ln P_t = \sum_{i=0}^{n} \beta_i \ln R_{t-i} + \beta_{n+1} \ln O_t + \beta_{n+2} \ln E_t + \beta_{n+3} \ln W_t + U_t \qquad (4.7)$$

where U_t is the disturbance term. The parameters of (4.7) could be estimated directly using ordinary least squares. However, this method of estimation is subject to several difficulties. First, the length of the production-oriented research and extension lag is unknown. Attempts to determine the lag length from the data by fitting a long lag and then examining the significance of the coefficients are destined to be unsuccessful because the various lagged values of R will be highly intercorrelated. This in turn leads to imprecise estimates of the lagged coefficients and makes inferences about them difficult to draw. Second, one of the crucial assumptions of the ordinary least squares procedure is that of zero covariance for the disturbance terms. This assumption is likely to be violated if Equation (4.7) is estimated directly, given the time series data which is employed in this study to estimate the length of the lag associated with R. The techniques used to overcome these difficulties are discussed below.

Calculation of the Distributed Lag Coefficients

To begin this discussion on the calculation of the distributed lag coefficients, a quotation by R. Bellmon (5) seems quite appropriate:

> The fault of so many mathematical studies of this type is not so much in sinning as in the lack of realization that one is sinning, or even a lack of acknowledgement of any conceivable type of sin. (p. 15)

The purpose of this section is to confess the sins associated with the use of the particular distributed lag technique employed in this paper and the means by which the absolution of those sins was sought.

Consider the simple distributed lag model,

$$y_t = w_o x_t + w_1 x_{t-1} + \dots + w_n x_{t-n} + e_t \tag{4.8}$$

where y_t is the value of the dependent variable y at time t; $x_t, x_{t-1}, \dots, x_{t-n}$ are the values of the explanatory variable x at times t, t-1, ..., t-n; and e_t is the value of the disturbance e at time t. As indicated above, the distributed lag coefficients, or "weights", w_i can be estimated by ordinary least squares. However, it may be felt that the least squares estimates are not sufficiently precise since it will often be the case that there exists a high degree of multicollinearity in the explanatory variables $x_t, x_{t-1}, \dots, x_{t-n}$. A solution to this problem is to introduce a priori information into the estimation procedure by imposing restrictions on the weights.

Typically, this a priori information is drawn from the theory underlying the estimating equation. For the case at hand, it is clear from the theoretical framework developed in Chapter III that the weights lie on a polynomial. In 1965, Almon (3) introduced a technique for estimating the weights of a distributed lag by means of a polynomial specification. This is the lag technique employed in the present study.

The essence of the Almon lag technique is to estimate the distributed lag model shown in Equation (4.8) subject to the restriction that the weights lie on a polynomial of degree p. It is assumed that there exist parameters $\alpha_0, \alpha_1, \ldots, \alpha_p$ such that

$$w_i = \alpha_0 + \alpha_1 i + \alpha_2 i^2 + \ldots + \alpha_p i^p, \qquad (4.9)$$
$$i = 0, 1, \ldots, n; \; p \leq n.$$

This reduces the number of parameters to be estimated from n+1 to p+1. The procedure for estimating the α parameters and transforming these into estimates of the original weights is explained in several sources, including Johnston (28).

Once the decision to use the Almon technique has been made, the user has implicitly answered two questions. Hopefully, these answers are based upon theoretical considerations. First, he has committed himself to the proposition that there is indeed a lag present. The presence or absence of a lag cannot be tested by the Almon lag technique since the nature of the technique is to "smear" the contemporaneous influence back through time (52, p. 12). Second, he has restricted the weights to lie on a polynomial of degree $p < n$; a restriction which, if true, will lead to estimates that are unbiased, consistent, and more efficient than the least squares estimates. If, on the other hand, the a priori restriction is not true, the Almon lag technique will produce estimates which are generally inferior to those yielded by the least squares estimation of Equation (4.8).

The theoretical framework developed in Chapter III lends specific a priori information about the form of the distributed lag weights which suggests that the Almon lag technique is appropriate for analyzing the production-oriented research and extension lag. In applying this method one also must select (a) the appropriate length of the lag, (b) the appropriate degree of the polynomial, and (c) the endpoint restrictions to be imposed on the sequence w_i. In this study, these choices were based upon the theory and statistical criteria.

The choice of the length of the lag is extremely touchy in the Almon specification. Understatement or overstatement of the length is a specification error which can lead to biased and inconsistent estimates and invalid tests. The theory of Chapter III regarding the lag does not yield a priori information on its length. One procedure commonly used is to terminate the lag at the point where the next distributed lag coefficient is not statistically significant from zero. This procedure has several deficiencies. It is possible to obtain statistically significant coefficients in periods beyond this termination point. Also, the choice of a lag length cannot be made on the basis of t-tests since these tests are invalid when the lag length has not been chosen correctly (52, p. 13). The alternative procedure used in the present study was to try a number of different lag lengths with the final choice based upon Theil's $\bar{R}^2$ (minimum standard error) criterion (60).

The choice of the degree of the polynomial is also important. Fortunately, the theory of the production-oriented research and extension lag gives a clear indication of the appropriate degree; one would expect the weights to lie on a second degree polynomial.[2] Higher order polynomials yield weights that oscillate in sign; a characteristic

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[2] In the course of estimating the distributed lag coefficients, third and fourth degree polynomials were also specified. The second degree polynomial, however, consistently yielded estimates that exhibited lower standard errors and were more in keeping with the theory developed in Chapter III.

which is not in keeping with the *a priori* information available. There are undoubtedly isolated instances where early adopters of a new technology have suffered decreases in productivity in the early going, however, it is most difficult to imagine a situation where the overall contribution of a dose of production-oriented research and extension expenditures to aggregate agricultural productivity would be less than zero.

Almon suggests that the "endpoint" constraints $w_{-1} = w_{n+1} = 0$ (or, what is the same idea, $w_0 = w_n \cong 0$) should always be imposed. That this is the case is not at all clear. Trivedi (64) and others have shown that in many cases the imposition of endpoint restrictions causes substantial biases. Essentially, as with other restrictions, their imposition increases the efficiency of estimation if the restrictions are true, and it leads to biased and inconsistent estimates if the restrictions are false. Therefore, they should not be applied as a routine matter. Rather, the equation should be estimated both with and without the endpoint constraints so that a choice between the constrained and unconstrained versions can be made on the basis of some explicit criterion (52, p. 13). This is the procedure followed in the present study. The classical F test designed in such a manner as to test the truth or falsity of the hypothesis that the endpoints are zero is the criterion employed.[3]

One final point about the Almon lag technique should be made before leaving the subject. Almon's original approach utilized Lagrangian

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[3] See Carlos Toro-Vizcarrondo and T. D. Wallace (63) for an explanation of the appropriate test statistic.

interpolation polynomials. However, according to Cooper (12),

> . . . because of a simpler exposition and lack of general understanding among economists and economics students alike of the nature of Lagrangian interpolation techniques, a direct, polynomial approximation approach is gradually being adopted in the classroom and in computer programs. (p. 32)

As Cooper demonstrates, the direct approach can be hampered by multicollinearity in the transformed variables. In view of this, the original Almon approach is utilized in this study.

Covariance of the Disturbance Terms

As pointed out above, there are circumstances in which the assumption of a serially independent disturbance term may not be very plausible. Fortunately, there are tests available that allow one to test for the presence of autocorrelated disturbances. The Durbin-Watson "d" statistic has become an accepted small-sample test and it is employed in this study.

As shall be seen in the next chapter, autocorrelation was in fact found to be a problem in estimating Equation (4.7). In order to obtain a more amenable estimation problem, it is assumed that the disturbance term U_t in Equation (4.7) follows a first-order autoregressive scheme. The estimating equation is transformed into

$$\begin{aligned} \ln P_t - \rho \ln P_{t-1} = {} & \sum_{i=0}^{n} \beta_i (\ln R_{t-i} - R_{t-i-1}) \\ & + \beta_{n+1} (\ln O_t - \rho \ln O_{t-1}) \\ & + \beta_{n+2} (\ln E_t - \rho \ln E_{t-1}) \\ & + \beta_{n+3} (W_t - \rho W_{t-1}) + e_t \end{aligned} \qquad (4.10)$$

where $e_t = U_t - \rho U_{t-1}$. Durbin's (15) two-stage procedure was employed to estimate the ρ parameter. According to Johnston (28, p. 265), this method yields estimators that are preferable to ordinary least squares, Cochrane-Orcutt, Prais-Winsten, and nonlinear estimators.

Having established a theoretical and empirical framework to guide the investigation, the results of their applications are considered in the next two chapters.

CHAPTER V

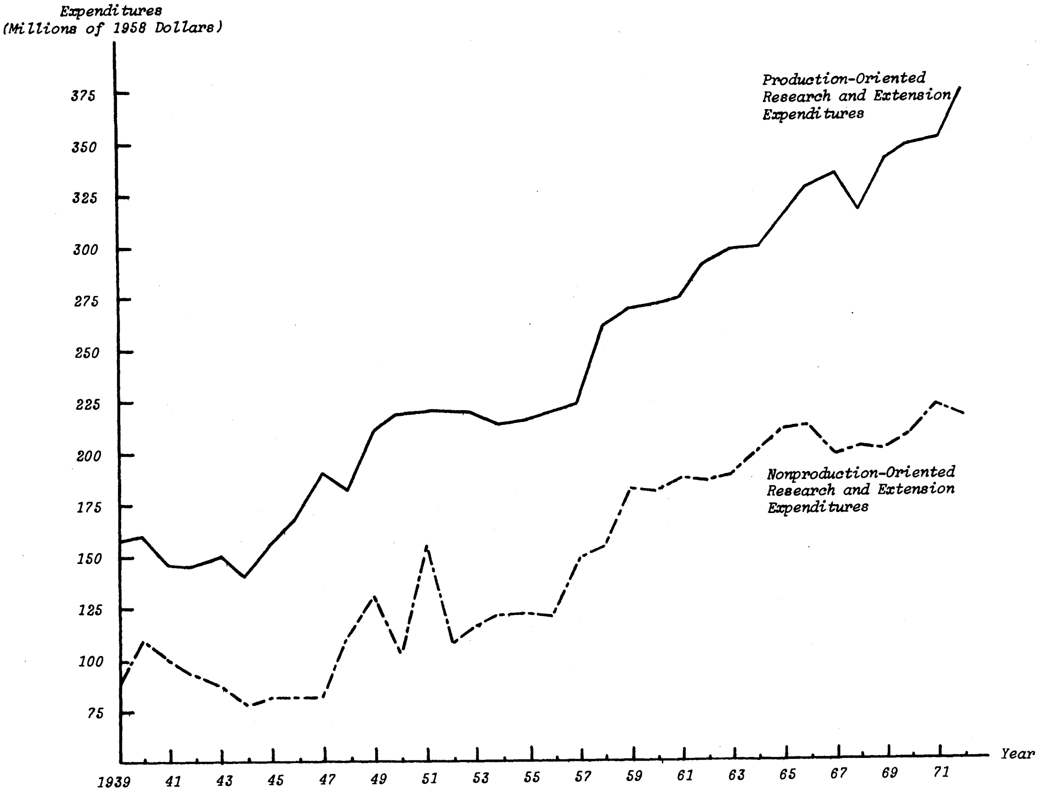
ESTIMATES OF THE FORM OF THE TIME LAG AND THE CONTRIBUTION OF RESEARCH AND EXTENSION TO AGRICULTURAL PRODUCTIVITY

Trends in the Original Data

To estimate the relationship shown in Equation (4.10), data on production-oriented research and extension expenditures, agricultural productivity, nonproduction-oriented research and extension expenditures, weather, and education variables for the 1939 to 1972 period were collected. In this section, long-run movements of these variables are analyzed.

For the period 1939 to 1972, all variables except weather exhibit strong secular upward trends (see Figure 7). The productivity index (P) and the index of educational attainment among farmers and farm workers (E) grew at annual average rates of 1.71 percent and 1.61 percent, respectively. Production-oriented research and extension expenditures (R) and nonproduction-oriented research and extension expenditures (O) increased at higher average rates of 2.98 percent and 3.32 percent per annum, respectively.

Because of the strong secular trends in the time series data for three of the variables that are proposed to explain the behavior of productivity over time (E, O, and R), the simple correlations between them are quite high (see Table V). Only the weather variable exhibits a



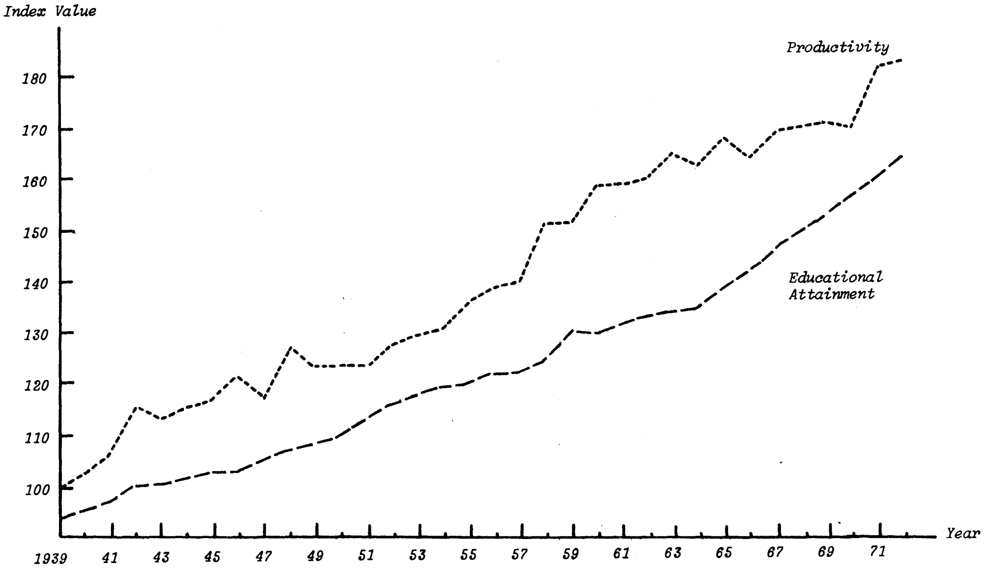


Figure 7. Long-run Movements of Education, Productivity, Production-Oriented Research and Extension, and Nonproduction-Oriented Research and Extension

rather low correlation with the other explanatory variables. A more generally reliable guide to the degree of collinearity between the explanatory variables has been suggested by Farrar and Glauber (19). Specifically, they suggest a consideration of the coefficient of multiple determination between each explanatory variable and the remaining explanatory variables. As shown in Table VI, this test also indicates that there exists a strong linear dependence between the explanatory variables. This means that use of the data in its original form in regression analysis would violate one of the basic assumptions of the general linear model; namely, that of no linear dependence between the explanatory variables.

TABLE V

SIMPLE PEARSON CORRELATION COEFFICIENTS BETWEEN PRODUCTION-ORIENTED RESEARCH AND EXTENSION (R), NONPRODUCTION-ORIENTED RESEARCH AND EXTENSION (O), EDUCATION (E), AND WEATHER (W) VARIABLES, 1939-1972

	R	O	E	W
R	1.0000	0.9557	0.9786	0.0585
O		1.0000	0.9236	0.0933
E			1.0000	0.0802
W				1.0000

TABLE VI

COEFFICIENTS OF MULTIPLE DETERMINATION BETWEEN EACH EXPLANATORY VARIABLE AND THE REMAINING EXPLANATORY VARIABLES; ORIGINAL DATA

Regression Equation	R^2
$R_t = \alpha + \beta_1 E_t + \beta_2 O_t + \beta_3 W_t$	0.977
$E_t = \alpha + \beta_1 R_t + \beta_2 O_t + \beta_3 W_t$	0.960
$O_t = \alpha + \beta_1 R_t + \beta_2 E_t + \beta_3 W_t$	0.919

As might be expected, the variables exhibit little variation about their respective means. The coefficient of variation for production-oriented research and extension expenditures is only 4.70 percent.[1] It is slightly smaller for the education index, 3.44 percent, and somewhat larger for nonproduction-oriented research and extension expenditures, 10.17 percent.

Transformation of the Data and the Final Fitted Relationship

The productivity change model was specified in Equation (4.1) as

$$P_t = \prod_{i=0}^{n} R_{t-i}^{\beta_i} \, O^{\beta_{n+1}} \, E^{\beta_{n+2}} \, e^{\beta_{n+3} W_t}.$$

---

[1] The coefficient of variation of a variable is equal to the standard deviation of the variable divided by its mean.

It was pointed out in Chapter IV that a common practice is to use ordinary least squares to fit this equation to time series data in the natural logarithmic form:

$$\ln P_t = \sum_{i=0}^{n} \beta_i \ln R_{t-i} + \beta_{n+1} \ln O_t + \beta_{n+2} \ln E_t + \beta_{n+3} W_t + U_t \tag{5.1}$$

where U_t is the disturbance term. However, it was further suggested that this procedure often violates two basic assumptions of the ordinary least squares estimating procedure (27, p. 11). These violations alter the properties of the estimated coefficients. The most serious violation is the lack of independence of the disturbance terms, which arises from the correlation between time periods of the values of excluded variables. Although the estimated coefficients are unbiased, they are no longer the minimum variance estimators. This renders tests of hypotheses invalid that are performed under the assumption that the disturbances are independent. The second violation concerns high correlations between the independent variables which, in the preceding section, were demonstrated to exist. As a result of this violation, multicollinearity becomes potentially serious which in turn produces least-squares estimators with usually large variances.

To test whether these potential problems are in fact significant for the present study, Equation (5.1) was fitted to the data. Both second and third degree polynomials were employed and the length of the lag associated with the R variable was allowed to vary from 3 to 24 years. In most cases, the Durbin-Watson small sample test for autocorrelation was inconclusive at the five percent level of significance. In those instances where the test was not inconclusive, the hypothesis of non-autocorrelated disturbance terms was rejected at the five percent level in favor of the hypothesis of positive autocorrelation. In addition, the estimated coefficients exhibited behavior normally associated with a high degree of multicollinearity. Estimates of coefficients were quite sensitive to particular sets of data. For instance, the coefficient associated with the education variable ranged from -.074 to 1.22, while that associated with nonproduction-oriented research and extension expenditures varied from .032 to .204. For these reasons, Equation (5.1) was rejected as an acceptable relationship for estimating the contributions of the explanatory variables to agricultural productivity.

An alternative form of Equation (4.1), which totally eliminates the time trend from the data and substantially reduces the correlation of the model's disturbance terms and of the explanatory variables, is obtained by taking first differences of Equation (5.1):

$$\begin{aligned}\ln P_t - \ln P_{t-1} &= \sum_{i=0}^{n} \beta_i(\ln R_{t-i} - \ln R_{t-i-1}) + \beta_{n+1}(\ln O_t - \ln O_{t-1}) \\ &\quad + \beta_{n+2}(\ln E_t - \ln E_{t-1}) + \beta_{n+3}(W_t - W_{t-1}) + e_t \qquad (5.2)\end{aligned}$$

where $e_t = U_t - U_{t-1}$.

This procedure yields a linear approximation of $\frac{d \ln P_t}{dt}$ in discrete time. That is, $\frac{d \ln P_t}{dt} = \frac{1}{P_t} \frac{dP_t}{dt} \simeq \Delta \ln P_t$ for small changes.

This specification of the model incorporates the implicit assumption that the first-order autocorrelation coefficient of the U series is equal to one. To illustrate this, consider the simple model below:

$$Y_t = X_t^{\beta} e^{\mu_t} \qquad t = i, \ldots, n \qquad (5.3)$$

$$\mu_t = \rho\mu_{t-1} + \epsilon_t \qquad (5.4)$$

where ρ is the first-order autocorrelation coefficient, $|\rho| \leq 1$, and ε_t satisfies the assumptions $E(\varepsilon_t) = 0$ and $E(\varepsilon_t \varepsilon_{t+s}) = \sigma_\varepsilon^2$ when $s = 0$ and $E(\varepsilon_t \varepsilon_{t+s}) = 0$ when $s \neq 0$ for all t. From Equation (5.3) it follows that

$$\ln Y_t = \beta \ln X_t + \mu_t \tag{5.5}$$

and

$$\mu_{t-1} = \ln Y_{t-1} - \beta \ln X_{t-1}. \tag{5.6}$$

Combining Equations (5.4) - (5.6) yields the following relationship:

$$\ln Y_t = \beta \ln X_t + \rho\ (\ln Y_{t-1} - \beta \ln X_{t-1}) + \varepsilon_t \tag{5.7}$$

or

$$\ln Y_t - \rho \ln Y_{t-1} = \beta\ (\ln X_t - \rho \ln X_{t-1}) + \varepsilon_t. \tag{5.8}$$

It is apparent from Equation (5.8) that if $\rho = 1$, the model reduces to a log first difference model such as shown in Equation (5.2). The conclusion to be drawn from this analysis is that one should not specify a log first difference model without some _a priori_ reason for believing that the disturbance terms of the model exhibit near perfect first-order autocorrelation. By the same line of reasoning, if $\rho = 0$, Equation (5.8) reduces to the log linear model specified in Equation (5.1). These alternative assumptions about the degree of autocorrelation of the disturbances represent two extreme cases. Given the serious consequences of misspecifying ρ, neither assumption should be made without prior knowledge of this parameter or at least attempting to estimate its size in order to determine if it is in fact reasonably close to 0 or 1.

As indicated in Chapter IV, the Durbin two-stage procedure was employed in the present study to estimate the autocorrelation parameter. The model specified in Equation (4.10) and reproduced below was estimated assuming that the lag associated with production-oriented research and extension expenditures follows a second degree polynomial.

$$\begin{aligned} \ln P_t - \rho \ln P_{t-1} = {} & \sum_{i=0}^{n} \beta_i (\ln R_{t-i} - \rho \ln R_{t-i-1}) \\ & + \beta_{n+1} (\ln O_t - \rho \ln O_{t-1}) \\ & + \beta_{n+2} (\ln E_t - \rho \ln E_{t-1}) \\ & + \beta_{n+3} (W_t - W_{t-1}) + e_t \end{aligned}$$

where $e_t = U_t - \rho U_{t-1}$. Various lag lengths ranging from 7 through 16 years were estimated for both the case when no endpoint constraints were imposed and also the case when the endpoints were constrained to approximately equal zero. These estimations produced estimated first-order autocorrelation coefficients which ranged in size from .52 to .65. In most cases, the Durbin-Watson small sample test for autocorrelation resulted in rejection of the hypothesis of positively autocorrelated disturbance terms at the five percent level of significance. In all other cases, the test was inconclusive. Based upon the size of the $\hat{\rho}$'s and the above test results, both the log linear model (Equation (5.1)) and the log first difference model (Equation (5.2)) were discarded in favor of the first-order autoregression model specified in Equation (4.10).

Not only did the autoregression model alleviate the problem of autocorrelation of the disturbance terms, it also greatly decreased the collinearity between the explanatory variables. As shown in Table VI, the smallest coefficient of multiple determination between each explanatory variable and the remaining explanatory variables yielded by the original data was 0.919. When the data was transformed according to the specification shown in Equation (4.10), the regression results indicate that the degree of multicollinearity has been reduced substantially, although perhaps not as much as one would like (see Table VII). The coefficient of multiple determination between the education index and the other explanatory variables is still large enough (0.65) to perhaps cause the precision of estimation to fall. The stability of the coefficients across different sets of data (different lag lengths), however, leads one to conclude that multicollinearity is no longer a serious problem.

TABLE VII

COEFFICIENTS OF MULTIPLE DETERMINATION BETWEEN EACH EXPLANATORY VARIABLE AND THE REMAINING EXPLANATORY VARIABLES; TRANSFORMED DATA[a]

Dependent Variable	R^2
$\sum_{i=0}^{n} (\ln R_{t-i} - \hat{\rho} \ln R_{t-i-1})$	0.575
$(\ln E_t - \hat{\rho} \ln E_{t-1})$	0.655
$(\ln O_t - \hat{\rho} \ln O_{t-1})$	0.468

[a] Transformed according to Equation (4.10). The value of $\hat{\rho}$ was assumed to equal 0.60 for the purpose of this Farrar-Glauber test.

Another observation emerging from the estimation of the autoregression model was that the regression coefficient of nonproduction-oriented research and extension expenditures was never significantly different from zero even at the fifteen percent level. Therefore, this variable was dropped from Equation (4.10) and the parameters reestimated. This exclusion produced almost no change in the coefficient of multiple determination adjusted for degrees of freedom and only minor changes in the size and statistical significance of the other explanatory variables (see Table VIII). It is therefore concluded that nonproduction-oriented research and extension expenditures do not significantly contribute to changes in agricultural productivity.

One final conclusion to be drawn from the estimations of the autoregression models concerns the appropriateness of the imposition of endpoint constraints on the lag weights associated with production-oriented research and extension expenditures, i.e., the restriction that the two endpoints of the lag must approximately equal zero. The distributed lag weights generated by the unrestricted (no endpoint constraints) autoregression model with 0 excluded do not entirely conform to the theoretical framework developed in Chapter III. Specifically, the coefficients generated by this model include negative weights, implying that the contribution of production-oriented research and extension expenditures to agricultural productivity is negative over part of its lifetime (see Figure 8). In view of this, Equation (4.10) with 0 excluded was also estimated under the assumption that the endpoints of the time form are approximately equal to zero. The "best" lag length (minimum standard error of estimate) for both the unrestricted and the restricted model was then identified (13 years in both cases) and the

TABLE VIII

THE IMPACT OF EXCLUDING NONPRODUCTION-ORIENTED RESEARCH AND EXTENSION EXPENDITURES FROM THE ESTIMATING EQUATION[a]

Explanatory Variable	Results When O is Included in the Model	Results When O is Excluded from the Model
$\ln O_t - \rho \ln O_{t-1}$	0.0005	
	(0.0165)	
$\ln E_t - \rho \ln E_{t-1}$	0.7527	0.7599
	(3.1888)	(3.2205)
$W_t - \rho W_{t-1}$	0.0019	0.0019
	(3.5946)	(3.7988)
$R_t - \rho R_{t-1}$	0.0635	0.0617
$R_{t-1} - \rho R_{t-2}$	0.0605	0.0586
$R_{t-2} - \rho R_{t-3}$	0.0559	0.0540
$R_{t-3} - \rho R_{t-4}$	0.0498	0.0479
$R_{t-4} - \rho R_{t-5}$	0.0422	0.0405
$R_{t-5} - \rho R_{t-6}$	0.0331	0.0316
$R_{t-6} - \rho R_{t-7}$	0.0224	0.0213
$R_{t-7} - \rho R_{t-8}$	0.0102	0.0095
$R_{t-8} - \rho R_{t-9}$	-0.0035	-0.0037
$R_{t-9} - \rho R_{t-10}$	-0.0188	-0.0183
$R_{t-10} - \rho R_{t-11}$	-0.0356	-0.0344
$R_{t-11} - \rho R_{t-12}$	-0.0539	-0.0519
$R_{t-12} - \rho R_{t-13}$	-0.0737	-0.0709
$R_{t-13} - \rho R_{t-14}$	-0.0951	-0.0913
$\sum_{i=0}^{n} \beta_i$[b]	0.0573	0.0546
$\bar{R}^2$	0.9998	0.9998
SEE[c]	0.02171	0.02109
DW[d]	1.68	1.76
ρ[e]	0.63	0.66

---

[a] The minimum standard error of the estimate criterion was used to select the most appropriate lag length for the R variable from the set of autoregression models estimated under the imposition of no endpoint constraints. As inferred by the above table, this length was determined to be 13 years in both those models which included and those which excluded the O variable. Numbers in parentheses are t-values.

[b] A joint F test of the null hypothesis that all the regression coefficients for the R's are equal to zero was rejected at the one percent level of significance.

[c] Standard error of the estimate.

[d] Durbin-Watson "d" statistic.

[e] The estimated value of the first-order autoregression coefficient of the disturbances.

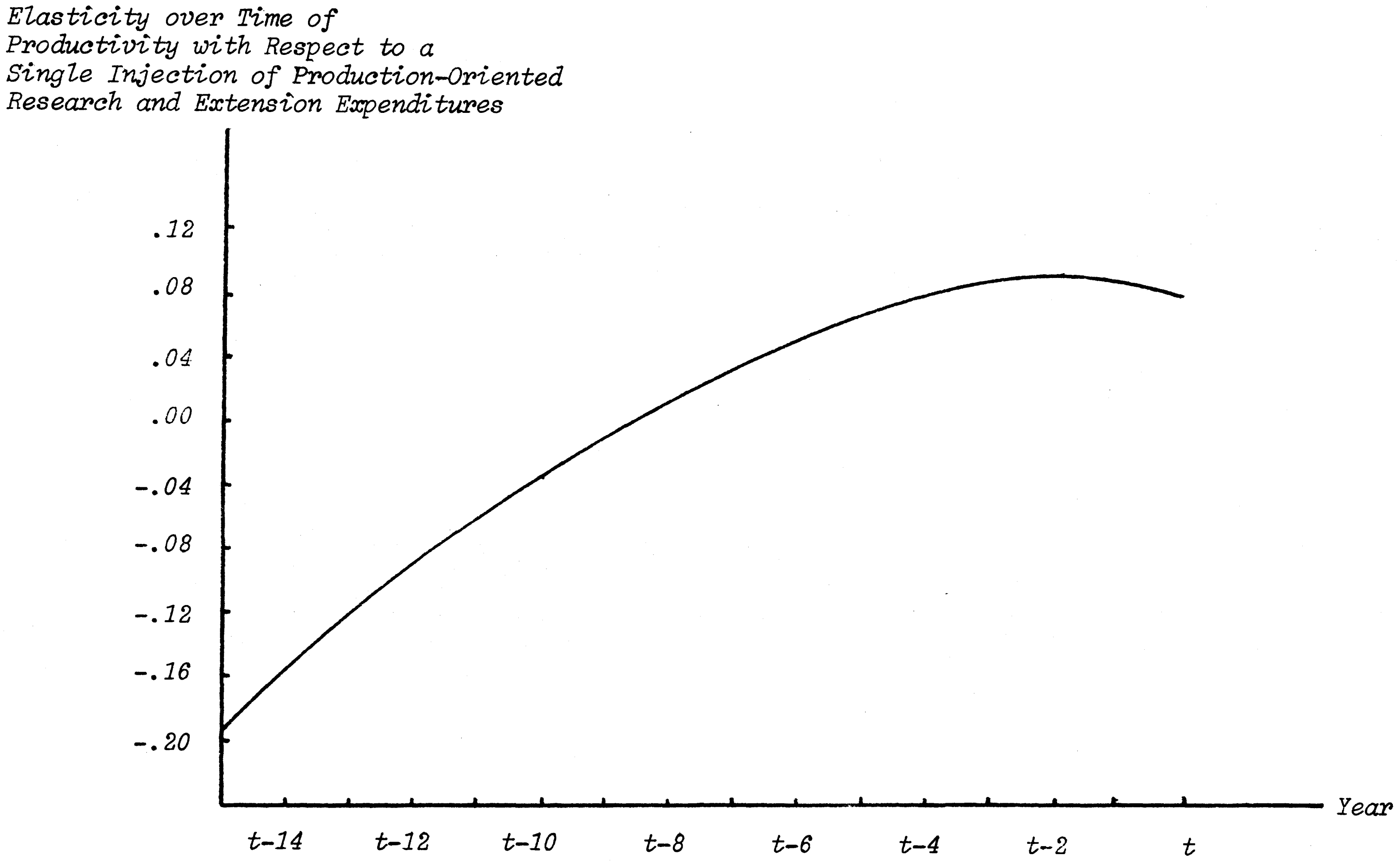


Figure 8. Time Form of the Contribution of Research and Extension to Agricultural Productivity in the United States; Estimation Based on Equation (4.10) Assuming No Endpoint Constraints

appropriateness of the endpoint constraints was tested using the following F statistic:

$$F_{m,\ T-K} = \frac{SSE(\hat{\beta}) - SSE(b)}{m} \div \frac{SSE(b)}{T-K}$$

where $SSE(\hat{\beta})$ is the calculated error sum of squares obtained by estimating the restricted autoregression model; SSE(b) is the calculated error sum of squares from the unrestricted model; m is the dimension of the array of endpoint constraints; T is the number of observations, and K is the number of independent variables.[2] The null hypothesis that the endpoint constraints are appropriate was not rejected on the basis of this test; the calculated F value was only 0.085, far below the appropriate critical point of the F distribution at the one percent level of significance.

It is meaningful that the standard error of the estimate yielded by the restricted model was for every respective lag length lower than that obtained by estimating the unrestricted model. For the "best" lag length of 13 years, the standard error of the estimate for the restricted model was 0.0204 as compared to 0.0211 for the unrestricted model. Given this, along with the results of the F test performed above, it is concluded that more reliable structural estimates are obtained from adoption of the restriction that the endpoints of the distributed lag weights associated with production-oriented research and extension expenditures are approximately equal to zero.

The final form of the estimating equation is therefore shown in

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[2] This test is described in Carlos Toro-Vizcarrondo and T. D. Wallace (63, p. 559).

Equation (5.9):

$$\begin{aligned} \ln P_t - \hat{\rho} \ln P_{t-1} = &\sum_{i=0}^{n} \beta_i (\ln R_{t-i} - \hat{\rho} \ln R_{t-i-1}) \\ &+ \beta_{n+1} (\ln E_t - \hat{\rho} \ln E_{t-1}) \qquad (5.9) \\ &+ \beta_{n+2} (W_t - \hat{\rho} W_{t-1}) + e_t \end{aligned}$$

where it is assumed that $\beta_o = \beta_n \approx 0$. The results of estimating this equation for the U. S. are considered in the next section.

Results from the National Data and Their Interpretation

The results from fitting Equation (5.9) to annual national data for the 1939 to 1972 period are reported in Table IX. The length of the lag associated with production-oriented research and extension expenditures was varied from 7 through 16 years and the degree of the polynomial by which the distributed lag weights were constrained was two in all cases. The coefficients of multiple determination are all quite high and the Durbin-Watson "d" statistics all indicate that positive autocorrelation is not a significant problem.

Recall that the criterion by which the "best" lag is to be selected is that lag with the smallest standard error of estimate. This statistic steadily declines as the lag length is increased, reaches a minimum at a length of 13 years, and increases thereafter. Therefore, it is concluded that a "dose" of production-oriented research and extension expenditures injected in year t will affect agricultural productivity in year t and continue to affect it for the following 13 years. From Figure 9, it can be seen that the hypothesized time form of a dose of expenditures is exhibited by the distributed lag weights generated by

TABLE IX

EQUATION (5.9) REGRESSION RESULTS: UNITED STATES DATA[a]

Explanatory Variable	Lag Length (number of years)				
	7	8	9	10	11
$\ln E_t - \hat{\rho} \ln E_{t-1}$	0.8387	0.8340	0.8393	0.8209	0.7856
	(4.9936)	(4.5962)	(4.2950)	(3.9249)	(3.1705)
$W_t - \hat{\rho} W_{t-1}$	0.0018	0.0018	0.0018	0.0018	0.0019
	(4.0466)	(4.0744)	(4.0980)	(4.1122)	(4.3277)
$R_t - \hat{\rho} R_{t-1}$	0.0012	0.0011	0.0008	0.0006	0.0013
$R_{t-1} - \hat{\rho} R_{t-2}$	0.0021	0.0019	0.0014	0.0017	0.0023
$R_{t-2} - \hat{\rho} R_{t-3}$	0.0027	0.0025	0.0019	0.0023	0.0031
$R_{t-3} - \hat{\rho} R_{t-4}$	0.0030	0.0029	0.0022	0.0028	0.0038
$R_{t-4} - \hat{\rho} R_{t-5}$	0.0030	0.0030	0.0024	0.0030	0.0042
$R_{t-5} - \hat{\rho} R_{t-6}$	0.0027	0.0029	0.0024	0.0031	0.0044
$R_{t-6} - \hat{\rho} R_{t-7}$	0.0021	0.0025	0.0022	0.0030	0.0044
$R_{t-7} - \hat{\rho} R_{t-8}$	0.0012	0.0019	0.0019	0.0028	0.0042
$R_{t-8} - \hat{\rho} R_{t-9}$		0.0011	0.0014	0.0023	0.0038
$R_{t-9} - \hat{\rho} R_{t-10}$			0.0008	0.0017	0.0031
$R_{t-10} - \hat{\rho} R_{t-11}$				0.0006	0.0023
$R_{t-11} - \hat{\rho} R_{t-12}$					0.0013
$R_{t-12} - \hat{\rho} R_{t-13}$					
$R_{t-13} - \hat{\rho} R_{t-14}$					
$R_{t-14} - \hat{\rho} R_{t-15}$					
$R_{t-15} - \hat{\rho} R_{t-16}$					
$R_{t-16} - \hat{\rho} R_{t-17}$					
$\sum_{i=0}^{n} \beta_i$[b]	0.0177	0.0196	0.0175	0.0249	0.0381
$\bar{R}^2$	0.999	0.999	0.999	0.999	0.999
SEE[c]	0.02194	0.02191	0.02190	0.02185	0.02184
DW[d]	2.25	2.27	2.31	2.34	2.39
$\hat{\rho}$[e]	0.729	0.735	0.745	0.756	0.819

TABLE IX (Continued)

Explanatory Variable	Lag Length (number of years)				
	12	13	14	15	16
$\ln E_t - \hat{\rho}\ln E_{t-1}$	0.7663	0.7851	0.7501	0.7493	0.7299
	(3.2118)	(3.0440)	(2.8138)	(2.6632)	(2.5554)
$W_t - \hat{\rho}W_{t-1}$	0.0021	0.0020	0.0020	0.0020	0.0020
	(4.7306)	(4.7337)	(4.4566)	(4.3708)	(4.3906)
$R_t - \hat{\rho}R_{t-1}$	0.0013	0.0009	0.0011	0.0010	0.0010
$R_{t-1} - \hat{\rho}R_{t-2}$	0.0023	0.0017	0.0021	0.0019	0.0020
$R_{t-2} - \hat{\rho}R_{t-3}$	0.0032	0.0024	0.0030	0.0027	0.0028
$R_{t-3} - \hat{\rho}R_{t-4}$	0.0039	0.0029	0.0036	0.0033	0.0034
$R_{t-4} - \hat{\rho}R_{t-5}$	0.0043	0.0033	0.0042	0.0038	0.0040
$R_{t-5} - \hat{\rho}R_{t-6}$	0.0046	0.0036	0.0045	0.0042	0.0044
$R_{t-6} - \hat{\rho}R_{t-7}$	0.0047	0.0037	0.0048	0.0045	0.0047
$R_{t-7} - \hat{\rho}R_{t-8}$	0.0046	0.0037	0.0049	0.0046	0.0049
$R_{t-8} - \hat{\rho}R_{t-9}$	0.0043	0.0036	0.0048	0.0046	0.0050
$R_{t-9} - \hat{\rho}R_{t-10}$	0.0039	0.0033	0.0045	0.0045	0.0049
$R_{t-10} - \hat{\rho}R_{t-11}$	0.0032	0.0029	0.0042	0.0042	0.0047
$R_{t-11} - \hat{\rho}R_{t-12}$	0.0023	0.0024	0.0036	0.0038	0.0044
$R_{t-12} - \hat{\rho}R_{t-13}$	0.0013	0.0017	0.0030	0.0033	0.0040
$R_{t-13} - \hat{\rho}R_{t-14}$		0.0009	0.0021	0.0027	0.0034
$R_{t-14} - \hat{\rho}R_{t-15}$			0.0011	0.0019	0.0028
$R_{t-15} - \hat{\rho}R_{t-16}$				0.0010	0.0020
$R_{t-16} - \hat{\rho}R_{t-17}$					0.0010
$\sum_{i=0}^{n} \beta_i$[b]	0.0438	0.0369	0.0515	0.0519	0.0595
$\bar{R}^2$	0.999	0.999	0.999	0.999	0.999
SEE[c]	0.02113	0.02036	0.02060	0.02101	0.02116
DW[d]	2.14	2.29	2.30	2.29	2.20
$\hat{\rho}$[e]	0.795	0.839	0.830	0.830	0.819

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[a] Numbers in parentheses are t values, all of which exceed the critical t value at the 2.5 percent level except that of the Pacific region.

[b] A joint F test for each region of the null hypothesis that all the regression coefficients for the R's are equal to zero was rejected at the one percent level of significance.

[c] Standard error of the estimate.

[d] Durbin-Watson "d" statistic.

[e] The estimated value of the first-order autoregression coefficient of the disturbances.

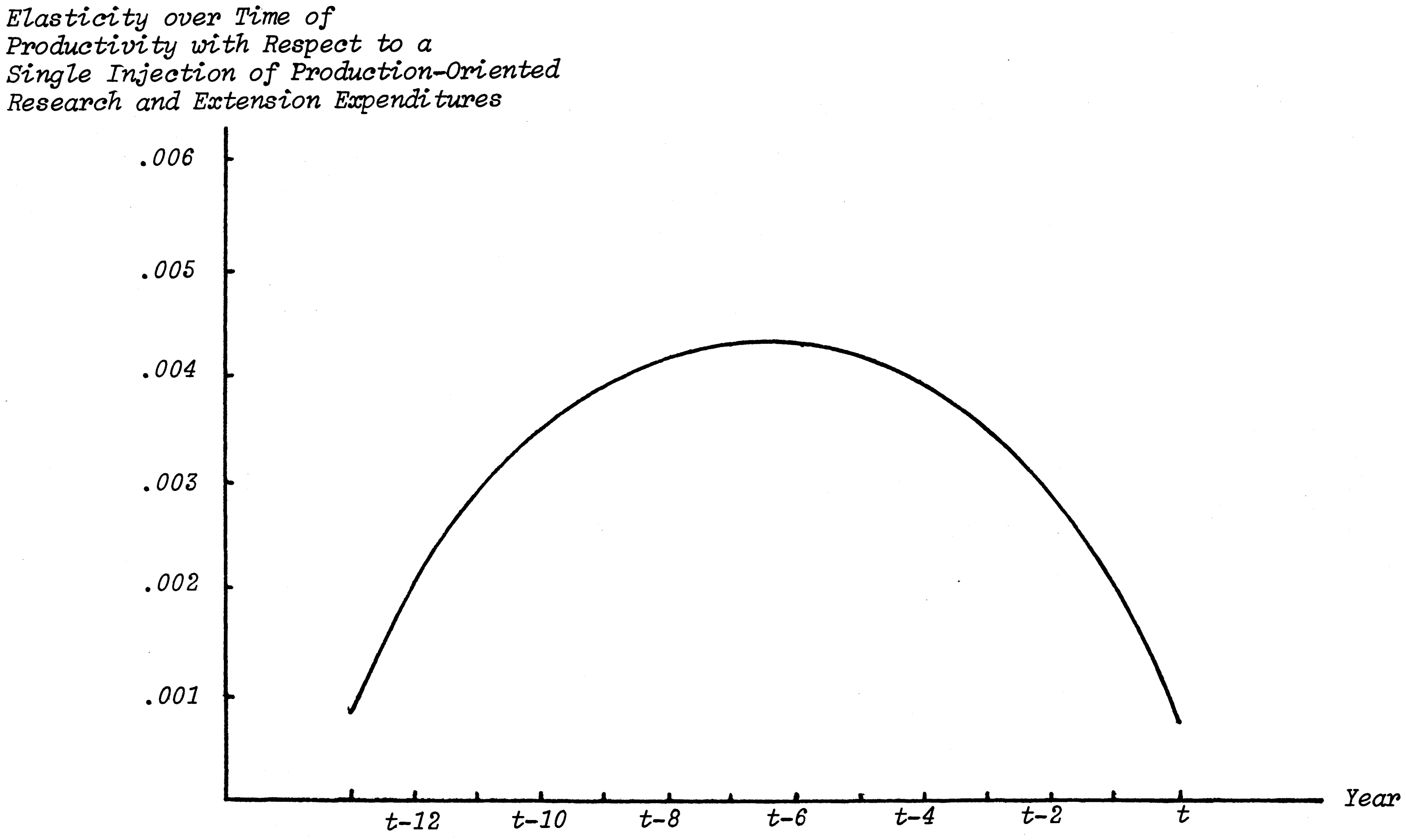

Figure 9. Time Form of the Contribution of Research and Extension to Agricultural Productivity in the United States; Estimation Based on Equation (5.9)

Equation (5.9); the weights follow the shape of an inverted U. With reference to the 13 year lag, the contribution of a dose of production-oriented research and extension expenditures to agricultural productivity is relatively small in the early years, builds to a maximum, and declines thereafter.[3]

The positive and statistically significant (at the one percent level) sum of the distributed lag weights suggests that a one percent increase in production-oriented research and extension expenditures will, over its lifetime, bring about approximately a .037 percent increase in productivity. This .037 percent increase in productivity will be distributed through time in the manner indicated by the optimal lag weights.

While the sum of the estimated coefficients of R may appear to be rather small, the implied effect in terms of the dollar value of output is quite large. This can be seen by calculating the increase in the value of agricultural output brought about by a one dollar increase in expenditures on production-oriented research and extension; i.e., the marginal product (MP) of R. Given the specification of the model shown in Equation (5.9), each individual distributed lag coefficient is a direct estimate of the elasticity of agricultural productivity with respect to production-oriented research and extension expenditures in the appropriate time period. The sum of these coefficients is an estimate of the total elasticity over the entire life of a dose of R. That is,

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[3] The maximum contribution occurs at a 6 1/2 years. This is the result of the imposition of the constraint that the endpoints of the distributed lag weights must approximately equal zero.

$$\sum_{i=0}^{n} \beta_i = \frac{\Delta P}{\Delta R} \cdot \frac{R}{P} \qquad (5.10)$$

where Δ denotes the absolute change in a variable over the entire period. To approximate the marginal product of R, this elasticity is multiplied by the ratio of the average level of productivity over the time period in question to the average level of production-oriented research and extension expenditures over the period:

$$\sum_{i=0}^{n} \beta_i \cdot \frac{\overline{P}}{\overline{R}} = \frac{\Delta P}{\Delta R} \cdot \frac{R}{P} \cdot \frac{\overline{P}}{\overline{R}} \approxeq \frac{\Delta P}{\Delta R} \,. \qquad (5.11)$$

where a bar over a variable name indicates the average of that variable. Since it is desirable to know the increase in agricultural output brought about by a one dollar increase in R, the result obtained in Equation (5.11) must be adjusted by converting the numerator, ΔP, to its equivalent in terms of agricultural output. This conversion can be made by calculating the average net increase in the value of output over the period due to a one point increase in productivity and multiplying:[4]

$$\frac{\Delta P}{\Delta R} \cdot \frac{\Delta Y}{\Delta P} = \frac{\Delta Y}{\Delta R} \approxeq MP \qquad (5.12)$$

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[4] In order to more fully define the components of Equation (5.12), consider the following production function:

$$Q = f(K, L)$$

where Q is the physical quantity of output,
K is the physical quantity of capital,
L is the physical quantity of labor.

If the production function is homogeneous of degree one, then by Euler's theorem

$$Q = \frac{\partial f}{\partial K} \cdot K + \frac{\partial f}{\partial L} \cdot L$$

or

$$Q = MP_k \cdot K + MP_l \cdot L \qquad (1)$$

where Y is the value of agricultural output net of increases in the value of inputs.

Performing these calculations for the national data when the lag length is 13 years yields an estimated MP of $4.30. This means that the value of agricultural output increases approximately $4.30 for each additional dollar spent on R. This estimate of the return to R, however, does not reflect the fact that the increments in output are distributed over time. In order to determine the present value (PV) of a one dollar investment in production-oriented research and extension, it is necessary to discount the increases in output back through time. This calculation is performed according to the formula below:

$$PV = \sum_{i=0}^{n} \frac{MP_{t+i}}{(1+r)^i} , \qquad (5.13)$$

---

where MP_i is the marginal product of the ith input. Multiplying both sides of the above equation by the price of output (P) yields

$$PQ = P \cdot MP_k \cdot K + P \cdot MP_l \cdot L$$

or

$$V = VMP_k \cdot K + VMP_l \cdot L \qquad (2)$$

where V is the value of output, and VMP_i is the value of marginal product of the ith input.

If agriculture is operating under conditions of pure competition, the factors of production are paid the values of their marginal products, i.e.,

$$VMP_k = r$$

$$VMP_l = w$$

where r is the price of capital and w is the wage rate. Incorporating this assumption yeilds

$$V = rK + wL. \qquad (3)$$

This is the arithmetic formula used to aggregate inputs in computing the official USDA productivity index used in this study. At the base

$$V_o = r_o K_o + w_o L_o \qquad (4)$$

and at period 1

$$V_1 = r_1 K_1 + w_1 L_1 \qquad (5)$$

where the subscript denotes the time period. Had the production where MP_{t+i} is the marginal product of R in time t+i and the total marginal product, MP, is distributed through time in the manner indicated by the optimal lag weights; r is the externally determined discount rate. Estimates of the discounted marginal product of production-oriented research and extension expenditures for alternative discount rates are shown in Table X.

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function and factor marginal productivity (or, equivalently, the factor price weight) stayed constant from the base period to period 1, the same quantity of inputs in period 1 (K_1 and L_1) would have produced

$$V_1^* = r_o K_1 + w_o L_1 \qquad (6)$$

where V_1^* is the value of output which <u>would</u> have been produced with the inputs in period 1 (K_1 and L_1) had no productivity change occurred since the base period. V_1 is the value of output <u>actually</u> produced with inputs K_1 and L_1 under the technical conditions in period 1. Thus, the ratio of V_1 to V_1^* is a measure of productivity change from the base year to year 1. Let P_{o1} denote a change in productivity between the base period and period 1. Then,

$$P_{o1} = V / V_1^* . \qquad (7)$$

Dividing (6) by (4) gives

$$\frac{V_1^*}{V_o} = \frac{r_o K_1 + w_o L_1}{r_o K_o + w_o L_o}$$

or

$$V_1^* = V_o \frac{r_o K_1 + w_o L_1}{r_o K_o + w_o L_o} . \qquad (8)$$

Substituting (8) into (7) yields

$$P_{o1} = \frac{V_1}{V_o} \cdot \frac{r_o K_o + w_o L_o}{r_o K_1 + w_o L_1}$$

or

$$P_{o1} = \frac{V_1 / (r_o K_1 + w_o L_1)}{V_o / (r_o K_o + w_o L_o)} . \qquad (9)$$

This is the basic equation used to compute the official USDA productivity index (although there are seven official input classifications).

TABLE X

DISCOUNTED MARGINAL PRODUCTS OF PRODUCTION-ORIENTED RESEARCH AND EXTENSION EXPENDITURES AT ALTERNATIVE DISCOUNT RATES: U.S. DATA

Discount Rate (r)	Discounted Marginal Product of R
5 percent	$3.03
6	2.83
7	2.66
8	2.50
9	2.35
10	2.21
11	2.09
12	1.97
13	1.87

From (9), it directly follows that the value of the index in year 2 is given by

$$P_{o2} = \frac{V_2/(r_oK_2 + w_oL_2)}{V_o/(r_oK_o + w_oL_o)} . \tag{10}$$

The change in the productivity index between year 1 and year 2 is

$$\Delta P = \frac{V_2/(r_oK_2 + w_oL_2)}{V_o/(r_oK_o + w_oL_o)} - \frac{V_1/(r_oK_1 + w_oL_1)}{V_o/(r_oK_o + w_oL_o)} . \tag{11}$$

The change in the value of output over the same period is $V_2 - V_1$, while the change in the value of inputs can be written as $(r_oK_2 + w_oL_2) - (r_oK_1 + w_oL_1)$. The change in the value of output net of changes in the value of inputs is defined in the text above as ΔY, where $\Delta Y = V_2 - V_1 - [(r_oK_2 + w_oL_2) - (r_oK_1 + w_oL_1)]$.

As indicated in Chapter II, perhaps the most informative measure of the return to investment in production-oriented research and extension expenditures is the marginal internal rate of return, i.e., that rate of return, r, which results in

$$1 - \sum_{i=0}^{n} \frac{MP_{t+i}}{(1+r)^i} = 0. \tag{5.14}$$

The marginal internal rate of return to R based on the national data and the "best" lag length of 13 years is approximately 26.5 percent. This is the rate of interest at which the present worth of the net increase in the value of agricultural output resulting from an investment of one dollar in production-oriented research and extension is equal to the initial investment.

It would also be interesting to know what has been happening to the marginal internal rate of return over time. If it is assumed that the estimated time form for the 1939 to 1972 period also holds for any given subperiod, this question can be answered by applying Equation (5.14) to the calculated marginal products of selected subperiods. The results of this procedure are summarized in Table XI. Apparently, the marginal return has been declining over time, although it remains substantial.

All of the measures of the return to production-oriented research and extension cited thus far are subject to a common bias resulting from a failure to include the contribution of private sector research and extension in the model. The theoretical framework presented in Chapter III indicated that one would expect some contribution to productivity from this source. The magnitude of this contribution is likely to be considerably smaller than that of the public sector contribution since much of the private research and extension activity will be reflected in input prices. Since private research and extension data are not accessible except in a very few instances, the actual bias in the R coefficient cannot be known. Using the limited data available, however, Evenson (17, p. 72) has estimated that the effect of private research and extension is to bias the contribution of public research and extension upward by a factor of 1.22. Adjusting the R coefficients by this factor in an attempt to derive an estimate of the return to public sector production-oriented research and extension results in an adjusted marginal internal rate of return of approximately 22 percent for the 1939 to 1972 period and an adjusted marginal product of about $3.50.

TABLE XI

MARGINAL INTERNAL RATES OF RETURN (IN PERCENTAGES) TO PRODUCTION-ORIENTED RESEARCH AND EXTENSION DURING SPECIFIED TIME PERIODS

Period	Rate of Return
1939-1948	30.5
1949-1958	27.5
1959-1968	25.5
1969-1972	23.5

The other explanatory variables of Equation (5.9) also behave as expected. The coefficient of the education variable was 0.78 for the "best" lag of 13 years and is statistically significant at the one percent level. A literal interpretation is that a one percent increase in the index of educational attainment of farmers and farm workers will bring about a .78 percent increase in agricultural productivity. Due to the rather extensive amount of interpolation involved in the construction of the education index, however, this coefficient should be thought of as a general order of magnitude rather than an exact measurement of the elasticity of productivity with respect to changes in education.

The weather variable in this model has a coefficient of 0.002 and was also significant at the one percent level. This means that a one point increase in the value of the weather index brings about a .002 point increase in the level of agricultural productivity, other things constant. Alternatively, one can view this coefficient as meaning that the elasticity of productivity with respect to weather is about .2 when the weather index is at its mean value of 101.57.

CHAPTER VI

RESULTS FROM THE REGIONAL DATA AND THEIR INTERPRETATION

An attempt was made to fit Equation (5.9) to annual data for each of the ten farm production regions of the U. S. over the 1939 to 1972 period (see the Appendix for a map of these regions). However, the high collinearity between the education variable and the production-oriented research and extension variable for several of the regions proved serious in the sense that the estimated parameters had an unsatisfactorily low degree of precision.

In view of this, the estimate of the education parameter obtained from fitting the national data to Equation (5.9) was incorporated into the model. This in effect "corrects" the P variable for the influence of education. The fitted equation for each of the regions is therefore shown by the following:

$$(\ln P_t - \hat{\rho} \ln P_{t-1}) - [0.78 (\ln E_t - \hat{\rho} \ln E_{t-1})] = \sum_{i=0}^{n} \beta_i (\ln R_{t-i} - \hat{\rho} \ln R_{t-i-1}) + \beta_{n+1} (W_t - \hat{\rho} W_{t-1}) \qquad (6.1)$$

where 0.78 is the predetermined coefficient of the education variable and the endpoints of the distributed lag weights are again constrained to approximately equal zero.

The results from fitting Equation (6.1) to the annual regional data

TABLE XII

EQUATION (6.1) REGRESSION RESULTS: REGIONAL DATA

Explanatory Variable	Region				
	North-east	Lake States	Corn Belt	Northern Plains	Appala-chian
$W_t - \hat{\rho}W_{t-1}$	0.0023	0.0014	0.0039	0.0042	0.0036
	(3.7442)	(2.2904)	(7.6164)	(13.7280)	(5.0758)
$R_t - \hat{\rho}R_{t-1}$	0.0009	0.0012	0.0007	0.0007	0.0011
$R_{t-1} - \hat{\rho}R_{t-2}$	0.0017	0.0023	0.0013	0.0013	0.0020
$R_{t-2} - \hat{\rho}R_{t-3}$	0.0023	0.0032	0.0018	0.0017	0.0028
$R_{t-3} - \hat{\rho}R_{t-4}$	0.0029	0.0039	0.0022	0.0021	0.0034
$R_{t-4} - \hat{\rho}R_{t-5}$	0.0033	0.0045	0.0025	0.0024	0.0039
$R_{t-5} - \hat{\rho}R_{t-6}$	0.0035	0.0049	0.0027	0.0025	0.0042
$R_{t-6} - \hat{\rho}R_{t-7}$	0.0036	0.0051	0.0028	0.0026	0.0044
$R_{t-7} - \hat{\rho}R_{t-8}$	0.0036	0.0052	0.0028	0.0025	0.0044
$R_{t-8} - \hat{\rho}R_{t-9}$	0.0035	0.0051	0.0027	0.0024	0.0042
$R_{t-9} - \hat{\rho}R_{t-10}$	0.0033	0.0049	0.0025	0.0021	0.0039
$R_{t-10} - \hat{\rho}R_{t-11}$	0.0029	0.0045	0.0022	0.0017	0.0034
$R_{t-11} - \hat{\rho}R_{t-12}$	0.0023	0.0039	0.0018	0.0013	0.0028
$R_{t-12} - \hat{\rho}R_{t-13}$	0.0017	0.0032	0.0013	0.0007	0.0020
$R_{t-13} - \hat{\rho}R_{t-14}$	0.0009	0.0023	0.0007		0.0011
$R_{t-14} - \hat{\rho}R_{t-15}$		0.0012			
$\sum_{i=0}^{n} \beta_i^b$	0.0365	0.0551	0.0280	0.0239	0.0438
$\bar{R}^2$	0.9111	0.9833	0.9859	0.9904	0.9912
SEE^c	0.03315	0.02595	0.03393	0.02851	0.03608
DW^d	2.29	2.08	1.89	2.08	2.16
$\hat{\rho}^e$	0.829	0.713	0.576	0.579	0.686

TABLE XII (Continued)

Explanatory Variable	Region				
	South-east	Delta States	Southern Plains	Mountain	Pacific
$W_t - \rho W_{t-1}$	0.0038	0.0027	0.0049	0.0018	0.0003
	(5.4282)	(6.4858)	(8.7224)	(4.9086)	(0.7784)
$R_t - \rho R_{t-1}$	0.0009	0.0018	0.0005	0.0018	0.0030
$R_{t-1} - \rho R_{t-2}$	0.0017	0.0032	0.0010	0.0033	0.0054
$R_{t-2} - \rho R_{t-3}$	0.0023	0.0044	0.0014	0.0044	0.0072
$R_{t-3} - \rho R_{t-4}$	0.0029	0.0052	0.0017	0.0052	0.0084
$R_{t-4} - \rho R_{t-5}$	0.0033	0.0056	0.0019	0.0057	0.0090
$R_{t-5} - \rho R_{t-6}$	0.0035	0.0058	0.0020	0.0059	0.0090
$R_{t-6} - \rho R_{t-7}$	0.0036	0.0056	0.0021	0.0057	0.0084
$R_{t-7} - \rho R_{t-8}$	0.0036	0.0052	0.0021	0.0052	0.0072
$R_{t-8} - \rho R_{t-9}$	0.0035	0.0044	0.0020	0.0044	0.0054
$R_{t-9} - \rho R_{t-10}$	0.0033	0.0032	0.0019	0.0033	0.0030
$R_{t-10} - \rho R_{t-11}$	0.0029	0.0018	0.0017	0.0018	
$R_{t-11} - \rho R_{t-12}$	0.0023		0.0014		
$R_{t-12} - \rho R_{t-13}$	0.0017		0.0010		
$R_{t-13} - \rho R_{t-14}$	0.0009		0.0005		
$R_{t-14} - \rho R_{t-15}$					
$\sum_{i=0}^{n} \beta_i$[b]	0.0364	0.0461	0.0211	0.0469	0.0662
$\bar{R}^2$	0.9774	0.9237	0.9940	0.9937	0.9975
SEE[c]	0.03965	0.04176	0.03979	0.02238	0.01927
DW[d]	2.07	2.15	1.74	1.84	1.45
ρ[e]	0.640	0.828	0.291	0.577	0.463

[a] Numbers in parentheses are t-values; all exceed the critical t value at the one percent level.

[b] A joint F test of the null hypothesis that all the regression coefficients for the R's are equal to zero was rejected at the one percent level of significance for all lag lengths.

[c] Standard error of the estimate.

[d] Durbin-Watson "d" statistic.

[e] The estimated value of the first-order autoregression coefficient of the disturbances.

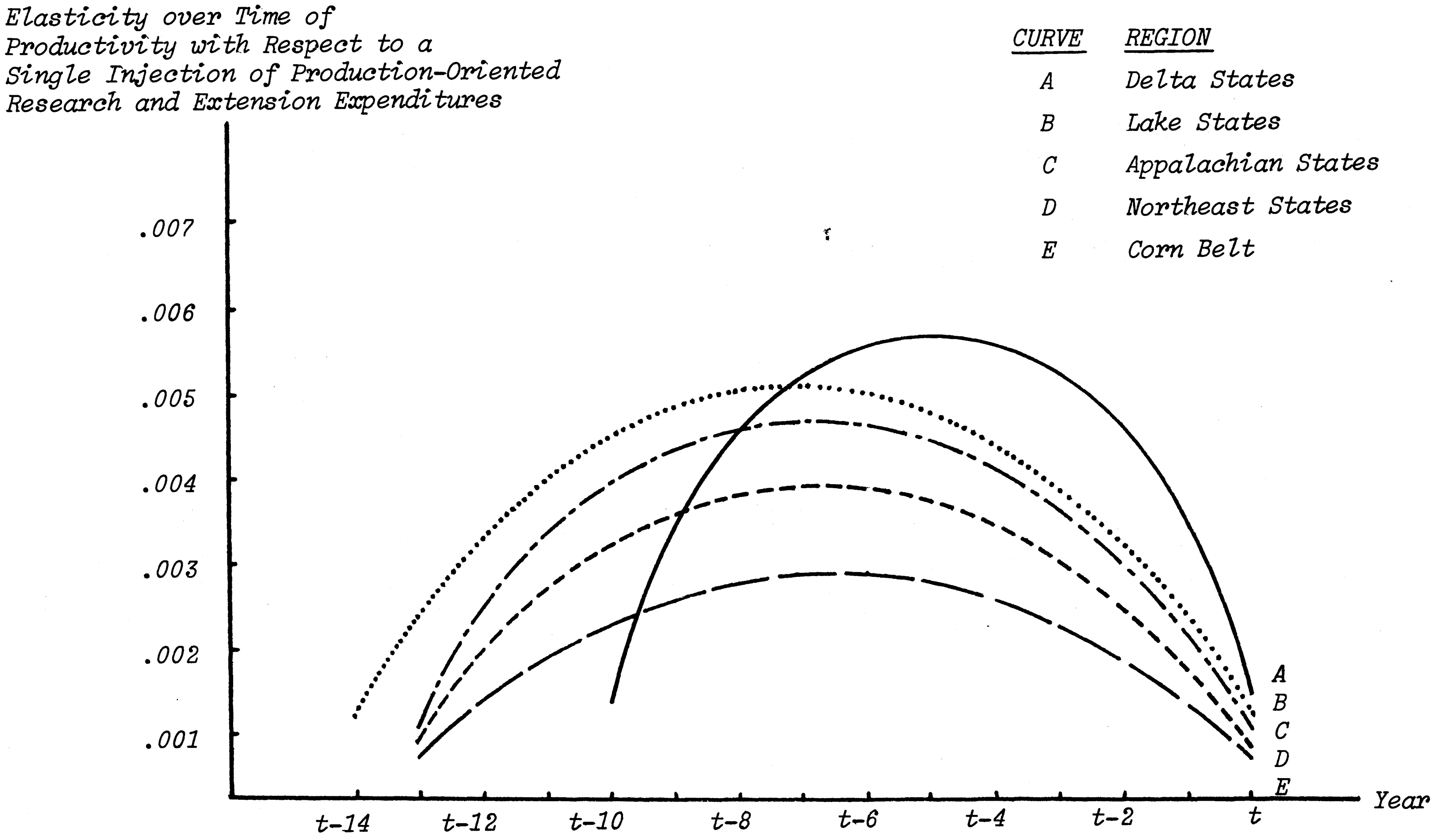

Figure 10. Time Forms of the Contribution of Research and Extension to Agricultural Productivity for Ten Farm Production Regions

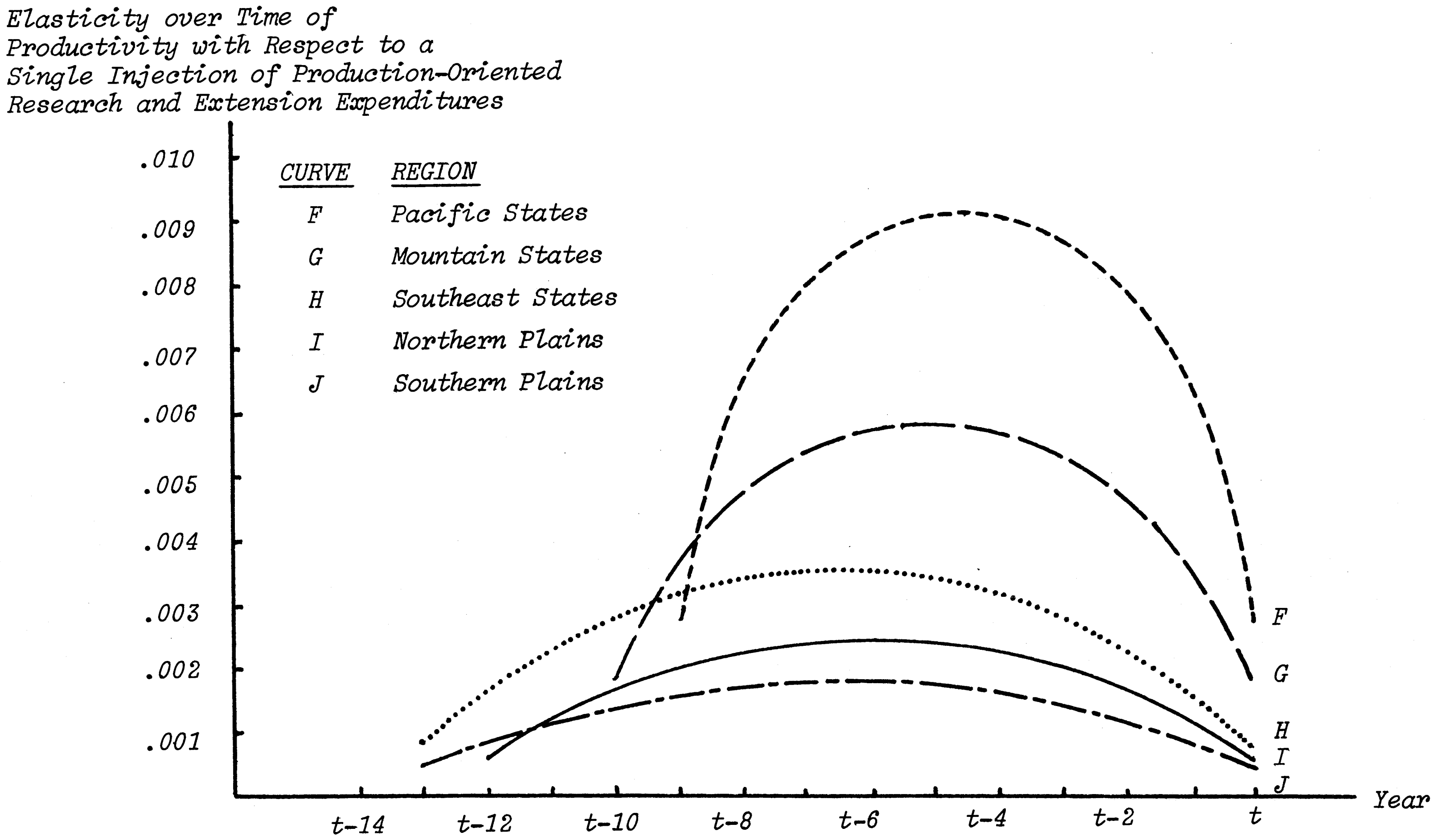

Figure 10 (Continued)

which are most important in explaining these regional time form differences. Determinants of the relative productivity performance between regions are also considered. Due to the limited number of observations available and the nonparametric techniques employed, any conclusions which result from the analysis must be regarded as descriptions of tendency, not as statistically proven facts based upon sound testing of hypotheses.

Regional Differences in the Length of the Production-Oriented Research and Extension Lag

In order to understand fully the reasons for regional differences in the total length of the lag associated with R, one would have to have full knowledge of the determinants of each of the component lags discussed in Chapter III. While this information is not available, it is still possible to suggest some of the key elements involved and examine the direction of their influence.

With this in mind, the following hypotheses regarding the length of the production-oriented research and extension lag are advanced:

1. The total length of the lag will be shorter, the greater the production-oriented research and extension expenditures per dollar of agricultural output. Relatively great research expenditures per dollar of output shorten the length of the lag between the time the investment is made and the time commercially adoptable knowledge is actually forthcoming. Similarly, relatively great extension expenditures shorten the adoption lag, i.e., the lag between the time the new technology is available and the time it is actually adopted by farmers.

2. The total length of the lag will be longer, the greater the weather variability in the region. This is because increased weather variability tends to lengthen the adoption lag due to the higher degree of uncertainity regarding the profitability of the technology.

3. The total length of the lag will be shorter, the better the absolute weather conditions in the region. This hypothesis suggests itself due to the relationship between "good" weather and "high" profitability from farming. Presumably, farmers with relatively high profits will be in an economic position to adopt new technologies earlier than those farmers who earn relatively low profits.

4. The total length of the lag will be shorter, the higher the ratio of crop output to livestock output in the region. This is because the component lag associated with agricultural research related to livestock production is inherently longer than that related to crop production due to the longer gestation period of livestock.

5. The length of the total lag will be shorter, the higher the level of educational attainment among farmers and farm workers in the region. Farmers with higher levels of education are better equipped as entrepreneurs to assimilate technical information and translate it into efficiency gains in production.

To test these hypotheses, the regions were ranked on the basis of their standing relative to the national norm over the 1939 to 1972 period in each of the categories described above. Kendall rank correlation coefficients (29) between the regions ranked according to the length of their lag and all of the categories were then calculated.[1]

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[1] The ranking of a region for any given variable was determined as follows: First, the average regional value of the variable in question

The results of this procedure are reported in Table XIII.

These coefficients must be interpreted quite cautiously. Ideally, one would like to employ a multiple rank correlation technique to determine the strength and direction of influence between the dependent variable and the explanatory variables; such a technique would allow one to measure the relationship between two variables while holding all other variables constant. Unfortunately, such a nonparametric technique is not available. This means that one is confined to the use of simple rank correlation coefficients to investigate the relationships. Given that these coefficients are impure in the sense that they are not purged of the influence of all other variables, it is appropriate to restrict the analysis primarily to an investigation of the signs of the coefficients. Little meaning should be attached to their magnitudes.

On the basis of the signs of these coefficients, four of the five hypotheses advanced above are not rejected. That is, regions with

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was expressed as a percent of the average national value of the same variable, that is:

$$Y = \frac{\sum_{t=1939}^{1972} (X_t/34)}{\sum_{t=1939}^{1972} (US_t/34)}$$

where X_t is the value in time t of the regional observation on the variable in question, US_t is the value in time t of the national observation on the variable, and Y is the regional average expressed as a percent of the national average over the 1939 to 1972 period. Each region was then assigned a rank from one to ten on the basis of its Y value. Regressions were also run using the Y values; however, due to the lack of variation between regional Y values for several of the extremely limited number of observations available, more acceptable results in a statistical sense were obtained when nonparametric techniques were employed. The tradeoff for these enhanced statistical properties is that the Kendall rank correlation coefficient is not purged of the influence of left-out variables.

TABLE XIII

KENDALL RANK CORRELATION COEFFICIENTS BETWEEN REGIONAL LAG LENGTH AND HYPOTHESIZED KEY DETERMINANTS OF THE LENGTH OF THE LAG[a]

Hypothesized Determinant	Correlation Coefficient
Production-Oriented Research and Extension Expenditures per Dollar of Agricultural Output in the Region	-0.388 (0.146)
Weather Variability	-0.051 (0.847)
Weather Conditions	-0.409 (0.122)
Ratio of Value of Crop Output to Value of Livestock Output in the Region	-0.491 (0.066)
Level of Educational Attainment	-0.307 (0.247)

[a] Numbers in parentheses are significance probabilities (the probability that a correlation coefficient that large or larger would arise by chance were the variables truly independent).

relatively large outlays of production-oriented research and extension expenditures[2] per dollar of agricultural output have relatively short lags; regions with relatively good weather exhibit relatively short lags; regions with substantial livestock production tend to have relatively long lags, and regions with relatively high levels of educational attainment among farmers and farm workers have relatively short lags.

The direction of the relationship between weather variability and lag length is not the direction expected. The negative sign implies that regions with relatively great weather variation exhibit short lag lengths, even though the relationship is quite weak. Since this conclusion is counterintuitive, one must be reluctant to accept it without first seeking some other explanation for the sign of the coefficient in question. Two possible explanations are plausible. First, it could be that farmers in regions with great variation in the weather attach a subjective probability to the profitability of any newly adopted technology in order to arrive at the expected value of the technology. By mathematically adjusting for the influence of weather, the degree of uncertainty associated with the profitability of the technology is reduced; perhaps to the point where their ability to evaluate the benefits from adoption of a new technology are on a par with farmers in

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[2] Observations on the production-oriented research and extension expenditures series for each region were constructed in accordance with the estimated distributed lag weights for the region in question as reported in Table XII. That is,

$$R^*_{j,t} = \sum_{i=0}^{n} \beta_i R_{j,t-i}$$

where $R^*_{j,t}$ is the observation for region j in time period t.

regions where the weather is quite stable. In short, as the size of the estimated coefficient implies, it could be that there is no significant relationship between weather variation[3] and lag length. The second explanation hinges upon the manner in which the regional indexes were constructed (see the Appendix). The procedure followed, while being the best available alternative, was rough at best. As a result, the regional weather data series are not as clean as one would like and could therefore be the cause of the above counterintuitive result.

Thus far, the analysis has been concerned with measures of the correlation between two sets of rankings of the ten regions. It is also possible to determine the association among more than two sets of rankings by using the Kendall coefficient of concordance, W (30). The coefficient of concordance is essentially an index of the divergence of the actual agreement between the rankings as shown in the data from the maximum possible agreement. W may take on values from 0 (indicating perfect disagreement) and + 1 (indicating perfect agreement). With the correction for ties incorporated the Kendall coefficient of concordance is[4]

$$W = \frac{S}{\frac{1}{12} k^2(N^3 - N) - k \sum_T T}$$

where

S = sum of squares of the observed deviations from the mean of the sum of the ranks,

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[3] Weather variation was measured by the standard deviation of the weather index series for each region.

[4] A discussion of the Kendall coefficient of concordance and the appropriate tests of significance can be found in Sydney Siegel (55, pp. 229-239).

k = number of sets of rankings, i.e., the five hypothesized determinants plus the lag length,

N = number of entities ranked, i.e., the regions,

$T = \frac{\Sigma(t^3 - t)}{12}$ and t is the number of observations in a group tied for a given rank.

A coefficient of concordance was computed to determine the agreement between the ranking of the regions based upon lag length and the five sets of rankings corresponding to the hypothesized determinants. It was found that W = 0.2915. The significance of this observed value of W can be tested by determining the probability associated with its occurrence under the null hypothesis that the six sets of rankings are unrelated. It was found that the null hypothesis can be rejected at the 10 percent level of significance. This does not indicate a particularly strong relationship between the sets of rankings.

Regional Differences in the Marginal Contribution of Production-Oriented Research and Extension to Agricultural Production

Using the procedure developed for calculating the rate of return to national production-oriented research and extension expenditures, marginal internal rates of return were calculated for each of the ten regions. The results of these calculations are presented in Table XIV.

As was the case with lag lengths, the adjusted marginal internal rates of return vary considerably between the regions; from a high of 44.3 percent in the Pacific region to a low of 17.5 percent in the Southern Plains region. It is hypothesized that these differential rates of return between the regions can be explained by the following

TABLE XIV

MARGINAL INTERNAL RATES OF RETURN (IN PERCENTAGES) TO PRODUCTION-ORIENTED RESEARCH AND EXTENSION EXPENDITURES FOR TEN FARM PRODUCTION REGIONS OF THE UNITED STATES

Region	Lag Length	Rate of Return[a]	Adjusted Rate of Return[b]
Northeast	13	20.0	16.4
Lake States	14	43.0	35.2
Corn Belt	13	33.5	27.4
Northern Plains	12	28.5	23.4
Appalachian	13	28.0	23.0
Southeast	13	18.5	15.2
Delta States	10	33.5	27.5
Southern Plains	13	17.5	14.3
Mountain	10	27.5	22.5
Pacific	9	54.0	44.3

[a] The estimated rate of return without adjustment for bias caused by a failure to include private sector research and extension expenditures in the model.

[b] The estimated rate of return adjusted (by a factor of 1.22 as estimated by Evenson (17)) for private sector research and extension expenditures.

key determinants:

1. The higher the marginal internal rate of return, the lower the region's production-oriented research and extension expenditures per dollar of agricultural output. This hypothesis is based upon the assumption that regional expenditures on production-oriented research and extension have placed the investing entity somewhere on that portion of the production surface that is characterized by declining but positive marginal productivity of the research and extension input.

2. The higher the marginal internal rate of return, the higher the level of educational attainment of farmers and farm workers in the region. Farmers with relatively high levels of educational attainment are more likely to take full advantage of new technologies due to their superior ability to assimilate information into the decision-making process and act upon it.

3. The higher the marginal internal rate of return, the better the absolute weather conditions in the region. This hypothesis again suggests itself due to the relationship between "good" weather and high profitability. If a region experiences consistently good weather over time, the level of profits earned by farmers in the region will be consistently higher and more farmers will be in an economic position to adopt a new technology at any given point in time than would otherwise be the case. Thus, the benefits of the new technology will be spread over a larger base of agricultural output.

The procedure employed to test these hypotheses is that used in the preceding section. The regions were ranked on the basis of their standing relative to the national norm over the 1939 to 1972 period in the categories suggested above. Rank correlation coefficients between the regions ranked according to their marginal internal rate of return and all of the categories were then calculated. The results are reported in Table XV.

TABLE XV

KENDALL RANK CORRELATION COEFFICIENTS BETWEEN REGIONAL MARGINAL INTERNAL RATES OF RETURN TO PRODUCTION-ORIENTED RESEARCH AND EXTENSION AND HYPOTHESIZED DETERMINANTS OF THE RATE OF RETURN[a]

Hypothesized Determinant	Correlation Coefficient
Production-Oriented Research and Extension Expenditures per Dollar of Agricultural Output	-0.114 (0.652)
Educational Attainment	0.270 (0.281)
Weather	0.315 (0.209)

[a] Numbers in parentheses are significance probabilities (the probability that a correlation coefficient that large or larger would arise by chance were the variables truly independent).

The hypothesis that public sector investment has reached the stage of declining marginal productivity is not rejected by these results. This tends to support the finding from the national data that the marginal internal rate of return has declined over time. Also, regions with relatively high levels of educational attainment apparently enjoy a relatively high rate of return to investments in production-oriented research and extension. Finally weather, quite likely operating through its effect on profitability, would appear to play a role in determining the marginal return to production-oriented research and extension expenditures.

A coefficient of concordance, W, was also calculated to test the strength of the relationship between the ranking of the regions on the basis of their marginal internal rates of return and the rankings of the hypothesized determinants of that rate of return. It was found that $W = 0.1122$. The null hypothesis that the four sets of rankings are unrelated can be rejected at the 30 percent level of significance, indicating a rather weak relationship between the sets of rankings.

Relative Productivity of the Regions

It would also be of interest to know if factors such as production-oriented research and extension expenditures, weather, and education are important determinants of the relative productivity of the regions.

In an attempt to shed some light on this question, the regions were ranked according to their productivity over the 1939 to 1972 period relative to the productivity of the United States. The results of this ranking are shown in Table XVI.

The regions were similarly ranked according to the following three factors: absolute weather conditions, level of educational attainment among farmers and farm workers, and production-oriented research and extension expenditures per dollar of agricultural output. Correlation coefficients were then calculated. The results of these calculations are shown in Table XVII.

TABLE XVI

RANKING OF THE REGIONS ACCORDING TO THEIR PRODUCTIVITY RELATIVE TO THE NATIONAL NORM: 1939-1972

Region	Rank (1 = "best" performance)
Northeast	2
Lake States	7
Corn Belt	9
Northern Plains	1
Appalachian	10
Southeast	5
Delta States	6
Southern Plains	3
Mountain	4
Pacific	8

TABLE XVII

CORRELATION COEFFICIENTS BETWEEN THE REGIONS RANKED ACCORDING TO RELATIVE PRODUCTIVITY AND HYPOTHESIZED DETERMINANTS[a]

Hypothesized Determinant	Correlation Coefficient
Educational Attainment	0.244 (0.325)
Production-Oriented Research and Extension Expenditures per Dollar of Agricultural Output	0.135 (0.590)
Weather	-0.111 (0.655)

[a] Numbers in parentheses are significance probabilities (the probability that a correlation coefficient that large or larger would arise by chance were the variables truly independent).

The correlation coefficients behave for the most part as one would expect. Based upon the signs of coefficients, the conclusions suggested by them are as follows: regions with relatively high levels of educational attainment exhibit relatively high productivity; and regions which expend relatively large sums on production-oriented research and extension per dollar of agricultural output are rewarded with relatively high productivity.

The puzzling result emerging from these calculations is the sign on the coefficient between relative productivity performance and absolute weather conditions in the region. Interpreted literally, the negative sign implies that regions with the poorest weather conditions over the 1939 to 1972 period experienced relatively high productivity, other things constant. The only sensible interpretation of this result is that it is an artifact of the technique used to construct the regional weather indexes.

The coefficient of concordance, W, between rankings based on relative productivity performance and the hypothesized determinants was found to be .1033. Therefore, the null hypothesis that the four sets of rankings are unrelated can be rejected at the 30 percent level of significance. As was the case with the other coefficients of concordance, the relationship between the sets of rankings appears to be rather weak. This is quite possibly due to the inferiority of the regional data relative to the data for the U. S.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The specific objectives of this study were to:

1. Develop a theoretical framework in which the contribution to agricultural production of identified sources of productivity change could be conceptualized and confront this framework with data;

2. Examine the role of the public sector in stimulating technical change in agriculture, with particular emphasis on evaluating the form of the time lag between public investment in research and extension activities and the ensuing contribution to agricultural production;

3. Evaluate the rate of return to public sector agricultural research and extension expenditures;

4. Examine the regional impact of public sector research and extension expenditures with an eye towards explaining the differential rates of return to these public investments, the differential levels of productivity and the differential time forms of the research and extension-output relationships between the ten farm production regions of the U. S. defined by the USDA.

5. Formulate, based upon empirical results of this study, public policy implications regarding investments in agricultural research and extension.

Each of these objectives and the conclusions emerging from the pursuit to accomplish them are considered below.

The Theoretical and Empirical Frameworks

In Chapter III, a theoretical model was developed for explaining the behavior of aggregate agricultural productivity over time. Productivity change was defined as changes in output per unit of time which cannot be explained by changes in the quantities of inputs employed per unit of time. Two major sources of productivity change were defined; sources whose impacts on productivity are made by increasing the stock of knowledge regarding the industrial arts, i.e., sources of technical change; and sources whose impacts on productivity are made by altering the physical and/or economic environment in which production takes place.

Specific sources of technical change that were identified include the educational attainment of farmers and farm workers (E) and production-oriented research and extension activities (R). This latter specific source refers to activities that are conducted in an effort to bring about technical change in agriculture by enhancing the state of the industrial arts and the application of these arts. It was hypothesized that production-oriented research activity does not immediately bear fruit in terms of improvements in the techniques of agricultural production. Rather, the time form of the total lag between production-oriented research and extension activities and growth in agricultural productivity is the convolution of several individual lags: the lag between the time funds are invested in research and the time inventions actually begin to appear; the lag between the invention of an idea or device and its development to a commercially applicable stage; the lag between the development of a commercially applicable idea or device and its extension to potential users and their subsequent adoption of the idea or device due to irrelevance or obsolescence. This hypothesized time form of the effect of production-oriented research and extension activities on agricultural productivity resembles an inverted U.

Other sources of productivity change in agriculture that were identified include the weather (W) and nonproduction-oriented research and extension activities (O). Nonproduction-oriented research and extension activities are those activities which seek to improve agricultural productivity by favorably altering the physical and/or economic environment in which production takes place, as well as to enhance consumer welfare.

Based upon these observations, the productivity change model was specified as

$$P_t = \prod_{i=0}^{n} R_{t-i}^{\beta_i} \; O_t^{\beta_{n+1}} \; E_t^{\beta_{n+2}} \; e^{\beta_{n+3} W_t} \qquad (7.1)$$

where

P_t is the value of the official USDA aggregate productivity index for agriculture in time t,

R_{t-i} is a distributed lag function of public sector production-oriented research and extension expenditures in the current period and n preceding periods,

O_t is public sector nonproduction-oriented research and extension expenditures in the current time period,

E_t is the value in the current period of an index of educational attainment of farmers and farm workers,

W_t is the value in the current period of a weather index.

To confront this theoretical framework with data, observations on each of the variables for the 1939 to 1972 period were collected.

The fitted equation developed in Chapter IV was

$$\begin{aligned} \ln P_t - \hat{\rho} \ln P_{t-1} = &\sum_{i=0}^{n} \beta_i (\ln R_{t-i} - \hat{\rho} \ln R_{t-i-1}) \\ &+ \beta_{n+1} (\ln O_t - \hat{\rho} \ln O_{t-1}) \\ &+ \beta_{n+2} (\ln E_t - \hat{\rho} \ln E_{t-1}) \\ &+ \beta_{n+3} (W_t - \hat{\rho} W_{t-1}) + U_t - \hat{\rho} U_{t-1} \end{aligned} \qquad (7.2)$$

where $\hat{\rho}$ is the estimated first-order autocorrelation coefficient and U_t is the disturbance term.

The Almon technique (3) was used to estimate the distributed lag coefficients, and Durbin's two-stage procedure (15) for estimating the ρ parameter was employed.

The Role of the Public Sector in Stimulating Productivity Change in Agriculture

From the estimation of Equation (7.2), it was concluded that nonproduction-oriented research and extension expenditures do not contribute significantly to changes in agricultural productivity. Therefore, this variable was dropped from the model.

It was further concluded that a "dose" of production-oriented research and extension expenditures injected in year t will affect agricultural productivity in year t and continue to affect it for the following 13 years. The hypothesized time form described above was exhibited by the estimated distributed lag weights; the weights followed the shape of an inverted U. The contribution of a dose of production-oriented research and extension expenditures to agricultural productivity is relatively small in the early years, builds to a maximum, and declines thereafter.

The positive and statistically significant sum of the distributed lag weights suggests that a one percent increase in production-oriented research and extension expenditures will, over its lifetime, bring about a .037 percent increase in productivity. This implies an undiscounted marginal product of approximately $4.30 for each additional dollar spent on R, or a discounted marginal internal rate of return of about 26 percent. An adjustment for the influence of private sector research and extension lowers this rate of return to about 22 percent. In addition, it was found that the marginal internal rate of return to production-oriented research and extension expenditures has been declining over time; from 30.5 percent for the 1939 to 1948 period to 23.5 percent for the 1969 to 1972 period.

The level of educational attainment of farmers and farm workers and weather were also found to have significant influences on agricultural productivity.

Evaluation of the Rate of Return to Public Sector Production-Oriented Research and Extension Expenditures

The rate of return to public sector production-oriented research and extension expenditures can be evaluated on the basis of three criteria. First, it can be compared to a rate of interest that presumably reflects the opportunity cost of capital in the economy. Second, it would also be of interest to know if the (declining) marginal internal rate of return is above or below the average internal rate of return. Third, a comparison can be made between the estimate obtained in the present study and estimates from earlier studies.

Determining the "correct" rate for discounting public investments has been one of the most controversial topics in the theory of public finance.[1] There currently exist at least three schools of thought on the subject, each of which is briefly considered below.

The "social rate of time-preference" school of thought is based on the argument that the government must have a longer time-horizon than individual citizens, since the government must be concerned with providing capital goods and services for as yet unborn generations. Since individuals' time-horizons are shorter than those of the entire society, they cannot be relied upon to express society's preferences for future capital goods. Instead, the government must make a decision about the social rate of time-preference and use that rate to discount the investments it makes. The rate most often cited as filling this role is the long term government borrowing rate, which is about 7 percent at the time of this writing.

The second school of thought evolved when, during the 1960's, some economists began to argue that government investments withdraw resources from the private sector and that the correct discount rate for the government to use is the opportunity cost of capital in the private sector. According to Singer (56, p. 256), if capital markets function efficiently, the opportunity cost of capital in the private sector can be most easily measured as the pretax rate of return in the corporate sector (currently about 15 percent).

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[1] The Joint Economic Committee Compendium contains two papers on the selection of the "correct" discount rate: William J. Baumol's "On the Discount Rate for Public Projects" and J. Hirschleifer and David L. Shapiro's "The Treatment of Risk and Uncertainty." An overview of the controversy is presented by Neil M. Singer (56. pp. 237-247).

The final school of thought argues that the government uses resources that would not otherwise have been made available for investment and that the opportunity cost of capital in the private sector is therefore irrelevant. Instead, the appropriate discount rate should be determined by the sources of government funds. In other words, a determination of where the government's investible funds come from must be made, along with the opportunity cost in each of these alternative uses. An average of these opportunity costs must then be constructed, weighted by the proportions of total government investment financed from each source of funds. Krutilla and Eckstein (32) have estimated this rate at 5 to 6 percent in a period of low interest rates. More recently, Eckstein has put the weighted average of opportunity costs at about 8 to 9 percent.[2] According to Singer (56, p. 242), this source of funds rule generally yields a lower discount rate for public investment than the private opportunity cost rule.

It is not the goal of this section to argue the relative merits of the three approaches to determination of the "correct" discount rate. Consideration of the controversy is appropriate for the present study only in that it provides a range of discount rates against which the marginal internal rate of return to production-oriented research and extension expenditures can be compared.

The discount rates proposed above vary from a low of about 7 percent to a high of 15 percent. The estimated marginal internal rate of return to public production-oriented research and extension expenditures, about 19 percent over the 1969 to 1972 period adjusted for the

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[2] Statement of Otto Eckstein (66, pp. 50-57).

influence of private research and extension expenditures, compares favorably with this range. Apparently, continued public sector investment in production-oriented research and extension remains desirable, even though the return to this investment appears to be declining over time.

As a second means of evaluating the marginal internal rate of return, one can consider its relationship to the average internal rate of return in recent years. Employing the "value of inputs saved" technique and Equation (2.1) as explained in Chapter II, the average internal rate of return for the 1969 to 1972 period is approximately 30 percent as compared to a marginal internal rate of return adjusted for private research and extension expenditures of about 19 percent over the same period. Based upon these calculations, one can conclude that the public sector is presently operating in that stage of the "productivity production function" which is characterized by declining but positive marginal product and marginal product less than average product.

Finally, consider the comparability of the estimate obtained in the present study to those estimates of the marginal internal rate of return cited in previous efforts. Of the studies discussed in Chapter II, only two yield results which are directly comparable to the marginal internal rate of return estimated in the present study: Griliches' aggregate production function study (23) and Evenson's productivity index study (17). As interpreted by Peterson (48), their estimates of the rate of return are about 53 percent and 48 percent respectively, adjusted for private research and extension expenditures. These estimates are obviously much higher than the 22 percent rate of return obtained in this study.

The difference between the estimates is traceable to three major factors. First, there is a difference in the periods considered: Griliches employed cross-section data from the years 1949, 1954, and 1959; Evenson's time series data spanned the 1938 to 1963 period. The present study, on the other hand, spans the 1939 to 1972 period. Since the marginal internal rate of return has been declining over time, inclusion of the more recent years would tend to lower the estimate for the entire period.

Second, there are major differences between the studies in the manner in which observations on the research and extension variables were constructed. Griliches' measure of the variable includes only the sum of the expenditures of the state agricultural experiment stations and the extension services. He also uses an admittedly crude lag structure. Evenson's measure of the variable is much more similar to the measure used in the present study in that the expenditures of essentially the same public agencies were included. He also submits that his study "focuses on the contribution of only that research and extension effort directed toward increasing production of food and fiber at the farm level" (17, p. 4), i.e., production-oriented expenditures. However, it is never clearly explained by Evenson exactly how production-oriented expenditures were distinguished from nonproduction-oriented expenditures. He does suggest that, in 1965, "roughly 40 percent of the research by public and private agencies directed to agriculture was not directly designed to increase farm production" (17, p. 4). If this 40 percent rule was applied to expenditures in each year over the 1938 to 1963 period in order to obtain data on production-oriented research and extension expenditures, Evenson's measure would be significantly different than that of the present study, since production-oriented expenditures in each year were determined independently in the latter.

Finally, the differences in the estimates of the internal marginal rate of return could be due to what are hopefully the more refined techniques of estimation employed in the present study.

The Regional Impact of Public Sector Research and Extension Expenditures

Data for the 1939 to 1972 period on each of ten farm production regions of the United States were also collected and run against a model similar to that shown in Equation (7.2). Unfortunately, the quality of the regional data was not on a par with that of the national data. Therefore, the conclusions emerging from the regional analysis are not as firm as those regarding the U. S. as a whole.

The total length of the production-oriented reseach and extension lag was found to range from a low of 9 years for the Pacific region to a high of 14 years for the Lake States region. This length is apparently directly related to the ratio of the value of crop output to the value of livestock output in the region, and indirectly related to the level of production-oriented research and extension expenditures per dollar of agricultural output in the region and the level of educational attainment of farmers and farm workers.

The marginal internal rate of return to production-oriented research and extension expenditures also varied significantly between the regions, ranging from a high of 54 percent in the Pacific region to a low of 17.5 percent in the Southern Plains region when no adjustment is made for private sector research and extension expenditures. Determinants of this rate of return appear to be weather conditions in the region, production-oriented research and extension expenditures per dollar of agricultural output, and the level of educational attainment. The better the weather conditions in the region, the higher the rate of return; the higher the level of educational attainment among farmers the higher the rate of return; and the lower the production-oriented research and extension expenditures per dollar of agricultural output, the higher the marginal internal rate of return.

An attempt to explain the observed differential levels of productivity between the regions yielded the following conclusions: regions with relatively high levels of educational attainment and regions which expend relatively large sums on production-oriented research and extension per dollar of agricultural output are rewarded with relatively high productivity.

Public Policy Implications of the Study

The implications game is a tricky one. There exists at one and the same time a desire to draw as many recommendations from the study as possible and also an obligation not to violate the boundaries of the analysis. The persuasion of the author is to play the game on the conservative side; only those implications which are firmly grounded in the analysis will be advanced in this section.

This study indicates that the marginal internal rate of return to production-oriented research and extension expenditures by the public sector has been declining over time. It now appears to be around 20 percent. While this is still relatively high, the strong likelihood that it is approaching the social discount rate indicates that public administrators must become more attuned to the specific research program areas they seek to fund. While it is apparently the case that aggregate agricultural research expenditures are a socially desirable investment, the same claim for each and every research program area must be increasingly questioned in the future. Additional studies on specific areas of agriculture such as beef, soybeans, and wheat would be most helpful in this process.[3]

Public administrators would also be well-advised to remember that there is a rather lengthy lag between the time research funds are appropriated and the time agricultural productivity is affected. This increases the need for reliable projections of key determinants of agricultural productivity. The role of probabilistic forecasting is particularly critical at the present time in light of the fact that, for the first time in recent history, researchers engaged in activities affecting the future state of the arts in agriculture are finding their research bounded by resource and social constraints.[4]

Another implication of the present study, as well as previous studies, is that growth in aggregate agricultural productivity is somewhat insensitive to increased production-oriented research and extension expenditures. It has been estimated in the present study that a one percent increase in R leads to only a .037 percent increase in

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[3] The National Economic Analysis Division, Economic Research Service, USDA is currently studying productivity change in the U. S. and the ten farm production regions as it relates to crop production and livestock production.

[4] This statement is based upon a series of interviews conducted with professional researchers in the Agricultural Research Service, the Economic Research Service, the Extension Service, and the Cooperative State Research Service during November, 1974.

productivity. Given the stock of knowledge regarding the industrial arts in agriculture upon which further research is building, this rather low sensitivity is not surprising. This is particularly true when one remembers that a primary goal of present agricultural research is to maintain the status quo, i.e., to maintain the present stock of knowledge in the face of new environmental constraints, new pests, etc. As might be expected, the variable which exerts the most influence over agricultural productivity in any given year is the weather; a variable over which public administrators hold no control.[5]

Nonproduction-oriented research and extension expenditures cannot be justified on the grounds that they significantly influence agricultural productivity, based on the historical data employed in this study. Rather, the justification for these large expenditures must be found in enhanced consumer welfare, enhanced quality of life, or other such sources of social benefits.

Finally, there are significant differences in the rates of return to production-oriented research and extension expenditures between the regions. This means that there are greater social benefits to be gained by investing in some regions rather than others. In particular, those regions with relatively high rates of return should receive relatively large injections of production-oriented research and extension expenditures.

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[5] The elasticity of productivity with respect to weather is .2 when the weather index is at its mean of 101.57. This elasticity times the coefficient of variation of the weather data series yields .034. The elasticity of the education index, on the other hand, is .78, which, when multiplied by the coefficient of variation of education, yields .026. Finally, the elasticity of productivity with respect to production-oriented research and extension expenditures, .037, times its coefficient of variation is only .002.

BIBLIOGRAPHY

(1) Agricultural Policy Institute. United States Agricultural Policy: Foreign and Domestic. Proceedings of a Conference. Raleigh, N. C.: North Carolina State University, January, 1968.

(2) Allen, P. G., and R. E. Howitt. "The Allocation of Research and Extension Expenditures in Agriculture." Paper presented at American Agricultural Economics Association annual meeting, College Station, Texas, August 18-21, 1974.

(3) Almon, Shirley. "The Distributed Lag Between Capital Appropriations and Expenditures." Econometrica, 30 (January, 1965), 178-196.

(4) American Association of University Professors. AAUP Bulletin. Washington, D.C.: Annual Issues, 1950-1972.

(5) Bellmon, R. Adaptive Control Processes: A Guided Tour. Santa Monica: Rand Corporation, 1969.

(6) Boucher, Wayne I., Theodore J. Gordon, and James E. Lamson. Candidates and Priorities for Technology Assessments. Report prepared for the National Science Foundation. Glastonbury, Conn.: The Futures Group, 1973.

(7) Brown, M. On the Theory and Measurement of Technical Change. Cambridge: Cambridge University Press, 1966.

(8) The Budget of the United States Government. Washington, D.C.: Annual Issues, 1929-1972.

(9) Burnham, B., Leroy Quance, and A. Howell. "1980 and Beyond: The Impact of Research and Development Expenditures on Agriculture Production Efficiencies." Paper presented at the American Agricultural Economics Association annual meeting, Edmonton, Alberta, Canada, August 8-11, 1973.

(10) Cline, Philip L. "Sources of Productivity Change in U. S. Agriculture." Paper submitted to National Economic Analysis Division, Economic Research Service, U. S. Department of Agriculture, Washington, D.C., 1974.

(11) Cochran, Thomas C., and Thomas B. Brewer. Views of American Economic Growth: The Industrial Era. New York: McGraw-Hill Book Co., 1966.

(12) Cooper, Phillip J. "Two Approaches to Polynomial Distributed Lags Estimation: An Expository Note and Comment." The American Statistician, 26 (June, 1972), 32-35.

(13) De Leeuw, Fi. "The Demand for Capital Goods by Manufacturers, A Study of Quarterly Time Series." Econometrica, 30 (July, 1962), 407-423.

(14) Draper, N. R. and H. Smith. Applied Regression Analysis. New York: John Wiley and Sons, 1966.

(15) Durbin, J. "Estimation of Parameters in Time-Series Regression Models." Journal of the Royal Statistics Society, Ser. B, 22 (January, 1969), 139-153.

(16) Durost, Donald D. and L. Don Lambert. "Is Farm Productivity Leveling?" The Farm Index, 10 (September, 1971), 4-5.

(17) Evenson, Robert E. "The Contributions of Agricultural Research and Extension to Agricultural Productivity." (Ph.D. dissertation, University of Chicago, 1968.)

(18) Evenson, Robert and Finis Welch. "Agricultural Research and Extension in the U. S." Paper written at the Economic Growth Center. New Haven, Conn.: Yale University, 1974.

(19) Farrar, D. E. and R. R. Glauber. "Multicollinearity in Regression Analysis: The Problem Re-visited." Review of Economics and Statistics, 49 (May, 1967), 92-107.

(20) Green, H. A. John. Aggregation in Economic Analysis. Princeton: Princeton University Press, 1964.

(21) Griliches, Zvi. "Distributed Lags: A Survey." Econometrica, 35 (January,1967), 16-49.

(22) Griliches, Zvi. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." Journal of Political Economy, 66 (October,1958), 419-431.

(23) Griliches, Zvi. "Research Expenditures, Education, and the Aggregate Agricultural Production Function." The American Economic Review, 54 (December, 1964), 961-974.

(24) Griliches, Zvi. "The Sources of Measured Productivity Growth: United States Agriculture, 1940-1960." Journal of Political Economy, 71 (August, 1963), 331-346.

(25) Heady, Earl O. Economics of Agricultural Production and Research Use. Englewood Cliffs, N.J.: Prentice-Hall, 1952.

(26) Ho, Yhi-Min. Agricultural Development of Taiwan 1903-1960. Kingsport, Tenn.: Vanderbilt University Press, 1966.

(27) Huffman, Wallace E. and James R. Lothian. "An Explanation of the Growth of Nominal Income in the United Kingdom, 1933-1935." Stillwater, Oklahoma, April 1, 1974.

(28) Johnston, J. *Econometric Methods*, 2d ed. New York: McGraw-Hill, 1972.

(29) Kendall, M. G. "A New Measure of Rank Correlation." *Biometrika*, 30 (1938), 81-93.

(30) Kendall, M. G. *Rank Correlation Methods*. London: Griffin, 1948.

(31) Kost, William E. "Weather Indexes, 1950-1963." *Quarterly Bulletin of Michigan Agricultural Station*, 47 (August, 1964), 18-42.

(32) Krutilla, John V. and Otto Eckstein. *Multiple Purpose River Development*. Baltimore: John Hopkins Press, 1958.

(33) Lambert, L. D. "Regional Trends in the Productivity of American Agriculture." (Ph.D. dissertation, Michigan State University, 1973.)

(34) Latimer, Robert George. "Some Economic Aspects of Agricultural Research and Education in the United States." (Ph.D. dissertation, Purdue University, 1964.)

(35) Lave, L. *Technological Change: Its Conception and Measurement*. Englewood Cliffs, N.J.: Prentice-Hall, 1966.

(36) Lu, Y. C. "Measuring Productivity Change in U. S. Agriculture." Paper submitted to National Economic Analysis Division, Economic Research Service, U. S. Department of Agriculture, Washington, D.C., 1974.

(37) Lu, Yao-Chi. "On Measuring Productivity Change Using an Arithmetic Formula." Paper submitted to National Economic Analysis Division, Economic Research Service, U. S. Department of Agriculture, Washington, D.C., 1974.

(38) Lu, Yao-Chi. "A Production Function Approach to Measuring Productivity Growth." Paper presented at the American Agricultural Economic Association meetings, College Station, Texas, 1974.

(39) Lu, Yao-Chi. "Productivity Change in U. S. Agriculture, 1910-1972." Paper submitted to National Economic Analysis Division, Economic Research Service, U. S. Department of Agriculture, Washington, D.C., 1974.

(40) Lu, Yao-Chi. "Projecting Productivity and Technological Change in U. S. Agriculture." Paper submitted to National Economic Analysis Division, Economic Research Service, U. S. Department of Agriculture, Washington, D.C., 1973.

(41) Lu, Yao-Chi. "Regional Comparisons of Productivity Growth in U. S. Agriculture, 1939-1972." Paper presented at the Western Agricultural Economics Association meetings, Moscow, Idaho, 1974.

(42) Lu, Yao-Chi, and Philip L. Cline. "Productivity Change in U. S. Agriculture over the Next 50 Years." Paper submitted to National Economic Analysis Division, Economic Research Service, U. S. Department of Agriculture, Washington, D.C., 1974.

(43) Mansfield, Edwin. The Economics of Technological Change. New York: W. W. Norton and Co., 1968.

(44) Mansfield, Edwin. Technological Change. New York: W. W. Norton and Co., 1971.

(45) Marschak, Jacob. "Economics of Inquiring, Communicating Deciding." American Economic Review, 58 (May, 1968), 1-18.

(46) Mitchell, J. Murray, Jr. A Critical Appraisal of Periodicities in Climate. Ames: Iowa State University Center for Agricultural Economic Development, Report 20, 1964.

(47) Peterson, Willis L. "Return to Poultry Research in the United States." Journal of Farm Economics, 49 (August, 1967), 656-669.

(48) Peterson, Willis L. "The Returns to Investment in Agricultural Research in the United States." In Resource Allocation in Agricultural Research. Edited by Walter L. Fishel. Minneapolis: University of Minnesota Press, 1971, 139-162.

(49) Quinn, James B. "Technological Forecasting." Harvard Business Review, 46 (April, 1967), 89-106.

(50) Rosenburg, Nathan, ed. The Economics of Technological Change. Baltimore: Penguin Books, 1971.

(51) Ruttan, V. W., and T. T. Stout. "Regional Differences in Factor Shares in American Agriculture: 1925-1957." Journal of Farm Economics, 42 (February, 1960), 52-68.

(52) Schmidt, Peter, and Roger N. Waud. "The Almon Lag Technique and the Monetary Versus Fiscal Policy Debate." Journal of the American Statistical Association, 68 (March, 1973), 11-19.

(53) Schultz, T. W. The Economic Organization of Agriculture. New York: McGraw-Hill, 1953.

(54) Schultz, T. W. The Economic Value of Education. New York: Columbia University Press, 1963.

(55) Siegel, Sidney, Nonparametric Statistics for the Behavioral Sciences. New York: McGraw-Hill, 1956.

(56) Singer, Neil M. Public Microeconomics. Boston: Little, Brown and Co., 1972.

(57) Smith, Warren J. "The Effect of Weather Upon the Yield of Corn." Monthly Weather Review, 42 (May, 1914), 78-87.

(58) Stigler, George J. Employment and Compensation in Education. National Bureau of Economic Research Occasional Paper No. 33. New York: National Bureau of Economic Research, Inc., 1950.

(59) Stallings, J. L. "Indexes of the Influence of Weather on Agricultural Output." (Ph.D. dissertation, Michigan State University, 1958.)

(60) Theil, H. Economic Forecasts and Policy, 2d ed. Amsterdam: North Holland Publishing Co., 1961.

(61) Thompson, Louis M. Weather Variability and the Need for a Food Reserve. Ames: Iowa State University Center for Agricultural Economic Development, Report 25, 1966.

(62) Tintner, Gerhard. Econometrics. New York: John Wiley and Sons, 1965.

(63) Toro-Vizcarrondo, Carlos, and T. D. Wallace. "A Test of the Mean Square Error Criterion for Restrictions in Linear Regression." Journal of the American Statistical Association, 63 (June, 1968), 558-572.

(64) Trivedi, P. K. "A Note on the Application of Almon's Method of Calculating Distributed Lag Coefficients." Metroeconomica, 22 (September-December, 1970), 281-286.

(65) Tweeten, Luther G., and Fred K. Hines. "Contributions of Agricultural Productivity to National Economic Growth." Agricultural Science Review, 3 (Second quarter, 1965), 40-45.

(66) U. S. Congress. Joint Committee on Economics. Economic Analysis of Public Investment Decisions: Interest Rate Policy and Discounting Analysis. Hearings before the Subcommittee on Economy in Government, 90th Cong. 2d. sess., 1968.

(67) U. S. Department of Agriculture. Agricultural Statistics, 1947. Washington, D.C.: Government Printing Office, 1948.

(68) U. S. Department of Agriculture. Agricultural Statistics, 1973. Washington, D.C.: Government Printing Office, 1973.

(69) U. S. Department of Agriculture. Major Statistical Series of the U. S. Department of Agriculture, Vol. 2, Agricultural Production and Efficiency. Agriculture Handbook No. 365. Washington, D.C.: Government Printing Office, April, 1970.

(70) U. S. Department of Agriculture. Agricultural Research Administration. *Report on the Agricultural Experiment Stations.* Washington, D.C.: Government Printing Office, annual issues 1930-1954.

(71) U. S. Department of Agriculture. Agricultural Research Service. *Report on the Agricultural Experiment Stations.* Washington, D.C.: Government Printing Office, annual issues, 1955-1961.

(72) U. S. Department of Agriculture. Cooperative State Experiment Station Service. *Funds for Research at State Agricultural Experiment Stations.* Washington, D.C.: Government Printing Office, annual issues, 1962-1964.

(73) U. S. Department of Agriculture. Cooperative State Research Service. *Funds for Research at State Agricultural Experiment Stations and Other State Institutions.* Washington, D.C.: Government Printing Office, annual issues, 1965-1972.

(74) U. S. Department of Agriculture. Economic Research Service. *Changes in Farm Production and Efficiency, 1964.* Statistical Bulletin No. 233. Washington, D.C.: Government Printing Office, 1964.

(75) U. S. Department of Agriculture. Economic Research Service. *Changes in Farm Production and Efficiency, 1972.* Statistical Bulletin No. 233. Washington, D.C.: Government Printing Office, 1972.

(76) U. S. Department of Agriculture. Economic Research Service. *Changes in Farm Production and Efficiency, 1973.* Statistical Bulletin No. 233. Washington, D.C.: Government Printing Office, 1973.

(77) U. S. Department of Agriculture. Federal Extension Service. *Annual Report of Cooperative Extension Work in Agriculture.* Washington, D.C.: Government Printing Office, annual issues,1930-1956.

(78) U. S. Department of Agriculture. Federal Extension Service. "Annual Report of County Extension Agents." Extension Service Work Sheets. Washington, D.C., 1964, 1968, and 1969.

(79) U. S. Department of Agriculture. Federal Extension Service. *Extension Activities and Accomplishments.* Extension Service Circulars. Washington, D.C.: Government Printing Office, annual issues, 1929-1962.

(80) U. S. Department of Agriculture. Federal Extension Service. "Sources of Funds Allotted for Cooperative Extension Work in the States and Puerto Rico." Washington, D.C.: Government Printing Office, annual issues, 1956-1972. Mimeographed.

(81) U. S. Department of Agriculture. Soil Conservation Service. Report of the Chief of the Soil Conservation Service, 1935. Washington, D.C.: Government Printing Office, 1936.

(82) U. S. Department of Agriculture, and the Association of State Universities and Land Grant Colleges. A National Program of Research for Agriculture. Washington, D.C.: Government Printing Office, 1966.

(83) U. S. Department of Commerce. Bureau of the Census. Census of Agriculture, 1969, Vol. 2, General Report, Chapter 3, "Farm Management, Farm Operators." Washington, D.C.: Government Printing Office, 1973.

(84) U. S. Department of Commerce. Bureau of the Census. Population Characteristics, Educational Attainment: March 1968. Series P-20 No. 182. Washington, D.C.: Government Printing Office, 1969.

(85) U. S. Department of Commerce. Bureau of the Census. Population Characteristics, Educational Attainment: March 1969. Series P-20 No. 194. Washington, D.C.: Government Printing Office, 1970.

(86) U. S. Department of Commerce. Bureau of the Census. Population Characteristics, Educational Attainment: March 1971. Series P-20 No. 229. Washington, D.C.: Government Printing Office, 1971.

(87) U. S. Department of Commerce. Bureau of the Census. United States Census of Population, 1970, Educational Attainment. Subject Report PC(2)-5B. Washington, D.C.: Government Printing Office, 1973.

(88) U. S. Department of Commerce. Bureau of the Census. United States Census of Population, 1970, Occupational Characteristics. Subject Report PC(2)-7A. Washington, D.C.: Government Printing Office, 1973.

(89) U. S. Department of Commerce. Office of Business Economics. Survey of Current Business. Washington, D.C.: Government Printing Office, July issues, 1966-1972.

(90) U. S. Department of Commerce. Office of Business Economics. The National Income and Product Accounts of the United States, 1929-1965. Washington, D.C.: Government Printing Office, 1966.

(91) U. S. Department of Health, Education, and Welfare. Office of Education. Digest of Educational Statistics, 1973, by W. Vance Grant and C. George Lind. DHEW Publication No. (OE) 74-11103. Washington, D.C.: Government Printing Office, 1974.

(92) U. S. Department of Treasury. Bureau of Accounts. Combined Statement of Receipts, Expenditures, and Balances of the United States Government. Washington, D.C.: Government Printing Office, annual issues, 1929-1972.

(93) Welch, Finis. "Measurement of the Quality of Schooling." American Economic Review, 56 (May, 1966), 379-392.

(94) "The World Food Crisis." Time, 104 (November 11, 1974), 66-83.

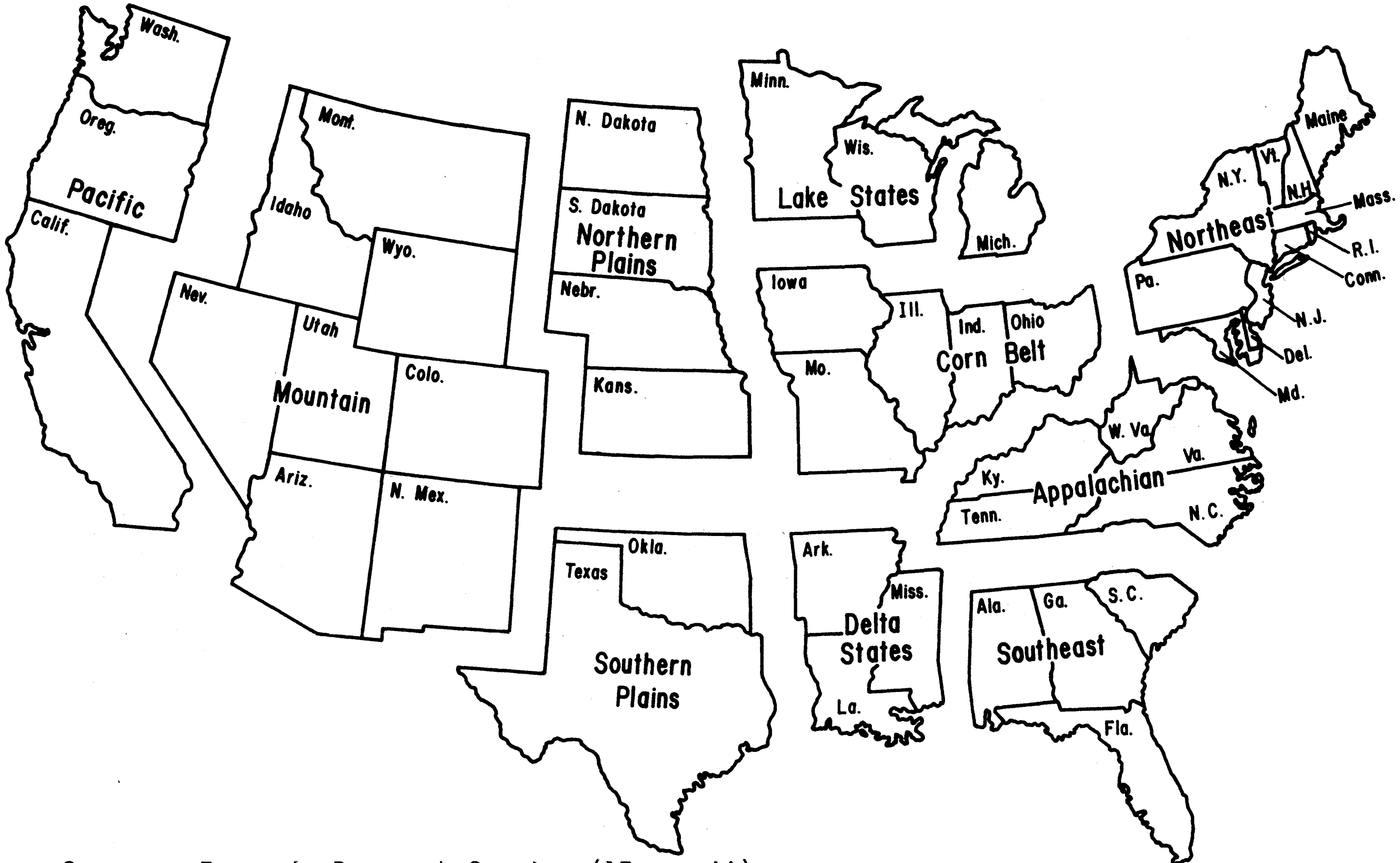
APPENDIX

DATA

Contained in Tables XVIII through XXVIII are the basic time series data for the United States and the ten U. S. Department of Agriculture (USDA) farm production regions shown in Figure 11. As inferred by this figure, data pertain to the 48 contiguous states unless otherwise noted. The omission of Alaska and Hawaii in this study results from the fact that this is the form in which some of the data are reported by the USDA. This is not a serious omission, however, for in 1971 only about 0.2 percent of the total number of farms in the 50 states were in Alaska and Hawaii and they contained only about 0.4 percent of the land in farms (75, p. iii).

Data on the expenditures of the various public sector agencies under consideration are reported for the 1929 to 1972 period. Observations on all other series begin in 1939. This difference in the periods spanned by the data is a consequence of the estimating form of the empirical equations selected as being most representative of the relationship between research and extension and productivity. That is, use of lagged values of production-oriented research and extension expenditures requires that earlier observations on this series be available in order to retain as many degrees of freedom as possible.

Empirical examination of the theoretical framework developed in Chapter III of this study gives rise to one problem which directly



Source: Economic Research Service (17, p. ii).

Figure 11. The Ten Farm Production Regions of the United States as Defined by the Economic Research Service, USDA

TABLE XVIII

TIME SERIES DATA, 48 CONTIGUOUS STATES

YEAR	USDA PRODUCTIVITY INDEX (1967=100)	EDUCATIONAL ATTAINMENT INDEX	WEATHER INDEX	PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
				ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				7015	267	14976	0	12988	35246	13909	730	10041	24680
1930				8219	326	16162	0	13670	38377	19928	774	10524	31226
1931				9384	354	16264	0	13871	39873	16104	1142	11488	28734
1932				9910	450	16123	0	12582	39065	13329	1138	10980	25447
1933				8049	351	14097	0	11491	33988	12347	1094	10396	23837
1934				7002	297	13312	0	13017	33628	14310	881	6736	21927
1935				7367	328	13700	0	11105	32500	12899	879	9123	22901
1936				8466	343	14876	4851	16658	45194	13812	1033	11339	26184
1937				8606	342	15967	19119	16193	60227	14719	1040	13464	29223
1938				9116	156	17923	19108	16437	62740	17446	630	14753	32829
1939	60.00	94.6	98.1	9284	215	18662	19224	16743	64128	25574	581	15209	41364
1940	62.00	96.0	86.1	9101	1062	19211	19580	16697	65651	25584	1974	15850	43408
1941	64.00	97.4	107.1	8848	1577	20227	15351	16866	62869	23634	2929	16076	42639
1942	69.00	98.8	111.8	9250	1340	22181	18490	13706	64967	23749	2392	20220	46361
1943	68.00	100.2	101.7	9137	1165	21578	20562	13898	66340	18206	1449	20504	40159
1944	69.00	101.6	101.0	8960	1168	23182	21033	13978	68321	18974	1205	21680	41859
1945	70.00	103.0	106.8	10189	1044	24221	26297	14679	76430	18973	1331	22768	43072
1946	72.00	104.4	100.8	11525	1440	28546	31806	18036	91353	19333	980	25634	45947
1947	70.00	105.8	96.5	13733	1267	35434	41617	21415	113466	39666	1230	31331	72227
1948	76.00	107.2	118.4	14767	1011	44129	36471	23943	120321	53994	982	35031	90007
1949	73.00	108.6	93.9	15858	1104	50043	45085	25855	137945	28782	1040	38462	68284
1950	73.00	110.0	102.3	18978	1367	58475	49676	28758	157254	77264	1247	42958	121469
1951	73.00	113.0	100.9	19187	1356	62794	49831	29323	162491	38077	1119	44912	84108
1952	76.00	116.0	95.8	19879	1256	69536	52050	30866	173587	40442	1003	47474	88919
1953	77.00	118.0	95.6	21873	851	72356	54682	30200	179962	41919	3774	52540	98233
1954	78.00	119.0	96.1	23177	863	80297	54268	31668	190273	41145	3884	55813	100842
1955	81.00	120.0	104.2	24983	998	87831	52062	35792	201666	37846	5106	61469	104421
1956	82.00	121.0	89.4	27648	1361	100091	55599	38848	223547	63978	5652	67585	137215
1957	83.00	122.0	103.2	37967	1421	108989	59141	42311	249829	66209	6445	72979	145633
1958	89.00	124.6	113.8	42652	1570	124765	66357	46510	281854	95939	7197	81265	184401
1959	90.00	129.5	96.0	45123	1589	130455	71825	47170	296162	96945	7460	84224	188629
1960	93.00	129.2	108.2	46390	1579	141055	75014	48336	312374	94261	7211	89117	190589
1961	94.00	131.0	102.3	53034	3175	145432	81185	51152	333978	99784	5822	97979	203585
1962	95.00	133.0	97.4	56261	3277	156222	88906	56659	361325	103305	4913	98148	206366
1963	98.00	134.0	105.1	58624	3079	165847	93260	59885	380695	116985	6663	104184	227832
1964	97.00	135.0	101.2	63277	3360	187008	96512	62852	413009	128542	6656	110293	245491
1965	100.00	138.8	104.3	75945	4788	205864	103165	66685	456447	132427	5350	117019	254796
1966	97.00	142.6	101.4	86742	5069	224722	108475	72621	497629	115096	6257	126888	248241
1967	100.00	146.4	100.5	93037	5899	234021	111265	75785	520007	129287	6223	131844	267354
1968	101.00	150.3	102.7	101308	5718	264457	113974	80202	565659	136962	7551	138928	283441
1969	101.00	153.7	103.8	107742	6576	278553	117697	86772	597340	144254	6477	148382	299113
1970	101.00	157.2	96.9	100037	6854	301118	131094	105410	644513	167228	8934	177949	354111
1971	108.00	161.6	105.0	119020	7625	324692	138874	120246	710457	163812	7592	200410	371814
1972	109.00	166.0	105.1	126032	7622	348266	166830	130263	779013	231792	9635	214349	455776

TABLE XIX

TIME SERIES DATA, NORTHEAST REGION

YEAR	USDA PRODUCTIVITY INDEX (1967=100)	EDUCATIONAL ATTAINMENT INDEX	WEATHER INDEX	PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
				ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				112	4	2964	0	2526	5606	223	12	1953	2188
1930				148	6	3657	0	2651	6462	359	14	2041	2414
1931				188	7	4190	0	2682	7067	322	23	2222	2567
1932				218	10	4171	0	2629	7028	293	25	2294	2612
1933				193	8	3965	0	2595	6761	296	26	2347	2659
1934				182	8	3335	0	2771	6296	372	23	1434	1829
1935				206	9	3281	0	2299	5795	361	25	1888	2274
1936				254	10	3472	406	2863	7005	414	31	1949	2394
1937				275	11	3672	1429	2719	8106	471	33	2261	2765
1938				310	5	3871	1523	2794	8503	593	21	2508	3122
1939	54.48	94.1	101.5	344	8	4109	1573	2821	8855	946	21	2562	3529
1940	55.90	95.5	87.6	355	41	4121	1576	2758	8851	998	77	2619	3694
1941	55.62	96.9	101.7	363	65	4238	1189	2758	8613	969	120	2628	3717
1942	59.84	98.3	100.5	398	58	4200	1270	2223	8149	1021	103	3280	4404
1943	59.04	99.7	93.4	420	54	4176	1399	2187	8236	837	67	3227	4131
1944	60.73	101.1	88.8	430	56	4486	1369	2196	8537	911	58	3405	4374
1945	61.19	102.5	93.7	509	52	4696	1695	2311	9264	949	57	3585	4601
1946	66.45	103.9	103.7	622	78	5218	2446	2670	11034	1044	53	3795	4892
1947	65.42	105.3	101.0	810	75	6109	3599	3356	13949	2340	73	4910	7323
1948	66.89	106.7	116.8	930	64	7236	3078	3720	15028	3402	62	5443	8907
1949	66.97	108.1	100.8	1078	75	8639	3806	3742	17340	1957	71	5567	7595
1950	68.00	109.5	118.6	1366	98	9776	4289	4115	19644	5563	90	6148	11801
1951	69.00	112.5	115.5	1477	104	10247	4135	4291	20254	2932	86	6572	9590
1952	69.00	115.5	101.0	1610	102	10961	4289	4512	21474	3276	81	6941	10298
1953	73.00	117.5	102.1	1881	73	12193	4528	4543	23218	3605	325	7904	11834
1954	75.00	118.5	106.9	2086	78	13159	4579	4718	24620	3703	350	8314	12367
1955	75.00	119.5	108.4	2373	95	14494	3938	5329	26229	3595	485	9153	13233
1956	79.00	120.5	95.2	2571	127	15491	4198	5753	28140	5950	526	10008	16484
1957	78.00	121.5	103.2	3455	129	17338	4533	6256	31711	6025	586	10790	17401
1958	85.00	124.1	116.4	3753	138	18643	5326	6724	34584	8443	633	11748	20824
1959	85.00	129.0	94.9	3881	137	19764	5837	7002	36621	8337	642	12502	21481
1960	89.00	128.7	111.9	3897	133	20198	5942	6956	37126	7918	606	12916	21442
1961	92.00	130.5	105.6	4296	257	21201	6281	7231	39266	8083	472	13852	22407
1962	89.00	132.5	89.2	4445	259	23002	6872	8205	42783	8161	388	14214	22763
1963	91.00	133.5	95.3	4514	237	23584	7177	8768	44280	9008	513	15254	24775
1964	93.00	134.5	94.8	4682	249	28530	7397	9237	50095	9512	493	16210	26215
1965	96.00	138.3	98.0	5468	345	30086	7877	9806	53582	9535	385	17209	27129
1966	92.00	142.1	90.1	6072	355	31643	8252	10356	56678	8057	438	18095	26590
1967	100.00	145.9	100.5	6233	395	34875	8436	10840	60780	8662	417	18859	27938
1968	95.00	149.8	93.8	6585	372	40409	8614	11635	67615	8903	491	20154	29548
1969	99.00	153.2	97.0	6788	414	43822	8868	12287	72179	9088	408	21012	30508
1970	102.00	156.7	96.9	6102	418	4459	9849	15714	36542	10201	545	26529	37275
1971	103.00	161.1	93.7	7022	450	48066	10405	18380	84323	9665	448	30634	40747
1972	93.00	165.5	78.4	7058	427	51540	12467	19636	91128	12980	540	32311	45831

TABLE XX

TIME SERIES DATA, LAKE STATES REGION

				PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
YEAR	USDA PRODUCTIVITY INDEX (1967=100)	EDUCATIONAL ATTAINMENT INDEX	WEATHER INDEX	ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				260	10	1414	0	925	2609	515	27	715	1257
1930				312	12	1483	0	1020	2827	757	29	785	1571
1931				357	13	1497	0	1078	2945	612	43	892	1547
1932				377	17	1462	0	930	2786	507	43	811	1361
1933				306	13	1326	0	860	2505	469	42	778	1289
1934				273	12	1343	0	903	2531	558	34	467	1059
1935				287	13	1370	0	780	2450	503	34	640	1177
1936				330	13	1419	239	1174	3175	539	40	799	1378
1937				336	13	1465	746	1216	3776	574	41	1011	1626
1938				365	6	1600	889	1218	4078	698	25	1094	1817
1939	62.89	95.1	98.1	371	9	1805	839	1248	4272	1023	23	1133	2179
1940	65.00	96.5	87.6	364	42	1686	904	1202	4198	1023	79	1141	2243
1941	63.79	97.9	96.4	354	63	1770	888	1238	4313	945	117	1180	2242
1942	68.86	99.3	102.1	379	55	1843	1087	1004	4368	974	98	1480	2552
1943	66.40	100.7	88.4	375	48	1854	1172	1059	4508	746	59	1563	2368
1944	66.08	102.1	84.2	367	48	1895	1254	1004	4568	778	49	1558	2385
1945	70.69	103.5	96.9	418	43	2043	1632	1107	5243	778	55	1718	2551
1946	72.20	104.9	87.7	507	63	2582	1749	1406	6307	851	43	1999	2893
1947	70.67	106.3	83.1	659	61	3205	2067	1628	7620	1904	59	2381	4344
1948	76.79	107.7	104.2	753	52	4153	1814	1793	8565	2754	50	2623	5427
1949	75.71	109.1	87.0	872	61	4849	2447	2014	10243	1583	57	2997	4637
1950	75.00	110.5	99.3	1101	79	5342	2703	2213	11438	4481	72	3306	7859
1951	77.00	113.5	102.4	1190	84	5995	2692	2211	12172	2361	69	3386	5816
1952	80.00	116.5	97.1	1292	82	6925	2849	2418	13566	2629	65	3718	6412
1953	80.00	118.5	95.6	1509	59	7330	2981	2437	14316	2892	260	4239	7391
1954	81.00	119.5	100.2	1669	62	7709	2987	2562	14989	2962	280	4515	7757
1955	82.00	120.5	107.0	1924	77	8481	2966	3051	16499	2914	393	5239	8546
1956	86.00	121.5	95.2	2157	106	10039	3233	3278	18813	4990	441	5703	11134
1957	87.00	122.5	109.9	2999	112	11233	3545	3662	21551	5231	509	6315	12055
1958	91.00	125.1	113.8	3455	127	11982	4053	3898	23515	7771	583	6812	15166
1959	93.00	130.0	97.1	3700	130	12657	4497	3951	24935	7949	612	7054	15615
1960	94.00	129.7	109.4	3850	131	13535	4957	4694	27167	7824	599	8717	17140
1961	99.00	131.5	104.5	4508	270	13841	5477	4106	28202	8482	495	7866	16843
1962	97.00	133.5	97.4	4838	282	14741	5882	4628	30371	8884	423	8018	17325
1963	102.00	134.5	105.1	5100	268	15337	6241	4869	31815	10178	580	8472	19230
1964	99.00	135.5	96.9	5632	299	16607	6528	5139	34205	11440	592	9018	21050
1965	98.00	139.3	96.0	6835	431	18345	7046	5509	38166	11916	481	9667	22065
1966	101.00	143.1	103.4	7894	461	20084	7477	5838	41754	10474	569	10200	21243
1967	100.00	146.9	100.5	8559	543	21454	7735	6447	44738	11894	573	11215	23682
1968	102.00	150.8	105.7	9523	537	21955	7986	6709	46710	12874	710	11621	25205
1969	99.00	154.2	106.7	10235	625	23641	8308	7424	50233	13704	615	12696	27015
1970	102.00	157.7	102.6	9604	658	27747	9319	9034	56362	16054	858	15250	32162
1971	107.00	162.1	107.8	11545	740	29304	9936	10330	61855	15890	736	17218	33844
1972	107.00	166.5	105.1	12477	755	30861	12011	11173	67277	22947	954	18386	42287

TABLE XXI

TIMES SERIES DATA, CORN BELT REGION

YEAR	USDA PRODUCTIVITY INDEX (1967=100)	EDUCATIONAL ATTAINMENT INDEX	WEATHER INDEX	PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
				ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				288	11	2979	0	2270	5548	570	30	1755	2355
1930				370	15	2750	0	2368	5503	897	35	1823	2755
1931				469	13	2456	0	2383	5326	805	57	1974	2836
1932				535	24	2596	0	2112	5267	720	61	1843	2624
1933				467	20	1872	0	1866	4225	716	63	1688	2457
1934				434	18	2233	0	2151	4836	887	55	1113	2055
1935				494	22	2214	0	1851	4581	864	59	1521	2444
1936				601	24	2350	660	2725	6360	981	73	1855	2909
1937				645	26	2457	2285	2641	8054	1104	78	2196	3378
1938				720	12	3014	2187	2692	8625	1378	50	2417	3845
1939	64.63	94.0	101.5	780	18	2961	2128	2739	8626	2148	49	2488	4685
1940	62.83	95.4	81.7	801	93	3079	1972	2755	8700	2251	174	2615	5040
1941	66.35	96.8	105.3	814	145	3502	1596	2796	8853	2174	269	2665	5108
1942	71.77	98.2	105.3	897	130	4095	1622	2246	8990	2304	232	3313	5849
1943	70.17	99.6	96.7	923	118	3598	1820	2269	8728	1839	146	3347	5332
1944	68.20	101.0	87.2	941	123	3819	1940	2275	9098	1992	127	3528	5647
1945	69.96	102.4	93.7	1111	114	3728	2384	2434	9771	2068	145	3776	5989
1946	76.31	103.8	99.3	1245	156	4421	3149	2949	11920	2088	106	4191	6385
1947	64.28	105.2	69.8	1456	134	5902	4412	3378	15282	4205	130	4942	9277
1948	81.08	106.6	124.7	1551	106	6574	4064	3964	16259	5669	103	5800	11572
1949	75.10	108.0	92.5	1649	115	6913	5149	4085	17911	2993	108	6076	9177
1950	74.00	109.4	87.5	1955	141	8549	5773	4346	20764	7958	128	6491	14577
1951	72.00	112.4	83.4	1957	138	9189	5828	4340	21452	3884	114	6648	10646
1952	76.00	115.4	84.0	1988	126	10770	6087	4643	23614	4044	100	7140	11284
1953	75.00	117.4	79.9	2165	84	10843	6428	4500	24020	4150	374	7829	12353
1954	76.00	118.4	83.9	2271	85	12018	6205	4688	25267	4032	381	8262	12675
1955	79.00	119.4	91.5	2423	97	11788	6241	5165	25714	3671	495	8871	13037
1956	82.00	120.4	77.8	2737	135	14473	6641	5728	29714	6334	560	9966	16860
1957	82.00	121.4	89.8	3835	144	14516	7074	6331	31900	6687	651	10919	18257
1958	88.00	124.0	97.9	4393	162	17218	8085	7945	37803	9882	741	13882	24505
1959	90.00	128.9	84.8	4738	167	17213	8803	6733	37654	10179	783	12021	22983
1960	93.00	128.6	98.4	4917	167	18753	9009	6921	39767	9992	764	12852	23608
1961	94.00	130.4	95.6	5728	343	18932	9809	7340	42152	10777	629	14060	25466
1962	94.00	132.4	90.2	6189	360	20640	10829	8329	46347	11364	540	14428	26332
1963	99.00	133.4	100.8	6566	345	21640	11389	8915	48855	13102	746	15509	29357
1964	95.00	134.4	92.7	7214	383	26443	11814	9323	55177	14654	759	16361	31774
1965	100.00	138.2	101.2	8810	555	29274	12656	9784	61079	15362	621	17168	33151
1966	96.00	142.0	98.3	10149	593	32106	13336	10656	66840	13466	732	18619	32817
1967	100.00	145.8	100.5	11071	702	30783	13705	11346	67607	15385	741	19739	35865
1968	99.00	149.7	102.7	12258	692	37325	14065	12601	76941	16572	914	21829	39315
1969	97.00	153.1	104.8	13252	809	36894	14549	13696	79200	17743	797	23421	41961
1970	92.00	156.6	90.2	12505	857	42070	16232	15864	87528	20904	1117	26781	48802
1971	107.00	161.0	108.7	14997	961	47764	17222	18282	99226	20640	957	30470	52067
1972	106.00	165.4	109.7	16132	976	53458	20719	19672	110957	29669	1233	32370	63272

TABLE XXII

TIME SERIES DATA, NORTHERN PLAINS REGION

YEAR	USDA PRODUCT-IVITY INDEX (1967=100)	EDUCA-TIONAL ATTAIN-MENT INDEX	WEATHER INDEX	PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
				ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				807	31	882	0	901	2621	1600	84	696	2380
1930				921	37	1053	0	950	2961	2232	87	731	3050
1931				1023	39	1029	0	965	3056	1755	124	800	2679
1932				1050	48	1029	0	843	2970	1413	121	736	2270
1933				829	36	755	0	731	2351	1272	113	662	2047
1934				700	30	754	0	847	2331	1431	88	438	1957
1935				715	32	761	0	778	2286	1251	85	639	1975
1936				796	32	886	270	1214	3198	1298	97	827	2222
1937				783	31	881	1257	1190	4142	1339	95	989	2423
1938				802	14	1038	1080	1177	4111	1535	55	1057	2647
1939	46.94	95.6	56.5	789	18	961	1295	1219	4282	2174	49	1107	3330
1940	53.41	97.0	64.2	746	87	1038	1589	1192	4652	2098	162	1132	3392
1941	63.99	98.4	108.9	690	123	1076	1384	1188	4461	1843	228	1133	3204
1942	74.73	99.8	131.2	694	100	1178	1777	944	4693	1781	179	1393	3353
1943	69.02	101.2	111.7	658	84	1203	1949	922	4816	1311	104	1360	2775
1944	71.25	102.6	111.7	618	81	1300	1979	953	4931	1309	83	1478	2870
1945	74.95	104.0	123.2	672	69	1424	2500	996	5661	1252	88	1544	2884
1946	74.30	105.4	102.3	749	94	1655	3093	1177	6768	1257	64	1672	2993
1947	75.53	106.8	105.4	879	81	1729	4172	1363	8224	2539	79	1994	4612
1948	79.03	108.2	121.6	945	65	2381	3917	1570	8878	3456	63	2297	5816
1949	67.11	109.6	73.2	999	70	2571	4808	1705	10153	1813	66	2536	4415
1950	76.00	111.0	100.8	1177	85	3401	5366	1989	12018	4790	77	2971	7838
1951	72.00	114.0	89.2	1170	83	3645	5437	2097	12432	2323	68	3213	5604
1952	77.00	117.0	90.6	1193	75	4249	5686	2252	13455	2427	60	3464	5951
1953	71.00	119.0	79.9	1312	51	4319	5884	2108	13674	2515	226	3666	6407
1954	73.00	120.0	82.6	1367	51	4836	5733	2267	14254	2428	229	3995	6652
1955	70.00	121.0	80.3	1449	58	5904	5499	2471	15381	2195	296	4243	6734
1956	70.00	122.0	65.0	1576	78	6262	5858	2719	16493	3647	322	4731	8700
1957	80.00	123.0	99.2	2126	80	6827	6459	2822	18314	3708	361	4868	8937
1958	97.00	125.6	128.4	2303	85	8304	7062	2963	20717	5181	339	5176	10746
1959	83.00	130.5	82.6	2392	84	8592	7657	3112	21837	5138	395	5557	11090
1960	98.00	130.2	118.0	2459	84	10830	8074	3090	24537	4996	382	5739	11117
1961	89.00	132.0	92.3	2758	165	10324	8777	3302	25326	5189	303	6326	11818
1962	97.00	134.0	99.5	2869	167	10828	9516	3857	27237	5269	251	6682	12202
1963	95.00	135.0	97.5	2931	154	11439	9979	4087	28590	5849	333	7110	13292
1964	94.00	136.0	90.5	3164	168	13012	10323	4280	30947	6427	333	7510	14270
1965	99.00	139.8	101.2	3721	235	14380	11031	4568	33935	6489	262	8016	14767
1966	98.00	143.6	101.4	4164	243	15750	11596	6287	38040	5525	300	10985	16810
1967	100.00	147.4	100.5	4373	277	17296	11891	5153	38990	6076	292	8966	15334
1968	102.00	151.3	108.6	4660	263	21074	12177	5562	43736	6300	347	9636	16283
1969	107.00	154.7	116.4	4956	302	21530	12572	5987	45347	6636	298	10238	17172
1970	100.00	158.2	98.8	4502	308	23085	13999	6842	48736	7525	402	11550	19477
1971	116.00	162.6	122.8	5237	335	23274	14827	7685	51358	7208	334	12809	20351
1972	117.00	167.0	120.8	5419	328	23463	17808	7950	54968	9967	414	13082	23463

TABLE XXIII

TIME SERIES DATA, APPLACHIAN REGION

				PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
YEAR	USDA PRODUCTIVITY INDEX (1967=100)	EDUCATIONAL ATTAINMENT INDEX	WEATHER INDEX	ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				253	10	1235	0	1582	3080	501	26	1223	1750
1930				296	12	1312	0	1662	3282	717	28	1279	2024
1931				347	13	1320	0	1683	3363	596	42	1394	2032
1932				367	17	1120	0	1510	3014	493	42	1317	1852
1933				298	13	966	0	1353	2630	457	40	1224	1721
1934				266	11	956	0	1601	2834	544	33	828	1405
1935				280	12	1016	0	1388	2696	490	33	1140	1663
1936				322	13	1191	422	2266	4214	525	39	1542	2106
1937				336	13	1343	1693	2190	5575	574	41	1821	2436
1938				356	6	1414	1718	2207	5701	680	25	1981	2686
1939	71.77	74.6	101.5	362	8	1459	1694	2280	5803	997	23	2072	3092
1940	71.59	76.0	84.6	364	42	1473	1615	2327	5821	1023	79	2209	3311
1941	70.85	77.4	100.0	354	63	1630	1310	2334	5591	945	117	2225	3287
1942	76.82	78.8	98.8	370	54	1712	1710	1920	5766	950	96	2832	3878
1943	72.79	80.2	91.7	375	48	1809	1890	2024	6146	746	59	2986	3791
1944	77.16	81.6	101.0	367	48	2010	2016	2091	6532	778	49	3244	4071
1945	77.32	83.0	111.7	418	43	1915	2643	2123	7142	778	55	3292	4125
1946	82.42	84.4	115.4	496	62	2239	3377	2689	8863	831	42	3823	4696
1947	78.70	85.8	108.4	618	57	2549	4266	3101	10591	1785	55	4537	6377
1948	81.75	87.2	121.6	709	49	3437	3776	3470	11441	2592	47	5078	7717
1949	76.91	88.6	96.7	793	55	4214	4510	3799	13371	1439	52	5652	7143
1950	77.00	90.0	115.6	987	71	5199	4894	4283	15434	4018	65	6399	10482
1951	81.00	93.0	121.4	1036	73	5538	4966	4330	15943	2056	60	6632	8748
1952	79.00	96.0	105.0	1113	70	5672	5304	4554	16713	2265	56	7005	9326
1953	79.00	98.0	100.8	1269	49	6069	5759	4428	17574	2431	219	7704	10354
1954	82.00	99.0	108.3	1391	52	6465	5624	4663	18195	2469	233	8217	10919
1955	86.00	100.0	118.3	1549	62	7813	5601	5371	20396	2346	317	9225	11888
1956	92.00	101.0	106.8	1714	84	8599	6011	5826	22234	3967	350	10135	14452
1957	83.00	102.0	105.9	2392	90	9898	6320	6369	25069	4171	406	10984	15561
1958	90.00	104.6	117.8	2687	99	11184	7154	6595	27719	6044	453	11524	18021
1959	91.00	109.5	100.5	2888	102	11491	7738	7037	29256	6204	477	12566	19247
1960	95.00	109.2	114.3	2969	101	11901	7887	6868	29726	6033	462	12755	19250
1961	97.00	111.0	112.3	3447	206	12747	8564	7347	32311	6486	378	14073	20937
1962	99.00	113.0	113.8	3657	213	14508	9611	8403	36392	6715	319	14557	21591
1963	101.00	114.0	124.6	3869	203	16293	10114	8867	39346	7721	440	15425	23586
1964	102.00	115.0	122.5	4176	222	16940	10498	9264	41100	8484	439	16256	25179
1965	97.00	118.8	113.7	5088	321	19516	11252	9905	46082	8873	358	17382	26613
1966	95.00	122.6	104.5	5812	340	22093	11862	10367	50474	7711	419	18115	26245
1967	100.00	126.4	100.5	6327	401	22018	12197	11175	52118	8792	423	19442	28657
1968	95.00	130.3	92.8	6889	389	24775	12523	11596	56172	9313	513	20087	29913
1969	101.00	133.7	100.9	7434	454	26251	12960	12584	59683	9954	447	21519	31920
1970	100.00	137.2	95.0	6903	473	29867	14464	15585	67292	11539	616	26311	38466
1971	101.00	141.6	90.0	8331	534	32317	15352	17648	74182	11467	531	29412	41410
1972	103.00	146.0	92.2	8822	534	34731	18476	19764	82327	16225	674	32523	49422

TABLE XXIV

TIME SERIES DATA, SOUTHEAST REGION

				PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
YEAR	USDA PRODUCTIVITY INDEX (1967=100)	EDUCATIONAL ATTAINMENT INDEX	WEATHER INDEX	ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				877	33	1064	0	1274	3248	1739	91	984	2814
1930				1052	42	1191	0	1340	3625	2551	99	1032	3682
1931				1229	46	1152	0	1360	3787	2110	150	1126	3386
1932				1328	60	1021	0	1176	3585	1786	152	1026	2964
1933				1103	48	933	0	1006	3090	1692	150	911	2753
1934				980	42	914	0	1149	3085	2003	123	595	2721
1935				1053	47	951	0	997	3048	1845	126	819	2790
1936				1236	50	1212	262	1639	4399	2017	151	1116	3284
1937				1282	51	1313	1420	1581	5647	2193	155	1314	3662
1938				1386	24	1586	1613	1617	6226	2652	96	1452	4200
1939	56.27	79.8	82.6	1448	34	1575	1763	1617	6437	3990	91	1468	5549
1940	58.70	81.2	75.9	1447	169	1810	1807	1741	6974	4068	314	1653	6035
1941	54.82	82.6	78.5	1443	255	1899	1576	1752	6925	3829	474	1670	5973
1942	62.05	84.0	87.5	1526	221	2258	2023	1455	7483	3919	395	2147	6461
1943	64.12	85.4	93.4	1535	196	2035	2167	1393	7326	3059	243	2056	5358
1944	65.07	86.8	93.3	1532	200	2365	2265	1452	7814	3245	206	2253	5704
1945	66.51	88.2	105.2	1773	182	2538	2768	1515	8776	3301	232	2349	5882
1946	65.60	89.6	90.6	1971	246	3330	3286	1899	10732	3306	168	2700	6174
1947	64.74	91.0	90.6	2307	213	4335	4156	2272	13283	6664	207	3325	10196
1948	67.42	92.4	108.9	2451	168	5051	3581	2405	13656	8963	163	3519	12645
1949	63.03	93.8	81.5	2585	180	4872	4321	2700	14658	4691	170	4017	8878
1950	66.00	95.2	74.1	3036	219	5680	4710	2868	16513	12362	200	4284	16846
1951	72.00	98.2	84.8	3012	213	6171	4732	2951	17079	5978	176	4520	10674
1952	68.00	101.2	66.9	3081	195	6970	4853	3045	18144	6269	155	4684	11108
1953	77.00	103.2	76.0	3325	129	6723	5235	2985	18397	6372	574	5193	12139
1954	70.00	104.2	69.0	3453	129	8657	5182	3135	20556	6131	579	5526	12236
1955	83.00	105.2	90.1	3648	146	9043	5040	3566	21443	5526	745	6123	12394
1956	83.00	106.2	75.5	3981	196	10997	5279	3819	24272	9213	814	6643	16670
1957	78.00	107.2	76.4	5353	200	11591	5512	4163	26819	9335	909	7181	17425
1958	82.00	109.8	86.0	5929	218	13490	6150	4515	30302	13336	1000	7888	22224
1959	84.00	114.7	72.6	6137	216	13574	6603	4728	31258	13185	1015	8443	22643
1960	88.00	114.4	89.8	6216	212	14522	7045	4786	32781	12631	966	8889	22486
1961	92.00	116.2	87.8	6947	416	14404	7636	5078	34481	13072	763	9726	23561
1962	94.00	118.2	89.2	7258	423	16141	8284	5702	37808	13326	634	9877	23837
1963	97.00	119.2	96.4	7445	391	17280	8679	6075	39870	14857	846	10569	26272
1964	93.00	120.2	90.5	7846	417	19824	8972	6559	43618	15939	825	11511	28275
1965	97.00	124.0	100.1	9189	579	22029	9581	6961	48339	16024	647	12215	28886
1966	92.00	127.8	94.2	10322	603	24235	10064	7588	52812	13696	745	13257	27698
1967	100.00	131.6	100.5	10792	684	23757	10314	7986	53533	14997	722	13894	29613
1968	90.00	135.5	82.9	11549	652	28824	10556	8351	59932	15614	861	14466	30941
1969	95.00	138.9	90.2	11959	730	30072	10891	9111	62763	16012	719	15580	32311
1970	96.00	142.4	86.4	10904	747	32668	12122	11887	68328	18228	974	20068	39270
1971	108.00	146.8	101.2	12616	808	34853	12832	13454	74563	17364	805	22423	40592
1972	105.00	151.2	94.0	13107	793	37038	15404	14424	80766	24106	1002	23734	48842

TABLE XXV

TIME SERIES DATA, DELTA STATES REGION

				PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
YEAR	USDA PRODUCTIVITY INDEX (1967=100)	EDUCATIONAL ATTAINMENT INDEX	WEATHER INDEX	ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				421	16	846	0	983	2266	835	44	760	1639
1930				534	21	740	0	968	2263	1295	50	746	2091
1931				647	24	732	0	922	2325	1111	79	763	1953
1932				733	33	536	0	821	2123	986	84	717	1787
1933				636	28	581	0	730	1975	975	86	661	1722
1934				588	25	499	0	901	2013	1202	74	466	1742
1935				648	29	586	0	795	2058	1135	77	653	1865
1936				787	32	649	332	1342	3142	1285	96	914	2295
1937				843	34	783	1471	1330	4461	1442	102	1105	2549
1938				930	16	832	1560	1342	4680	1779	64	1204	3047
1939	57.14	75.8	106.7	993	23	857	1649	1335	4857	2736	62	1213	4011
1940	54.24	77.2	81.7	1019	119	894	1772	1293	5097	2865	221	1228	4314
1941	57.26	78.6	108.9	1035	185	995	1452	1315	4982	2765	343	1253	4361
1942	63.24	80.0	118.3	1119	162	1201	1540	1084	5106	2874	289	1598	4761
1943	60.34	81.4	111.7	1142	146	1192	1834	1179	5493	2276	181	1739	4196
1944	62.96	82.8	113.2	1165	152	1292	1893	1144	5646	2467	157	1775	4399
1945	61.07	84.2	113.4	1376	141	1425	2356	1229	6527	2561	180	1906	4647
1946	58.72	85.6	87.7	1521	190	1457	2723	1550	7441	2552	129	2203	4884
1947	60.87	87.0	96.5	1772	163	2235	3440	1809	9419	5117	159	2647	7923
1948	71.18	88.4	143.7	1846	126	2506	2933	1939	9350	6749	123	2838	9710
1949	61.72	89.8	96.7	1935	135	3554	3570	2180	11374	3511	127	3242	6880
1950	63.00	91.2	121.6	2258	163	3973	3872	2383	12649	9194	148	3560	12902
1951	65.00	94.2	127.2	2226	157	4207	3985	2385	12960	4417	130	3653	8200
1952	68.00	97.2	120.7	2246	142	4227	4085	2405	13105	4570	113	3699	8382
1953	74.00	99.2	131.0	2406	94	4482	4202	2416	13600	4611	415	4203	9229
1954	74.00	100.2	123.2	2480	92	4880	4228	2450	14130	4403	416	4319	9138
1955	85.00	101.2	157.7	2598	104	5635	4110	2836	15283	3936	531	4870	9337
1956	82.00	102.2	119.6	2931	144	6402	4302	3080	16859	6782	599	5359	12740
1957	75.00	103.2	115.3	4100	153	6709	4487	3361	18810	7151	696	5796	13643
1958	78.00	105.8	119.1	4692	173	8180	4990	3655	21690	10553	792	6387	17732
1959	91.00	110.7	125.0	5054	178	9085	5391	3932	23640	10858	836	7022	18716
1960	89.00	110.4	134.0	5335	182	9605	5439	3950	24511	10840	829	7335	19004
1961	95.00	112.2	127.9	6205	371	10300	5904	4102	26882	11675	681	7856	20212
1962	97.00	114.2	118.9	6695	390	10917	6499	4582	29083	12293	585	7938	20816
1963	105.00	115.2	140.9	7094	373	10968	6785	4668	29888	14155	806	8120	23081
1964	107.00	116.2	139.5	7783	413	12539	6990	4959	32684	15811	819	8702	25332
1965	106.00	120.0	131.4	9493	599	13814	7440	5243	36589	16553	669	9200	26422
1966	100.00	123.8	113.7	11103	649	15090	7791	5517	40150	14732	801	9640	25173
1967	100.00	127.6	100.5	12095	767	16788	7961	5972	43583	16807	809	10390	28006
1968	109.00	131.5	110.6	13373	755	17783	8126	6152	46189	18079	997	10657	29733
1969	104.00	134.9	100.9	14437	881	19381	8363	6486	49548	19330	868	11091	31289
1970	111.00	138.4	100.7	13605	932	19620	9285	7587	51029	22743	1215	12809	36767
1971	114.00	142.8	104.1	16544	1060	21608	9806	9068	58086	22770	1055	15113	38938
1972	118.00	147.2	107.9	17771	1075	23596	11745	9652	63839	32683	1359	15882	49924

TABLE XXVI

TIME SERIES DATA, SOUTHERN PLAINS REGION

YEAR	USDA PRODUCT-IVITY INDEX (1967=100)	EDUCA-TIONAL ATTAIN-MENT INDEX	WEATHER INDEX	PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
				ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				624	24	753	0	922	2323	1238	65	713	2016
1930				731	29	1016	0	1001	2777	1774	69	770	2613
1931				835	32	880	0	1043	2790	1433	102	864	2399
1932				882	40	866	0	949	2737	1186	101	828	2115
1933				716	31	832	0	864	2443	1099	97	782	1978
1934				623	26	746	0	1046	2441	1274	78	541	1893
1935				663	30	771	0	854	2318	1161	79	701	1941
1936				762	31	897	551	1469	3710	1243	93	1000	2336
1937				775	31	944	2170	1447	5367	1325	94	1204	2623
1938				820	14	1368	2207	1452	5861	1570	57	1304	2931
1939	58.26	89.9	74.0	836	19	1307	2106	1511	5779	2302	52	1372	3726
1940	63.78	91.3	78.8	819	96	1360	2142	1468	5885	2303	178	1394	3875
1941	62.59	92.7	87.5	805	144	1395	1795	1504	5643	2151	267	1433	3851
1942	67.71	94.1	90.7	842	122	1588	2632	1199	6383	2161	218	1769	4148
1943	64.36	95.5	81.7	831	106	1709	3238	1210	7094	1657	132	1784	3573
1944	72.10	96.9	93.3	815	106	1648	3513	1205	7287	1727	110	1870	3707
1945	64.80	98.3	75.6	927	95	1685	4447	1215	8369	1727	121	1885	3733
1946	67.50	99.7	70.1	1003	125	2166	5127	1450	9871	1682	85	2062	3829
1947	75.88	101.1	96.5	1154	106	2309	6282	1712	11563	3332	103	2504	5939
1948	70.54	102.5	88.4	1181	81	3283	5481	1771	11797	4320	79	2590	6989
1949	85.98	103.9	111.9	1221	85	3653	6723	1996	13678	2216	80	2970	5266
1950	72.00	105.3	93.4	1385	100	4145	7223	2310	15163	5640	91	3451	9182
1951	70.00	108.3	89.2	1324	94	4234	7164	2322	15138	2627	77	3556	6260
1952	73.00	111.3	85.3	1312	83	4719	7515	2371	16000	2669	66	3647	6382
1953	77.00	113.3	90.4	1356	53	4380	7457	2232	15478	2599	234	3884	6717
1954	79.00	114.3	93.4	1344	50	5116	7515	2403	16428	2386	225	4234	6845
1955	81.00	115.3	98.6	1374	55	5677	7254	2708	17068	2082	281	4652	7015
1956	79.00	116.3	76.6	1493	73	6396	7689	2912	18563	3455	305	5066	8826
1957	85.00	117.3	104.5	2012	75	6790	8093	3150	20120	3509	342	5432	9283
1958	97.00	119.9	131.0	2261	83	7835	8741	3362	22282	5085	381	5874	11340
1959	97.00	124.8	103.8	2346	83	8163	9252	3418	23262	5041	388	6102	11531
1960	103.00	124.5	124.2	2366	81	10097	9787	3692	26023	4807	368	6856	12031
1961	106.00	126.3	117.9	2652	159	9340	10589	3734	26474	4989	291	7152	12432
1962	99.00	128.3	99.5	2757	161	8321	11440	4154	26833	5062	241	7195	12498
1963	100.00	129.3	105.1	2873	151	9483	11920	4259	28686	5732	326	7410	13468
1964	102.00	130.3	107.6	3037	161	9084	12257	4534	29073	6170	319	7957	14446
1965	110.00	134.1	121.0	3569	225	10461	13025	4657	31937	6224	251	8172	14647
1966	102.00	137.9	106.5	3990	233	11838	13618	5054	34733	5294	288	8830	14412
1967	100.00	141.7	100.5	4280	271	12046	13894	5171	35662	5947	286	8996	15229
1968	109.00	145.6	117.5	4559	257	13066	14161	5739	37782	6163	340	9940	16443
1969	101.00	149.0	100.9	4741	289	14573	14554	6225	40382	6347	285	10645	17277
1970	107.00	152.5	102.6	4302	295	15870	16138	7655	44260	7191	384	12922	20497
1971	98.00	156.9	90.9	5118	328	17757	17022	8999	49224	7044	326	14998	22368
1972	110.00	161.3	110.6	5293	320	19644	20365	10219	55841	9735	405	16815	26955

TABLE XXVII

TIME SERIES DATA, MOUNTAIN REGION

YEAR	USDA PRODUCT-IVITY INDEX (1967=100)	EDUCA-TIONAL ATTAIN-MENT INDEX	WEATHER INDEX	PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
				ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				1291	49	1312	0	831	3483	2559	134	642	3335
1930				1479	59	1410	0	913	3861	3587	139	703	4429
1931				1652	62	1403	0	952	4079	2834	201	797	3832
1932				1695	77	1371	0	868	4011	2279	195	758	3232
1933				1344	59	1234	0	784	3421	2062	183	709	2954
1934				1141	48	1173	0	848	3210	2333	144	439	2915
1935				1164	52	1254	0	698	3168	2038	139	573	2750
1936				1304	53	1284	1344	1035	5020	2127	159	705	2991
1937				1291	51	1346	5084	994	8766	2208	156	826	3190
1938				1322	23	1217	4786	1018	8366	2503	91	913	3507
1939	60.18	97.8	91.2	1309	30	1396	4659	1047	8441	3606	82	952	4640
1940	63.77	99.2	87.6	1247	145	1426	4692	1012	8522	3505	270	961	4736
1941	69.83	100.6	123.2	1177	210	1461	2840	1029	6717	3143	390	980	4513
1942	71.83	102.0	115.0	1193	173	1725	3242	810	7143	3064	309	1194	4567
1943	73.97	103.4	118.4	1133	144	1631	3356	823	7087	2258	180	1213	3651
1944	72.42	104.8	99.5	1075	140	1823	3126	805	6969	2277	145	1249	3671
1945	72.40	106.2	108.4	1182	121	1860	3820	838	7821	2201	154	1300	3655
1946	73.72	107.6	100.8	1395	174	2186	4576	1075	9406	2339	119	1528	3986
1947	76.47	109.0	106.9	1730	160	2423	6272	1299	11884	4998	155	1900	7053
1948	77.99	110.4	113.7	1934	132	3334	5299	1496	12195	7073	129	2189	9391
1949	72.84	111.8	85.6	2173	151	3789	6639	1612	14364	3943	142	2399	6484
1950	74.00	113.2	106.7	2695	194	4491	7282	1884	16546	10971	177	2815	13963
1951	75.00	116.2	103.8	2820	199	4678	7307	1941	16945	5597	164	2973	8734
1952	79.00	119.2	98.4	3022	191	5256	7609	2041	18119	6147	152	3138	9437
1953	84.00	121.2	108.7	3456	134	5193	7998	1958	18739	6623	596	3406	10625
1954	78.00	122.2	97.5	3778	141	5778	7954	2025	19676	6707	633	3569	10909
1955	81.00	123.2	108.4	4197	168	6386	7387	2225	20363	6358	858	3821	11037
1956	82.00	124.2	90.6	4590	226	7799	8018	2417	23050	10620	938	4206	15764
1957	87.00	125.2	116.6	6227	233	8705	8435	2610	26210	10858	1057	4503	16418
1958	93.00	127.8	124.4	6910	254	9948	9440	2897	29449	15542	1166	5061	21769
1959	90.00	132.7	101.6	7220	254	10256	10124	3020	30874	15511	1194	5393	22098
1960	91.00	132.4	111.9	7330	249	11610	10266	3136	32591	14893	1139	5823	21855
1961	91.00	134.2	101.2	8273	495	11475	11067	4334	35644	15566	908	8301	24775
1962	93.00	136.2	96.4	8664	505	12445	12231	3646	37491	15909	757	6315	22981
1963	96.00	137.2	102.9	8911	468	13315	12777	3890	39361	17782	1013	6768	25563
1964	93.00	138.2	99.1	9492	504	15379	13171	4045	42591	19281	998	7099	27378
1965	98.00	142.0	101.2	11240	709	16594	14027	4318	46888	19599	792	7577	27968
1966	96.00	145.8	98.3	12664	740	17811	14698	4579	50492	16804	914	8173	25891
1967	100.00	149.6	100.5	13397	849	20201	15027	4802	54276	18617	896	8355	27868
1968	102.00	153.5	102.7	14386	812	21219	15345	5016	56778	19449	1072	8688	29209
1969	104.00	156.9	102.8	15084	921	21220	15801	5448	58474	20196	907	9316	30419
1970	109.00	160.4	98.8	13805	946	22935	17550	6376	61612	23077	1233	10765	35075
1971	112.00	164.8	99.4	16187	1037	25123	18543	7231	68121	22278	1033	12052	35363
1972	112.00	169.2	96.8	16888	1021	27311	22221	7752	75193	31060	1291	12757	45109

TABLE XXVIII

TIME SERIES DATA, PACIFIC REGION

				PRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)						NONPRODUCTION-ORIENTED PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES (CURRENT DOLLARS 000)			
YEAR	USDA PRODUCTIVITY INDEX (1967=100)	EDUCATIONAL ATTAINMENT INDEX	WEATHER INDEX	ARS	ERS	SAES	SCS	CES	TOTAL	ARS	ERS	CES	TOTAL
1929				2083	79	1527	0	774	4463	4131	217	599	4947
1930				2375	94	1550	0	797	4816	5759	224	614	6597
1931				2637	99	1605	0	793	5134	4525	321	656	5502
1932				2725	124	1751	0	744	5344	3665	313	649	4627
1933				2157	94	1633	0	701	4585	3309	293	635	4237
1934				1814	77	1359	0	800	4050	3706	228	414	4348
1935				1856	83	1495	0	665	4100	3251	222	547	4020
1936				2074	84	1516	365	930	4969	3384	253	633	4270
1937				2040	81	1763	1564	886	6334	3488	246	736	4470
1938				2106	36	1983	1545	919	6589	4030	146	824	5000
1939	69.42	98.2	89.5	2052	48	2232	1518	926	6776	5652	128	841	6621
1940	71.37	99.6	78.8	1939	226	2324	1511	948	6948	5449	420	900	6769
1941	73.18	101.0	101.7	1823	325	2261	1321	952	6682	4869	603	907	6379
1942	74.76	102.4	90.7	1831	265	2381	1587	822	6886	4702	474	1213	6389
1943	75.84	103.8	93.4	1745	223	2371	1737	833	6909	3477	277	1228	4982
1944	76.96	105.2	88.8	1649	215	2544	1678	852	6938	3491	222	1322	5035
1945	76.91	106.6	95.3	1763	181	2913	2051	911	7819	3282	230	1413	4925
1946	81.26	108.0	96.4	2017	252	3292	2280	1170	9011	3383	171	1662	5216
1947	79.87	109.4	93.5	2348	217	4638	2951	1497	11651	6783	210	2191	9184
1948	79.98	110.8	97.9	2466	169	6174	2528	1814	13151	9017	164	2655	11836
1949	80.73	112.2	85.6	2553	178	6989	3112	2021	14853	4634	167	3007	7808
1950	81.00	113.6	115.6	3018	217	7919	3564	2366	17084	12285	198	3534	16017
1951	83.00	116.6	119.9	2974	210	8890	3585	2455	18114	5902	173	3759	9834
1952	86.00	119.6	111.5	3022	191	9787	3773	2625	19398	6147	152	4038	10337
1953	89.00	121.6	111.3	3193	124	10724	4210	2593	20844	6120	551	4512	11183
1954	92.00	122.6	116.4	3337	124	11679	4261	2758	22159	5925	559	4861	11345
1955	90.00	123.6	121.1	3398	136	12610	4025	3070	23240	5147	694	5272	11113
1956	92.00	124.5	102.2	3898	192	13633	4370	3316	25409	9021	797	5768	15586
1957	93.00	125.6	120.6	5467	205	15382	4683	3588	29325	9534	928	6189	16651
1958	93.00	128.2	119.1	6270	231	17981	5356	3956	33794	14103	1058	6913	22074
1959	97.00	133.1	108.3	6768	238	19660	5923	4237	36826	14542	1119	7564	23225
1960	94.00	132.8	114.3	7051	240	20651	6608	4244	38794	14328	1096	7883	23307
1961	94.00	134.6	102.3	8220	492	22868	7081	4577	43238	15467	902	8768	25137
1962	96.00	136.6	103.6	8889	518	24679	7741	5153	46980	16322	776	8925	26023
1963	97.00	137.6	108.4	9321	490	26508	8199	5487	50005	18601	1059	9547	29207
1964	99.00	138.6	111.9	10251	544	28650	8562	5511	53518	20824	1078	9670	31572
1965	100.00	142.4	106.4	12531	790	31361	9229	5934	59845	21850	883	10413	33146
1966	103.00	146.2	106.5	14573	852	34072	9780	6379	65656	19336	1051	11145	31532
1967	100.00	150.0	100.5	15909	1009	34802	10105	6891	68716	22108	1064	11989	35161
1968	104.00	153.9	105.7	17526	989	38027	10422	6841	73805	23694	1306	11850	36850
1969	107.00	157.3	106.7	18855	1151	41169	10831	7523	79529	25244	1133	12865	39242
1970	109.00	160.8	103.5	17807	1220	42664	12136	8865	82692	29767	1590	14965	46322
1971	112.00	165.2	106.9	21424	1372	44626	12929	9169	89520	29486	1367	15281	46134
1972	114.00	169.6	105.1	23064	1395	46588	15614	10021	96682	42418	1763	16489	60670

concerns the time series data. The theoretical distinction between production-oriented research and extension expenditures and nonproduction-oriented expenditures is much clearer than the empirical distinction. Also, the desire to investigate sources of productivity change on a regional level requires that some assumptions about the data be made. Since the method used to deal with these two problems varies from one data series to the next due to differences in the types of information available, each series is considered in turn.

Productivity Indexes

The official USDA productivity indexes for the U. S. and the ten farm production regions are published annually in Changes in Farm Production and Efficiency, Statistical Bulletin No. 233, Economic Research Service, USDA. Data for the 1950 to 1972 period on the U. S. and ten regions are from the 1973 issue (76). U. S. data for the 1939 to 1949 period are from the 1964 issue of Statistical Bulletin No. 233 (74). Official regional indexes for the 1939 to 1949 period are not published by the USDA. However, these indexes were extended back to 1939 by one of the present authors of the official USDA indexes, L. D. Lambert, and reported in his "Regional Trends in the Productivity of American Agriculture" (33, p. 75).

For a detailed explanation of the construction of these series the reader is referred to either (69) or Lambert (33). For the purposes of this Appendix, a brief discussion of the methodology should suffice.

The series are computed by taking the ratio of the USDA index of total farm output to the USDA index of agricultural inputs. The index of farm output measures yearly changes in the volume of farm production available for human use. Output is measured in the year in which it is marketed.

The index of total agricultural inputs measures the yearly changes in the volume of resources used to produce farm output. Interfarm sales are omitted, and capital resources are measured on a flow of services basis.

Both the index of farm output and the index of agricultural inputs are calculated by means of a Laspayres arithmetic constant price-weight formula. Weighted average prices received or payed by farmers in a given region are used as weights in constructing the indexes for the regions. The quantity-price aggregates for the ten farm production regions are summed to obtain the quantity-price aggregates upon which the U. S. index is based. The reference base period used is 1967. Average 1957-59 prices are used as weights for 1955 and subsequent years; average 1947-49 prices are used for the 1939 to 1955 period. Since more than one set of price weights is used in computing the indexes, the series are spliced at 1955.

Educational Attainment Index

The educational attainment index is an updated version of a series reported by Robert Evenson in "The Contribution of Agricultural Research and Extension to Agricultural Production" (17). For the series used in this study, 1965 to 1972 observations were based upon 1970 Census of Population subject reports PC(2)-5B and PC(2)-7A, Educational Attainment (87) and Occupational Characteristics (88) respectively. Years-of-schooling-completed estimates for farmers and farm managers and for farm laborers and foremen are also reported for 1968, 1969, and 1971 in

Current Population Reports, Educational Attainment (84, 85, 86). Observations for the years in which data were not available were obtained by linear extrapolation.

In each year for which data were available, the proportion of males in each schooling class as a percent of total employment in two occupational groups (farmers and farm managers, and farm laborers and foremen) was calculated. These calculations for 1970 are shown below:

	Occupational Group			
	Farmers and Farm Managers		Farm Labor and Foremen	
	Male	Female	Male	Female
No School Years	10,008	740	41,938	6,162
Elementary:				
1-4 years	51,390	1,955	108,459	14,180
5-7 years	152,436	6,979	144,890	26,586
8 years	327,772	13,662	105,548	22,727
High School:				
1-3 years	222,259	14,848	129,067	33,174
4 years	435,220	21,091	135,228	39,005
College				
1-3 years	98,892	7,139	44,334	7,689
4 and over	52,395	3,137	11,601	1,869

Since the total number in the two occupational groups is 2,286,580, the proportion of males in each schooling class was found by dividing each entry in the columns labeled male by 2,286,589. For the Farmers and Farm Managers group with no school years this calculation is 10,008 ÷ 2,286,589 = .0043.

	Occupational Group	
	Farmers and Farm Managers	Farm Labor and Foremen
No School Years	.0043	.0183
Elementary:		
1-4 years	.0224	.0474
5-7 years	.0666	.0633
8 years	.1433	.0461
High School:		
1-3 years	.0972	.0564
4 years	.1903	.0591
College:		
1-3 years	.0432	.0193
4 and over	.0229	.0050

The column for each occupational group was then weighted by the number of weeks worked by each group, expressed as a percent of the total weeks worked by both groups. The weight for the Farmers and Farm Managers group in 1970 is .6217 and the corresponding weight for the Farm Laborers and Foremen group is 1 - .06217 = .3782. This weighting of each occupational group yields:

	Occupational Group	
	Farmers and Farm Managers	Farm Labor and Foremen
No School Years	.0026	.0069
Elementary:		
1-4 years	.0139	.0179
5-7 years	.0414	.0239
8 years	.0890	.0174
High School:		
1-3 years	.0604	.0213
4 years	.1183	.0223
College:		
1-3 years	.0268	.0072
4 and over	.0142	.0018

These two series are then summed across schooling classes and the proportion of the total represented by each schooling class is calculated. For the no school years class, this calculation is .0026 + .0069 = .0095 which is .0095 ÷ .4853 = .0195 of the total.

		Proportion of Total
No School Years	.0095	.0195
Elementary:		
1-4 years	.0318	.0655
5-7 years	.653	.1345
8 years	.1064	.2192
High School:		
1-3 years	.0817	.1683
4 years	.1406	.2897
College:		
1-3 years	.0340	.0700
4 and over	.0160	.0329
Total	.4853	1.0000

Finally, the schooling class proportions are weighted by a set of income-schooling weights derived in Finis Welch, "Measurement of the Quality of Schooling" (93).

The weights used are as shown below:

	Proportion of Total		Welch Weights		Contribution to Education Index
No School Years	.0195	x	0	=	.0000
Elementary:					
1-4 years	.0655	x	.25	=	.0163
5-7 years	.1345	x	.65	=	.0874
8 years	.2192	x	1.00	=	.2192
High School:					
1-3 years	.1683	x	1.63	=	.2743
4 years	.2897	x	2.26	=	.6547
College:					
1-3 years	.0700	x	2.64	=	.1848
4 and over	.0329	x	4.24	=	.1394
				Total	1.572

The value of the educational attainment index for 1970 is therefore 1.572 x 100 = 157.2, adjusted for age, sex, and income.

Regional indexes of educational attainment comparable to the U. S. index could not be calculated with existing published data. Since an attempt to do so using unpublished data was beyond the time and budget constraints of this effort and outside the major line of inquiry of the study, an alternative technique for constructing regional indexes was adopted.

It was assumed that the trend in educational attainment among farmers and farm managers and farm laborers and foremen has been the same across regions over time. This assumption meant that the relative positions of the regions need only be known in one year in order to construct the regional indexes for the 1939 to 1972 period. As it was desirable to associate these regional indexes with the U. S. index, adjusted for age, sex, and income, Equation (A.1) was employed in their calculation:

$$E_i^{1970} = \frac{\sum_{j=1}^{n} (M_j^{1970} \times O_j^{1969}) \, / \sum_{j=1}^{n} O_j^{1969}}{M_{us}^{1970}} \times E_{us}^{1970} \qquad (A.1)$$

where E_i^{1970} = the educational attainment index value for region i in 1970,

M_j^{1970} = the median school years completed by persons 25 years and over in state j in 1970,

O_j^{1969} = the number of farm operators in state j in 1969,

M_{us}^{1970} = the median school years completed by persons 25 years and over in the U. S. in 1970,

E_{us}^{1970} = the educational attainment index value for the U. S. in 1970, n = the number of states in region i.

The median school years completed data was taken from the Digest of Educational Statistics, 1973 edition, written by W. Vance Grant and C. George Lind (91). Farm operator information is from the 1969 Census of Agriculture (83, p. 197).

Having obtained the educational attainment index value for each region in 1970, the remianing regional index values were obtained by adjusting each U. S. index value for the 1939 to 1972 period by the difference between the 1970 U. S. index value and the 1970 regional index value.

Weather Index

The conceptual framework for measuring the influence of weather on crops in this study is based upon the hypothesis that variations in yields of crops where as many variables as possible are held constant over time are attributable to the influence of weather after trend has been removed to account for increases or decreases in the fertility level of the soil. It is assumed that the trend due to fertility changes over time can be removed by fitting a regression line of yield on time.

U. S. data for the 1939-50 period are from J. L. Stallings, "Indexes of the Influence of Weather on Agricultural Output" (59); for the 1950-63 period from William E. Kost, "Weather Indexes, 1950-1963" (31).

The procedure followed to obtain weather index values for the U. S. over the 1964-72 period was to run a linear regression of the U. S. crop yield index as reported in Changes in Farm Production and

Efficiency (76, p. 11) on time, attributing the residual to weather. The three year average crop production index value for the 1961-63 period was spliced with the average weather index value for the same period. While this procedure is basically the same as that employed by Stallings and Kost, it is inferior in the sense that their data was generated in a more controlled setting (Experiment Station plots) and they were thus able to hold more variables constant over time. It is, however, the best feasible alternative.

Regional indexes of the influence of weather on crops are not available, however crop production indexes by region are reported in Changes in Farm Production and Efficiency (76). In order to utilize both the information provided by the U. S. weather index and the regional crop production statistics, the regional weather indexes were computed using Equation (A.2):

$$W_{it} = \frac{Y_{it}}{Y_{u.s._t}} \times W_{u.s._t} \qquad (A.2)$$

where

W_{it} = the weather index value for region i in year t;

Y_{it} = the crop production index value for region i in year t;

$Y_{u.s._t}$ = the crop production index value for the U. S. in year t;

$W_{u.s._t}$ = the weather index value for the U. S. in year t.

Public Sector Expenditures on Research and Extension in U. S. Agriculture, 1929-72

Tables XVIII through XXVIII present the basic time series data on the U. S. and regional expenditures of those USDA agencies which are responsible for agricultural research and extension.

Agricultural Research Service

The Agricultural Research Service (A.R.S.) is the primary agency of the U. S. Department of Agriculture engaged in research in the physical and biological sciences. It also conducts research relating to the utilization and marketing of agricultural products, research on nutrition and consumer use, and carries out those control and regulatory programs of the Department of Agriculture which involve enforcement of plant and animal quarantines and control of plant and animal diseases and pests.

The A.R.S. was established within the Department of Agriculture by Departmental Memorandum 1320, Supplement 4, dated November 2, 1953. In 1972, the Animal and Plant Health Services division of the A.R.S. was established as a separate entity within the Department of Agriculture. In order to extend the expenditures series back through time to 1929, it is necessary to identify the lineage of the A.R.S.

Upon its formation, the A.R.S. subsumed the various research bureaus formerly grouped under the Agricultural Research Administration. The Agricultural Research Administration was in turn established by Executive Order 9069 of February 23, 1942, and to it were transferred the Bureau of Animal Industry, the Bureau of Dairy Industry, the Bureau of Agricultural Chemistry and Engineering, the Bureau of Entomology and Plant Quarantine, the Bureau of Home Economics, the Office of Experiment Stations, and the Beltsville Research Center. By Administrator's Memorandum 5, dated February 13, 1943, certain divisions of the Bureau of Agricultural Chemistry and Engineering were transferred to the

Bureau of Plant Industry, which was then redesignated the Bureau of Plant Industry, Soils, and Agricultural Engineering. Also at this time, the Bureau of Home Economics was merged with other divisions of the Bureau of Agricultural Chemistry and Engineering to form the Bureau of Human Nutrition and Home Economics.

Prior to 1942, the bureaus which comprised the Agricultural Research Administration existed as separate entities in the Department of Agriculture. Between 1929 and 1942 several consolidation measures were undertaken. The Bureau of Agricultural Chemistry and Engineering was established when the Bureau of Agricultural Engineering was merged with the Bureau of Chemistry and Soils by order of the Secretary of Agriculture, October 16, 1938. The Bureau of Agricultural Engineering was in turn established on July 1, 1931, pursuant to the Agricultural Appropriation Act of 1932, continuing the work of the Division of Agricultural Engineering of the Bureau of Public Roads. The Bureau of Entomology and Plant Quarantine was established by the Agricultural Appropriations Act of 1935, effective July 1, 1934, combining the Bureau of Entomology and the Bureau of Plant Quarantine.

Using this family tree as a guide, the total expenditures series for the A.R.S. was compiled from actual outlays of the appropriate agencies on a checks-issued basis as annually reported in Combined Statement of Receipts, Expenditures and Balances of the United States Government (92). Extraordinary outlays in the early years reported as emergency expenditures were not included. These were largely transfers under the National Industrial Recovery Act and Public Works Administration and were not research-oriented in nature. Also, payments to State Agricultural Experiment Stations were not included in order to avoid double-counting since these payments were treated as Experiment Station expenditures.

Data on production-oriented expenditures of the A.R.S. were not available. The annual Budget of the United States Government (8), however, contains a functional breakdown of appropriations by activity which is in sufficient detail to allow isolation of those activities which affect production. Therefore, it was assumed that actual appropriations authorized by Congress to be established for the fiscal year for a particular activity are equal to and adequately reflect the actual outlays made on that activity. Based upon this assumption, the production-oriented expenditures series is constructed by summing in each year the appropriations for those research activities carried on by the A.R.S. which are judged to ultimately affect the state of technology in agriculture.

The contribution of the A.R.S. to nonproduction-oriented activities was then given by the difference between total A.R.S. expenditures in any given year and the A.R.S. production-oriented expenditures in that year.

Since the A.R.S. is entirely federally funded by Congressional appropriations, it was not possible to directly measure production-oriented A.R.S. expenditures in any particular region of the United States. Some decision rule must therefore be adopted by which A.R.S. expenditures can be apportioned among the ten farm production regions.

The institutional nature of agricultural research in the United States has created regional dispersion of State Agricultural Experiment Stations. Since 1930, the U. S. Department of Agriculture has located a significant amount of its research activity in these state experiment stations, often directly locating scientists there. According to Evenson and Welch (18, p. 15), this activity has accounted for approximately 20 percent of the state research effort since 1935. For the purpose of allocating A.R.S. expenditures among the regions, it is assumed that the regional share distribution of U. S. Department of Agriculture research conducted within the state experiment stations also holds for A.R.S. expenditures.

Presented in Table XXIX are the U. S. Department of Agriculture research shares by region 1925 to 1965, as reported by Evenson and Welch. The data as reported by them are at 10 year intervals and linear extrapolation was employed in the present study to obtain yearly observations for the 1929 to 1972 period.

Economic Research Service

The Economic Research Service (E.R.S.) was created in the Department of Agriculture by Secretary's Memorandum 1446, Supplement 1, dated April 3, 1961, under authority of Reorganization Plan 2 of 1953. Its major activities are conducting farm economics research dealing with the economic problems of agricultural production and resource use, marketing economics research relating to the distribution and merchandising of agricultural commodities, and domestic and foreign economic analyses dealing with the supply and demand of farm products and related areas.

As was the case with the A.R.S., the lineage of the E.R.S. must be identified in order to extend the time series expenditures data for the E.R.S. back to 1929. The Agricultural Marketing Service was reestablished within the Department of Agriculture under the authority of

TABLE XXIX

U. S. DEPARTMENT OF AGRICULTURE RESEARCH SHARES BY REGION, 1925-1965

	Region	1925	1935	1945	1955	1965
1.	Northeast	-	.028	.050	.095	.072
2.	Lake States	-	.039	.041	.077	.090
3.	Corn Belt	-	.067	.109	.097	.116
4.	Northern Plains	-	.097	.066	.058	.049
5.	Appalachaia	-	.038	.041	.062	.067
6.	Southeast	-	.143	.174	.146	.121
7.	Delta	-	.088	.135	.104	.125
8.	Southern Plains	-	.090	.091	.055	.047
9.	Mountain	-	.158	.116	.168	.148
10.	Pacific	-	.252	.173	.136	.146

Source: Robert Evenson and Finis Welch (18, p. 17).

Reorganization Plan 2, Memorandum 1320, Supplement 4 of the Secretary of Agriculture dated November 2, 1953. From the time of its formation till the creation of the E.R.S. in 1961, the Agricultural Marketing Service performed marketing research and conducted economic and statistical analyses of the agricultural sector. In 1961, the economic and statistical analysis functions were transferred to the E.R.S.

The forerunner of the economic and statistical analysis section of the Agricultural Marketing Service was the Bureau of Agricultural Economics. It was established on July 1, 1922, pursuant to the Agricultural Appropriations Act of 1923, approved May 11, 1922. The Bureau was abolished by Department Memorandum 1320, Supplement 4, dated November 2, 1953, and its functions transferred to the Agricultural Marketing Service and the Agricultural Research Service.

The total expenditures series for the E.R.S. was compiled from two different sources. During the period in which the E.R.S. existed, 1961 to 1972, actual outlays on a checks-issued basis as annually reported in _Combined Statement of Receipts, Expenditures and Balances of the United States Government_ (92) were used. Due to the fact that its forerunner, the Agricultural Marketing Service, carried on many activities besides those transferred to the E.R.S. in 1961, it was necessary to refer to the _Budget of the United States Government_ (8) for a breakdown of activities in sufficient detail to allow only those transferred functions to be included in the E.R.S. expenditure series. Thus, the observations of the total expenditures series for the E.R.S. for the years 1953 to 1961 are actually the appropriations established by Congress for marketing research and economic and statistical analysis activities carried on within the Agricultural Marketing Service during those years.

Much the same type of problem was encountered in attempting to insure that only those activities of the Bureau of Agricultural Economics which were consistent with those undertaken by the E.R.S. were included in the E.R.S. total expenditure series. Between the years of 1942 and 1952, the Bureau of Agricultural Economics carried on two major activities: economic investigations and crop and livestock estimates. Since crop and livestock estimates have been conducted since 1961 by the Statistical Research Service of the U. S. Department of Agriculture, this activity is not in the domain of the E.R.S. Given these facts, observations of the total expenditure series for the E.R.S. for the years 1942 to 1952 were taken as those appropriations established by Congress for economic investigation activities within the Bureau of Agricultural Economics.

During the years 1939 to 1941, crop and livestock estimates were conducted by the Agricultural Marketing Service. Therefore, the total obligations for economic investigations of the Bureau of Agricultural Economics were employed as total E.R.S. expenditures over the 1938-1941 period.

Prior to 1938, the Bureau of Agricultural Economics again had the responsibility for making crop and livestock estimates as well as conducting other activities which do not parallel those undertaken by the E.R.S. today. During the 1929 to 1937 period, total E.R.S. expenditures were taken to equal total obligations of the Bureau of Agricultural Economics for only those activities related to current E.R.S. activities, i.e., farm management and practice, marketing and distributing farm products, and analysis of foreign competition and demand.

Following the procedure used to isolate production-oriented expenditures of the A.R.S., annual issues of the Budget of the United States Government (8) were employed to compile a similar series for the E.R.S. That is, the E.R.S. production-oriented expenditures series was constructed by summing in each year the Congressional appropriations for those research activities conducted by the E.R.S. which were judged to ultimately affect the level of technology in agriculture.

The contribution of the E.R.S. to nonproduction-oriented activities was then given by the difference between total E.R.S. expenditures in any given year and the E.R.S. production-oriented expenditures in that year.

In order to apportion the federally funded E.R.S. expenditures among the ten farm production regions, a procedure identical to that employed for the A.R.S. as outlined above was adopted.

State Agricultural Experiment Stations

The Hatch Act of March 2, 1887, provided for the establishment of an agricultural experiment station in connection with the land-grant college in each State and Territory and authorized an annual Federal grant of funds for the partial support of these stations. Over time, the Adams, Purnell, Bankhead-Jones, Research and Marketing Acts, and other supplementary acts have successively provided funds for increasing the scope of agricultural research at the State level. The State legislatures have also encouraged and supported research by consistently appropriating funds for the solution of agricultural problems within their own states. In addition, the State Agricultural Experiment Stations (S.A.E.S.) are partially financed by funds made available by private cooperators. While the primary charge of the Experiment Stations is scientific research, they also perform an extension service by testing new techniques and speeding their introduction to new areas.

Data on total S.A.E.S. expenditures for 1929-53 were obtained from annual issues of the _Report on the Agricultural Experiment Stations_ (70); for 1954-60 from _Report on the Agricultural Experiment Stations_ (71); for 1961-63 from _Funds for Research at State Agricultural Experiment Stations_ (72); and for 1964-72 from _Funds for Research at State Agricultural Experiment Stations and Other State Institutions_ (73). Observations for 1965 and 1972 are extrapolations.

This information is available at the state level, which permits aggregation up to the regional level by summing the total funds available to each state in any given region, less any balances carried over from the previous year.

Experiment Station production-oriented expenditures comprise by far the greater part of total Experiment Station expenditures.[1] For this reason, production-oriented expenditures were taken to be equal to total expenditures by the S.A.E.S. The contribution of the Experiment Stations to nonproduction-oriented activities was therefore zero.

Cooperative Extension Service

The major function of the Cooperative Extension Service (C.E.S.) as stated in the enabling legislation of July 1, 1914, known as the Smith-Lever Act, is ". . . to aid in diffusing among the people of the

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[1] Over the period 1970 to 1973, expenditures of one typical Experiment Station which were judged to affect the technological environment of agriculture amounted to more than 98 percent of total expenditures.

United States useful and practical information on subjects relating to agriculture and home economics, and to encourage the application of the same. . ." This charge clearly identifies the Extension Service's function as applied education directed to helping people solve the various problems which they encounter from day to day in agriculture, home economics, and related subjects. Thus, the C.E.S. takes research results of the U. S. Department of Agriculture and the state experiment stations and transmits this information from researchers to interested people.

Data on total C.E.S. expenditures for the period 1929-55 are from annual issues of the Annual Report of Cooperative Extension Work in Agriculture (77). Data on the 1956-72 period are from unpublished reports of the Federal Extension Service, U. S. Department of Agriculture (80). Since these data are available on a state basis, total regional C.E.S. expenditures were obtained by summing the total expenditures of all states comprising a particular region.

Extension Service personnel are involved in four major program areas: agriculture and natural resources, home economics, 4-H youth groups, and community resource development. Only the first of these directly affects technology in agriculture. In order to isolate these production-oriented expenditures, the advice of Federal Extension Service administrators was followed and the percent of total Extension workers' time devoted to agriculture and natural resource activities was used to weight total C.E.S. expenditures. Through this weighting process, a truer reflection of the expenditures on activities affecting the technological environment can be obtained than if, say, the salaries of agriculture extension agents were used as a proxy. This is because agents frequently cross program areas in their day-to-day work.

The distribution of Extension workers' time devoted to activities affecting agricultural technology is shown in Table XXX. Data for the period 1929-62 are based upon information contained in annual issues of Extension Activities and Accomplishments (79). Observations for 1964, 1968, and 1969 are compiled from unpublished cooperative Extension work sheets entitled "Annual Report of County Extension Agents" (78). An observation for 1973 was obtained from "Long Range Programs Plans for Fiscal Years 1975-79, Tentative," an unpublished communication of the Extension Service. Data for years in which observations were not available were constructed by linear extrapolation. It was assumed that this national distribution of Extension workers' time holds across regions.

The contribution of the C.E.S. to nonproduction-oriented activities was given by the difference between total C.E.S. expenditures in any given year and the C.E.S. production-oriented expenditures in that year.

Soil Conservation Service

The Soil Conservation Service (S.C.S.) was established within the Department of Agriculture under the Soil Conservation Act, approved April 27, 1935. The broad objectives of the S.C.S. are (81),

> . . . to propagate the use of soil conservation practices in agriculture through the medium of demonstration; to effect at the same time a maximum control of erosion on as large an area of agricultural land as possible; and to ascertain the fundamental scientific facts essential to the development and improvement of soil-conservation methods and techniques. (p. 3)

The nature of the activities of the S.C.S. is somewhat different

TABLE XXX

PERCENTAGE DISTRIBUTION OF EXTENSION WORKERS' TIME BY ACTIVITIES AFFECTING AGRICULTURAL TECHNOLOGY VS. OTHER ACTIVITIES, 1929-1972

Year	Production-Oriented Activities	Year	Production-Oriented Activities
1929	.564	1951	.395
1930	.565	1952	.394
1931	.547	1953	.365
1932	.534	1953	.362
1933	.525	1955	.368
1934	.659	1956	.365
1935	.549	1957	.367
1936	.595	1958	.364
1937	.546	1959	.359
1938	.527	1960	.350
1939	.524	1961	.343
1940	.513	1962	.366
1941	.512	1963[a]	.365
1942	.404	1964	.363
1943	.404	1965[a]	.353
1944	.392	1966[a]	.364
1945	.392	1967[a]	.365
1946	.413	1968	.366
1947	.406	1969	.369
1948	.406	1970[a]	.372
1949	.402	1971[a]	.375
1950	.401	1972[a]	.378

[a] Obtained by extrapolation.

from that of the other agencies discussed above in that S.C.S. activities are not intended to increase agricultural productivity. The object of soil conservation is to conserve the productive capacity of the soil, i.e., to maintain the status quo. Of course, in the absence of conservation measures, the quality of the land input would deteriorate over time and thus productivity would decrease.

S.C.S. expenditures on research are quite small in relation to total S.C.S. expenditures. The great bulk of total S.C.S. effort consists of providing technical assistance to farmers in soil conservation districts.

Data on expenditures of the S.C.S. for soil conservation operations for the 1936 to 1961 period were obtained from Robert George Latimer (34, pp. 391-397). These data were reported by Latimer by state, which allowed aggregation up to the regional level. Observations for the 1962 to 1972 period for the U. S. are from annual issues of the Budget of the United States Government (8) and are obligated funds for soil conservation operations which may differ slightly from actual expenditures. Regional expenditures for the 1962 to 1972 period were obtained by regressing 1950 to 1961 expenditures for each region on time. The predicted regional expenditures were then forced to sum to the total expenditures figure for the U. S.[2]

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[2] The mean value of each region's share of total S.C.S. expenditures and its standard deviation for the 1950 to 1961 period are shown below.

Region	Mean	S.D.	Region	Mean	S.D.
Northeast	12.46	0.55	Southeast	10.60	0.15
Lake States	17.11	1.31	Delta States	13.07	0.41
Corn Belt	8.41	0.17	Southern Plains	7.30	0.30
Northern Plains	9.30	0.12	Mountain	6.99	0.18
Appalachian	9.54	0.30	Pacific	12.74	0.85

Price Deflators

All research and extension expenditure data were deflated in order to reflect real changes in the variables over time.

Since research salaries are the major item in the personnel component of the research bill and these salaries have not always moved with the Consumer Price Index or other indicators of the price level, the portion of total expenditures spent on scientific personnel is deflated by an index of average salaries of college and university teachers. For the 1929 to 1949 period, these figures are reported by George J. Stigler (58, pp. 44-45). Salary information published by the American Association of University Professors (4) was used to update the Stigler index. These index values are presented in Table XXI.

The residual portion of total research and extension expenditures after having removed personnel costs is deflated by the implicit price deflator for government purchases of goods and services. The 1929 to 1965 observations are from *The National Income and Product Accounts of the United States*, 1929-1965 (90, pp. 158-159). Both deflators used 1958 as the base year.

TABLE XXXI

INDEX OF AVERAGE SALARIES OF COLLEGE AND UNIVERSITY TEACHERS, 1929-1972
(1958 = 100)

Year	Salary in Current Dollars	Index Value	Year	Salary in Current Dollars	Index Value
1929	3,056	43.9	1951[a]	4,901	70.3
1930	3,065	44.0	1952[a]	5,243	75.3
1931	3,134	45.0	1953[a]	5,585	80.2
1932	3,111	44.6	1954[a]	5,927	85.1
1933[a]	2,963	42.5	1955[a,b]	6,267	89.9
1934[a]	2,815	40.4	1956[a]	6,711	96.3
1935	2,666	38.3	1957[b]	7,156	102.7
1936	2,732	39.2	1958[b]	6,966	100.0
1937	2,843	40.8	1959[b]	7,604	109.1
1938	2,861	41.1	1960	7,949	114.1
1939[a]	2,873	41.2	1961	8,309	119.3
1940	2,886	41.4	1962	8,752	125.6
1941[a]	2,889	41.5	1963	9,127	131.0
1942	2,892	41.5	1964	9,623	138.1
1943	2,988	42.9	1965	10,186	146.2
1944	3,282	47.1	1966	10,829	155.4
1945	3,236	46.4	1967	11,530	165.5
1946	3,429	49.2	1968	13,537	194.3
1947	3,705	53.2	1969	13,066	187.6
1948	4,098	58.8	1970	13,792	198.0
1949	4,217	60.5	1971	14,266	204.8
1950[a]	4,559	65.4	1972	14,887	213.7

[a] Obtained by linear extrapolation.

[b] AAUP data includes fringe benefits in these years. To reconcile the the difference between total compensation and salary, fringe benefits were assumed to be 6.4 percent of total compensation (the 1960-1962 average) and the reported figures were adjusted downward.

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