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A CENTURY OF PRODUCTIVITY CHANGE IN U.S. AGRICULTURE: AN ANALYSIS OF THE ROLE OF INVENTION, RESEARCH AND EXTENSION

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A Century of Productivity Change in U.S. Agriculture: An Analysis of the Role of Invention, Research and Extension

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A considerable body of literature now exists which reports *ex post* evaluations of the contribution of agricultural research and extension toward increased productivity in U.S. agriculture. Several of these studies are "Cost-Benefit" calculations in which the attribution of benefits, to research, is made on non-statistical criteria.[1] Other studies have utilized statistical models to estimate the relationship between production (or productivity) and research investment.[2] None of these studies has consistently shown that agricultural research was productive prior to the 1930's and some authors have concluded that the early experiment station system was not highly productive.[3]

This paper attempts to examine the relationship between productivity and investment in agricultural research, agricultural invention and agricultural extension and schooling over a long span of history, 1870-1971. The methodology utilized is based on a statistical decomposition of productivity change in time series and combined time-series cross-section data.

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[1]See Griliches (1958) and Peterson (1966) for examples.

[2]See Griliches (1964), Evenson (1968) and Peterson (1966).

[3]See Peterson and Fitzharris (1975).

Part I of the paper develops the decomposition specification. Part II summarizes the measured total factor productivity series. Part III discusses investment in research, extension and inventive activities over the period. Part IV reports analyses of the data from the early and the early modern period, 1870-1950, and Part V deals with the modern period, 1950-71. A summary is offered in the final section.

I. Productivity Measurement and Decomposition

The total factor productivity measurement concept utilizes a growth relationship which is based on production behavior under static technology. In a setting where all producers know about and use the most efficient existing technology, the production process can be described by an aggregate production function:

$$(1) \qquad Y = F(X_1, X_2, \ldots X_n)$$

If (1) is homogenous of degree one and all producers maximize profits, output growth is well approximated by:[1]

$$(2) \qquad \dot{y} = \sum_{i=1}^{n} S_i \dot{x}_i$$

In (2) output growth rates are determined as a cost share weighted average of growth rates in inputs, $\dot{x}_i$.

There are several reasons why (2) may not (and actually does not) accurately describe output growth:

[1]This is obtained by simply differentiating (1) and substituting profit maximizing conditions.

a) Output growth rates, $\dot{y}$, may be measured with error.

b) Input growth rates, $\dot{x}_i$, may be measured with error. (This includes "left-out" inputs.

c). Cost shares, S_i, may be measured with error.

d) Technology which exists and is not utilized may be adopted by producers.

e) New technology may become available and be adopted by producers.

If measurement errors (a, b, c) are not too serious, a natural extension of the above analysis is to define the rate of total factor productivity growth as:

$$(3) \quad \dot{p} = \dot{y} - \sum_{i=1}^{n} S_i \dot{x}_i$$

We could then associate measured total factor productivity growth, $\dot{p}$, with producer management and information processing skills, information supply activities, and technology production activities. This is essentially what is done in this analysis with some modifications. To justify this procedure, however, one must be able to argue that other measurement problems are not severe.

The literature on growth accounting or "explanation of productivity growth"[1] has focused on measurement. It is important to note that there are two types of measurement issues. The first is direct mismeasurement of input and output growth rates when no new technology is being utilized i.e., when (1) describes actual production. The second arises because the marginal products of inputs, and hence their prices, are affected by the utilization of new technology. Both types of errors are important, and

[1]See Griliches and Jorgenson (1967) and the debate with Denison (1971).

the first type is conceptually easier to deal with. Clearly, if through varying types of investment, the real productivity of inputs is increased in a setting of constant technology, proper measurement should capture this. Land, for example, may be drained, or leveled and investment in canals and irrigation systems may be made. This can be handled by converting improved land to a standardized unit in the measurement of input growth rates or by treating different types of land as separate inputs with appropriate costs shares reflecting differential productivity.

Labor similarly can be improved in quality through investment in new skills. Schooling-income relationships have been utilized to measure labor force growth in growth accounting studies. They have generally accounted for a substantial part of residual productivity growth as measured by $\dot{p}$ in (3). Machines and chemicals similarly can be improved through investment.

The second issue in input measurement impinges on these adjustments. Welch (1968) has shown that a substantial part of the observed schooling-income relationship is due to the dynamic nature of technological change. Thus, part of the returns to schooling are more appropriately treated as joint returns to schooling and to investment in technology production.

In general one can say that if all inputs involved in the production of technology were included in the growth accounting equation and all producers were maximizing profits, a relatively complete accounting of growth could be obtained. The following characterization of production is more realistic than (1).

$$(4) \quad Y^* = F^* (X_1, X_2 \ldots X_n, I, S, A)$$

This allows for a direct specification of public sector inputs, roads, communication etc., (I), skills (S), and the age and experience structure of technology (A).[1] The analogue to (2) for (4) would be

$$(5) \quad \dot{y}^* = \sum_i (S_i' \, x_i' + S(S_i' - S_i)(\dot{x}_i' - \dot{x}_i) + S_i(\dot{x}_i' - \dot{x}_i) + (S_i' - s_i) \, \dot{x}_i'$$

$$+ \; \alpha \dot{i} + \beta \dot{S} \; + \gamma \dot{a}$$

where errors in cost share measurement $(S_i' - S_i)$, and input growth rates $(x_i' - \dot{x}_i)$ are explicitly considered. The contributions of public goods skills, and time (through technology aging) are also considered. If we were to add another term to explicitly consider the products of research and other invention activity we should have a relative complete accounting of growth.

In practice we do not have enough information to apply (5) directly to data. However, a two stage procedure is feasible. There are a well established standard procedures for measuring input and output growth, however they neglect public goods, skills, and technology related factors. They may also be subject to some errors of cost share measurement. The following section describes these measures in some detail. And we will take these total factor productivity measures as dependent variables in the statistical decomposition model. The independent variables will then be investments in extension, schooling, invention, and research, described in the following sections in greater detail.

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[1]The age of technology is important because learning requires time, and as technology becomes older, producers learn more about it.

II. Measured Total Factor Productivity in U. S. Agriculture

Two basic series on measured total factor productivity (TFP) in United States agriculture are available. The first is the official series of the United States Department of Agriculture. The origins of this series can be found in several USDA publications, most prominently in Loomis, R.A. and Barton, G.T. "Productivity of Agriculture U.S.:1870-1958," Agricultural Research Service, Technical Bulletin No. 1238, published in 1956. In recent years, updated productivity indexes and basic production series have been published in annual supplements to USDA Statistical Bulletin 233. In 1972, this source published productivity indexes on a cross-section basis for the ten major producing regions in the United States (for the 1939-71 period) for the first time.

The second basic series is taken from a paper by Landau and Evenson [1973] which in turn relied heavily on the earlier work of MacEachern [1964]. The Landau-Evenson study developed alternative TFP measurements to the USDA time series for the entire sector and to the USDA series for the ten production regions. It provided, in addition, TFP series on a state basis for the 1949-1971 period, and extended the production region series back to 1925.

The Landau-Evenson series (in addition to being provided for more detailed geographic areas) is calculated in a manner closely approximating the Divisia Index, shown by Richter [1971] to have superior index number properties under conditions of changing factor prices. The USDA series is basically a Laspeyres price weighted output quantity index divided by a Laspeyres price weighted input quantity index, as follows:

$$(6) \qquad P_{USDA}(t) = \frac{\sum_{i=1}^{m} P_{io}\, Q_{it}}{\sum_{i=1}^{m} P_{io}\, Q_{io}} \Bigg/ \frac{\sum_{j=1}^{n} W_{jo}\, I_{jt}}{\sum_{j=1}^{n} W_{jo}\, I_{jo}}$$

P_i, W_j : output and input prices

Q_i, I_j : output and input quantities

This index is usually multiplied by 100 and is thus equal to 100 in the base period. This index does not measure a shift in production functions well when factor ratios change, unless, of course, the production function is linear. Nadiri (1972) points out, however, that by shifting the weights (not just the base period) used in the calculation frequently and "chain-linking" the index together over time, it is a much more suitable measure.

Solow (1958) had shown that among constant weight specifications, geometric price weights were superior to simple linear price weights.

$$(7) \qquad P_{Geom}(t) = \frac{\sum_{i=1}^{m} C_{io}\, LN(Q_{it})}{\sum_{i=1}^{m} C_{io}\, LN(Q_{io})} \Bigg/ \frac{\sum_{j=1}^{n} S_{jo}\, LN(I_{jt})}{\sum_{j=1}^{n} S_{jo}\, LN(I_{jo})}$$

C_i and S_j are output and input shares

In this formulation, if a Cobb-Douglas production function has been used, changes in factor proportions are appropriately handled. A movement along an isoquant is distinguished from a movement to a superior isoquant.[1/]

[1]Nelson (1964) has shown the relationship between the elasticity of substitution and productivity change under condition of changing factor proportions.

The expression for changes in the Chain linked Geometric index is:

(8) $$P_{CLG}(t)/P_{CLG}(t-1) = \frac{\sum_{i=1}^{m} C_{i(t-1)} LN(Q_{it})}{\sum_{i=1}^{m} C_{i(t-1)} LN(Q_{i(t-1)})} \Bigg/ \frac{\sum_{j=1}^{n} S_{j(t-1)} LN(I_{jt})}{\sum_{j=1}^{n} S_{j(t-1)} LN(I_{j(t-1)})}$$

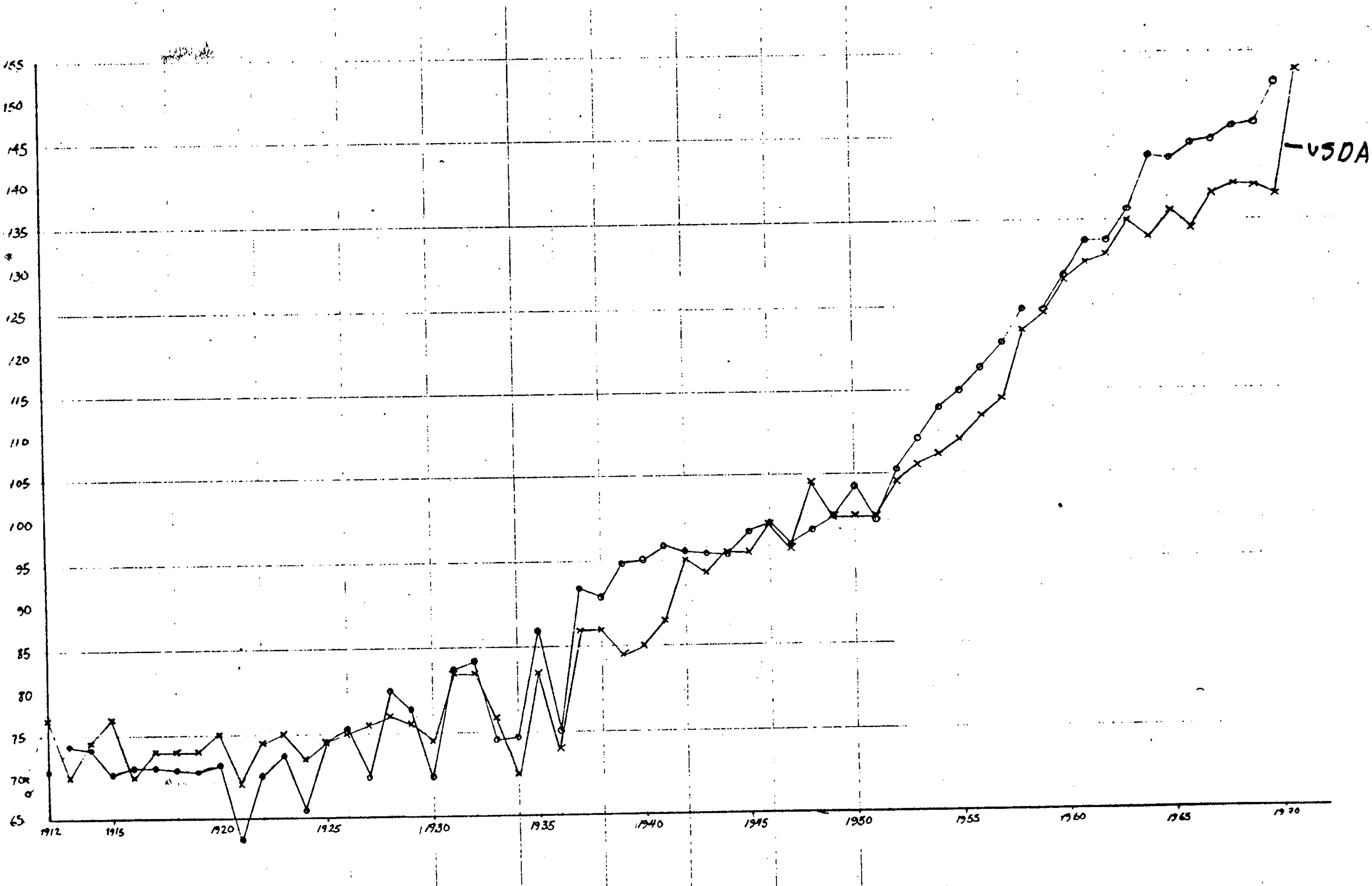
The annual changes in the index specified in (8) can, of course, be incremented into a TFP time series and set equal to 100 in a chosen base year. The series requires annual input and output prices which are not used in the USDA series, but which are available. The Landau-Evenson series is not strictly comparable to the USDA series in terms of the treatment of land and building capital and in the valuation of labor. Details are set forth in the appendix.

The Aggregate United States Series

In figure 1 the USDA index of Total Factor Productivity is plotted for the 1910 to 1971 period. For comparison the CLG index (Landau-Evenson) is also plotted for the period. Both series are on a 1949 base. These aggregate series show the course of change for the sector in its major dimensions over the period. Since we do not have data on a regional basis prior to 1925, we are unable to explore the behavior or the series in the early years as fully as we would like.

The period prior to 1925, however, is an important period from many points of view. It exhibits changes created under conditions differing significantly from those of later years. The public sector research activities of the experiment stations were underway well before 1920 in all states, but had

Figure 1. Total Factor Productivity: U.S. Agriculture 1879-1971



specificity to geo-climatic and economic conditions. The longest regional time series available is the CLG index computed by Landau and Evenson (based on data provided by MacEachern [1964]) for the years 1927 to 1939. These data are exhibited in Figure 2.

The indexes presented in Figure 2. are actually 3-year moving averages of the annual data by region. The North Central region includes the Corn Belt, Northern Plains, and Lake States USDA Production regions. The Southern region encompasses the Delta, Appalachain, Southern Plains and Southeastern USDA production regions. The Mountain region includes the Mountain and Pacific USDA production regions. The Northeast region is not included.

The regions have a common base in 1927, and if we examine the ranking of the regions by decades, we notice unusual cyclical behavior. The North Central region ranks first for all years after 1937. Its advantage by 1960 is impressive. The South, on the other hand, ranked below all other regions in 1950, but by 1970, had moved well ahead of the Pacific and Mountain regions.

The performance of the Pacific region is somewhat puzzling. Until 1935, this region led all others, then was relatively stagnant until 1945. During the 1945 to 1955 decade, it again performed well, only to be relatively stagnant in the following several years. Since 1962 it has again led other regions in rate of change. It appears to be a "leading" series region, in that periods of rapid change in the Pacific region are followed by periods of rapid change in other regions.

The cyclical behavior exhibited in these series has a number of possible sources, part of which appear to be related to the cyclical nature of

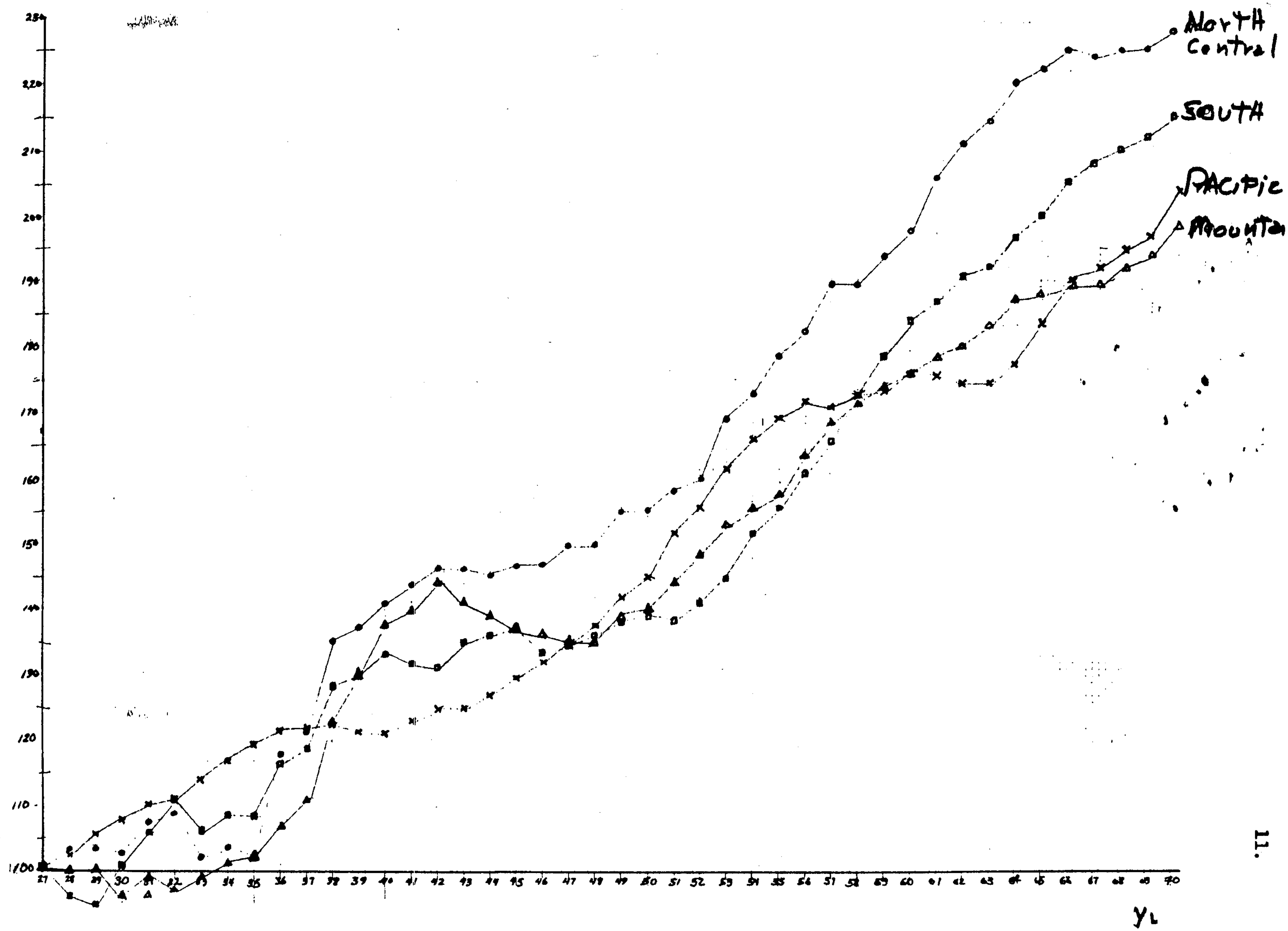


Figure 2. Productivity Indexes 1926 - 1971

economic conditions in the regions. Part is due to cyclical investment patterns in research and extension, and part to the process of indirect diffusion of technology from region to region. The thesis of D. Landau [1973], relating productivity gains to economic pressures to economize is broadly consistent with the data. Productivity gains are systematically more rapid following a period of relative economic distress. The rapid gains in the middle and late 1930's, for example, could be at least partially due to producer response to the conditions of the late 1920's and early 1930's which forced producers to economize and to undertake adjustments in a later period. Periods of relative prosperity on the other hand are not conducive to rapid adjustment. The relatively strong performance of the South after 1950, is related to the shift in research emphasis toward that region that occurred after World War II, as well as to the economic adjustment process.

The series for all 10 USDA Production Regions for 1941 to 1970 are shown in Figure 3. These series are "smoothed", as were the previous regional indexes. They are 3-year moving averages of the annual series which eliminates most of the weather-induced variation. For each region, two series are given. The USDA series is the recently reported regional series in Statistical Bulletin 233. Each region series is expressed on a 1940 = 100 base. The second series, the CLG series, is expressed relative to a national base, and the national mean of the two series is equal in 1949. Each CLG regional series is "scaled" relative to this national mean. For the 3-year period 1949-1951, the ratio of the value of total production (in 1950 prices) to the total costs of all inputs, valued at regional prices, was computed for each region. The regional ratio divided by the national mean ratio then was the scaling factor used in plotting the CLG series.

This procedure was designed to give a measure of real productivity between regions to enable somewhat more realistic comparisons. The scaling factor and the 1970 average scaled productivity levels are presented in Table 1. The 1970 levels of the two series differ significantly. Only part of this difference is due to the scaling factor as can be seen by comparing the GCL and USDA levels when calculated on a common base (1949=100). The GCL procedures themselves make a significant difference in several of the regions. We believe that the GCL procedures are superior to the USDA series and that the scaling procedure has merit, even though the regional price data are not as refined as they might be.

Table 1. Regional Productivity Scaling Factors and Productivity Levels

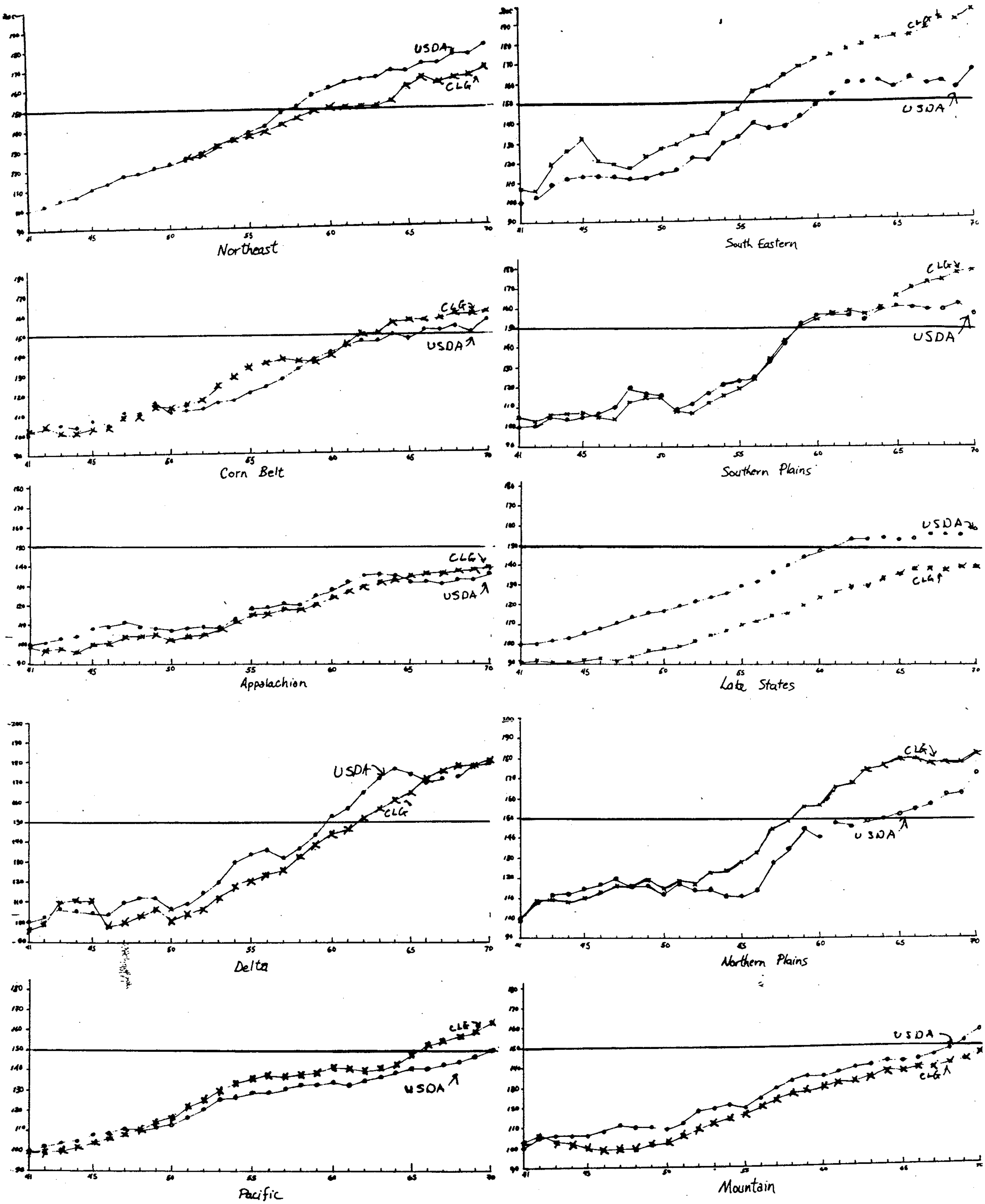
Region	Scaling Factor	1970 Average GCL TFP scaled 1939-41 = 100		1970 average USDA TFP 1939-41 = 100
		Gross	Net	
1. Northeast	1.013	171.3	169.2	181.3
2. Lake States	.914	141.0	154.3	160.4
3. Corn Belt	1.019	160.4	157.5	157.0
4. Northern Plains	.990	182.6	184.4	172.6
5. Appalachain	.985	139.5	141.6	136.5
6. Southeast	1.049	194.5	182.3	165.4
7. Delta	. 961	180.7	188.0	179.4
8. Southern Plains	1.049	179.1	170.7	156.9
9. Mountain	1.021	145.7	142.8	159.1
10. Pacific	.986	164.2	166.5	150.2

Consequently, we believe that the best estimates of relative efficiency of farm production, given input and output prices and existing natural resources, is that of the scaled CLG series. The CLG series, with a 1939-41 base, is the best indicator of the change in efficiency (unexplained) since 1940. All of the series indicate that the Delta, the Southeast and the Northern Plains have done very well over the 32-year period. Appalachia has clearly done least well. The performance of the Corn Belt and Pacific regions has, by all measures, not been extraordinary. It would probably be the judgment of many that these two regions should rank at the top by these measures, and that the Southeast and Delta regions might be expected to rank considerably lower. Those judgments are based on partial productivity evidence and casual empiricism, both of which are less appropriate to objective measurement of efficiency than the CLG series reported here.

As Figure 3 indicates, the changes of TFP gains over time differs considerably among regions. The three leading regions as of 1970, the Delta, the Southeast, and the Northern Plains, interestingly, realized few gains from 1940 to the early 1950's. Their gains were very rapid in the late 1950's and early 1960's, and this pattern constrasts strongly with other regions.

The cyclical behavior of these series is also quite apparent, though the timing of the cycles differs among regions. As noted, the leading regions experienced little productivity growth until the early 1950's. The Pacific and Northeast regions were experiencing TFP increases somewhat earlier, and all regions tend to show a slowdown in the late 1960's.

FIGURE 3. Regional Production Indexes 1941-70



State TFP Indexes, 1949-71

The CLG series was computed for each state for the 1949-71 period, and Table 2. summarizes these data by state and region. Two index levels are reported in the table. The first, termed the gross productivity index, is the 1969-70-71 average level of the CLG index on a 1949-50 = 100 base. It is calculated as previous indexes have been. The net productivity index is computed by excluding certain purchased inputs from both the output and input series. Output is converted to "value-added by farm resources" by subtracting the purchases of feed, livestock, seed, fertilizer, and miscellaneous repairs and fuel expenses. These items are also excluded from the input index. The TFP index, so constructed, is then an index of "value added per unit of land, labor, and farm capital."

The gross productivity series for each state follows the pattern discussed in connection with the region indexes. The leading states in terms of productivity increase since 1950 are Mississippi, North Dakota, Arkansas, Alabama, Louisiana, and Kansas. It may be something of a surprise that these states have outperformed California, Iowa, and Illinois by a wide margin, however, it should be noted that we are measuring productivity gains over a relatively short period of time. And as mentioned earlier, the regional evidence suggests that the leading states in the 1950 to 1970 period had experienced relatively slow productivity growth in earlier years. Part of their gains can probably be attributed to a late realization of gains that other states managed in earlier years.

Table 2. 1969 - 1970 - 1971 Average Gross and Net Productivity Levels

United States Agriculture - States and Regions

State	Productivity Gross	Productivity Net	Sealing Factor
Northeast Region			
1. Maine	157.9	164.8	1.09
2. New Hampshire	133.8	122.4	.94
3. Vermont	139.3	134.9	.89
4. Massachusetts	143.7	137.1	1.00
5. Rhode Island	139.4	134.9	1.00
6. Connecticut	139.6	130.1	1.04
7. New York	127.5	120.8	.98
8. New Jersey	131.2	118.5	1.06
9. Pennsylvania	136.8	133.7	.93
10. Delaware	154.6	147.8	1.11
11. Maryland	144.9	141.4	.95
Regional Total	137.7	132.8	1.01
Lake States Region			
12. Michigan	139.5	137.6	.90
13. Wisconsin	138.0	136.3	.94
14. Minnesota	148.4	143.3	.91
Regional Total	143.2	139.8	.92
Corn Belt Region			
15. Ohio	144.8	141.8	.92
16. Indiana	154.2	154.9	1.00
17. Illinois	137.5	124.4	1.10
18. Iowa	138.2	123.9	1.02
19. Missouri	141.0	136.4	1.02
Regional Total	141.6	132.6	1.02
Northern Plains Region			
20. North Dakota	186.9	217.0	1.01
21. South Dakota	155.3	156.7	.96
22. Nebraska	142.9	129.7	1.00
23. Kansas	161.4	158.9	.98
Regional Total	158.4	156.5	.99

State	Productivity Gross	Productivity Net	Seali Fact
Appalachian Region			
24. Virginia	131.8	132.1	.9
25. West Virginia	124.2	111.1	.8
26. Kentucky	142.5	143.6	.9
27. North Carolina	135.8	136.0	1.0
28. Tennessee	138.4	130.3	.9
Regional Total	136.8	135.1	.9
South Eastern Region			
29. South Carolina	150.6	156.6	.9
30. Georgia	152.9	146.2	1.0
31. Florida	142.7	140.3	1.3
32. Alabama	168.8	167.2	.9
Regional Total	153.3	150.6	1.0
Delta Region			
33. Mississippi	194.6	201.1	.8
34. Arkansas	171.8	150.5	1.0
35. Louisiana	163.6	148.0	1.1
Regional Total	177.9	167.5	.9
Southern Plains Region			
36. Oklahoma	148.4	141.8	.9
37. Texas	158.6	140.2	1.0
Regional Total	156.2	140.6	1.0
Mountain Region			
38. Montana	149.8	148.9	1.1
39. Idaho	156.6	137.1	.8
40. Wyoming	130.8	111.7	1.0
41. Colorado	140.6	117.1	.9
42. New Mexico	153.0	126.5	1.0
43. Arizona	124.7	74.5	1.3
44. Utah	135.3	119.4	.9
45. Nevada	131.0	92.8	1.2
Regional Total	142.4	118.9	1.0
Pacific Region			
46. Washington	156.5	150.3	.9
47. Oregon	143.4	139.3	.8
48. California	138.0	111.5	1.0
Regional Total	141.4	120.1	.9

III. Invention, Research and Extension Investment in U. S. Agriculture

Research and Extension in the 19th Century

Danhoff (1969), in his excellent summary of agricultural change in the northern United States from 1820 to 1870, emphasizes the role of three major institutions in this period. The agricultural press, particularly several leading farm magazines, functioned as the major communication media or information supply agency of the period. Input suppliers advertised their wares which consisted of improved plows, cultivators and harness equipment, and in later years, reapers, threshing machines, grain drills and other implements were also important. A second major institution of the period was the agricultural society, which organized agricultural fairs and actively promoted technology transfer through field trials and experimentation.

The U.S. Patent Office set up an agricultural division in 1839 that was the forerunner to the Department of Agriculture, established in 1862. This activity initiated federal government efforts to aid agriculture. Its chief function was the testing and distribution of seeds, many of them imported from Europe, Asia, and Africa. This office also initiated governmental efforts to disseminate information through the annual reports of the Patent Office.

The 19th Century was characterized by a high rate of European immigration and a continuous process of settlement on new lands. This rather special set of circumstances itself facilitated the change process. Communication channels between Europe and the United States were well maintained. New immigrants brought new techniques of production with them. The very process of establishing farms in new conditions forced the settlers to experiment, and to learn to modify and adapt old technology to the new conditions. As new lands were opened up, new soil types, new climatological factors, new drainage problems and new insect and disease problems forced farmers to adapt and modify techniques of production.

These were factors that contributed to the large number of inventions of relevance to agriculture that were patented in the 19th Century. Schmookler [1966] and Feller [1965] have studied this inventive activity largely from a "demand for inventions" perspective. They show that patenting activity and economic activity were closely related, with changes in economic activity "leading" changes in inventive activity as measured by patents. Table 3 summarizes patented inventions in 13 technology fields of relevance. These data have been utilized to construct a "stock of inventions" variable which is utilized in later analyses.

After 1870, a number of new institutions became important and public sector investment in research was increased. The U.S. Department of Agriculture was created in 1862 and took over the functions of the agricultural division of the Patent Office. Prior to 1870 several universities had established agricultural colleges. The University of Michigan Agricultural College, established in 1837 (later re-established as a separate agricultural college in 1855) and the agricultural colleges of New York (1853) and Maryland (1856) were the first of these new institutions.

Table 3. Patenting Activity Agricultural Technology Fields

Technology Fields

		Harvesting Equipment				Animal Related Fields				Tillage Equipment			
		Hay Handling (1)	Grain Reaping Threshing (2)	Corn Husting (3)	Mech. & Cotton Husting (4)(5)	Dairy Equips. (6)	Lvstk. Housing (7)	Poultry Equip. (8)	Animal Harness (9)	Crop Husbandry (10)	Planters Drills (11)	Cultivation (12)	Plow (13)
1.	Pre 1830	2	13	0	0	0	0	0	1	0	0	0	91
2.	1830-39	17	89	38	0	0	1	0	1	0	12	7	108
3.	1840-49	22	74	32	0	0	5	3	10	2	52	18	97
4.	1850-59	216	178	121	8	2	35	1	59	17	332	55	225
5.	1860-69	903	401	143	30	10	292	11	226	84	997	691	934
6.	1870-79	742	455	186	37	17	514	21	393	104	1172	640	669
7.	1880-89	668	544	142	94	16	923	97	727	80	1661	656	438
8.	1890-99	411	246	102	97	30	849	112	529	83	1263	489	341
9.	1900-09	484	355	171	183	77	717	343	456	83	1131	470	392
10.	1910-19	441	241	124	331	196	1100	385	302	225	875	381	339
11.	1920-29	213	182	128	387	139	808	367	91	156	274	242	228
12.	1930-39	147	162	97	622	62	425	282	28	239	421	112	125

The movement to establish agricultural colleges culminated in the Morrill or Land Grant College Act of 1862 which established funding for a college of agriculture in each state. The early agricultural colleges were not necessarily research-oriented. Many of them disdained the "impractical' study of science and stressed "practical" vocational training. Curricula were developed to train farmers, not research scholars, however the Hatch Act of 1887, which provided federal funding for experiment station research in each state, facilitated the integration of scientific research and the teaching functions of the agricultural colleges. The passage of the Hatch Act was of great significance to the organization of agricultural research in the U.S. It was not a small achievement to have developed an integrated science-based research-teaching-extension system. Few countries in the world have managed it. The basic conflict that had to be resolved was that between the "practical" forces and the "scientific" forces. This conflict continues even today within the experiment stations.

It was, in retrospect, fortunate that the colleges and experiment stations were forced to deal with one another. The practical men forced the scientists to orient themselves toward real problems. Evidence presented in a later section indicates that the early experiment stations were quite productive, largely due to their role in efficiently testing new techniques and speeding their introduction to new areas. The availability of new implements made agronomic work important, as the experiment stations themselves produced few new mechanical inventions. Invention was largely taking place in the private sector, and increasingly came to be concentrated in the larger farm machinery firms. Progress in biological-based technological improvement was very slow, largely because the known techniques of plant and animal breeding at the time had limited potential. It was not until the modern phase of agricultural development that major advances of a biological nature were made.

This modern stage has its origins in the science-oriented work of the stations in the late 1800's and early 1900's, though productivity gains stemming from this work were significant only after 1920. The development of hybrid corn can be seen as the prototype sequence of the application tion of science. The science of genetics was established after the pioneering work of Mendel in 1866 and Darwin in 1876. In fact, Darwin's work had an important influence on the early work on corn hybridization by Beal at Michigan Agricultural College. Shortly after 1990, Schull, at Cold Spring Harbor, and East, at the Connecticut Agricultural Experiment Station, were experimenting with hybridization

of corn with the objective of improving the knowledge of genetics. It was their work, however, which / enabled H.K. Hayes and Jones at Connecticut to breed the first hybrids. Jones had developed the double cross hybrid by 1918, and by 1923 or so most of the experiment stations in the U.S. were introducing some experimental work and developing inbred lines to be used by breeders. Henry A. Wallace combined the breeding and commercial skills to make these seeds available to the Iowa farmer by the late 1920's.[1]

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[1]For an account of this history see Bradfield (1968).

Research and Extension in the 20th Century

Table 4. summarizes public sector investment in agricultural research and extension since 1890. The expenditure data are in constant 1959 dollars to enable comparisons over time,[1] and all expenditure data refer to research and extension oriented to agricultural production only. Here we note that the system was relatively small prior to 1910. Most of the funding on research in the State Agricultural Experiment Stations (SAES) was from federal Hatch Act funds. The United States Department of Agriculture (USDA) had developed the Beltsville, Maryland station with several others, and was investing almost as much on research in these stations as were the states.

The 1910 to 1925 period exhibits a significant expansion in both SAES and USDA research as well as the development of the Federal Extension Service. After 1920, expenditures on the Vocational Agricultural Education system also became significant. In contrast to the earlier period, the contribution from state governments then became significant, both in support of research and extension. The Granges and the Farm Bureaus were

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[1]The price index used to deflate current expenditures is taken from Evenson [1968]. It is constructed by deflating separately the expenditures on professional staff by an index of university professors' salaries, technical and clerical staff (skilled labor), equipment (metal and metal equipment), and building investment (building materials). The 1970 deflation is based on an index constructed by NSF [1972].

Table 4 Expenditures on Research and Extension Oriented to Improved Agricultural Production Technology.

Public Sector: U.S. Agriculture 1890 to 1970

Millions of Constant 1959 Dollars

Year	EXPENDITURES ON RESEARCH State Agri.Exp. Stations Total	State Funded %	Federal Funded %	USDA %	USDA outside state	Expenditures on Public Extension Service	Vocational Agri. Programs	Soil Conservation Service
1890	3.7	.22	.78		1.0	.1		
1900	4.7	.34	.66		4.0	.5		
1910	14.2	.39	.61		18.2	.9		
1915	13.1	.72	.28		24.0	7.2		
1920	11.0	.77	.23		18.8	17.8	11.9	
1925	16.3	.85	.15		22.7	23.6	16.8	
1930	29.0	.73	.27		37.0	29.6	23.3	
1935	30.4	.57	.27	.16	25.4	26.9	25.9	2.1
1940	43.4	.54	.28	.18	46.0	41.3	45.9	32.7
1945	43.8	.56	.23	.20	37.5	39.1	39.9	48.1
1950	74.5	.63	.17	.20	32.0	54.0	56.2	74.4
1955	96.4	.63	.17	.20	34.2	58.3	64.7	70.1
1960	132.2	.55	.15	.30	33.6	65.0	64.7	78.1
1965	147.8	.58	.16	.26	26.0	68.9		
1970	158.9	.66	.16	.18	42.0			

Sources: Latimer [1962]
Evenson [1968]

USDA work sheets

also instrumental in developing both state and federal support for research, and to an even greater extent for extension.

After 1925, a further major expansion of the research system took place, again with significant state support. Data for 1935 indicate a significant new pattern of investment. The federal government in expanding the USDA research now began to locate a significant amount of its research activity in the states, often locating scientists directly in the state experiment stations. Much of this expansion took place in the southern states.

The post World War II expansion of the research system was most rapid from 1945 to 1960 , and virtually all of this expansion took place in the state experiment stations. The USDA investment outside the state experiment stations has changed little since 1930. Since we are considering production oriented research only in this table, we should note that the USDA has expanded its research programs in the utilization and marketing of farm products very significantly since 1945. Additionally, it is interesting to note that the federal government through its investment decisions has been very influential in changing the research system, even though state governments have provided the majority of the funds. In the 1930's and 1940's it located much of its investment in the "lagging" regions, chiefly the south. In this way it had a major impact on the regional nature of productivity. In the 1950's and 1960's it shifted emphasis to marketing and utilization research, to a much greater extent than would have occured if the states were determining the investment pattern.

Research expenditures rose less rapidly in the 1960's. In fact, they may have declined after 1966. Expenditures on the extension service and vocational agricultural programs have probably declined in real terms since reaching peak levels in the early 1950's.

We do not have detailed data on the research activities in the private sector that are of direct relevance to improvements in the efficiency of agricultural production. The available data are summarized in Table 5, where the expenditures reported are for "research and development." It is difficult to compare these with the expenditures in the public sector because much of the research in the public sector does not lead to a saleable product, and does not involve the same kind of development that characterizes new farm implements, pesticides, etc. On the other hand, the public sector expenditures do support what might be called, "development" as many field trials, for example, may be classified.

For comparative purposes, we would include only a portion of the research in the farm machinery and agricultural chemicals industries as the private sector counterpart of the public sector expenditures reported in Table 5. The expenditures in the food and kindred products sector are mostly for utilization research and the marketing of agricultural goods after they leave the producing sector. The National Science Foundation data indicate that approximately three-fourths of the research and development expenditures are for "development." If we make the crude adjustment to production oriented research and development expenditures that one-half of these expenditures are comparable to public sector activities called research, we find that during the 1950's the private sector accounted for approximately one-fourth of the total agricultural research budget, and the

Table 5. Research and Development Expenditures by Private Industrial Firms of Relevance to U.S. Agriculture.

Millions of Constant 1959 Dollars

	1952	1958	1960	1965	1970
Production Oriented:					
Agricultural Chemicals (SIC 287)	31	35	27	52	67
Farm Machinery (SIC 352)	31	58	72	78	60
Product Oriented:					
Food & Kindred Products	61	72	88	107	118

Source: National Science Foundation, "Research and Development in Industry 1970," NSF 72-309 for 1960, 1965, 1970.

Latimer R. [1962] for 1952-1958.

private share rose to roughly 40 percent during the 1960's.

It is always difficult to draw a line delineating research that is or is not oriented to particular economic activity. The data in Table 3. and later tables referring to the public sector include some production oriented research undertaken outside the state universities. That is, for example, if any USDA funding is involved, research conducted in a private university is included. Nonetheless a great deal of agriculturally related research is missed. Research in plant and animal physiology, in plant and animal genetics, in cytology, in experimental design, and a number of other fields of science is of direct importance to applied agricultural research. We have only one estimate of the magnitude of this research activity. In 1965, a USDA study group estimated that expenditures for agriculturally related research was approximately seventy percent of the public sector spending on agricultural research. If we accept this estimate for purposes of a crude allocation of research effort relevant to agriculture in 1965, the public sector (SAES plus USDA) accounts for slightly less than one half of the total, and the private sector, roughly 20 percent. The remainder is agriculturally related research. Since much of the latter spending is from public funds, agricultural research is predominately a public sector activity.

In Tables 6 and 7 we present data showing public sector investment in production oriented research and extension for each of the ten USDA Production Regions. From Table 6 we can see marked regional differences in the ratio of research to extension especially in the pre-World War II years. The four southern regions, Appalachia, the Southeast, the Delta, and the Southern Plains, all invested more in extension than in research prior to 1940. All other regions expended significantly more on research than on extension, and by 1965 all ten regions were spending more on research by a large margin.

The regional share data in Table 6 show the change in emphasis somewhat more clearly. In 1915, the four southern regions acoounted for only 22 per cent of national research expenditures, but spent 42 percent of the extension budget. By 1955, the southern regions had increased their research share to 35 percent and had further increased it to almost 38 percent by 1965. While their expension share had fallen to less than 40 percent by 1955.

The regional share table also provides data on the allocation of USDA research by regions. This activity became significant after 1930 and has accounted for approximately 20 percent of the state research effort since 1935. It is quite clear that this activity favored the southern states. In 1935 the four southern regions received 36 percent of this activity, and by 1945, 45 percent of it went to the south. It was particularly significant in the Southeast and Delta regions. In 1945, USDA research in two or three southern states approximately doubled the state research effort.

Not all of the southern regions have exhibited the same pattern of research expansion, however. The Delta region, with a large boost from USDA research, had realized much of its increase by 1945. In the Southeast region, the major expansion occured between 1945 and 1955. The Appalachain region, on the other hand, did not show a major expansion until 1965.

Table 6. Research and Extension Investment Shares by Region 1915 to 1965

Region	1915	1925	1935	1945	1955	1965
1. Northeast						
Research	.193	.186	.208	.179	.130	.099
USDA Res.	-	-	.028	.050	.095	.072
Extension	.154	.186	.207	.157	.158	.145
2. Lake States						
Research	.134	.127	.091	.072	.087	.075
USDA Res.	-	-	.039	.041	.077	.090
Extension	.080	.073	.069	.075	.084	.083
3. Corn Belt						
Research	.182	.220	.142	.148	.127	.103
USDA Res.	-	-	.067	.109	.097	.116
Extension	.151	.186	.167	.166	.154	.150
4. No. Plains						
Research	.095	.071	.061	.058	.065	.070
USDA Res.	-	-	.097	.066	.058	.049
Extension	.078	.077	.070	.068	.069	.066
5. Appalachaia						
Research	.088	.081	.064	.073	.078	.118
USDA REs.	-	-	.038	.041	.062	.067
Extension	.139	.123	.125	.145	.143	.145
6. Southeast						
Research	.045	.034	.082	.109	.120	.119
USDA Res.	-	-	.143	.174	.146	.121
Extension	.117	.090	.090	.103	.099	.099
7. Delta						
Research	.042	.045	.042	.076	.075	.070
USDA Res.	-	-	.088	.135	.104	.125
Extension	.080	.066	.072	.084	.077	.082
8. So. Plains						
Research	.042	.039	.051	.071	.073	.068
USDA Res.	-	-	.090	.091	.055	.047
Extension	.082	.076	.077	.083	.074	.073
9. Mountain						
Research	.097	.089	.125	.080	.093	.142
USDA Res.	-	-	.158	.116	.168	.148
Extension	.057	.062	.063	.057	.061	.065
10. Pacific						
Research	.082	.108	.130	.133	.151	.136
USDA Res.	-	-	.252	.173	.136	.146
Extension	.061	.061	.060	.062	.081	.090

Regional Research and Extension "Intensities"

The data presented to this point do not adequately indicate how much research effort is being devoted to the solution of particular problems. It is difficult to obtain a measure of research "intensity" or research expenditures per "problem." Later we will use a measure based on geo-climate region and on commodity complexity, but here we want a simple summary measure. The research intensity measure that we present in Table 7. is research expenditures per thousand dollars of commodity value. Research intensities for all livestock and livestock products and for all crops are then calculated for each of the ten regions.

By this measure, the southern regions, even in 1951, were not lagging behind the rest of the country. In 1951, the southeast region had the highest livestock research intensity, and ranked 5th in crop research intensity. The Delta region also had relatively high research intensities. The Corn Belt, on the other hand, ranked low.

This measure, as we have noted, is an imperfect one for several reasons. First, the intensities are not corrected for crops fed to livestock. The value of forage and pasture crops not marketed should be subtracted from the livestock intensity deflator and added to the crop intensity deflator. Doing so would bring the intensities more closely in line with one another. Of more importance, the dollar value of production in a region is not necessarily an indicator of the difficulty of producing

Table 7. Research Orientation by Region: U.S. Agriculture 1951 and 1963
Expenditures (in 1959 dollars) on Research by Orientation

Region	LIVESTOCK		CROPS		ECONOMIC & ENGINEERING		BASIC	
	Expend-iture	EXP/ Commodity[a] Value	Expend-iture	Expend-iture per $000 Commodity Value	Expend-iture	Share of Research Expend-itures	Expend-iture	Share
1. Northeast								
1951	3.66	1.79	5.86	5.96	.54	.047	1.27	.112
1963	6.03	2.65	7.42	7.47	1.06	.062	2.51	.147
2. Lake States								
1951	2.48	1.12	2.68	3.62	.48	.074	.84	.130
1963	3.91	1.56	4.10	4.38	.78	.076	1.59	.154
3. Corn Belt								
1951	4.48	.88	3.21	1.71	.77	.078	1.41	.143
1963	6.47	1.16	4.04	1.40	1.19	.084	2.44	.172
4. No. Plains								
1951	2.24	1.14	1.55	1.51	.27	.059	.54	.118
1963	4.47	1.85	3.14	2.26	.70	.075	.97	.104
5. Appalachaia								
1951	2.19	1.81	2.63	1.41	.49	.082	.66	.110
1963	4.48	3.07	3.95	2.15	.81	.076	1.40	.131
6. Southeast								
1951	2.22	3.22	3.89	2.37	.69	.087	1.06	.134
1963	5.67	4.33	7.24	4.45	.91	.060	1.38	.891
7. Delta								
1951	1.22	2.32	2.70	2.64	.68	.135	.46	.091
1963	3.73	2.41	4.22	2.60	.55	.057	1.23	.126
8. So. Plains								
1951	2.32	1.79	2.24	1.90	.40	.074	.43	.080
1963	3.72	2.40	3.89	2.59	.65	.067	1.38	.143
9. Mountain								
1951	2.84	2.21	2.38	2.60	.61	.088	1.06	.153
1963	5.21	3.30	4.74	4.07	1.01	.092	1.67	.132
10. Pacific								
1951	3.93	3.00	4.91	2.18	1.75	.067	1.47	.132
1963	6.77	3.70	9.53	3.59	1.54	.073	3.07	.146

[a]dollars research per thousand dollars of commodity value.

new technology of value. The Corn Belt, for example, may have a more homogeneous set of geo-climate factors within it than the Southeast. If so, a research finding in the Corn Belt will be adopted over more units of production. Hence, the research activity per economic problem may well be higher in the Corn Belt.

In addition to research directly oriented to livestock and crop production, two additional categories are shown. The economics and engineering research includes only production oriented research, but basic research includes phytopathology, soil science, botany, zoology, genetics, and plant and animal physiology in agricultural research institutions. Regional differences in the shares of economics and engineering are somewhat greater than in the share of basic research, as the southern regions have relatively high shares of economics and engineering research and low shares of the more basic research.

In Table 8 roughly comparable data for extension activities are presented. Extension activities are measured in man-days by county

Table 8. **Extension Orientation by Region 1951 and 1963**

Region	Extension Days by Orientation: 1951 and 1963 (000 days by county staff)						Extension Days Per $1,000,000 Commodity Value		Extension days per Commercial Farm	Ratio: State to County Staff 1962	
	Crops	Livestock	Marketing	Soil & Water Management	Planning & Management	Farm Building & Machinery	Crops	Live-stock		Crops	Livestock
1. Northeast											
1953	32.65	38.66	4.21	6.61	5.12	5.62	33.2	18.9	.163		
1961	33.56	33.67	6.94	4.39	9.07	7.50	36.4	14.8	.274	.71	.51
2. Lake States											
1953	15.16	20.28	3.67	9.12	3.36	4.35	20.4	9.1	.107		
1961	17.01	21.25	7.34	9.16	7.89	4.71	18.2	8.1	.159	.34	.36
3. Corn Belt											
1953	33.44	46.62	5.11	21.71	12.78	7.18	17.8	9.1	.122		
1961	31.21	40.78	6.46	15.85	17.09	7.63	10.8	7.3	.144	.41	.40
4. No. Plains											
1953	17.92	20.52	2.23	6.10	2.16	2.42	17.5	10.5	.135	.39	.36
1961	20.37	25.54	1.88	5.49	5.53	3.13	14.7	10.6	.191		
5. Appalachian											
1953	59.69	65.27	9.44	12.88	13.14	8.95	32.2	54.0	.163	.24	.20
1961	58.92	67.59	14.53	11.66	17.21	9.50	32.1	46.4	.330		
6. Southeast											
1953	57.33	52.75	10.94	7.96	8.13	5.26	34.9	76.7	.220	.17	.21
1961	58.05	47.14	8.08	7.97	11.41	4.80	35.6	36.0	.351		
7. Delta											
1953	44.21	42.27	5.16	5.30	6.10	4.14	43.3	80.3	.158	.14	.11
1961	47.24	44.84	6.34	6.91	13.86	5.03	36.6	52.5	.361		
8. So. Plains											
1953	28.40	48.57	3.62	11.45	4.17	3.08	24.1	37.5	.196	.26	.11
1961	28.41	45.92	2.39	7.33	6.66	2.57	18.9	29.7	.260		
9. Mountain											
1953	18.62	22.40	2.33	5.97	1.93	1.63	20.3	17.5	.254	.34	.35
1961	18.67	22.39	2.82	4.96	3.04	1.30	16.0	14.2	.315		
10. Pacific											
1953	30.20	21.90	1.64	6.65	2.53	2.10	13.4	16.7	.231		
1961	35.34	21.09	3.67	7.96	3.87	2.08	13.4	11.5	.341	.30	.21

staff members only. Data for 1962 on the ratio of state staff to county staff are presented and afford a more complete view of the extension program, and here we offer two bases for comparison. The first, extension days devoted directly to crop and livestock production problems, shows that the southern regions have the most intensive extension activity oriented to producers by the country staff in livestock. Even when a correction is made for the fact that these regions have the lowest ratios of state staff to county staff, this remains the case. By this measure, they also have relatively high crop extension intensity, although the Northeast region ranks higher.

The second indicator, extension days per farm, shows a somewhat altered picture. The regional disparity is much reduced and the Mountain and Pacific regions show up as more extension intensive. The southern states are relatively extension intensive by this measure also. All regions increased extension per farm significantly from 1953 to 1961, largely because of the decline in the number of farms. The proportionate decrease in the number of farms was greatest in the Delta and Southeast regions. It is interesting to note that of the several categories of extension effort reported, only the activities devoted to the planning and management of the farm enterprise were increased in every region.

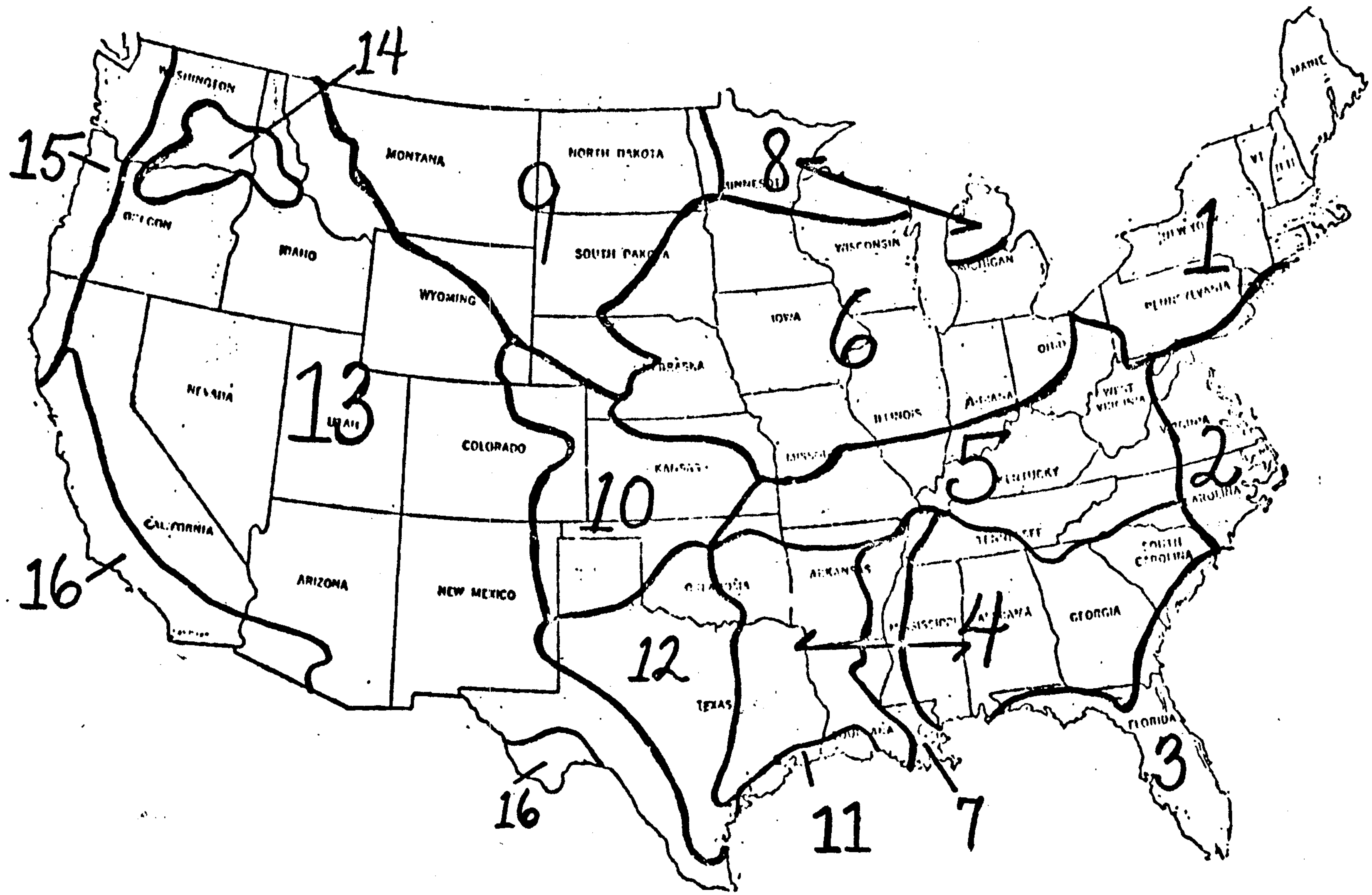
Research and Extension Expenditures in Geo-Climate Regions

The issue of research "deflation" to obtain a measure of research effort per research problem is a difficult one. As we have noted, research per state, research per farm, and research per unit of commodity value all have imperfections. In this section we offer a measure based on geo-climate zones or regions that is closer to a meaningful measure than the more conventional measures. We will use this definition in later econometric specifications which relate research effort to productivity. We deflate research by the "adjusted" number of commodities and the number of geo-climate zones within a state. We also use the regional research classifications to define the research activity relevant to the producers in each state.

It is not possible, unfortunately, to obtain from the geography literature a standardized set of homogeneous crop production regions for the United States. It is not an easy task, since several climate factors and a large set of soil and topology characteristics are important to crop production, and any attempt to define regions involves the explicit or implicit weighting of these factors. Of course, a number of them are reasonably highly correlated and this simplifies the task. Soil characteristics are determined to a large extent by climate factors, for example, and the definition of a geo-climate zone does not require a decision as to whether climate factors or soil characteristics are more important.

The extent or level of detail to incorporate into the definition of regions or zones is also arbitrary. It could be fine enough to distinguish between very small differences in soil texture, for example, and the soil surveys prepared for many countries in the United States by the Soil Conservation Service have such detail. Unfortunately, we are dealing with more aggregate economic units and require a broader definition. In particular, we want a region to be defined in terms that are meaningful

Figure 4. Geo-Climate Regions, U.S. Agriculture



Regions based on 1957 Yearbook of Agriculture.

to the transfer of technology between states.

We concluded that the regions and sub-regions defined by the researchers in preparing the 1957 Yearbook of Agriculture were best suited to our purpose. With some minor modifications to the regions presented in that report, we developed the regional configuration shown in Figure 4. In all there are 16 regions, each defined on the basis of relative homogeneity of soil and climate factors. Each region has from one to five sub-regions (40 in all), and most sub-regions and all regions extend across state boundaries.

In Table 9. research expenditures in constant dollars by region are presented for selected years. The allocation of research expenditure to regions was done on a commodity basis. For each of 21 commodities, state research was alloted to each sub-region according to the share of that commodity produced in the region. The regional totals then are the sum of commodity research plus a proportional allocation of the non-commodity oriented research.

Commodity Orientation of State Agricultural Experiment Station Research

In Table 10 we present a summary of research expenditures by commodity in the State Agricultural Experiment Station system in 1966. It was possible to divide the production oriented research into two subcategories, production-increasing and "maintenance" research. The production increasing research included improving biological efficiency, mechanization of cultivation and harvesting, crops' reproductive performance, feed efficiency livestock. The concept of maintenance of technical gains is very important in agriculture, because, in contrast to most mechanical technology, bio-chemical technology is subject to real loss or depreciation from diseases, insect pests, and internal parasites.

Table 9 Research Expenditures by Geo-Climate Region
millions of 1959 dollars

Region	1915	1935	1950	1965	1969 Expenditures per Sub-region
1. Northeast Dairy Region	2.09	3.84	8.29	13.35	4.45
2. Middle Atlantic Coastal Plain	.53	1.43	3.28	4.75	2.38
3. Florida and Coastal Flatwoods	.13	.94	2.68	4.63	4.63
4. Southern Uplands	.95	2.86	9.60	19.42	3.88
5. East-Central Uplands	1.42	2.39	6.28	10.84	2.17
6. Midland Feed Region	3.45	6.50	15.85	24.15	4.83
7. Mississippi Delta	.19	.45	1.55	3.17	3.17
8. Northern Lake States	.03	.01	.23	.37	.37
9. Northern Great Plains	1.17	1.76	3.99	6.55	2.18
10. Winter Wheat and Grazing Region	.61	1.50	4.26	7.15	3.57
11. Coastal Prairies (Texas-La.)	.01	.01	.02	.33	.33
12. Southern Plains	.18	.47	1.42	2.46	1.23
13. Mountain States Grazing-Irrigated Region	.85	2.26	5.42	8.95	4.48
14. Pacific Northwest Wheat Region	.34	.80	2.79	4.82	4.82
15. North Pacific Valleys	.01	.01	.35	.56	.56
16. Dry Western Mild-Winter Region	.76	3.23	7.61	16.98	5.66

Table 10. Commodity Orientation of State Agricultural Experiment Station Research 1951, 1961.

Commodity	Research Expenditures in millions of 1959 dollars		1966 Research Expenditures			
	1951	1961	Millions of 1959 dollars	Expenditure per 1000 dollars of product	Share of "Maintenance Research"	Expenditures per Scientist Man-year
Livestock	19.59	32.92	67.42	2.72	.40	53,534
Beef	14.33	18.13	17.48	1.67	.38	56,475
Dairy	4.37	7.11	15.99	2.91	.36	55,971
Swine	2.29	2.90	8.28	2.01	.45	60,272
Sheep & Lambs	1.25	2.22	5.52	16.33	.37	48,733
Poultry	3.87	5.88	14.36	3.47	.37	49,362
Other	3.49	6.69	5.77	-	.59	53,729
Crops Total	19.19	27.88	81.81	4.45	.43	36,567
Cereals	4.03	5.60	14.06	2.13	.40	34,340
Corn	-	-	5.65	2.23	.38	34,484
Sorghum	-	-	1.11	1.92	.18	30,248
Wheat	-	-	3.67	1.81	.52	35,475
Rice	-	-	.66	1.63	.36	32.031
Other small grains	-	-	2.98	5.63	.38	34.799
Cotton	1.16	1.42	9.69	6.14	.52	40,103
Oil seeds	.56	.70	4.72	1.64	.35	38,052
Soybeans	-	-	2.53	1.01	.31	36,544
Peanuts	-	-	1.21	4.48	.47	41,436
Other	-	-	.93	11.62	.33	37,556
Tobacco	.73	.81	3.51	2.90	.49	39,723
Sugar Crops	.28	.38	2.65	4.38	.53	37,656
Pasture & Forage	3.47	5.31	10.57	-	.22	36,972
Horticultural Crops	8.21	11.94	26.86	6.25	.50	35,596
Citrus Fruits	1.14	2.19	3.80	7.60	.51	38,122
Decid. Fruits & Nuts	2.47	3.15	10.71	8.86	.49	36,711
Vegetables	3.03	4.20	10.25	5.07	.49	33,586
Potatoes	.82	.68	2.10	3.57	.57	36,208
Miscellaneous Crops	.75	1.72	11.54	-	.33	32,714

In Table 10. we provide research expenditures by commodity in 1959 dollars for 1951, 1961, and 1966. The reader should be cautioned that the 1966 data are not strictly comparable to the 1951 and 1961 data. They include USDA research located in the states and because of a more detailed breakdown of the research program, the 1966 data are more accurately production oriented. The 1951 and 1961 data are comparable, however, and indicate that research expenditures on beef, dairy, sheep and lambs, poultry pasture and forage, and citrus crops were increased by more than 50 percent over the decade.

The 1966 data enable more accurate comparative statistics and three are provided. The first, reasearch expenditures per thousand dollars of commodity value, indicates relative research emphasis. This measure shows that crops receive more emphasis than livestock. It might be argued that research on pasture and forage should be allocated to the livestock sector, but even if this were done, crops would still be more research intense. Within the livestock group, sheep and lambs are very research intense. Within the crop sector one finds that the cereal grains and soybeans have low research intenseities while cotton and the horticultural crops are quite research intense.

The second measure offered in the table is the share of maintenance research by commodity. Here we find that wheat, sugar, cotton and the horticultural crops are quite research intense.

The second measure offered in the table is the share of maintenance research by commodity. Here we find that wheat, sugar, cotton and the horticultural crops have half or more of their research effort devoted to maintenance. The other cereal grains, the oil seeds, and all livestock except swine, have relatively low maintenance shares.

The final computation presented in Table 10 measures a characteristic of the research system itself. The 1966 data allow a calculation of expenditures per scientist man-year by research program area. This gives some indication of the scientific equipment and related technical staff associated with different research programs. The average spending per scientist man-year by commodity are clearly highest for livestock research. Relatively little variation in the averages within the livestock and commodity groups is apparent.

[1] Statistical analysis did not reveal significant differences in these figures by state or region. Most of the state variance in this measure is associated with the commodity mix in the states.

IV. Productivity Decomposition Analysis: 1870 to 1950

We turn now to a productivity decomposition analysis for the 1870 to 1950 period. The period of pre-modern growth, 1870-1925 will be considered first. We have included the period of relative stagnation in productivity growth in this analysis because we wish to put the data to a strong test. Previous authors have concluded that productivity growth during this pre-modern period is not systematically related to research or inventive activity. The evidence reported here indicates otherwise.

The specification utilised in this analysis is:

$$P = a + b_1 \text{ INV} + b_2 \text{ RES} + b_3 \text{ LANDQ}$$

where:

P is the Kendrick index of Gross Factor Productivity for the 1870 to 1925 period. INV is an invention index defined as:

$$\text{INV} = \sum_i \sum_j E_{ij} \, CP_{ij} / \sum_i \sum_j E_{ij}$$

where CP_{ij} is the cumulated stock of patents (lagged ten years) in technology field i, originating in region j.[1] E_{ij} is the "related" economic activity associated with the technology field and region. This index is summarized in Table 11. RES is a research based knowledge stock. It is the cumulated research expenditures in constant dollars from 1850 to date. A time lag is built into the construction of this variable. This time lag structure was indirectly "estimated" by constructing several alternative stocks with differing time lags between research expenditure and full

[1]This presumes an average lag of ten years between invention and farm productivity import. This is roughly the same as estimated for the time lag for research.

Table 11. Inventive Activity Summary

Period	Cumulated patents relevant to agriculture	Activity weighted cumulated patents index, INV
1850-59	1,944	73
1860-69	6,666	261
1870-79	11,607	426
1880-89	17,703	469
1890-99	22,255	461
1900-09	27,117	445
1910-19	32,007	477
1920-29	35,292	487
1930-39	38,014	467

research impact (3, 8, and 18 years) and differing rates of knowledge depreciation (0, .5, and 1 percent). The stock variable which supposed a time lag of 18 years between expenditure and maximum results (with weights rising linearly) and a depreciation rate of 1 percent per year minimized the residual sum of squares and was taken as the best estimate of the time shape.

LANDQ is a land quality index. It was constructed as follows: First the average yield levels of wheat, oats, and corn for each state for the decades 1880, 1890, 1900, and 1910 were regressed on the percent change in "improved" acreage in the prior ten year period, the percent change in improved acreage in the prior 10 to 20 year period, and the percent change in improved acreage in the prior 20-30 year period. The ratios of improved land to total land under cultivation in the 10, 20, and 30 prior were also included as dependent variables. These regressions, which are reported in Table 12, allowed estimates of soil exhaustion factors. A negative coefficient on prior rates and ratios indicates that rapid prior expansion lowers current yields through soil exhaustion phenomena. Soil exhaustion appeared to be significant in the Eastern and Western states but not in the Middle states.

Second, a standardized land series was constructed by adjusting for yield level changes and for soil exhaustion. The yield level adjustment takes into account the relative expansion of acreage in high and low yield states. If acreage expanded more rapidly in high than in low yielding regions the yield adjustment treated this as a rise in land quality. The soil exhaustion adjustment was based on prior expansion in improved acerage and the regression coefficients. LANDQ was defined then as the ratio of the yield and exhaustion adjusted land series to the land series used in the TFP calculation.

Table 12. Soil Exhaustion Regression Analysis

Dependent Variable: Weighted average yield per acre of wheat, corn and oats (where weights are shares of value crops).

Independent variables	Eastern States	Middle States	Western States
Percent change in improved land in prior to	-3.1 (1.0)	7.5 (1.0)	- .4 (.1)
Percent change in improved land 10-20 prior years	.5 (.2)	14.1 (2.6)	5.5 (1.3)
Percent change in improved land 20-30 years prior	.3 (.1)	.05 (.1)	8.1 (1.5)
Ratio: Improved to total land 10 years prior	-9.5 (.8)	-2.9 (.3)	-5.9 (1.5)
Ratio: Improved to total land 20 years prior	2.1 (.2)	7.6 (1.0)	-11.6 (3.4)
Ratio: Improved to total land 30 years prior	-1.1 (.1)	4.6 (.5)	-7.7 (.8)
R^2	.97	.92	.89

Regressions include state dummy variables. Observations are for 1880, 1890, 1900 and 1910.

The regression results obtained for this period are reported in Table 13. They quite clearly refute the earlier conclusion that productivity change for this period is unrelated to inventive activity and to research investment. They also refute the hypothesis that soil exhaustion was a major determinant of productivity change.

The agricultural research variable is highly significant and indicates that the early experiment station system was indeed productive. A rough calculation of the marginal product of an addition to the research stock can be made. A one dollar addition to the stock increases the output index (holding inputs constant) by .00000009 units or roughly by $12.50 dollars in 1958 dollars. This implies an internal rate of return of approximately 65 percent.

It should be noted that the period of relatively slow productivity growth beginning around 1900 is included in this analysis. It is also interesting to note that the activity weighted patents index reported in Table 11. shows little growth after 1889 partly because overall inventive activity slowed down during the period and partly because of the relatively more rapid growth of economic activities and regions with low levels of inventive activities.

Next, consider the 1926-1950 period, a period when substantial biological invention was forthcoming. Hybrid corn was the major case although substantial improvements in animal health and nutrition practices and other crop varietal improvements were also being made. It was also a period of

Table 13. Regression Analysis: Productivity Decomposition 1868-1926

Dependent Variable: Kendrick index of Total Factor Productivity
40 annual observations

	Regression #1		Regression #2	
Independent variables	OLS	GLS	OLS	GLS
INV. (invention Index)	.526 (3.45)	.493 (3.29)	.521 (3.29)	.449 (2.90)
RES (research stock)	.901(E-7) (6.38)	.831(E-7) (5.71)	.913(E-7) (5.31)	.883(E-7) (5.31)
LandQ (land quality factor			3.037 (.13)	20.26 (.82)
Constant	52.80	54.79	45.29	45.59
R^2	.670	.605	.671	.601
R^2 (ADJ)	.644	.573	.634	.556

"t" ratios in parentheses.

transition from animal power to mechanical power, in field work. This transition produced a new series of invention by the farm machinery industry which is now a mature industry.

For this period we have total factor productivity series of the CLG type for four regions. The analysis uses these CLG indexes as independnet variables in a cross-section time-series analysis. Two alternative functional forms are utilized:

$$TFP = A\,(INV)^{\alpha_1}\,(TRES)^{\alpha_2 + \alpha_3(SRES)}\,e^{\alpha_4 W} + \text{Region and time effects}$$

$$TFP = B\,(TRES)^{\beta_1 + \beta_2(SRES) + \beta_3(INV)}\,e^{\beta_4 W} + \text{Region and time effects}$$

where:

TFP is the CLG index of total factor productivity.

INV Is the invention index defined earlier.

TRES is a stock of applied or technology oriented research for the and time period.

SRES is a stock of related scientific research for the region and time period.

The variable W is a national weather index constructed by Stallings (1957). It was not possible to construct a regional index.

In the first specification, TRES and SRES "interact" such that the productivity of technology research depends on the stock of scientific research. Scientific research is productive only through its effect on the productivity of applied research. In the second specification, invention is interacted with applied research in a similar way.

The variables, TRES and SRES were subjected to an approximate non-linear least squares procedure to estimate the time-shape. The applied research variable minimized the residual sum of squares when it took the form of a lag structure with rising weights for five years , constant weights for 6 years and declining weights for 11 years.

The SRES variable had weights rising for 15 years, constant for 20 years and declining for 25 years. Thus the average time lag between investment and impact was seven years for applied research and 20 years for scientific research by these estimates.

Table 14. reports results which indicate that invention, applied research, and related scientific research were all important determinants of productivity change for this period.

The specifications reported in Table 14 include time dummy variables which indicate that the invention and research variables which indicate that the invention and research variables account for only a part of the observed rise in total factor productivity over the period. Specification 1 associates approximately one-third of the observed (30 percent) growth in total

Table 14. -Regression Analysis: Determinants of Productivity: U.S. Agriculture 1927-1950 Regional Data

Dependent Variable: Logarithm Productivity Index (TFP)

Independent Variables	Regression (1)	Regression (2)
LN (INV)	1.40 (5.73)	
LN (TRES)	.106 (2.84)	-.106 (3.74)
LN (TRES * SRES)	.0000053 (1.57)	.0000082 (2.32)
LN (TRES * INV)		.00183 (4.29)
T1 (1927-1934)	-.108	-.197
T2 (1935-1941)	-.029	-.084
T3 (1942-1945)	-.038	-.053
Weather Index	.00037 (6.65)	.00035 (6.02)
Regional Dummy Variables	inc.	inc.
R^2	.582	.558
R^2(adj)	.528	.503

factor productivity growth from period 1 to period 4 (1946-1950) to the passage of time. Specification 2, which is inferior on statistical grounds, attributes almost two-thirds of the growth to time.[1]

Regression (1) implies that an added on thousand dollar investment in applied agricultural research would have contributed an additional stream of production rising to a value of approximately 11,400 dollars after 5 years, of this, $6,350 would be realized in the form of added product by producers in the state where the investment was made. The remainder would be realized by producers in other states with similar geo-climate regions. An added thousand dollars invested in related scientific research would result in added production rising to a value of $53,000 after 15 years. Of this, approximately one-third would be realized in the state making the investment.

[1] A Nerlove-Balaestra generalized least squares procedure was also applied to these data. The results were essentially unchanged.

V. Productivity Decomposition, 1948-1971

This section reports a decomposition analysis of the state total factor productivity data for the period 1948-71. A two stage process is utilized. First an analysis of the combined "time-shape" and "contiguity pattern" of applied agricultural research is undertaken. Secondly a more complete decomposition analysis is reported.

Time-Shape and Contiguity

The procedure utilized for the time shape--contiguity analysis is a partial correlation scanning procedure of a general research variable:

$$A\ (a,b,c,) + \alpha\ SA\ (a,b,c) + \beta\ RA(a,b,c)$$

A is the within-state applied research stock, SA the stock in similar sub-regions outside the state and RA the stock in similar regions (which includes the sub-regions) outside the state. The parameters a,b,c, refer to alternative time shapes, a is the time period of rising linear weights, b, the time period of constant weights, and c the period of declining linear weights. The parameters α and β are contiguity parameters. They measure the extent to which research in contiguous or similar regions is contributing to state productivity growth.

Table 15.reports the results of a partial correlation scanning analysis across varying time shape and contiguity parameters. The analysis is undertaken for Northern states (Northeast, Corn Belt and Lake States regions), Southern states (Appalachian, South East and Delta regions) and Western states (Northern Plains, Southern Plains, Mountain and Pacific regions). The highest partial correlation for the Northern states is for the variable

Table 15. Time Shape and Contiguity Estimates: U.S. Agriculture 1948-1971

Partial Correlations Coefficients Controlling for Sealing Parameter, Business Cycles and Education.

Northern States	$\alpha,\beta=0$	$\alpha=.25$	$\alpha=.5$	$\alpha=.75$	$\alpha=1$	$\beta=.25$	$\beta=.5$	$\beta=.75$	$\beta=1$
R (3, 4, 7)	.135	.324	.304	.284	.273	.224	.224	.219	.218
R (3, 4, 11)	.145	.321	.323	.303	.289	.225	.224	.222	.220
R (5, 6, 11)	.165	.339	.338	.314	.297	.234	.230	.226	.223
R (5, 6, 15)	.161	.323	.343	.325	.308	.229	.228	.227	.224
R (7, 8, 15)	.167	.326	.346	.327	.309	.234	.234	.231	.228
R (7, 8, 19)	.158	.304	.342	.331	.3.5	.227	.231	.239	.227
R (7, 8, 25)	.145	.277	.286	.266	.249	.278	.219	.218	.216
R (11, 12, 25)	.140	.274	.282	.267	.246	.273	.218	.217	.215
R (15, 20, 25)	.122	.221	.222	.202	.187	.221	.206	.206	.205
Southern States									
R (3, 4, 7)	.456	.487	.481	.474	.468	.266	.184	.107	.078
R (3, 4, 11)	.451	.484	.483	.478	.473	.395	.203	.143	.107
R (5, 6, 11)	.460	.490	.488	.482	.476	.310	.207	.146	.109
R (5, 6, 15)	.451	.483	.485	.482	.478	.328	.232	.171	.131
R (7, 8, 15)	.451	.483	.485	.482	.478	.329	.233	.172	.133
R (7, 8, 19)	.442	.475	.481	.480	.477	.337	.250	.190	.149
R (7, 8, 25)	.429	.465	.470	.469	.466	.464	.216	.157	.118
R (11, 12, 25)	.436	.471	.475	.471	.469	.471	.215	.155	.116
R (15, 20, 25)	.418	.452	.459	.458	.456	.452	.210	.151	.112
Western States									
R (3 4, 7)	.224	.234	.201	.171	.150	.268	.240	.203	.101
R (3 4, 11)	.237	.252	.230	.203	.181	.293	.253	.225	.208
R (5, 6, 11)	.248	.261	.238	.203	.186	.302	.258	.230	.212
R (5, 6, 15)	.253	.268	.254	.230	.207	.318	.278	.248	.226
R (7, 8, 15)	.257	.273	.257	.232	.208	.328	.280	.260	.228
R (7, 8, 19)	.258	.275	.266	.244	.222	.323	.292	.240	.238
R (7, 8, 25)	.295	.272	.254	.225	.199	.271	.286	.254	.233
R (11, 12, 25)	.259	.272	.251	.221	.193	.272	.283	.250	.229
R (15, 20, 25)	.257	.267	.245	.213	.184	.267	.295	.261	.240

constructed with a seven year lag from investment to peak effect, a further 8 year constant lag and a 15 year period of declining weights. The contiguity weight is half of the similar sub-regions outside the state, and the research variable is deflated by the number of commodities and sub-regions in the state. (See Appendix 2.)

The estimated time shape weights for the Southern states was 5, 6, 11, and the contiguity weight was .25 of the similar sub-regions. Note that very little difference exists between the Northern and Southern regions however. The Western region shows the same pattern in the sub-regions weight as the other regions. However, the contiguity weight is .25 of similar regions (which include the sub-regions) indicating a somewhat broader range of technology transferability.[1]

[1] An approximate standard error for the estimated average lag can be derived from the test for the significance of an additional variable in an equation. (See Theil, Economic Forecasts and Policy, [N. Y.: J. Wiley, 1964], p. 177 for a discussion of this test.) Consider the two equations:

$$B = a_1 + b_1 X_1 + b_2 X_2$$

$$P = a_1 + b_1 X_1 + b_3 X_3.$$

Let X_2 and X_3 be alternative research variables with differing lengths of lag. The variable X_3 can be conceptualized as being equal to X_2 plus a term which measures the difference between them. Let $b_3X_3 = b_2 X_2 + b_4 X_4$. After substitution, the hypothesis that $b_4 = 0$ can be tested even though we have no direct observation on X_4. The term X_4 will add to the explained variance of the dependent variable as long as the length of the lag is shorter than the "true" lag, because the positive terms included in it from the larger weights on more distant time periods will explain more than the explanation lost from the negative terms coming from lower weights on the more recent time periods.

We can thus compare a shorter or longer research lag variable with the estimated (highest R^2) research lag. The test statistic

$$\frac{\dfrac{\Delta \text{ Regression Sum of Squares}}{K-H}}{\dfrac{\text{Error Sum of Squares}}{T-K-1}}$$

is distributed as F^{K-H}_{t-k-1}. In this case, K is the number of independent variables, H is the number of additional variables, and T is the number of observations. We are not really adding a variable but comparing a research lag of n years with one of n+ z years, which should be the approximate equivalent.

Applying this test to the data in Table 15., we find that the estimated lag variables differ from the shortest lags, R(3,4,7) and the longest lags R(15,20,25) for all weights α, β in a highly significant fashion. The F values for this test ranged from 13.6 to more than 20, sufficient to easily reject the hypothese of no difference.

Table 16 reports the results of Productivity decomposition analysis for U.S. agriculture for the 1948-71 period. The general specification is:

$$TFP = C(ED)^{a_1}\,(EXT)^{a_2+a_3(ED)}\,AR^{\alpha_4+\alpha_5(BR)+\alpha_6(EXT)}\,EXP^{\alpha_7 PL+\alpha_8 BC+\text{Region--Time Dummies}}$$

where

<u>TFP</u> is the total factor productivity index (see Appendix 1)

<u>ED</u> is an index of years of school completed by farm operators. It is constructed from Census data and utilizes weights developed in a study by Welch (1966).

EXTECON is a composite variable based on extension expenditure plus expenditures on production-oriented economic (farm management) and applied engineering research (see Table 7)[1]

<u>AR</u> is the applied research stock variable. It is more fully defined in Appendix 2.

<u>BR</u> is an index of "basic" research constructed with time shape (a,b,c) weights of (11,12,25 α=.25) for Southern states, (15,20,25 α=.5) for Northern states and (15,20,25 β=.5) for Western states. These weights were estimated in a partial correlation scanning analysis. BR is undeflated.

<u>PL</u> is the scaling factor for states. (See Table 1, page 13 for the regional factors).

<u>BC</u> is a business cycle index designed to capture the productivity effects of the business cycle. It is constructed as the ratio of two moving averages of real farm income. Productivity gains are expected to be higher in the "trough" phases of the business cycle than in the "peak" phases because of adjustment pressures. See Landau (1973) for a fuller development of this point.

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[1] The EXTECON variable has geometrically declining time-shape weights. That is, 50 percent of the total impact is expected in the first year, 25 percent of the total in the second year, 12.5 in the third etc.

The specifications reported in Table 16 demonstrate the effect of adding the region-time dummy variables and of estimating separate coefficents for the three major regions of the country for the research variable. Specification 1 is included to show how much of the change in total factor productivity is associated with the region and time dummy variables. It also allows a relatively simple comparison of the proportion of the growth in total factor productivity change "explained" by the research and related variables.

The second specification is included to show the effects of the decomposition variables and to enable the reader to assess the effect of adding the region-time dummy variables in specification 3. An experiment in which a simple time trend variable replaced to region-time dummies was conducted. The results were essentially the same as those obtained for specification 3.

Specification 3 provides the basic decomposition results. The negative coefficients for the extension variable and the extension-education interaction variable do not mean that the marginal product of extension on education is negative. The negative extension-education effect is to be expected. It shows that extension or adult education is a substitute for formal schooling terms of its effect on farmer efficiency. In states with high levels of farmer schooling, extension activities have a smaller impact. The positive (and highly significant) research-extension interaction term shows these activities to be complements. We would expect extension to be more productive, the higher the level of research activity in a given state. The positive applied research--scientific research term also indicates that higher levels of scientific research increase the productivity of applied research. Thus, scientific research in the agricultural experiment

Table 16 Productivity Decomposition: U.S. Agriculture 1948-71

Dependent variable: LN (TFP)

Independent Variables	(1)	(2)	(3)	(4)	(5)
constant	4.69	4.25	4.73	4.77	4.86
LN (AR)		.04237	.0174		
		(.00997)	(.0085)		
LN (AR) South				.03309	.03407
				(.00856)	(.00086)
LN (AR) North				.01187	.00991
				(.00848)	(.00861)
LN (AR) West				.01874	.01882
				(.00887)	(.00903)
LN (ED)		.3143	.1770	.3540	.3731
		(.0404)	(.0362)	(.0426)	(.0419)
LN (EXTECON)		-.000276	-.0388	-.0394	-.0514
		(.01176)	(.0099)	(.0097)	(.0104)
LN (EXTECON)*ED		-.01223	-.00659	-.0116	-.0120
		(.00242)	(.00206)	(.0021)	(.0021)
LN (AR)*EXTECON		.1314 D-5	.1730 D-5	.1821 D-5	.1962 D-5
		(.0260 D-5)	(.0230 D-5)	(.0230 D-5)	(.0227 D-5)
Ln (AR)*BR		.2054 D-7	.0171 D-6	.2061 D-6	.2166 D-6
		(.8300 D-7)	(.0737 D-6)	(.0710 D-6)	(.0705 D-6)
LN (AR*GRAD)					.000247
					(.000071)
LN (AR*SCALE)					-.543 D-7
					(.600 D-7)
Productivity Scaling Factor (PL)		-.000136	-.00014	-.00016	-.00016
		(.000030)	(.000034)	(.00003)	(.00003)
Business Cycle Index (BC)		.34509	.2486	.2297	.2237
		(.0200)	(.0180)	(.0176)	(.0176)
1957-63 South Dummy	.165		.158	.076	.075
1957-63 North Dummy	.118		.074	.102	.102
1957-63 West Dummy	.156		.136	.113	.112
1964-71 South Dummy	.308		.246	.136	.132
1964-71 North Dummy	.246		.115	.128	.124
1964-71 West Dummy	.286		.192	.152	.149
R^2	.484	.413	.618	.573	.651
R^2 (ADJ)	.481	.409	.613	.569	.646

stations is productive through its impact on the productivity of applied research.

The fourth specification estimates seperate coefficients for the applied research (AR) variable for the three major regions of the study; South, North, and West. This extension shows that regional differences have existed. In particular, the southern states have realized faster rates of productivity growth and it appears that at least part of this is due to the research system. Note that in specification 3 which imposed a single AR coefficient, the time variable in the South accounts for almost 80 percent of the change in total factor productivity from the beginning of the period until the ending period. In specification 4 this proporation falls to less than 50 percent. In all three regions the variables account for 50 per cent or less of the "explanation" of productivity growth in specification 4.

The fourth specification extends the analysis further in an attempt to explore whether experiment station characteristics have an effect on the productivity of agricultural research. Two variables, a measure of the scale of the main experiment station (measured as number of scientists) and a measure of the size of graduate programs associated with the main experiment station (number of Ph.D's graduated annually in the (1950's) were interacted with the applied research variable. The results suggest that the size of the associated graduate program positively effects research productivity, but that scale *per se* does not.

The productivity scaling variable has the expected sign and can be interpreted as an indicator of "economic slack" in that states with relatively low scaling parameters have more potential for productivity growth. They have more "catching up" to do and catching up requires fewer resources than

than leading requires. The business cycle variable also indicates that as farm income falls in a cycle, total factor productivity rises. As the farm income cycle reaches a boom phase, total factor productivity slows down.

These results should be interpreted in the light of a certain amount of experimentation with the specifications. Alternative specifications were utilized in the study. Standard errors are reported as statistical indicators and simplistic applications of standard tests is not fully justified. On the whole, however, most of the results are quite robust with respect to changes in specification. In particular, a linear specification paralleling the log-linear specification yielded virtually identical results. Similarly, utilizing simple Time Trend variables in lieu of the Time-Region dummy variables did not alter the results appreciably. It should be noted that given the time-shape of the research effect, estimating such effects in the presence of timevariables constitutes a very strong test of the model.[1]

It is possible that some simultaneity exists in the reported results If research investment responds to total factor productivity, for example, a bias could be created. Recent work by Huffman and Miranowski (1978)

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[1]The extension variable was the only variable highly sensitive to specification. When deflated by a number of farms in the state, its marginal product was consistently negative. When deflated by the number of commodity-sub-regions as with the research variables the results were as reported here. It is difficult to say *a priori* which is the most proper deflation. If communication costs with individual farmers are of great importance, extension effort per farmer should matter. If not, the specification utilized here is most appropriate.

as well as earlier work by Peterson indicate that current and expected future farm and non-farm income are major determinants of current investment in research. Our specification relates past investment in research to current productivity charge. Since productivity change and farm income are not highly related it is unlikely that a serious bias exists. An experiment with a two stage least squares specification failed to alter the basic results.[1]

The regression results in Table 16 do allow several calculations of interest for policy. Table 17 reports the computed increase in the value of farm production which would have resulted had the relevant research and extension variables been increased by $1,000.

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[1]Excluded exogenous variables were:

- BC', an alternative business cycle index.
- n59, the number of farms in 1959.
- n69, the number of farms in 1969.
- CDC, the weighted number of crop commodities produced in the state.
- LDC, the weighted number of livestock commodities produced in the state.
- RGC, the number of crop geo-climate regions in the state.
- RGL, the number of livestock geo-climate regions in the state.

The 2SLS results accentuated the scientific research-applied research interaction term.

Table 17.

Computed Marginal Contribution of Changes in Research, Extension and Education Stocks.

1948-1971

Change in Farm Production due to:		Appropriated by State	Transferred to other states	Total
One Year of Primary Schooling				
Spec. (3)		$ 120		$ 120
Spec. (4)		260		260
$1,000 added to Extension applied Economics Stock				
Spec. (3)		2,947		2,947
Spec. (4)		2,173		2,173
$1,000 added to Scientific Research Stock				
Spec. (3)		755	$1,585	2,330
Spec. (4)		1,450	3,050	4,500
$1,000 added to Applied Research Stock				
Spec. (3)		6,820	5,180	12,000
Spec. (4)	South	14,100	7,100	21,000
	North	5,070	6,530	11,600
	West	8,270	3,930	12,200

Summary

This paper reports estimates of the impact of investment in agricultural research on farm production for three historical periods, 1868-1925, 1927-1950, and 1948-1971. It also provides an estimate of the impact of inventive activity for the first two periods. The contribution of extension and schooling investment is considered for the latter period. The results reported have been expressed in terms of added farm production associated with an increment to a research, extension or schooling "stock". In this concluding section these estimates will be summarized and expressed in terms of "internal rates of return". The paper has not addressed the matter of the distribution of the gains between producers and consumers.

Figure 5 summarizes the estimates obtained in terms of both the level and the time-shape. Internal rates of return are also reported (These rates are based on a time lag of two full years from investment in research before the first gains are realized). For purposes of comparison we can note that a research project generating a stream of benefits with the same time-shape as those reported for agricultural research in 1948-71 and rising to a level of only 35 cents per year would have yielded a rate of return of 20 percent. Bearing in mind that these are estimates and hence subject to error, it is readily obvious that they are comparatively high estimates.

It has not been possible to achieve complete comparability in terms of data and methodology for the three historical periods examined. Nonetheless, the results are probably comparable enough to indicate that investment in agricultural research has been highly productive over the entire period. Obviously, the nature of the research system has changed markedly over time. The early experiment station system appears to have productively exploited the potential for relatively simple activities. Much of the work

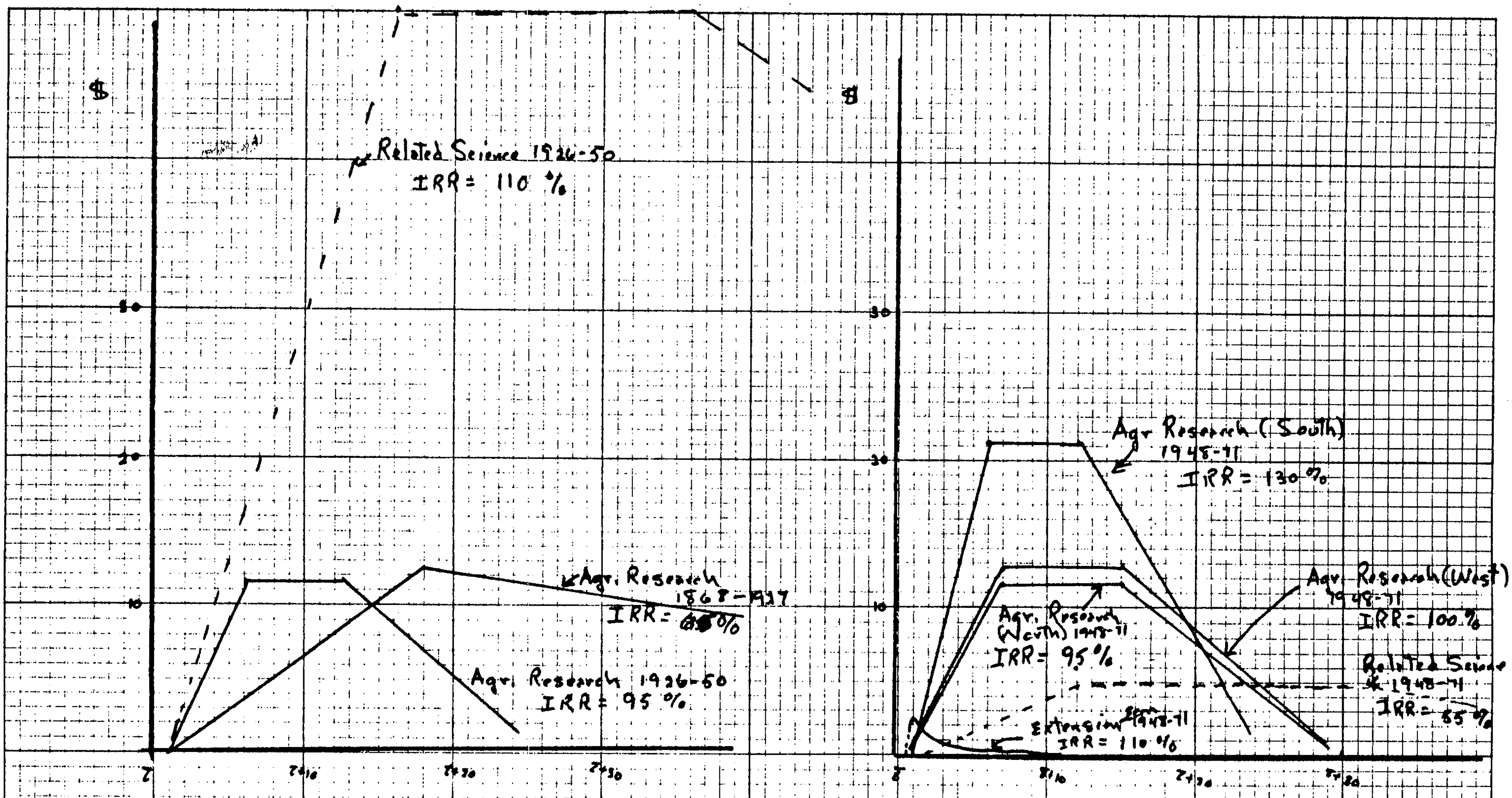

Figure 5. Estimated Marginal Agricultural Products: Research and Extension Investments

in those stations served to facilitate the transfer and adoption of technology produced by farmers and farm machinery manufacturors. This study has identified the related scientific research of the 1927-50 period as having extremely high productivity. The experiment stations which had invested most heavily in establishing a science base in the early decades of the twentieth century were best able to produce the new biologically based technology which became important during this period.

The most recent period appears to be one where the experiment stations in the South achieved a substantial amount of catching up. The entire system of applied and scientific research and extension was highly productive during the period. The slow down in productivity gains which characterized the late 1960's was at least in part due to the cessation of growth in investment in productivity producing activities.

This study is one of the first to obtain an estimate of the productivity of the agricultural extension service. The results should be interpreted with caution given their sensitivity to the specification utilized. The specification in which applied farm management research and applied agricultural engineering research was combined with extension activity yielded results consistant with *a priori* expectations. This combination of activities is designed, not to produce new technology, but to facilitate the efficient utilization of existing technology. The results indicate that this activity is productive when other applied research is producing a flow of new technology.

APPENDIX I

A-1 Methodology of Construction of CLG Indexes

For all pairs of years t and t-1 the change in productivity is calculated as the change in an <u>output</u> index relative to a change in an <u>input</u> index. That is:

A1 $$P(t)/P(t-1) = Q(t)/Q(t-1)/I(t)/I(t-1)$$

The output indexes were defined as:

A2 $$Q(t) = \sum_{i=1}^{12} P_{it}Q_{it} \Big/ \sum_{i=1}^{12} P_{it}(P_{i(t-1)}Q_{i(t-1)}) \Big/ \sum_{i-1}^{12} P_{i(t-1)}Q_{i(t-1)}$$

A3 $$Q(t-1) = \sum_{i=1}^{12} P_{i(t-1)}Q_{i(t-1)} \Big/ \sum_{i=1}^{12} P_{i(t-1)}(P_{i(t-1)}Q_{i(t-1)}) \Big/ \sum_{i=1}^{12} P_{i(t-1)}Q_{i(t-1)}$$

The expression Q(t)/Q(t-1) can be expressed as:

A4 $$\frac{R(t)}{R(t-1)} \cdot \frac{\sum_{i=1}^{12} P_{it}\, S_{i(t-1)}}{\sum_{i=1}^{12} P_{i(t-1)}S_{i(t-1)}}$$

Which is, the ratio of the change in total revenue between two years, "deflated" by a price index, which is a product share weighted price index. The product shares are from the previous year. In the case of the products used in computing the state CLG indexes, 12 product categories were used. This price index was computed separately for each state. National prices were used, but state product shares were used to compute them.

The input indexes were defined as:

A5 $$I(t) = \prod_{j=1}^{9} I_{jt}^{C_{j(t-1)}}$$

A6 $$I(t-1) = \prod_{j=1}^{9} I_{j(t-1)}^{C_{j(t-1)}}$$

A7 $$C_{j(t-1)} = w_{j(t-1)} I_{j(t-1)} / \sum_{j=1}^{9} w_{j(t-1)} I_{j(t-1)}$$

The change in the input index is thus a geometrical "cost" share weighted ratio of input quantities in these two periods. There are 9 input categories. Input quantities are expressed in annual cost terms and deflated by the appropriate price index. State cost shares differ, both because factor mixes differ by state, and because input prices (w_j) differ by state. State price indexes for both labor and land were used in the construction.

The change in productivity was constructed from year 1 to year 2, year 2 to year 3 etc., and these changes were simply accumulated to construct the TFP series. The "linkage" between years comes from the fact that period (t-1) weights are used in computing the change.

A-2 Product data

Twelve product categories were utilized: meat products, poultry and eggs, dairy products, miscellaneous livestock products, food grains, feed grains and hay, cotton, tobacco, oil bearing crops, vegetables, fruits and nuts, and miscellaneous crop products. Expenditure data for each category by state is taken from Farm Income, State Estimates USDA, Economic Research Service, Farm Income Situation - 214 Supplement. Price indexs for each product category are taken from Prices Received by Farmers from Agricultural Statistics. The deflator for fruit and nuts is simply called "fruits" in the Prices Received data. That for meat products is "meat animals." The "all crops" deflator is used for miscellaneous crop products. The livestock and livestock products deflator is used for the miscellaneous crop product category.

A-3 Input data

Nine input categories are used. They are labor, land services, depreciation of capital stock, machinery services, seeds, feeds purchased, livestock purchased, fertilizer, and miscellaneous operating expenses. Expenditures on all factors except land and labor, which we treat separately below, were taken from the USDA publication, Farm Income Situation. The price deflators utilized in the index for the last seven input categories are taken from Agricultural Statistics. Machinery services are deflated by the price index called "motor supplies." Depreciation is deflated by the simple average of the "farm machinery," and "motor vehicle" indexes. Miscellaneous operating expenses are deflated by the index "all commodities bought for use in production."

The land input variable is a difficult input to deal with because land prices are especially sensitive to productivity change. Basically, the proper price of land is an annual rental price, and land quantities should be measured in terms of standardized quality units. Both issues present problems. The best data on land prices are not rental rates, but transaction prices which are not necessarily proportional to rental rates. Also, land varies tremendously in quality and some attempt to account for these factors must be made. The definition of land quantity, L, is:

A8 $$L = H + EI*I + EP*P$$

In this expression H is harvested acreage, I is irrigated acreage and P is pasture acreage. The conversion factors, EI and EP, convert irrigated and pasture acreage into equivalent crop acreage for each state. They are taken from a study by Hoover [1962] and are based on crop-reporting district data for 1941. Harvested acreage is available in Agricultural Statistics on an annual basis. Irrigated acreage and pasture acreage are interpolated between Agricultural Census years.

L is thus quality adjusted for the ratio of irrigated and pasture land. The annual price of L for each state was calculated as:

A9 $$R = P * V * CR$$

Where P is the national price index of farm real estate (base = 1949). V is the price per harvested acre by state in 1949, the base year. CR is the estimated ratio of cash rent to the value of land on farms rented for cash in each state. V is calculated from the 1949 Census of Agriculture. P and R are taken from Farm Real Estate Market Developments. Additional data provided by W. Schofield of the USDA were also used. The ratio of cash rent to land values was averaged over several years to obtain a reasonably stable conversation factor.

The cost of labor is estimated as the sum of expenditures on hired labor--as reported by the USDA--and estimated cost of family labor. The cost of family labor was estimated as follows:

A10 EFL = (THLR - IHHL) * SFLS * WGE * 1.15

where ELF is the cost of family labor for the state in the given year. THLR is the number of required hours of labor for the production region as estimated annually by the USDA. IHHL is the number of hours of hired labor implicit in the figures on expenditures for hired labor. These implicit hours are found for each state in the region by dividing the expenditure on hired labor by the composite wage rate. This procedure should be superior to counting either hours of hired labor or numbers of hired laborers. It should pick up the lower wages paid women and child labor and the hours equivalent of the labor supplied by piece workers. The sum of these implicit hours of hired labor for all states in the region is subtracted from the THLR to get the number of hours of family labor required in the region. These hours are allocated to the various states in the production region by their shares in total number of family laborers for the region SFLS. This gives the number of hours of family labor required for each state. This figure is multiplied by the "composite wage" or weighted average of wages per hour of monthly, weekly, daily, and hourly farm labor for the state as estimated annually by the USDA (at least through 1971). Since family labor on average has more human capital, its alternative cost or potential non-farm earnings are higher. 1.15 is the correction for this factor based on the study "Parity Returns and the Position of Farmers." The 1.15 figure allows for the composition of family labor between operator and other family labor.

Deflated or "real labor input" is found by dividing the sum of expenditures for hired labor and family labor by the composite wage rate. This wage rate is the average hourly wage over the year for each state and was obtained from Farm Labor, USDA.

A-4 Regional Indexes

For the period 1949-1971, state data were aggregated to regions. Output indexes were aggregated by the state's share in regional output. Input indexes by regional input shares.

Prior to 1949, the regional indexes are based on data from MacEachern [1962]. In his study, quantity indexes of purchased inputs, buildings, non-real estate capital and labor were constructed. Also a deflated output series is reported by region. In computing factor shares, he was forced to compute one share as a "residual." On the basis of data available after 1949, the shares in which labor was treated as a residual were adjudged to be superior and were used to construct the productivity indexes reported here.

Appendix II

The Research Variable

The U.S. is partitioned into 16 producing regions and each region is further partitioned into two to six sub-regions. Our index of research impact is a simple variant of the index described above where pervasiveness is based upon contiguity, except that reference is either to "similar" regions or sub-regions.

Data for research expenditures are of course not provided for either regions or sub-regions but are state-based instead. Our approach is to pro-rate research expenditures among the sub-regions within each state, using the geographic distribution of revenues as a basis. Data are available to permit rather straightforward (if often somewhat arbitrary) allocations of research expenditures to 24 commodity based categories. These include five classes that are allocated to research on individual kinds of livestock production (beef, dairy, hogs, poultry, and sheep) and a sixth category of general livestock research that could not be allocated to the specified classes and is therefore dubbed as "basic," Similarly, there are 16 specific categories of crop research that can be allocated to individual commodities[1] plus one category that could be allocated to field crops but not to specific commodities and another that could be attributed only to general research on crop production. These are therefore "basic" crop research.

The distribution of commodity revenues among sub-regions of each state is calculated from data provided in

and the distribution of research is assumed to be the same. That is, if a particular sub-region of Iowa accounts for one-third of Iowa's corn production,

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[1]They include: barley, corn and sorghum, cotton, flax, forestry and forest products, fruits, hay, oats, peanuts, potatoes, rice, soybeans, sugarbeets and sugarcane, tobacco, vegetables, and wheat.

one-third of Iowa's expenditures on corn research are allocated to that sub-region. This procedure is followed in allocating each of the applied categories of expenditure and basic research which are pro-rated according to the average for the specific commodities. These components are then summed to obtain state-specific sub-region and region aggregates. The next step entails construction of the "borrowable stock" of research available to producers in a given state. If a state (K) contains a sub-region part (i) then research expenditures allocated to similar sub-regions of other states are aggregated. If this sub-region part accounts for fraction F_{iK} of all crop revenue within the state, then the total expense for similar sub-regions is given weight F_{iK} as these numbers are aggregated over the sub-regions that are part of the state.

Let e_{i_j} refer to crop research expenditures in geo-climatic sub-region type i of state j. Similar sub-region expenditures for state k are

$$e'_{iK} = \sum_{j \neq K} e_{i_j}$$

and the borrowable stock, R', available to state k is

$$R'_K = \sum_{i \epsilon K} F_{i_K} E'_{i_K}$$

An identical procedure is followed for livestock research and for similar regions.

The research index used in estimation is of the form

$$IR_K = \phi(R_K + \theta R'_K)$$

where R'_K indicates the stock of research in similar regions or sub-regions outside the state and θ, the weight factor, is an index of pervasiveness which is to be estimated. R_K refers to endigenous research expenditures for the state and ϕ is a congruency index that signals the degree of agreement between the distribution of farm receipts and the allocation of research funds.

Operationally defined. It is:

$$\phi = (1 - 1/2 \sum_i [c_i - r_i]^2)f + (1 - f) \tag{3}$$

where c_i refers to the fraction of crop (livestock) revenue obtained from the i^{th} commodity, r_i is the fraction of applied crop (livestock) research in the state allocated to that commodity, and f is the share of applied in total research. This congruency index is unity if the revenue and research expenditure distributions are identical and falls to the share of basic in total research if all applied research is devoted to commodities not produced within the state.

This index ranged between .99 in Illinois and .25 in Washington for crop research and for livestock reached a low of .77 in New York and a high of .99 in New Jersey. The unweighted mean for the 48 coterminous U.S. states if .57 for crop research and .93 for livestock.

Notice that research expenditures are not deflated by number of farms. The problem of identifying units for measuring knowledge is very real and is not addressed here except with respect to geographic pervasiveness. There is a real sense in which knowledge is scale free because as one user acquires information the stock available to others is not diminished. In this sense it does not seem reasonable to deflate by number of users. On the other hand, dissemination of the research product may be easier if the number of potential users is small and deflation by number of farms at least captures some elements of this effect.

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