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TWO BLADES OF GRASS:

RESEARCH FOR U.S. AGRICULTURE

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Abstract

This paper reports an analysis of determinants of changes in Total Factor Productivity (TFP) in U.S. agriculture over the 1950-1982 period. It reports separate measures of growth for the crop and livestock producing sectors. A statistical analysis relates TFP growth in each sector to past investments in public sector agricultural research and extension programs, private sector R&D, schooling of farmers, geo-climate factors, off farm employment opportunities, and farm policy regimes.

The study finds that TFP growth has been highest in the crop sector and that the combined crop and livestock sectors produced TFP growth rates well above these realized in the economy at large. Public sector agricultural research contributed to TFP growth in both sectors. A distinction is made between pre-technology science research and applied research and the study showed that those state research systems with highest investments in pre-technology science research contributed most to TFP growth. Investment in agricultural extension and farmer schooling also contributed to TFP growth. The study also showed that R&D in private sector firms supplying the sector contributed to TFP growth in the agricultural sector.

Two Blades of Grass: Research for U.S. Agriculture

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> And, he gave it for his Opinion; that whoever could make two Ears of Corn, or two Blades of Grass to grow upon a Spot of Ground where only one grew before; would deserve better of Mankind, and do more essential Service to his Country, than the whole Race of Politicians put together.
>
> Gulliver's Travels, Jonathan Swift, Ch. VII

The study of research as an economic activity had its origin in the Workshop on Agricultural Economics at the University of Chicago. D. Gale Johnson contributed to the early measurement of total factor productivity (TFP) for U.S. agriculture. T.W. Schultz reported the first computation of the economic value of improved agricultural technology in 1954 (Schultz 1953). Zvi Griliches reported the first study directly showing how agricultural scientists created economic value in their search for "two blades of grass where one grew before" in his classic study of hybrid corn in 1957 (Griliches 1958).

Today, some forty years after agricultural research, extension and the education of farmers were brought into the domain of economic analysis by D. Gale Johnson and his colleagues, studies of the economics of research for agriculture constitute a substantial body of economic literature. At least 22 prior studies of the contribution of research to U.S. agriculture have been published. For other countries, particularly for developing countries, the body of studies on this topic is also considerable. Echeverria (1990) reports more than 150 such studies for other countries.

In this paper another study of agricultural research and productivity is reported for U.S. agriculture. While the "TFP" decomposition methodology utilized in this study was developed quite early it continues to serve analysts well. The study adds to prior studies in several respects. It is the first study that has treated the crop and livestock production sector as distinct

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sectors. It is also one of the first studies to include private sector R&D as a determinant of TFP change. In addition, farm program variables are incorporated into the analysis and both public sector and private sector R&D "spill-in" are considered.

Part I of the paper provides a brief review of methods used in this and related studies. Parts II and III summarize the specification of the "decomposition" variables. Estimates are reported in Part IV. The final section reports estimates of "marginal products" and "internal rates of return to investments" for public sector "pre-invention" science research, public sector applied research, private sector industrial "spill-over" R&D, public sector extension and farmer education. These estimates are then compared with estimates obtained in prior studies for U.S. agriculture. The Appendix to the paper discusses the construction of the TFP indexes for the crop and livestock sectors used in the analysis.

I. Methods: A Brief Survey

Methods of analysis may be classified as non-statistical or statistical. Non-statistical or "imputation-accounting" methods are used when measures of technology and its actual use by farmers can be obtained. Statistical methods are used when one cannot actually measure technology directly, but can measure resources directed toward the production of technology. Statistical methods may be divided into TFP decomposition methods and "meta-function" methods. TFP decomposition entails two stages: (a) the measurement of TFP[1], and (b) statistical analysis of determinants of TFP.[2] Meta-function methods incorporate variables measuring determinants directly into a production, cost or profits function (e.g., Huffman and Evenson 1991). Statistical methods also allow for interactions between contributing variables.[3]

A. Imputation-Accounting Methods

When technology can be identified, as in Griliches' classic hybrid corn study, these methods entail the following steps:

1) Identifying the invented technology (in most cases this is a set of inventions rather than a single invention. For example, in the hybrid corn study, many hybrid varieties were considered).

2) Documenting all costs associated with producing, developing and diffusing the invention(s). With hybrid corn, this included all public and private costs.[4] These costs were incurred as long as 25 or 30 years before the realization of benefits in the hybrid corn case.

3) Estimating the cost advantage for early adopters. Some studies have used experiment station trials to make controlled "with-without" yield and cost comparisons. These comparisons, however, are generally not representative of farmers' fields, and most studies have attempted to obtain farm-level comparisons. (In the hybrid corn study both experiment station and farm data were used.)

4) Estimating the parameters of the adoption pattern and the adoption-advantage interaction. In general, a new invention(s) will be adopted first on economic units where the cost advantage in greatest. As adoption spreads, the advantage typically declines (unless, as with hybrid corn, the technology (as broadly defined) is itself undergoing continuous change).

5) Converting 3) and 4) to a benefits stream using the social (producers plus consumers) surplus method pioneered by Griliches.

6) Computing of present values of benefits and costs and internal rates of return. The standard procedure of benefit/cost analysis is to compute a present value of benefits and costs over time using some discount rate. The ratio of these present values is widely used as a financial measure of return on investment. Alternatively one can solve for the "internal" rate of return, i.e., the discount rate that equates the present value of benefits to the present value of costs. For most imputation-accounting studies, the analyst

must make some assumptions regarding the continuation of the benefit stream beyond the period of analysis. Will benefits continue in future periods?

The answer to this question is somewhat arbitrary in imputation-accounting studies. In the hybrid corn study, Griliches (1958) assumed that the 1957 (the ending period of the study) level of benefits would continue indefinitely but that the 1957 level of costs would also continue because they were required to maintain the benefits level. This was obviously a conservative assumption, as subsequent yield changes for corn show (Huffman and Evenson 1991, ch. 8). Thus, his study established a tradition for "conservative" calculations.

Unfortunately, an unusual computation in Griliches' study created severe problems for interpreting his results and for comparing them to later studies. Griliches computed the ratio:

$$(1) \qquad \frac{\sum_{t=1900}^{1957} \beta_t (1+r)^t \times r + \beta_{57}}{\sum_{t=1900}^{1957} C_t (1+r)^t \times r + C_{57}} = 7$$

The numerator, the cumulated benefits converted to a return r plus the 1957 level of benefits was interpreted to be a constant financial flow to continue into future years. The denominator is the comparable cost flow. The ratio 7 was then interpreted by many as a 700 percent rate of return on investment. This interpretation is simply wrong. The ratio is essentially a benefit/cost ratio and should be interpreted as such. It is highly sensitive to r, the discount rate used. Griliches also calculated an internal rate of return of approximately 40 percent, but the 700 percent figure is still widely quoted.[5]

B. Statistical Methods

Statistical methods for TFP decomposition or for meta-production or meta-profits function analysis are a means for estimating rather than inputing the contribution of changes in technology, infrastructure and policy environments faced by farmers to productivity change. Griliches (1963a, 1964) was a pioneer in this research. Other work includes Evenson (1968, 1980); Peterson (1967); Cline (1975); Bredahl and Peterson (1976); Evenson and Welch (1974); Evenson and Kislev (1975); Lee, Cline, and Quance (1979); and Braha and Tweeten (1986). These methods can be applied to the second stage of a TFP decomposition analysis as in this chapter or to a meta-profits function analysis as in Huffman and Evenson (1991) as well as to meta production function analysis.

Statistical methods are especially relevant when no direct measure of the inventions adopted or invention-productivity link is available. These methods rely on statistically identifying the link between investments in research, extension, and schooling (i.e., inputs) and production productivity or profits rather than between inventions (i.e., research output) and productivity. The key problems in statistical analysis are associated with the measurement of research, extension and related investment variables for the unit of observation. This requires attention to: 1) functional form, 2) simultaneity of investment and productivity changes, 3) the lag pattern or time-shape of the impact of investment on later productivity, 4) spatial relationships between investment and productivity (i.e., spill-ins and spill-overs), and 5) deflators. Variables that determined production, productivity or profits include: human capital (schooling of farmers, public sector extension), technological (public research, private sector research, public sector extension), and infrastructure (geoclimatic factors, weather variables, government policy).

In principle, research programs generate output in the form of new technology and extension, schooling and infrastructure programs facilitate the adoption and use of this improved technology by farmers. By statistically relating production, productivity or profits to variables measuring the "service flows" of research, extension, schooling and infrastructure activities, a link can be established even when new technology cannot be directly measured. The most difficult aspect of statistical studies is the specification of variables measuring these service flows.

Meta-production function studies include these variables in a production function specification. Questions of functional form and endogeneity of inputs have to be addressed in these studies. Similarly, meta-profits function specifications require that functional form issues and restrictions across equation be addressed. The TFP decomposition procedure utilized in this study side-steps these functional form issues in large part. The dependent variables (TFP indexes) are derived from production and input data using Divisia-type indexes which are appropriate for a range of underlying production technologies. These indexes are cumulated from a base period to eliminate year to year errors.[6]

Productivity indexes can be computed to reflect cross-sectional variation using efficiency indexes and variation over time in productivity. Efficiency indexes having a cross-sectional basis can be derived as the ratio of output valued at national mean prices to inputs valued at national mean prices for a particular year. Productivity indexes having only variation over time index each observation or state at 100 for the base year.

If all outputs and inputs were measured in constant quality units, a productivity index including cross-sectional and time-series variation would be ideal. Unfortunately, input quality is never fully accounted for, e.g., land quality. Thus, cross-sectional agricultural productivity differences must be used with caution. In this study there is a further reason for not disregarding cross-sectional differences in productivity. For example, Huffman & Evenson (1991, Chapter 10) report evidence that low production efficiency in 1949-50 may be associated with a higher-than-average rate of productivity growth later. If this is the case, the "catch-up" growth will bias an analysis of variation in productivity that examined only variation over time or cumulative productivity change.

Simultaneity between research investment and productivity change can also be a problem in studies of this type. However, two factors are relevant to questions of simultaneity in TFP decomposition. First, different "actors" are producing the TFP and the investment data. Farmers' actions produce the TFP data. Individual farms do not control public investments in research. (They do control their own investments in experimentations and information purchase but we are not considering these variables in this study.) This does not mean, however, that the public-sector investments in research and extension do not respond to farmers' interests (Huffman and Evenson 1991, ch. 8).

Second, a substantial time lag exists between the relevant research investments and productivity change. The lag is long, see below. Given this time lag, a recursiveness argument can be made. Even if research investment is responding to current productivity change it is past investment that is affecting current productivity change. This issue is discussed further in Huffman and Evenson (1991, Chapter 13). Little evidence exists for simultaneity bias in the U.S. case.

II. Specification Issues for Research and Extension Variables

A. Timing

Most variables affecting TFP have a lag that is typically distributed over time with different weights. These impact weights differ across variables. Consider research conducted in the SAES system. A research project may begin at time t. If it is directed toward the invention of new technology and is successful, new technology will be developed in one or more periods later than t. The technology then requires testing, further modification, and release to farmers. Farmers will then experiment with the new technology and fit it into their production activities. There may then be a further period of learning by the farmer before the full impact of the research investment will be realized. Some research projects are unsuccessful. Some projects produce both new technology and new intellectual capital that is useful in future research. Some are not designed to produce technology per se but have pretechnology science objectives.

Furthermore, technology, once adopted by farmers, may experience a real depreciation in its TFP impact. This stems from two sources. First, and probably most important in agriculture, real "deterioration" from exposure of a technology to pests and pathogens can occur. This is a common problem with new crop varieties and to some extent with animal improvements. Second, replacements with incomplete additivity occur. New inventions are continuously replacing older inventions because the new inventions are superior. In some cases the new technologies build upon or add to the older ones. In these latter cases, the TFP impact of the older technology does not disappear, but it becomes a part of the new technology. In other cases, this additivity may be incomplete. The new invention may have emerged from a different technology or sequence of inventions. In this case, it will not contain the full effect of the replaced technology.

In this study, three alternative time weight distributions are considered. All are trapezoidal in shape- having "a" years of increasing weights, "b" years of constant weights, and "c" years of decreasing weights. Thus the total effect of an investment in research is distributed over a total of a+b+c years. The three distributions are presented in Table 1. A minimum-mean-square-error statistical criterion was used to evaluate the performance of the different distributions. Distribution 3 was chosen as the best representation. These weights were applied to create both public and private agricultural research stock variables (see below).

Table 1. Alternative trapezoidal weight distributions for creating agricultural research stocks.

Distribution	Years for each segment of trapezoidal weights		
	a	b	c
1	5	6	15
2	7	6	20
3	9	6	30

The effects of extension programs on productivity also occur with a time lag, but it differs considerably from the research lag. Extension programs have direct and relatively quick impacts because of direct contacts with farmers. Because extension-farmer contacts are part of an education and learning process, the full impact on productivity will not occur immediately. After some time, the impact on productivity will be reduced because part of the information becomes obsolete either due to availability of new extension contacts or new information supplied by private firms. Much of the public extension effect is to enable processing and conversion of technical and price information into managerial decision-making earlier and more effectively. Alternative sources of information are of the "replacement with incomplete additivity" type. Hence, much, perhaps most, of extension's impact on productivity deteriorates within a relatively short period.[7]

Given the burden of estimation of other parameters in this study, the time-weight distribution for extension's impact on productivity was not estimated. Instead the distribution was imposed; it lasts only 3 years with time weights of .5, .15 and .25. Schooling impacts were specified to be permanent. Again, schooling-associated skills may deteriorate over time but this study does not attempt to estimate this effect except in interaction effects (see below). Government price policy variables are also assumed to have a 3-year impact on productivity.

B. Spatial-Geoclimate Spill-in of Technology

Because the unit of observation is a state and the phenomenon under examination is state productivity in a specific time period, research, extension and other variables should be defined in the way that they affect state productivity. For some variables, it seems that no appreciable spatial issue exists, because the variable is closely associated with agriculture of only one state. This is the case for schooling of farmers and also for extension activity in a state, but not for research activity in a state.

If one could actually measure technology in use by farmers directly, one could possibly trace its origins. For example, technology in use in a given state may have originated (i.e., been invented) in another state or even in another country. If so it can be said to have "spilled-in" to the state in question and "spilled-out" of the originating state. Using this spill-in and spill-out information, one could attribute the value of technology to its originating institution.

Many research impacts, particularly in the form of marginal inventions, are not easily measured. Thus, an indirect specification of a research investment "stock" variable is proposed. This requires information about how research program impacts spill across state boundaries to affect state agricultural productivity. Essentially this means specifying the spill-in and spill-out effects of new technology and of pretechnology findings for each state.

Some technologies spill far and wide. For example, a chemical herbicide developed in one state may be more valuable than the next best alternative in every U.S. state. In economic terms, it is the best technology in a broad range of locations. If all agricultural technology had this characteristic, one would specify a single national (or international) research stock using the time weights in Table 1. But most agricultural technology does not spill far and wide. Spilling is inhibited by local soil, climate, and even economic factors. The biological performance of a variety of corn, for example, is inhibited by changes in day length and length of growing season.

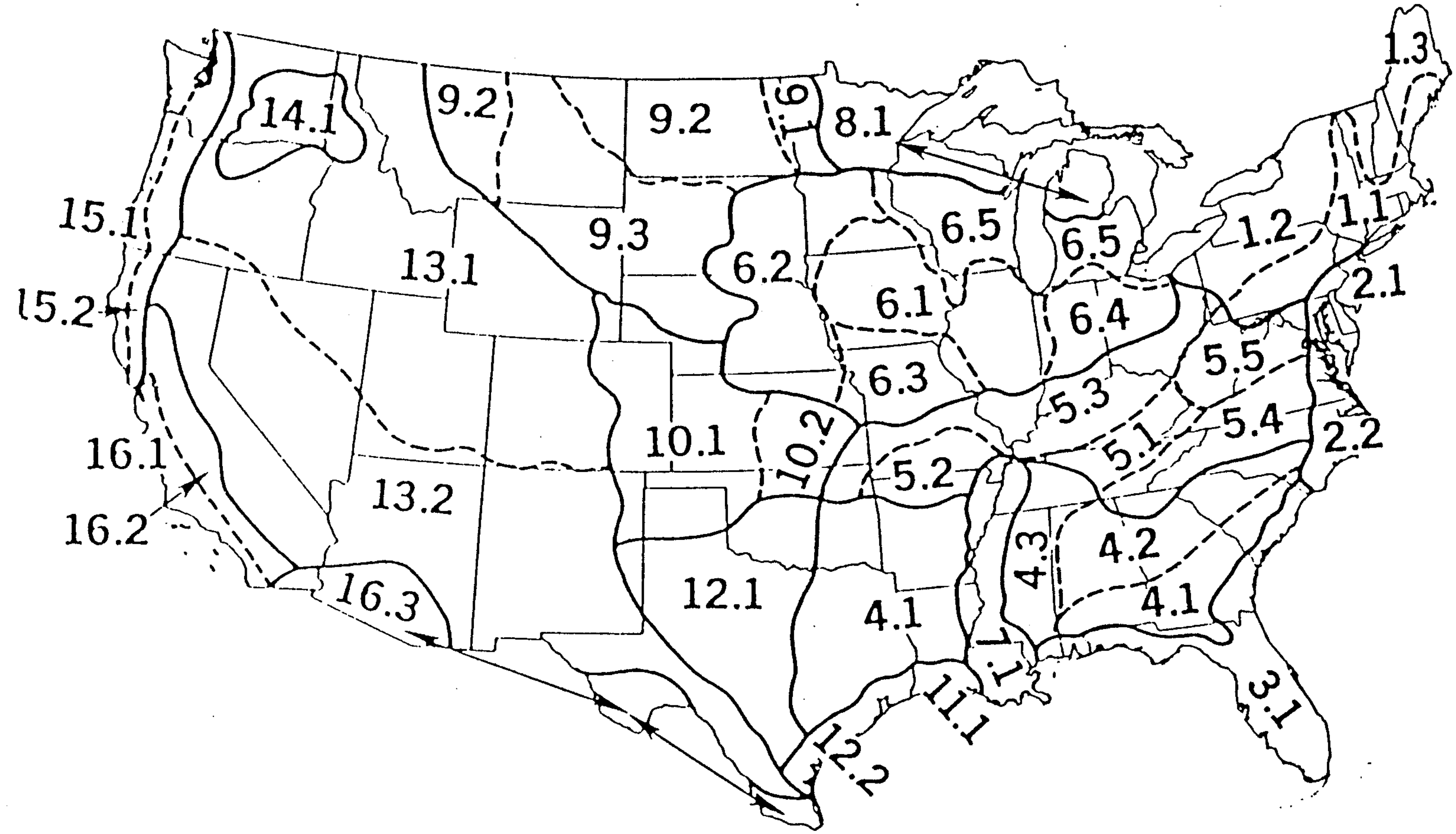
As crop and animal husbandry priorities were developed, "husbandry selection" modified many crop and animal species through selection for economically valuable characteristics. Considerable improvement in economic species occurred over the centuries before modern agricultural research started. Some of the natural inhibitors were reduced in scope and importance so that economic species exhibited much less fine tailoring to small niches than non-economic species. Nonetheless, the basic pattern of tailoring through location-specific husbandry selection was maintained.

With the advent of modern plant breeding and research practices, further selection to reduce inhibiting effects has taken place (e.g., modern high-yielding rice varieties in Asia have been selected for lower photoperiod sensitivity). At the same time, the existence of inhibitions (sometimes referred to as genotype-environment intervention (Evenson, et al. 1978)) has become a central feature of the organization and design of agricultural research systems (Englander 1981). In the SAES-USDA system, this principle, which can be thought of as a factor on the supply side of research, has combined with demand factors to encourage the development of state stations. Also, the establishment of branch or sub-stations has occurred because of imperfect spill-in of technology from other state units, and they can engage in productive niche-filling technology tailoring to helping their clientele farmers.

Of course, some technology spills in directly from one state to another. However, if all technology spilled broadly across soil and climate inhibitors, only a few of the state programs would be productive. The successful technology tailoring that SAESs do attests to limited direct spill-in but much of this activity can be thought of as indirect spill-in.

Given that most inhibitors to spill-in and spill-out effects are soil and climate factors, information on geographical distribution of similar soils and climates can assist in the specification of research spill-in variables that affect state TFP. Evenson (1972) developed a system of 16 geoclimate regions and 34 geoclimate subregions for the continental United States (Figure 1). Each state is located in one or more regions and subregions. A research variable incorporating a state's own research stock and spill-in research

Figure 1



Legend:
1. Northeast Dairy Region
2. Middle Atlantic Coastal Plain
3. Florida and Coastal Flatwoods
4. Southern Uplands

5. East-Central Uplands
6. Midland Feed Region
7. Mississippi Delta
8. Northern Lake States

9. Northern Great Plains
10. Winter Wheat and Grazing Region
11. Coastal Prairies
12. Southern Plains

13. Grazing-Irrigated Region
14. Pacific Northwest Wheat Region
15. North Pacific Valleys
16. Dry Western Mild-Winter Region

Figure 10.1 U.S. agricultural geo-climate regions and subregions.

stocks from other areas was specified of the following type:

$$(2)\quad R_i^* = R_i + (1-\alpha)\ RSS_i + (1-2\alpha)\ RSR_i$$

where R_i^* is the constructed research stock for state i, R_i is the state's own research stock, RSS_i is the research stock for other states in similar subregions to those in state i (excludes state i's stock), and RSR_i is the research stock of other states in the region where state i is located (excludes RSS_i). If state i has more than one region, the above expression is computed for every region and weighted by the region's relative importance. The parameter α is used to determine the weight of RSS_i and RSR_i relative to R_i.[8]

Equation 2 implicitly subsumes both direct and indirect spill-in of research. The specification imposes a spatial structure on the weights. Some research products produced in similar subregions (or regions) may be directly transferable, and these products are substitutes for a state's own research program. Other research findings outside the state indirectly spill-in by complementing the state's research program. The specification employed here does not seek to identify substitutability or complementary (that would require interaction terms). It seeks to measure net spill-in.

For this study α was estimated to be 0.5 for crop research and zero for livestock research.[9] What these differences mean is that livestock research benefits spill fully across state boundaries within a geoclimatic region but crop research only spills partially. This is consistent with earlier findings of Evenson and Welch (1974) and Evenson (1988).

For the private research variable, where the location of the research conducted could not be determined, spill-in was presumed to be general. That is, the impact of private research on productivity was independent of the location of its conduct.[10]

Variables representing the proportion of public-sector research conducted in branch or substations are also included to test for differential impacts of main station versus substation research on agricultural productivity.

C. Commodity Spill-in and Research Deflators

Because TFP indexes are available for crop and livestock sectors, the matching research stock variables must also be aggregated over crop and livestock research commodities. In addition, TFP for the sectors is measured as an index number, and state research (and extension) stocks should be consistent with this specification. This requires an adjustment that effectively deals with the size issues, i.e., that makes a small state comparable to a large state and that also deals with geoclimatic and aggregate commodity heterogeneity.

Consider the case where a single commodity is being produced in a single homogeneous region with no spill-in. In this case, a research stock should not be deflated at all. The size of the homogeneous region in question would not matter. Alternatively, suppose that the region is not homogeneous, but that there are subregions in it and that we have two states each with a different number of subregions. Each state has a station that seeks to tailor technology to each subregion. How do we define a meaningful research stock variable for the two states?

Consider two extremes. One is that the subregion characteristics do not inhibit technology spilling from one region to the other. In this case the subregions would not matter. At the other extreme, no significant spill-over takes place between subregions. In this case each subregion would require a separate research program and the aggregate program research stock could be defined as:

$$(3) \quad \sum_i S^c_i R_i$$

where S_i^c is the share of commodity production in the ith subregion. This weighted aggregate research stock presupposes not only that no spill-over between subregions occurs but that the system is optimally allocating research between subregions in proportion to the size of the subregions.

Some spill-over is likely to occur between subregions, and not all subregion allocations will be optimal. This would require a mixed or composite adjustment, for example:

$$(4) \quad \phi \sum_i R_i + \delta \sum S_i^c R_i + \lambda \sum (S_i^c - S_i^R)^2 R_i$$

where S_i^c is the share of commodity production in subregion i and S_i^R the share of research directed to subregion i. The third term of equation (4) is a correction for non-optimal subregion allocation of research effort. The first and second terms of equation (4) constitute a composite adjustment with weights ϕ and δ.

Typically data to <u>a priori</u> assign values to ϕ, δ, and λ do not exist. It is possible, however, to actually include the components of equation (4) as separate regressors $[\sum R_i, \sum S_i^c R_i, \sum (S_i^c - S_i^R)^2 R_i]$ in a decomposition specification and implicitly estimate ϕ, δ and λ.

The same issues arise when a research variable must be defined for an aggregation of commodities. Most agricultural research is commodity oriented, but there is a certain amount of spill-over between commodities so that a single commodity-share-weighted specification similar to the second term above does not represent all of the possible effects. A composite variable specification is required. The ideal definition of the research stock would include four research variables:

$$(5) \quad \sum_i \sum_j R_{ij}, \ \sum_i \sum_j s_i R_{ij}, \ \sum_i \sum_j S_j R_{ij}, \ \sum_i \sum_j (S_{ij}^c - S_{ij}^R)^2 R_{ij}$$

where i refers to geographical area and j refers to commodity. The last term adjusts for the difference between commodity production shares, S^{C}_{ij} and commodity research shares S^{R}_{ij}.

The econometric analysis reported in this paper include specifications of the research variables that approximate these four deflators.

For each commodity research program we have data measuring the proportion of the research directed toward or focused on 1) biological efficiency, 2) protection maintenance, 3) mechanical efficiency, and 4) managerial efficiency (see Huffman and Evenson 1991, Chapter 3). In addition, researchers report the proportion of their work that is "basic" or pretechnology-oriented as opposed to "applied" or technology-oriented.[11]

It is of considerable policy interest to determine a productive, if not optimal, mix of research foci among projects. It is also of interest to determine an effective mix of applied or invention-oriented research and basic or pretechnology science.

The procedure used to examine these questions is to construct foci share variables for biological efficiency and for pretechnology science and share interactions, and to include them in the set of variables explaining productivity. This will allow tests as to whether different foci emphases have different productivity effects.[12]

III. The Specification of the Equations for Crop, Livestock and Aggregate Productivity

A statistical decomposition analysis was conducted separately on the crop and livestock sectors, and on the combined crop and livestock sectors. Table 2 presents a list and definitions of variables used in the analysis. About one-half of the variables have sector-specific values because they relate to only crops (crop commodities) or only livestock (livestock commodities). Other variables are defined to have the same values for crop and livestock sectors and for the aggregate.

Table 2. Variable definitions and means: U.S. agricultural productivity decomposition analysis, 42 states, 1950-82.

Symbol	Definitions	Crop sector	Livestock sector	Aggregate[a/]
MFP	Multifactor productivity: divided by Divisia Input Index, normalized to 1.0 for the national mean 1949-52.	1.3668	1.3099	1.3392
RPB	Public commodity-oriented research stock in 1984 dollars, commodity share weights, time-lag pattern over 33 years of (7, 6, 20), spillin weights of (.5, 0) for crops and (1, 1) for livestock.	$14.7x10^6$	$30.4x10^6$	$24.7x10^6$
SS	Share of public-research stock allocated to pretechnology or basic sciences.	.355	.454	.404
SB	Share of public-research stock having a biological efficiency focus.	.448	.552	.498
SBRAN	Percentage of SAES staff located in branch research stations.		11.26	
DISP	Dissimilarity between production and public research: sum of squared difference between production and public research commodity shares.	.234	.110	.173
G	Commodity-geoclimatic similarity: sum of squared shares of agricultural production by geoclimatic subregion.		.710	
RPRC	Private agricultural research stock in mil 1984 dollars, commodity revenue weights, time-lag pattern (7, 6, 20).	5,356	1,755	3,609
EX	Public-extension stock having a commodity (crop, livestock) focus in days, time lag weights over 3 years of (.5, .25, .25).	15,076	11,506	13,344
EXIM	Public-extension stock having a management focus in days, time lag weights over 3 years of (.5, .25, .25).		11,235	
SIPRPB	Ratio of number of private agricultural research and extension staff to the number of public staff in 1970.		2.52	
ED	Schooling of farmers: average years of schooling completed by rural males 15-65 years of age (interpolated between Census of Population years).		9.15	
N	Number of farms of 49 acres or more.		54,879	

Table 2. (Continued)

Symbol	Definitions	Crop sector	Livestock sector	Aggregate[a]
WAGE	Real wage rate for manufacturing.		3.47	
NPSUPPORT	Government crop price support: weighted ratio of support price to market price for crops.		.227	
NPSUPMLK	Government milk price support: weighted ratio of milk support price to milk market price		.091	
NDVERSION	Government crop diversion payments: equivalent price ratio of direct government crop acreage payments.		.044	
DROUGHT	Drought dummy variable: equals 1 if rainfall is less than 1 standard deviation below normal, and 0 otherwise.		.159	
FLOOD	Flood dummy variable: equals 1 if rainfall is more than 1 standard deviation above normal, and 0 otherwise.		.157	
PREPLANT	Cumulative rainfall, February through July.		12.31	

a/ At the sample mean, the share of crop output in total output is 0.5148 and of livestock output is 0.4852.

Note: In cases where means are reported only for the livestock sector, the variables are common to all three sectors so the means would be the same for the crop and aggregate sectors.

The reduced-form specification of the productivity equations is reported in equation 6, Table 3. This equation is for aggregate productivity. The equations for crop and livestock productivity are similar, except that sector specific variables are included. For these sectors, the variable definitions include a "C" or an "L" wherever the variable takes on a different value in the different sectors. The specification of equation 6 is complex because it attempts an examination of many new aspects of agricultural productivity.

The specification has the following features:

1) It includes variables designed to measure the changing technology environment facing farmers. These are the variables created by using the public (RPB) and private (RPR) research variables. These variables incorporate timing, spillin, deflator, and foci features.

2) It includes variables believed to be closely associated with efficient management and adoption of technology. These variables measure public sector investments in crop- and livestock-oriented extension (EX/N and EX/G) and management extension (EXM/N), and farmers' schooling (ED).

3) It includes variables measuring selected characteristics of the price and economic policy environment. These are the manufacturing wage and indexes of price supports for crops (NPSUPPORT), for milk (NPSUPMLK), and for cropland diversion (NDVERSN).

4) It includes weather variables (DROUGHT, FLOOD, PREPLANT).

5) It includes trend (YEAR, $YEAR^2$) and geoclimate region dummy (D_ℓs) variables. They control for general trend-dominated effects and for some region-specific effects.

Further elaboration of the research variable is required. The public research variable incorporates three implicit deflators as well as a timing and spillin dimension. In constructing RPB, each type of commodity research is weighted by the production commodity shares. The estimated time-lag pattern is

Table 3. Equations for productivity decomposition.

Productivity decomposition:

(6) $$\ln MFP = \beta_0 + \beta_1 \ln RPB + \beta_2 \ln (RPB/G) + \beta_3 \ln (RPR/G) + \beta_4 \ln (EX/N) + \beta_5 \ln (EX/G) + \beta_6 \ln (EXM/N) \beta_7 \ln ED$$
$$+ \beta_8 SS \cdot \ln RPB + \beta_9 SB \cdot \ln RPB + \beta_{10} SS \cdot SB \cdot \ln RPB + \beta_{11} SBRAN \cdot \ln RPB + \beta_{12} SBRAN^2 \cdot \ln RPB + \beta_{13} (SBRAN/G) \ln RPB$$
$$+ \beta_{14} DISP \cdot \ln RPB + \beta_{15} DISP^2 \cdot \ln RPB + \beta_{16} \ln (RPR/G) \cdot \ln RPB + \beta_{17} SB \cdot \ln (RPR/G) \cdot \ln RPB + \beta_{18} \ln (EX/N) \cdot \ln RPB$$
$$+ \beta_{19} STPRPB \cdot \ln (RPR/G) + \beta_{20} \ln (EX/N) \cdot \ln (RPR/G) + \beta_{21} \ln (EX/N) \cdot \ln ED + \beta_{22} \ln (EXM/N) \cdot \ln ED$$
$$+ \beta_{23} DROUGHT + \beta_{24} FLOOD + \beta_{25} PREPLANT + \beta_{26} \ln WAGE + \beta_{27} NPSUPPORT + \beta_{28} NPSUPMLK + \beta_{29} NDVERSION$$
$$+ \beta_{30} YEAR + \beta_{31} YEAR^2 + \sum_{\ell=1}^{15} \delta_\ell D_\ell + \mu$$

Elasticity of productivity —

Public research:

(7) $$\eta_{RPB} = \frac{\partial \ln MFP}{\partial \ln RPB} = \beta_1 + \beta_2 + \beta_8 SS + \beta_9 SB + \beta_{10} SS \cdot SB + \beta_{11} SBRAN + \beta_{12} SBRAN^2 + \beta_{13} SBRAN/G + \beta_{14} DISP$$
$$+ \beta_{15} DISP^2 + \beta_{16} \ln (RPR/G) + \beta_{17} SB \ln (RPR/G) + \beta_{18} \ln (EX/N)$$

Public pretechnology science research:

(8) $$\eta_{RPRS} = SS [\eta_{RPR} + (\beta_8 + \beta_{10} SB)(1 - SS) \ln RPR]$$

Public nonpretechnology science research:

(9) $$\eta_{RPRNS} = (1 - SS) [\eta_{RPR} - (\beta_8 + \beta_{10} SB) SS \ln RPR]$$

Table 3. (Continued)

Public biological efficiency research:

(10) $\eta_{RPRB} = SB\ \{\eta_{RPR} + [\beta_9 + \beta_{10}\ SS + \beta_{17}\ \ln\ (RPR/G)]\ (1\text{-}SB)\ \ln\ RPR\}$

Public protection, management, mechanization research:

(11) $\eta_{RPRNB} = (1\text{-}SB)\ \{\eta_{RPR} - (\beta_9 + \beta_{10}\ SS + \beta_{17}\ \ln\ (RPR/G)\ SB\ \ln\ RPR\}$

Private research:

(12) $\eta_{RPR} = \frac{\partial \ln MFP}{\partial \ln RPR} = \beta_3 + \beta_{16}\ \ln\ RPB + \beta_{17}\ SB \cdot \ln\ RPB + \beta_{19}\ STPRPB + \beta_{20}\ \ln\ (EX/N)$

Public commodity extension:

(13) $\eta_{EX} = \frac{\partial \ln MFP}{\partial \ln EX} = \beta_4 + \beta_5 + \beta_{18}\ \ln\ RPB + \beta_{20}\ \ln\ RPR/G + \beta_{21}\ \ln\ ED$

Public management extension:

(14) $\eta_{EXM} = \frac{\partial \ln MFP}{\partial \ln EXM} = \beta_6 + \beta_{22}\ \ln\ ED$

Farmers' schooling:

(15) $\eta_{ED} = \frac{\partial \ln MFP}{\partial \ln ED} = \beta_7 + \beta_{21}\ \ln\ (EXT/N) + \beta_{22}\ \ln\ (EXM/N)$

represented by the set (7,6,20), and the spillin weights from subregions and regions are represented by (.5,0) for crops and (1.1) for livestock research. For the spillin weights of crop research, crop research conducted in states located in similar subregions has a weight of one-half relative to a weight of one for a state's own research. Crop research in other states has a weight of zero. For livestock research, research conducted by a given state and by other states in the same subregion or region have the same weight (1).[13]

The agricultural research stock can reasonably be expected to have some effects that spill perfectly into all geoclimatic areas of a state and other effects that are geoclimatic-specific. In these situations, it is a reasonable methodology to include research stock variables that are both unadjusted for geoclimatic complexity and are adjusted. This adjustment is made by using the variable G, the summation of squared geoclimate subregion output shares for a state. For a state have more than one geoclimatic subregion, G is less than one. The public agricultural research stock adjusted for geoclimatic regions is defined as RPB/G. When both ln(RBP) and ln(RPB/G) are included in the productivity equation, we epect the coefficient of ln(RPB/G) to be negative. This means that for a given public research stock (RPB), agricultural productivity will be lower when G is smaller or production in a state is split into a larger number of different geoclimatic subregions, other things equal.

Interaction terms between public research and other variables are created by using only RPB. Interaction terms are created with pretechnology science share (SS), biological efficiency research shares (SB), private research, public extension, differences in the match between agricultural commodity and research commodity importance, and the share of the SAES staff located in branch stations.

The coefficients of the interaction terms provide direct evidence for a test of differences in research productivity. The hypotheses include:

1) Pretechnology science research has a larger impact on agricultural productivity than other types of public agricultural research (Evenson 1983).

2) Biological efficiency focused research has a larger impact on agricultural productivity than protection, management, and mechanization research.

3) Public and private research are substitutes.

4) Public research and public commodity-oriented extension are complements.

5) The maximum impact of public agricultural research on productivity does not occur where agricultural commodity and research commodity shares are equal.

6) Productivity is increased by having part of the research staff located in branch stations and part at the central station.

For public-sector extension, it was possible to make a distinction between crop technology and livestock technology related extension and general management extension. The stock of extension is derived from annual extension staff days, using timing weights of .50, .25, and .25 for the current and 1- and 2-year lagged values.[14]

Commodity extension is deflated by number of farms having 49 acres or more (N) and by the geoclimate index (G). Deflating by number of farms reflects the tendency for using up extension resources to contact more farmers. Deflating by G incorporates the fact that geoclimate differences affect the usefulness of commodity-oriented extension. If a state has homogeneous soils and climate, farmers can more easily learn from one another in production and technology adopting decisions. When a state has several different geoclimatic regions, choosing appropriate agricultural technologies becomes more difficult. This is a geoclimatic environment where extension can be more productive.

The productivity of management extension is less affected by geoclimatic diversity than is commodity-oriented extension. Management information is widely applicable. Resources are used up on contacting farmers, and management extension is deflated by the number of farms.

Interaction terms for commodity-oriented extension are created with public and private research and with farmers' schooling. Management extension is interacted only with farmers' schooling. Several studies (Huffman 1974, Huffman 1981, Evenson 1980) have found that agricultural extension and farmers' schooling are substitutes.

Selected general price and agricultural programs variables are included in the productivity equations. The level of the manufacturing wage is important for affecting the attractiveness of labor to leave agriculture, taking part-time or full-time off-farm jobs, and developing and adopting new technology to save on agricultural labor. It is also likely that this variable may be "correcting" for actual labor used in farming. Government price support programs for milk and crops have reduced the price uncertainty faced by crop and livestock producers. This should increase productivity but these variables also affect real resources devoted to production.

Additional variables are included for weather, geoclimatic region effects, and time trends.

IV. Estimates of Crop, Livestock and Aggregate Productivity Decomposition Equations

Five sets of productivity equations -- each containing one equation for crop, one for livestock, and one for aggregate productivity -- were estimated. Each set is fitted as seemingly unrelated equations. The basic specification is reported in Table 3. Equation 6 and modifications of it were estimated where some of the research or extension variables are excluded. Specification (1) (see Table 4) contains public research, including a differentiation between pretechnology science and other sciences, and schooling. The other specifications are progressively richer. In specification (2), variables are also added for commodity extension, management extension, and interaction terms between extension and research and between extension and schooling. In the third specification, private research and interactions between public and private research are added. The fourth and fifth regressions include variables to differentiate the types of public research between biological efficiency and other foci types (protection, management, and mechanization) and an interaction term for private R&D and commodity extension. The fifth regression also includes an interaction variable between the biological efficiency share, public research, and private research.

The equations explaining crop, livestock, and aggregate productivity are reported in Tables 4, 5, and 6. Because of the complex specification of the productivity equations, including interaction terms, the impact of research, extension, and schooling on productivity is difficult to assess directly from these coefficient estimates. The productivity elasticities for the research, extension, and schooling variables (equations 7-15, Table 3) evaluated at the sample mean are reported in Table 7. These enable a clearer interpretation.

Before turning to an interpretation of the marginal productivity elasticities for the research, extension, and schooling variables, it will be useful to discuss the deflators, the interaction terms, and the price policy indicators.

Deflators - Geoclimate Heterogeneity (G)

The deflator strategy used here is to deflate the research variables by the commodity mix in each state and then to further deflate by G, a measure of geoclimate complexity and DISP (and DISP squared), a measure of "incongruence" between relative research program importance and commodity importance. The coefficients on PRBC/G, PRBL/G and RPB/G are expected to be negative, demonstrating that state research programs with more homogeneous geoclimate regions will be more productive (i.e., a higher G will lower the value of the

Table 4. Econometric productivity decomposition: U.S. crop sector, 42 states, 1950-82 (t-ratios are in parentheses)[a]

Independent variables	Dependent variable: ln (MFPC) (1)	(2)	(3)	(4)	(5)
ln RPBC	0.199 (5.43)	0.424 (10.83)	0.939 (7.46)	0.998 (7.66)	0.875 (6.49)
ln (RPBC/G)	-0.041 (1.10)	-0.364 (9.53)	-0.742 (8.84)	-0.635 (7.67)	-0.643 (7.68)
ln (RPRC/G)			-0.014 (1.68)	0.865 (5.11)	0.553 (3.12)
ln (EXC/N)		0.522 (3.64)	0.271 (1.72)	0.347 (2.29)	0.448 (2.93)
ln (EXC/G)		0.303 (22.45)	0.293 (19.27)	0.245 (16.43)	0.237 (15.80)
ln (EXM/N)		0.103 (0.69)	0.283 (1.86)	0.159 (1.09)	0.190 (1.31)
ln ED	0.424 (4.26)	0.114 (0.85)	-0.030 (0.22)	0.336 (2.42)	0.349 (2.52)
[ln RPBC]•SSC	-0.010 (1.43)	0.001 (0.19)	0.011 (1.63)	-0.023 (1.32)	-0.032 (1.76)
•SBC				0.023 (1.55)	-0.133 (3.33)
•SSC•SBC				0.129 (3.44)	0.149 (3.92)
•SBRAN	9.76×10^{-5} (0.64)	6.24×10^{-4} (4.30)	4.46×10^{-4} (3.08)	6.58×10^{-4} (4.85)	6.55×10^{-4} (4.84)
•$SBRAN^2$	-1.87×10^{-6} (0.53)	-1.21×10^{-5} (3.79)	-1.06×10^{-5} (3.15)	-1.72×10^{-5} (5.37)	-1.54×10^{-5} (4.84)
•SBRAN/G	-1.98×10^{-4} (2.63)	1.93×10^{-4} (2.69)	1.29×10^{-4} (1.63)	-7.91×10^{-5} (1.05)	-1.07×10^{-4} (1.42)
•DISPC	0.022 (2.39)	0.035 (4.40)	0.034 (4.11)	0.035 (4.36)	0.028 (3.51)

Table 4. (Continued)

Independent variables	Dependent variable: ln (MFPC) (1)	(2)	(3)	(4)	(5)
•DISPC^2	.008 (0.57)	-0.010 (0.78)	-0.012 (0.93)	-0.025 (1.99)	-0.013 (1.03)
•ln(RPRC/G)			-0.014 (1.68)	-0.034 (3.52)	-0.019 (1.94)
•SBC•ln(RPRC/G)					0.018 (4.29)
•ln(EXC/N)		-0.015 (2.56)	-0.011 (1.43)	0.004 (0.44)	-0.003 (0.35)
STPRPB•ln(RPRC/G)			0.002 (2.22)	0.003 (2.65)	0.002 (2.43)
ln(EXC/N)•ln(RPRC/G)				-0.021 (1.96)	-0.017 (1.53)
ln(EXC/N)•ln ED		-0.229 (3.32)	-0.125 (1.77)	-0.174 (2.15)	-0.189 (2.31)
ln(EXM/N)•ln ED		0.003 (0.04)	-0.085 (1.25)	-0.018 (0.28)	-0.030 (0.46)
DROUGHT	-0.006 (0.34)	-0.037 (2.38)	-0.035 (2.27)	-0.038 (2.69)	-0.037 (2.62)
FLOOD	-0.049 (3.15)	-0.033 (2.37)	-0.030 (2.14)	-0.029 (2.28)	-0.030 (2.30)
PREPLANT	0.012 (5.21)	0.002 (0.76)	0.002 (0.95)	0.001 (0.34)	$8.93x10^{-4}$ (0.48)
ln WAGE	-0.230 (3.43)	0.378 (5.62)	0.362 (5.46)	0.312 (4.82)	0.294 (4.56)
NPSUPPORT	0.763 (9.76)	0.316 (4.31)	0.347 (4.76)	0.388 (5.58)	0.398 (5.75)
NPSUPMLK	-1.125 (9.35)	-1.481 (13.06)	-1.448 (12.80)	-1.492 (14.17)	-1.448 (13.79)
NDVERSION	0.380 (2.02)	0.580 (3.41)	0.605 (1.57)	0.700 (4.43)	0.689 (4.37)

Table 4. (Continued)

Independent variables	Dependent variable: ln (MFPC)				
	(1)	(2)	(3)	(4)	(5)
YEAR	3.644 (9.09)	1.966 (4.33)	2.636 (5.66)	2.447 (5.60)	2.596 (5.93)
$YEAR^2$	9.23×10^{-4} (9.06)	-4.99×10^{-4} (4.32)	-6.76×10^{-4} (5.70)	-6.29 (5.64)	6.67×10^{-4} (5.97)
D1	-0.376 (7.12)	-0.592 (11.29)	-0.417 (7.16)	-0.321 (5.66)	-0.351 (6.18)
D2	-0.281 (5.90)	0.120 (2.47)	0.229 (4.38)	0.346 (6.56)	0.326 (6.18)
D3	0.590 (4.64)	1.024 (8.56)	0.861 (6.77)	1.000 (8.33)	0.894 (7.41)
D4	-1.035 (16.72)	-1.092 (19.00)	-0.880 (13.68)	-0.722 (11.72)	-0.726 (11.82)
D5	-0.903 (16.74)	-1.107 (19.46)	-0.889 (12.99)	-0.776 (11.67)	-0.807 (12.13)
D6	-0.383 (8.71)	-0.625 (11.62)	-0.433 (7.24)	-0.421 (7.28)	-0.455 (7.82)
D7	-0.653 (7.70)	-0.324 (4.09)	-0.072 (0.82)	0.225 (2.50)	0.257 (2.84)
D8	1.020 (1.22)	-0.067 (0.09)	0.320 (0.38)	0.512 (0.65)	0.300 (0.38)
D9	-.990 (20.60)	-0.939 (18.01)	-0.742 (13.12)	-0.944 (16.70)	-0.983 (17.21)
D10	-0.852 (15.34)	-1.116 (17.97)	-0.872 (12.79)	-1.114 (16.62)	-1.182 (17.30)
D11	2.766 (4.49)	0.001 (0.02)	-0.475 (0.79)	-1.291 (2.21)	-1.570 (2.69)
D12	-0.878 (8.61)	-0.826 (8.13)	-0.603 (5.64)	-0.149 (1.37)	-0.113 (1.02)
D13	-0.760 (17.28)	-0.493 (10.47)	-0.277 (5.08)	-0.471 (8.77)	-0.525 (9.62)

Table 4. (Continued)

Independent variables	Dependent variable: ln (MFPC) (1)	(2)	(3)	(4)	(5)
D14	1.189	0.686	0.729	0.880	0.872
	(8.41)	(5.24)	(5.53)	(6.97)	(6.93)
D15	-1.235	-1.511	-1.108	-0.955	-0.919
	(4.87)	(6.35)	(4.43)	(4.00)	(3.85)
Intercept	-3599.5	-1939.3	-2576.1	-2391.2	-2532.7
	(9.12)	(4.34)	(5.64)	(5.58)	(5.90)

[a]Each equation is fitted as part of a three-equation SUR system containing crop sector productivity, livestock sector productivity, and aggregate productivity.

Table 5. Econometric productivity decomposition: U.S. livestock sector, 42 states, 1950-82 (t-ratios are in parentheses)[a]

Independent variables	Dependent variable: ln (MFPL) (1)	(2)	(3)	(4)	(5)
ln RPBL	0.253 (7.10)	0.326 (7.96)	0.104 (1.13)	0.145 (1.52)	0.097 (1.02)
ln (RPBL/G)	-0.249 (8.43)	-0.349 (11.42)	-0.367 (7.18)	-0.456 (8.64)	-0.428 (8.07)
ln (RPRL/G)			-0.360 (2.34)	-0.383 (2.41)	-0.558 (3.43)
ln (EXL/N)		-0.252 (1.64)	0.158 (0.95)	0.023 (0.13)	-0.039 (0.22)
ln (EXL/G)		0.129 (10.72)	0.106 (8.53)	0.112 (8.67)	0.102 (7.95)
ln (EXM/N)		0.478 (4.10)	0.326 (2.81)	0.349 (2.96)	0.316 (2.70)
ln ED	1.098 (13.10)	0.667 (6.09)	0.760 (6.52)	0.854 (6.47)	0.854 (6.50)
[ln RPBL]•SSL	0.036 (3.87)	0.019 (2.50)	0.025 (3.17)	0.132 (3.89)	0.220 (5.87)
•SBL				0.103 (3.41)	0.025 (0.63)
•SSL•SBL				-0.168 (2.63)	-0.294 (4.30)
•SBRAN	-2.33×10^{-4} (1.91)	4.72×10^{-5} (0.41)	5.15×10^{-5} (0.45)	7.90×10^{-5} (0.67)	1.84×10^{-5} (0.16)
•$SBRAN^2$	1.29×10^{-5} (4.59)	7.52×10^{-6} (2.88)	9.56×10^{-6} (3.61)	9.94×10^{-6} (3.74)	1.14×10^{-5} (4.34)
•SBRAN/G	-1.13×10^{-4} (1.88)	-1.86×10^{-4} (3.25)	-2.42×10^{-4} (4.06)	-2.72×10^{-4} (4.51)	-2.74×10^{-4} (4.61)
•DISPL	0.028 (3.91)	0.032 (5.21)	0.027 (4.60)	0.028 (4.44)	0.027 (4.38)

Table 5. (Continued)

Independent variables	Dependent variable: ln (MFPL)				
	(1)	(2)	(3)	(4)	(5)
•DISPL^2	-0.015 (0.96)	-0.018 (1.43)	-0.014 (1.09)	-0.019 (1.51)	-0.023 (1.75)
•ln(RPRL/G)			0.026 (2.88)	0.030 (3.27)	0.030 (3.25)
•SBL•ln(RPRL/G)					0.015 (3.64)
•ln(EXL/N)		0.004 (0.38)	-0.017 (1.44)	-0.006 (0.52)	-0.002 (0.20)
STPRPB•ln(RPRL/G)			0.002 (2.48)	0.002 (2.07)	0.002 (2.04)
ln(EXL/N)•ln(RPRL/G)				-0.021 (1.95)	-0.024 (2.25)
ln(EXL/N)•ln ED		0.065 (1.01)	0.054 (0.81)	0.101 (1.34)	0.108 (1.41)
ln(EXM/N)•ln ED		-0.257 (4.97)	-0.192 (-3.72)	-0.198 (3.81)	-0.182 (3.52)
DROUGHT	0.047 (3.36)	0.028 (2.18)	0.029 (2.28)	0.028 (2.20)	0.031 (2.38)
FLOOD	-0.013 (1.05)	0.001 (0.13)	0.002 (0.14)	0.003 (0.24)	0.002 (0.15)
PREPLANT	0.005 (2.69)	-9.83×10^{-4} (0.57)	-8.37×10^{-4} (0.49)	-0.001 (0.73)	-0.001 (0.64)
ln WAGE	-0.513 (9.04)	-0.178 (3.07)	-0.203 (3.55)	-0.262 (4.50)	-0.258 (4.50)
NPSUPPORT	0.406 (6.04)	0.262 (4.07)	0.284 (4.41)	0.322 (4.96)	0.344 (5.36)
NPSUPMLK	0.793 (7.45)	0.825 (8.20)	0.863 (8.54)	0.772 (7.46)	0.751 (7.34)
NDVERSION	-0.330 (2.13)	-0.236 (1.66)	-0.211 (1.49)	-0.212 (1.49)	-0.159 (1.13)

Table 5. (Continued)

Independent variables	Dependent variable: ln (MFPL) (1)	(2)	(3)	(4)	(5)
YEAR	3.597 (10.07)	0.830 (2.16)	1.172 (2.88)	1.687 (4.10)	1.690 (4.14)
$YEAR^2$	-9.13×10^{-4} (10.06)	-2.09×10^{-4} (2.13)	-2.97×10^{-4} (2.87)	-4.30×10^{-4} (4.10)	-4.30×10^{-4} (4.13)
D1	-0.188 (3.63)	-0.192 (3.88)	-0.123 (2.35)	-0.170 (2.30)	-0.360 (4.30)
D2	0.831 (19.48)	1.083 (25.87)	1.117 (24.59)	1.144 (23.85)	1.135 (23.76)
D3	0.610 (5.68)	0.919 (9.04)	0.890 (8.61)	0.853 (7.78)	0.879 (8.08)
D4	0.641 (11.08)	0.654 (11.80)	0.764 (12.79)	0.702 (11.34)	0.729 (11.85)
D5	0.369 (7.26)	0.319 (6.40)	0.432 (7.64)	0.322 (5.45)	0.344 (5.87)
D6	0.051 (0.74)	0.039 (0.60)	0.100 (1.53)	0.006 (0.08)	-0.087 (1.13)
D7	0.951 (12.68)	1.114 (15.89)	1.170 (16.69)	1.056 (14.30)	1.056 (14.36)
D8	-0.425 (0.64)	-0.769 (1.22)	-0.197 (0.29)	-0.273 (0.40)	-0.530 (0.79)
D9	0.312 (6.16)	0.378 (7.50)	0.446 (8.16)	0.370 (6.50)	0.344 (6.01)
D10	0.522 (10.73)	0.440 (8.85)	0.522 (10.09)	0.474 (8.46)	0.483 (8.63)
D11	4.368 (8.81)	2.840 (6.09)	3.356 (7.06)	4.069 (8.34)	4.218 (8.74)
D12	0.183 (2.10)	0.249 (2.93)	0.346 (4.04)	0.363 (4.17)	0.372 (4.32)
D13	0.109 (2.71)	0.184 (4.81)	0.280 (6.76)	0.269 (5.85)	0.287 (6.23)

Table 5. (Continued)

Independent variables	Dependent variable: ln (MFPL)				
	(1)	(2)	(3)	(4)	(5)
D14	0.590	0.211	0.235	0.265	0.328
	(4.94)	(1.87)	(2.07)	(2.24)	(2.80)
D15	1.956	2.373	2.355	2.449	2.487
	(9.35)	(11.98)	(11.78)	(12.11)	(12.47)
Intercept	-3546.3	-828.7	-1157.0	-1657.0	-1660.7
	(10.09)	(2.19)	(2.90)	(4.10)	(4.14)

[a]/Each equation is fitted as part of a three-equation SUR system containing crop sector productivity, livestock sector productivity, and aggregate productivity.

Table 6. Econometric productivity decomposition: U.S. aggregate, agriculture, 42 states, 1950-82 (t-ratios are in parentheses)[a/]

Independent variables	Dependent variable: ln (MFP)				
	(1)	(2)	(3)	(4)	(5)
ln RPB	0.216 (8.24)	0.401 (16.76)	0.521 (6.64)	0.685 (8.00)	.064 (7.42)
ln (RPB/G)	-0.209 (8.42)	-0.408 (18.31)	-0.490 (14.05)	-0.545 (15.41)	-0.551 (15.50)
ln (RPR/G)			0.222 (1.76)	0.441 (3.17)	0.378 (2.69)
ln (EX/N)		0.477 (4.51)	0.614 (5.24)	0.508 (4.20)	0.588 (4.83)
ln (EX/G)		0.213 (26.79)	0.185 (22.05)	0.179 (21.51)	0.178 (21.34)
ln (EXM/N)		0.055 (0.58)	0.043 (0.47)	0.041 (0.44)	0.042 (0.45)
ln ED	0.921 (13.37)	0.530 (6.45)	0.522 (6.50)	0.700 (7.80)	0.665 (7.32)
[ln RPB]•SS	0.015 (2.43)	0.025 (5.00)	0.027 (4.96)	-0.008 (0.45)	-0.013 (0.74)
•SB				-0.001 (0.10)	0.040 (1.38)
•SS•SB				0.094 (2.68)	0.097 (2.72)
•SBRAN	$-1.67x10^{-4}$ (1.65)	$2.60x10^{-4}$ (2.99)	$2.06x10^{-4}$ (2.44)	$3.03x10^{-4}$ (3.61)	$3.07x10^{-4}$ (3.65)
•$SBRAN^2$	$2.19x10^{-6}$ (0.94)	$-4.62x10^{-6}$ (2.38)	$-1.18x10^{-6}$ (0.59)	$-3.04x10^{-6}$ (1.56)	$-2.69x10^{-6}$ (1.38)
•SBRAN/G	$1.55x10^{-5}$ (0.30)	$-5.75x10^{-6}$ (1.32)	$-1.03x10^{-4}$ (2.30)	$1.26x10^{-4}$ (2.79)	$1.35x10^{-4}$ (3.00)
•DISP	0.028 (4.30)	0.039 (7.32)	0.034 (6.50)	0.040 (7.34)	0.042 (7.73)

Table 6. (Continued)

Independent variables	Dependent variable: ln (MFP) (1)	(2)	(3)	(4)	(5)
•DISP^2	-0.009 (0.81)	-0.025 (2.67)	-0.021 (2.25)	-0.031 (3.24)	-0.035 (3.70)
•ln(RPR/G)			-0.003 (0.44)	-0.014 (1.80)	-0.008 (0.96)
•SB•ln(RPR/G)					-0.004 (1.31)
•ln(EX/N)		-0.010 (2.01)	-0.020 (2.90)	-0.007 (0.94)	-0.010 (1.34)
STPRPB•ln(RPR/G)			0.004 (5.71)	0.003 (5.04)	0.003 (5.32)
ln(EX/N)•ln(RPR/G)				-0.030 (4.95)	-0.030 (4.78)
ln(EX/N)•ln ED		-0.199 (4.31)	-0.172 (3.76)	-0.102 (1.86)	-0.119 (2.15)
ln(EXM/N)•ln ED		-0.019 (0.45)	-0.025 (0.61)	-0.020 (0.50)	-0.020 (0.48)
DOUGHT	0.028 (1.76)	-0.003 (0.28)	1.34×10^{-4} (0.01)	-0.004 (0.49)	-0.005 (0.57)
FLOOD	-0.036 (3.37)	-0.021 (2.36)	-0.018 (2.13)	-0.016 (1.92)	-0.016 (1.88)
PREPLANT	0.008 (5.17)	7.77×10^{-5} (0.06)	0.002 (0.15)	-9.91×10^{-4} (0.81)	-0.001 (0.87)
ln WAGE	-0.327 (7.17)	0.154 (3.60)	0.147 (3.56)	0.083 (1.97)	0.081 (1.93)
NPSUPPORT	0.444 (7.80)	0.175 (3.65)	0.185 (3.96)	0.211 (4.51)	0.232 (4.95)
NPSUPMLK	-0.086 (1.00)	-0.330 (4.45)	-0.164 (2.24)	-0.199 (2.74)	-0.217 (2.95)
NDVERSION	0.017 (0.13)	0.184 (1.72)	0.223 (2.16)	0.165 (1.64)	0.150 (1.48)

Table 6. (Continued)

Independent variables	Dependent variable: ln (MFP)				
	(1)	(2)	(3)	(4)	(5)
YEAR	3.320	1.312	1.472	1.820	1.853
	(11.85)	(4.65)	(5.19)	(6.36)	(6.37)
$YEAR^2$	-8.41	-3.32×10^{-4}	-3.76×10^{-4}	-4.66×10^{-4}	4.75×10^{-4}
	(11.81)	(4.63)	(5.21)	(6.40)	(6.41)
D1	-0.512	-0.593	-0.452	-0.327	-0.287
	(14.00)	(19.48)	(13.81)	(7.95)	(6.80)
D2	0.118	0.492	0.577	0.625	0.636
	(3.63)	(16.09)	(18.57)	(19.74)	(20.04)
D3	0.645	1.002	0.800	0.855	0.818
	(7.47)	(13.50)	(10.57)	(11.40)	(10.87)
D4	-0.431	-0.406	-0.198	-0.169	-0.172
	(10.43)	(11.64)	(5.02)	(4.37)	(4.42)
D5	-0.474	-0.539	-0.331	-0.370	-0.368
	(13.32)	(17.10)	(8.80)	(9.92)	(9.78)
D6	-0.322	0.466	-0.374	-0.339	-0.342
	(10.56)	(15.22)	(12.15)	(10.95)	(10.99)
D7	0.049	0.295	0.394	0.484	0.486
	(0.84)	(5.89)	(7.90)	(9.31)	(9.26)
D8	-1.253	-1.745	-1.041	-0.985	-0.681
	(2.19)	(3.62)	(2.01)	(1.92)	(1.31)
D9	-0.580	-0.477	-0.338	-0.412	-0.414
	(18.11)	(16.03)	(10.61)	(12.29)	(12.21)
D10	-0.339	-0.450	-0.287	-0.330	-0.337
	(9.30)	(13.49)	(7.69)	(8.77)	(8.88)
D11	2.679	0.770	0.732	1.050	1.019
	(6.46)	(2.21)	(2.10)	(2.93)	(2.85)
D12	-0.530	-0.457	-0.306	-0.172	-0.166
	(7.59)	(7.31)	(4.84)	(2.65)	(2.53)
D13	-0.600	-0.301	-0.133	-0.170	-0.170
	(21.20)	(11.43)	(4.29)	(5.16)	(5.15)

Table 6. (Continued)

Independent variables	Dependent variable: ln (MFP) (1)	(2)	(3)	(4)	(5)
D14	0.877	0.438	0.319	0.437	0.426
	(9.14)	(5.33)	(3.95)	(5.38)	(5.23)
D15	-0.067	0.070	0.216	0.344	0.378
	(0.38)	(0.48)	(1.42)	(2.29)	(2.52)
Intercept	-3277.4	-1297.5	-1444.0	-1782.8	-1813.8
	(11.89)	(4.68)	(5.19)	(6.36)	(6.36)

[a]Each equation is fitted as part of a three equation SUR system containing crop sector productivity, livestock sector, and aggregate productivity.

variable). This is strongly borne out in all three equations.

Commodity-Research Congruence (DISP and $DISP^2$)

Only under very restricted assumptions would one expect the optimal congruence between research and economic importance at the state level to be perfect, i.e., where each commodity had the same share of the state's research budget and commodity income. This would occur only if the "invention potential" or discovery potential was equal for each commodity. Nonetheless, it is intuitively clear that as incongruence increases beyond some level, research productivity would be impaired. The linear congruence term DISP is expected to be positive. The squared term coefficient is expected to be negative[15]

For all three equations, the squared terms $DISP^2$, $DISPL^2$, and $DISPC^2$ are negative as expected. The linear terms DISPC, DISPL, and DISP are positive, indicating that optimally efficient congruence is less than perfect congruence.

Branch Station Effects (SBRAN and $SBRAN^2$)

Research productivity is enhanced by branch station activity, but this enhancement is likely to have a diminishing effect as the proportion of a state's research conducted in stations outside the center rises. Accordingly, the coefficients on the linear terms are expected to be positive and the coefficients on the squared terms are expected to be negative. The signs of the SBRAN/G deflators should be negative.

The linear terms in all three equations are positive, showing that branch stations do enhance research productivity. The geoclimate interaction deflators are negative in all equations, showing that branch station enhancement is more effective the more complex and heterogeneous are geoclimate conditions in the state. The expected diminishing returns, i.e., (negative $SBRAN^2$) terms are borne out in the crops equation and in the aggregate equation, but not in the livestock equation. For the livestock equation, the linear term is not significant, the squared term is positive, and the geoclimate term is strongly negative. This suggests that the binding factor creating diminishing returns to branch station productivity in livestock is geoclimate complexity.

Public Research-Private Research Interactions

Is private research substituting for public research and hence lowering its productivity? If so, negative coefficients for LN(RPR/G) and SBCxLN(RPR/G) will be observed.

For the crop sector, equations (3) and (4) show negative interactions. Additional private research does appear to lower the impact of public research. Specification (5), however, shows that when the state has a large share of biological efficiency research, this is not the case. Thus, it appears that for crop research, private research is competitive with public research except when private research is highly oriented to biological efficiency. (See the following section on production elasticities for further insight on this.)

For livestock, the evidence is that private research complements or enhances public research and does so more strongly the higher the biological efficiency focus. In the aggregate, the interaction is weakly negative.

It should be noted that the variable STPRPBxLN(RPR/G) is also picking up a type of general interaction between private research and both public research and extension. This relationship is a substitute relationship.

Research and Extension Interactions

Extension programs are designed to facilitate information flows regarding technology. They should generally complement both private and public research programs.

The crop equation estimates show that commodity extension has little or no interaction with public research and a weak negative interaction with private research. For livestock, the evidence is similar, except that the private research interactions are more strongly negative. The aggregate estimates reinforce the picture. Public commodity extension programs appear not to have a complementary relationship with public research programs and appear to be substitutes for private-sector research.

Extension and Education Interaction

Most prior studies have found that farmer's education serves as a substitute for public extension programs. This study generally find this to be the case with both types of extension (commodity and management).

Public Policy Impacts

Four variables designed to measure public policy and nonfarm economy influences on productivity are included in these specifications. The estimates show that higher nonfarm wages do appear to generate MFP gains in crops, but to retard them in livestock production.

The price-support variables should have different effects on the different sectors. Price supports should facilitate farm efficiency through stabilizing prices. They can, of course, also induce resources to move from one sector to another. Estimates indicate that higher crop price supports stimulate both crop and livestock (and aggregate) MFP growth. Higher dairy price supports stimulate higher livestock MFP and lower crop MFP, suggesting some (unmeasured) diversion of resources from crop to livestock production. The aggregate estimates clearly suggest that crop programs have enhanced MFP growth while dairy programs have retarded it.

V. Marginal Productivity Elasticities - Research, Extension and Schooling

Table 7 reports the estimated marginal productivity elasticities (as computed at mean levels for the data where required as shown in equations 9-17 in Table 3). These are the key estimates obtained in this study. A discussion of the full economic implications of these results is deferred to the summary.

Table 7. Estimated marginal productivity elasticities: U.S. agriculture 1950-82.

Selected variables	Crop productivity (1)	(2)	(3)	(4)	(5)	Livestock productivity (1)	(2)	(3)	(4)	(5)	Aggregate productivity (1)	(2)	(3)	(4)	(5)
1. Public research: overall	.157	.087	.099	.095	.098	.021	-.019	-.032	.001	.006	.016	.022	.045	.050	.062
a. Science: pretechnology	.021	.035	.076	.168	.163	.162	.073	.090	.165	.249	.066	.108	.129	.175	.164
b. Foci: biol. efficiency				.314	.351				.114	.031				.178	.218
2. Public extension															
Sector commodity focus	-	.082	.105	.090	.072	-	.086	.094	.089	.075	-	.078	.091	.095	.092
Management focus	-	.109	.096	.120	.124	-	-.086	-.095	-.087	-.084	-	.013	-.012	-.004	-.002
3. Private R&D	-	-	.392	.360	.399	-	-	.080	.158	.133	-	-	.178	.247	.259
4. Farmers' schooling	.424	.400	.263	.585	.636	1.098	.980	.986	1.024	.988	.921	.815	.782	.863	.848
Performance criteria															
R^2(single eq.)	.800	.848	.852			.751	.760	.765			.800	.865	.874		
R^2(system)	.743	.878	.817			.743	.870	.817			.743	.870	.817		

The estimated marginal products and marginal internal rate of return are discussed there.

It may be useful to remind readers that these estimates are new in three important respects. First, they are the first estimates differentiating between crop and livestock sectors using state data for U.S. agriculture. Second, they are among the first estimates using a private R&D variable. And third, they are the first to report estimates based on "foci" differences.

The design of Table 7 reflects the testing strategy.[16] Equation (1) sought to estimate only public sector research and schooling effects (including pretechnology science). Equation (2) added public sector extension variables. Equation (3) adds private sector R&D variables and enables a comparison between estimates without (2) and with (3), the private R&D variables. Equation (4) and (5) attempt to explore the research foci dimension by including a distinction between research with a biological efficiency focus and other research.

It is best to begin with a discussion of the aggregate results, since they are the only results that are comparable to previous estimates. These results show that the public research MPE in equations (1) and (2) is relatively low overall, but relatively high for pretechnology science. In specification 2, a relatively high MPE for extension is obtained. The addition of the private R&D variables in specification (3) actually results in larger estimates of public research and extension effects. The MPE for public research (.05) is comparable to several prior estimates. The MPE for private R&D is quite high. Thus, it appears that private R&D has had important spillover effects to the farm sector. The failure in previous studies to include a private R&D variable, however, has probably not biased prior estimates of public research impacts upward.

Efforts to distinguish between research foci (biological efficiency versus other) and extension foci (commodity-focused versus general management) raises something of a puzzle. The estimates show that public-sector research with a biological efficiency focus (much of which is pretechnology science) has an extraordinarily high MPE, while other more management-oriented research has a negative MPE although the combined package has a positive MPE. The extension results are similar in that it is the commodity-focused extension that has the high MPE. Management extension actually has a negative MPE.

This puzzle (if that is what it is) is not solved by reference to the separate crop and livestock estimates. These estimates show that the bulk of the public-sector research impact occurs in the crop sector. This is also true for the private R&D impact, where the MPEs are highest in the crop sector. The public-sector research MPEs are low (even negative in specification 2 and 3) for the livestock sector. (The Appendix shows that TFP gains were lower for the livestock sector and that they were not highly correlated with crop TFP gains across states.) Nonetheless the same strong pattern of high MPEs for pretechnology science and biological efficiency foci for public research systems holds for both sectors. The differential between commodity-focused and general management extension holds only for the livestock sector (and this appears to be the result of private research which was a strong substitute for extension in this sector).

Are these results showing an inefficient "mix" of public research foci (even though they also show the overall package to be productive at least in crop production)? If so, are there explanations for this irrational mix?

To consider this issue, it is useful to review the evidence regarding deflators and interactions. The deflator evidence does not suggest clear reasons for the mix evidence. Geoclimate heterogeneity impinges on research impact and enhances extension impacts for both crop and livestock sectors. It also enhances branch station effectiveness.

There is also no strong evidence to suggest that too much research is conducted in branch stations or that actual congruence of research spending and commodity importance is grossly wrong.

The interactions evidence is a little more helpful. There is some evidence of strong competition or substitution from private R&D when the biological efficiency focus is low (e.g., 5) in each sector, but not in the aggregate. Private R&D also competes with extension. This evidence points in the direction of growing differential competition from private R&D that is reducing the effectiveness of the nonbiological efficiency public-sector research and of general extension.

VI. Economic Returns - A Summary

The estimated MPEs reported can be converted to "estimated marginal products" (EMPs).[17] These EMPs measure the dollars of product per dollar of investment holding all prices constant. The timing of these EMP effects is determined by the "time-shape" weights that were estimated or imputed in the estimation process itself. Given the EMPs, the time-shape weights, and the spillin weights, an investment simulation in which the "stream" over future periods of one dollar investment in time t can be undertaken.[18] The rate of interest that discounts this stream back to a value of one dollar in time period t is the estimated "marginal internal rate of return" (MIRR). It is, in effect, the return on investment realized by the taxpayers over the period in question. Table 8 reports EMPEs, EMPs, and MIRRs for several investment categories.

First, consider public research investments. In the aggregate, returns are exceptionally high, in the 40-45 percent range. Returns to public sector livestock research are moderate to low.

Rates of return to the pretechnology science focused research are higher than for all research and they are especially high in livestock research (in

Table 8 : **Estimated marginal productivity elasticities (EMPE), marginal products (EMP) and marginal internal rates of return (MIRR)**

	Crop Sector		Livestock Sector		Aggregate Sector	
	Equation 3	Equation 5	Equation 3	Equation 5	Equation 3	Equation 5
SAES-USDA Research						
All	.099/2.28/45	.098/2.25/45	—	.006/.23/11	.045/1.49/45	.062/2.66/43
Pre-tech. science	.076/1.75/40	.163/3.75/57	.090/3.33/54	.249/9.21/83	.129/4.28/60	.164/5.44/67
Private R&D	.392/11.18/90	.399/11.38/90	.080/3.75/57	.133/6.23/71	.178/6.26/71	.259/9.10/83
Public Extension						
Commodities (all)	.105/8.62/138	.072/5.91/101	.094/5.80/99	.075/4.63/81		
Farmers Schooling (1 yr)	—	.636/2486/17	—	.989/3127/22	—	.848/6146/37

part because they serve the private R&D sector). Under the assumption that the benefit flows from pretechnology science research would have required a 12-year period to rise to their maximum instead of the 7 built into the estimates, the aggregate MIRR for pretechnology science would have been approximately equal to the MIRR for all research. Thus, it seems safe to conclude that pretechnology science research has been at least as good from an investment-perspective as the more applied invention oriented research.

Public sector extension also appears to have been a good investment for the taxpayer. Although the management oriented extension appears to have little impact, the returns to investment on all extension including the managerial have been high. Returns to farmers' schooling in the aggregate are estimated to be high also.

The high returns to private sector R&D, obtained from the state multifactor productivity analysis, require a special interpretation. They are, in fact, returns to the public from private sector investment. Presumably the private firms doing this R&D also captured a return from their investment, but this calculation measures the benefits to the public not captured by the private firms through higher prices for their products.

These estimates can be directly compared with other estimates from previous studies in terms of the EMIRRs which have a reasonable degree of comparability between studies. Table 9 reports a summary of 22 previous studies in addition to the present studies. Since the earliest studies of Zvi Griliches in 1958 (and T.W. Schultz in 1953) the role of the SAES-USDA system has been quite extensively studied. The estimates obtained in the studies reported in this paper are, in general, consistent with earlier studies even though the methodology and scope of this study were broader than in previous studies (particularly as regards the treatment of private sector R&D).

Table 9 reports 36 estimated MIRRs for public sector research. Only the

Table 9: Comparative estimates of returns to research, extension and schooling for U.S. agriculture.

Study	Type	Commodity	Period	Spill-in proportion	Estimated MIRR
I. Public-research impacts					
Griliches, 1958	I-A	Hybrid corn	1940–1958		35–40
Griliches, 1958	I-A	Hybrid sorghum	1940–1957		20
Peterson, 1967	I-A	Poultry	1915–1960		21–25
Schmitz and Seckler, 1970	I-A	Tomato harvester	1958–1969		37–46
Peterson and Fitzharris, 1977	Meta-prod. fn.	Aggregate production	1937–1942		50
		Aggregate production	1947–1952		51
		Aggregate production	1957–1962		49
		Aggregate production	1957–1972		34
Griliches, 1964	Meta-prod. fn.	Aggregate production	1949–1959		35–40
Latimer, 1964	Meta-prod. fn.	Aggregate production	1949–1959		not signif.
Peterson, 1967	Meta-prod. fn.	Poultry production	1915–1960		21
Evenson, 1969	Meta-prod. fn.	Aggregate production	149–1959		47
Cline, 1975	Meta-prod. fn.	Aggregate production	1939–1948		41–50
Knutson & Tweeten, 1976	Meta-prod. fn.	Aggregate production	1949–1958		39–47
			1959–1968		32–39
			1969–1972		28–35
Bredahl & Peterson, 1976	Meta-prod. fn.	Cash grains	1969		36
		Poultry	1969		37
		Dairy	1969		43
		Livestock	1969		47
Davis, 1979		Aggregate production	1949–1959		66–100
			1964–1974		37
Evenson & Welch, 1979		Crop production	1964	.6	55
		Livestock production	1964	.85	55–60
Evenson, 1979	TFP decomp.	Aggregate production	1868–1926		65
	TFP decomp.	Aggregate production	1927–1950		95
	TFP decomp.	Aggregate production			
		South	1948–1971	.4	130
		North	1948–1971	.5	93
		West	1948–1971	.3	95
		USA	1948–1971	.7	45
White and Havlicek, 1982	Meta-prod. fn.	Aggregate production	1943–1977		36

Table 9 (continued

Study	Type	Commodity	Period	Spill-in Proportion	Estimated MIRR
Present study (sp. 5)	TFP decomp.	Crops (A)	1950-1982	.4	45
		Livestock (A)	1950-1982	.8	11
Huffman & Evenson	Meta-profit fn.	Aggregate production	1950-82	.6	43
		Crops	1949-1978	.4	62
II. Pre-technology impacts (public sector)					
Evenson, 1979	TFP decomp.	Aggregate production	1927-1950		110
	TFP decomp.	TFP decomposition	19		
Present study (sp. 5)	TFP decomp.	Crop production	1950-1982		57
		Livestock production	1950-1982		83
		Aggregate production	1950-1982		67
III. Private sector R&D impacts					
Evenson, 1979	TFP decomp.	Aggregate production	1868-1926	nc	significant
		(invention index)	1927-1950	nc	significant
Present study (sp 5)	TFP decomp.	Crop production	1950-1982	.97	90
		Livestock production	1950-1982	.97	71
		Aggregate production	1950-1982	.97	83
IV. Extension					
Huffman, 1976	TFP decomp.	Aggregate production	1964		110
Evenson, 1979	TFP decomp.	Aggregate production	1948-1971		100+
Huffman, 1981	Meta-prod. fn.	Aggregate production	1964		110
Lu, Quance and Liu, 1978	Meta-prod. fn.	Combined res. and ext.	1939-1972		25
Lu, Cline and Quance, 1979	Meta-prod. fn.	Combined res. and ext.	1939-1948		30.5
			1949-1958		27.5
			1959-1968		25.5
			1969-1972		23.5
Present study (sp. 5)	TFP decomp.	Crops extension	1950-1982		101
		Livestock extension	1950-1982		99
		Aggregate	1950-1982		82
V. Schooling - Impact on production					
Welch, 1970	Human capital	Aggregate production	1964		83
Present study (sp 5)	TFP decomp.	Aggregate production	1950-1982		37
Huffman & Evenson, 1980	Meta-profit fn.	Crop production	1949-1978		15

very early study of Latimer finds an insignificant productivity impact, although the result for livestock research in this study may be regarded to fall in the same category. Returns to pretechnology science research have been estimated in only one prior study. The present study confirms the prior estimates showing exceptionally high returns to this research.

As with pretechnology science, the contributions of the private sector to agricultural productivity have been estimated in only two prior studies. This is clearly an area calling for more study to confirm (or reject) these results. If confirmed, they illustrate an important avenue for technological progress and productivity gains. They further raise questions regarding the effectiveness of public sector research in a setting with expanded private sector R&D. Finally, the returns to schooling results from the present study confirm previous findings that schooling is an important determinant of production efficiency in agriculture.

FOOTNOTES

1. Antle and Capalbo (1988) also provide a review of these procedures.

2. The unfortunate tendency to identify the residual TFP measure as "technological change" without actual analysis created a poor reputation for TFP measures among many economists. This poor reputation continues because many economists have not followed the empirical literature seeking to analyze sources of growth in this residual.

3. This point is particularly relevant to identifying returns to investment in research. The contribution of research may be partially picked up by quality indexes. Welch (1970) reported that returns to schooling in U.S. agriculture were higher because of the flow of new technology.

4. The treatment of private costs can be handled in different ways. The hybrid corn study computed a return to combined public and private research spending. This is not the return realized by the private firms in the hybrid seed corn industry. They realized a lower rate of return because the higher prices that they could charge for superior seed did not capture the full value of the improved technology.

5. The absurdity of the 700 percent rate of return can be seen by realizing that a dollar invested at a 700 percent compound rate will grow into the world's GNP in approximately 20 years.

6. Let $M_t = P_t + e_t$, where M_t is measured TFP in t, P_t is true TFP in t, and e_t is the weather error in measured productivity, and $M_{t+1} = P_{t+1} + e_{t+1}$, then (1) $M_{t+1} - M_t = P_{t+1} - P_t + e_{t+1} - e_t$.

But $M_{t+2} - M_t = P_{t+2} - P_t + e_{t+2} - e_t$

$$= (M_{t+2} - M_{t+1}) + (M_{t+1} - M_t)$$

or

(2) $M_{t+n} - M_t = P_{t+n} - P_t + e_{t+n} - e_t$.

Thus, the error terms for the intermediate years do not appear in a cumulative productivity index (2). The cumulative index has the advantage that errors are a relatively small share of the measured productivity change and the specification of the weather variable can be made simpler. The effects of weather in t can be averaged out by taking a 3-4 year average as the beginning base of the series. A specification for weather in t+n is then all that is needed.

7. See Feder and Slade (1986) for a treatment of this problem in a study of extension impact in India.

8. Other specifications for equation (2) were also tried. They included

$R_i^* = R_i^{\beta_1} RSS_i^{\beta_2} RSR_i^{\beta_3}$ where the β_js are unknown coefficients.

9. An earlier study (Evenson 1988) for the 1948-71 period estimated $\alpha = .5$ for a specification utilizing aggregate, i.e., crops plus livestock, TFP.

10. Adams (1989) and Jaffe (1986) incorporate interindustry spillin effects into their productivity analyses.

11. This definition is, of course, subject to some differences in interpretation by researchers.

12. The charge that the public research system engages in "duplicative" field trials and too much state-specific management can be indirectly examined with these specifications.

13. The mean square errors for alternative α value (0, 0.1, 0.3, 0.4, 0.5) in the OLS specification of productivity containing all final variables were for the crop sector: .024606, .023930, .023192, .022594, .02282, .022247 and for livestock sector: .016046, .016285, .016636, .017037, .017287, .017726.

14. These weights were not estimated.

15. That is we expect diminishing optimal departures by congruences.

16. Joint tests for the significance of the coefficients entering into each elasticity reported in Table 7 were performed. In addition, tests on the actual elasticity levels - evaluated at mean levels were performed. The tests showed that all elasticities in the table exceeding .015 were significant at the .005 level.

17. The procedure for connecting the elasticity to a marginal product entails the following steps:

1) Compute MP = elasticity * mean output/mean research stock.
2) Compute the ratio of the research stock to annual investment. This implicitly adjusts for the deflation weighting.
3) Adjust for double counting due to spill-overs.

The relevant data for the computation are:

Means per SD	Crop sector	Livestock sector	Aggregate
Output ($000)	1993	1613	3607
Public res. ($ mil)	17.71	30.42	23.96
Private res. ($ mil)	358	198	278
Extension Com. (day)	25.719	17.814	23,325
Extension Manager (days)	17,257	17,257	17,257
Adjustments			
Public research	1.66	5.17	3.42
Private research	42	42	42
Deflation adj. pub. res.	.123	.135	.0645
pri. res.	.122	.137	.0647
ext.	1	1	.5
Value per ext. day	151	151	151

So for public crop research, the calculation of the EMP is .099 x (1991/17.71) x 1.66 x .123 = 2.25.

18. The MIRR is calculated as the rate of interest (r) that solves the following equation

$$1 = \sum_{i+t}^{t+n} W_i \, MP_i /(1 + r)^i$$

where the W_i, are the time weights for research and extension. Note that extension weights are very short (.5, .25 and .25) where it is presumed that the .5 weight applies in year T+1. Research weights have a rising pattern for 7 years, constant for 6 and declining for 20, so the MP impact is expected to last over a period of 33 years.

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APPENDIX

Crop and Livestock MFP Indexes for U.S. Agriculture

W. Huffman and
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Measuring MFP for the Crop and Livestock Sectors

The USDA publishes indices of farm output, input, and total factor productivity annually in Changes in Farm Production and Efficiency. Some information about the procedures used to construct these indices is available in Agricultural Handbook No. 365 (1970); more details appear in USDA (1980) and Hauver (1989). The output and input indices are Laspeyre's quantity indices with base-period price weights; the base periods are changed every ten years, and the historical series are spliced together. In 1980, an AAEA task force reviewed the USDA productivity series and made several recommendations for improving the series (USDA, 1980).

In the development of state TFP series, we have attempted to take account of most of the recommendations of the AAEA task force. Our most disaggregate measures are state productivity indexes for crop and livestock sectors. There are some data limitations that affect the state series to a greater degree than they affect regional or national aggregate series.

A Summary of Our Procedures

Our objective is to create new state productivity data for the aggregate farm sector and for the crop and livestock sectors. Gross output/gross input measures by state-sector units give the most insight to agricultural productivity. Intermediate inputs for one sector are purchased from the other agricultural sectors and from nonfarm industries. Productivity changes can be due to increased efficiency of use of intermediate inputs, primary inputs, and (or) other things. Furthermore, relative input prices may change over time and cause substitution between primary and intermediate inputs so that input cost shares change over time. Care must, however, be taken to perform consistent aggregation over sectors.

Within a multifactor productivity framework, it is insightful to split agricultural production into two major sectors: crop and livestock. First, crop and livestock production frequently occurs on different farms and in different geographical locations. Second, crop output is an input into livestock production, but livestock output is not generally an input into crop production. Third, the biology of crop and livestock production is different, and crop and livestock production can be expected to respond differently to local geoclimatic conditions and to research. With disaggregation, crop productivity effects can in principle be traced through the crop and livestock sectors. Thus, a clearer picture of agricultural productivity can be obtained from the two crop and livestock productivity indexes than from one productivity index of the aggregate output. The primary disadvantage to constructing sector-specific productivity indexes is that it is not easy to allocate some of the farm inputs between the two sectors, given the available data.

Farm Output Measures

Our output index is constructed from 34 different output categories. There are 26 crop categories and 8 livestock categories. Crop output that is fed to livestock is treated both as an output of the crop sector and as an input into the livestock sector. Feeder livestock are treated as an output in the state or region where they are produced, and the output of livestock feeding enterprises is net weight added to feeder livestock. Output in all cases was measured as calendar year production.

Where possible, all of our quantity indexes for outputs and inputs are the Tornqvist-Theil type. The output prices are "expected" farm level prices for each production year. The weights for constructing the quantity indexes are based upon farm level market prices. The weights for each item for each year t is the simple average of its revenue (cost) share weight in t and t-1.

Input Measures

Our input measures are derived largely from data presented in the USDA's Farm Income Statistics. This occurs because (i) we believe that these are reasonably good data and (ii) because we wanted to derive annual state level indexes. The input categories in the Farm Income Statistics are fertilizer, seed, repair and operation of capital items, hired labor, feed purchased, livestock purchased and miscellaneous expenses. The input categories that we derive measures for are sector-specific. For the crop sector, the input categories are: fertilizer, seed, land, labor, capital services and miscellaneous. For the livestock sector, they are feed purchased, feed fed on farms, hay, land, labor, capital services, and miscellaneous.[1] See Table A.1 for output and input shares.

Labor

The USDA measures man-hours of farm labor by summing labor requirements (per unit of production) over all planted acres or units of livestock. The labor input is based on benchmark figures for the time an average agricultural worker takes to cultivate an acre of the crop in question or to care for a particular type of livestock. The benchmark figures are infrequently revised. The resulting figures are grossed-up by 15 percent in an attempt to incorporate general farm time overhead.

Instead of using labor-requirements data, we based our estimate of farm input on direct measures of employment. We used two sources. For hired labor, we used expenditures on labor published in the USDA Farm Income Statistics. We divided by the average wage for agricultural laborers working for cash wages to obtain annual hired labor man-hours. We based our estimate of unpaid family and operator labor on the surveys of the Statistical Reporting Services (USDA) published in Farm Labor.[2]

We did use the USDA's benchmark data for average time spent on specific crop (labor per acre) and livestock production (labor per unit of output) to help us allocate labor between sectors.[3]

Feed Grains

Following the gross output/gross input concept, crop output fed to livestock is treated as crop sector output and as livestock sector input. Our approach is in contrast to the USDA which employs a net measure of productivity. Farm-grown intermediate products are netted out of outputs and inputs. Most notably, they compute feed input as a proportional constant multiplied by the quantity of livestock produced. (The constant varies by livestock type.) Of this total, a share is taken to represent value added outside the farm sector by commercial processors and is counted as farm input. The remaining share is considered as an intermediate product of the farm sector, and it is not counted as farm input. Thus, the estimated quantity of feed raised on farms and fed to livestock is subtracted from feed grain output.[4]

Land

Our land series is measured in cropland units and based on Census of Agriculture data. We obtained data from each census 1950-1983 for 3 classes of cropland (crop inputs):

(1) Irrigated cropland,

(2) Non-irrigated cropland,

(3) Idle cropland,

and 4 classes of pasture land (livestock inputs):

(1) Irrigated pasture land,

(2) Cropland pastured,

(3) Woodland pastured,

(4) Other pasture (chiefly rangeland).

The census series were interpolated between agricultural censuses and were converted to "non-irrigated cropland equivalents" using weights reported in a study by Hoover. Cropland in summer fallow, conservation uses (including acres set aside or diverted by the government program) and not harvested due to crop failure were included in idle cropland. A real cash rent series was then developed for the non-irrigated cropland and used as the input price.

Other Inputs

The capital input consists of a service flow on buildings and machines plus repair and operating expenses for buildings and machinery. The repair and operation of machinery and buildings input series were allocated between crop and livestock sectors using the same ratio used for allocating labor.

The service flow on buildings and machinery was computed from unpublished USDA data for depreciation on structures, tractors, trucks (farm use), automobiles (farm use) and other equipment. All of tractor services were allocated to crops, but other machinery services and buildings were allocated to crop and livestock sectors using the same ratio used for allocating labor.

Geoclimatic Regions

Geoclimatic regions are not confined to state boundaries, and they have somewhat more intra-region homogeneity than ERS agricultural production regions. Figure 1 depicts the 16 geoclimatic regions (Evenson 1982) and Table A.12 presents annual average aggregate multifactor productivity growth rates for the whole period 1950-82. Productiviy growth rates differ significantly across the geoclimatic regions. For crop, livestock and aggregate production, the Mississippi Delta had the highest average rate of productivity increase. The Northeast Dairy Region and Middle Atlantic Coastal Plain had the lowest average crop productivity growth rate (.75 and 1.07%), and the dry western mild-winter region (16) had the lowest average livestock productivity growth rate. In comparing productivity growth rates for the geoclimatic regions and ERS production regions, we note numerous similarities, e.g., Delta States and Mississippi Delta, Corn Belt and Midland Feed Region, Mountain States and Grazing Irrigated Region.

State Indexes

Productivity indexes (for total output and crop and livestock sectors) for the period 1950-82 have been constructed for 42 U.S. states (excludes six New England states, Alaska, and Hawaii). Table A.3 reports state acreage multifactor productivity estimates for 1950-1982 and efficiency estimates as of 1950. The states having the highest rate of multifactor productivity growth for the crop sector were Mississippi (3.99%) and Alabama (3.51%). At the other extreme, crop productivity in Utah, New York, and New Jersey declined slightly on average over the period 1950-1982. For livestock productivity, Mississippi, Arkansas, and Kentucky had the highest average growth rates (3.5-3.6%). Arizona and Nevada had a negative average livestock productivity growth rate during this period, and Iowa and Illinois are only slightly better-essentially no change on average in livestock productivity during 1950-1982. For aggregate output, Mississippi and Arkansas (Delta states) had the highest average productivity growth rates, 3.82 percent and 3.37 percent respectively. Arizona and Utah had productivity growth rates that were lowest, less than .25 percent on average.

The "efficiency index" for 1950 reported in Table A.3 was defined as

$$\sum_i \overline{P}_i Q_{is} / \sum_j \overline{R}_j I_{js}$$

where Q_{is} are outputs in states (s), I_{js} are inputs in states (s) and $\overline{P}_i$ and $\overline{R}_j$ are national average prices for outputs and inputs. The average of this efficiency index over all states is 1.00. The individual state ratios are true efficiency indexes only if all inputs and outputs are correctly measured in constant quality units.[5]

Table A.3 shows that considerable variation seemed to exist across the states in production efficiency in 1950. For the crop sector, the largest values of the index were for California (1.90), Kansas (1.78), Florida (1.66), and Washington (1.62). At the other extreme, low crop efficiency seemed to exist in West Virginia (.36), Nevada (.45), Wyoming (.46), South Carolina (.53), Oklahoma (.54) and Mississippi (.54). Thus, these indexes of crop production efficiency have a range that differs by about a factor of 5 times.

The range of values across the states for the livestock efficiency in 1950 is much smaller than for the crop index. The largest values of this index were for Delaware (1.58) and Florida (1.46). The states with the lowest livestock efficiency were West Virginia (.67), New Mexico (.68), Arizona (.69) and Kentucky (.72). These indexes of livestock efficiency differ by only a factor of 2 across the states.

Footnotes

1. The treatment of private costs can be handled in different ways. The hybrid corn study computed a return to combined public asnd private research spending. This is not the return realized by the private firms in the hybrid seed corn industry. They realized a lower rate of return because the higher prices that they could charge for superior seed did not capture the full value of the improved technology.
2. Our input measures are considerably different from those used by the USDA in its productivity measures (Hauver, 1989). Large differences exist for the land, labor, capital service, and feed inputs.
3. Also the AAEA Task Force concluded: "If the SRS' data were moved to a monthly survey instead of the current quarterly sampling, it would be our choice as a basis for the national labor input." Our approach adjusts the quarterly series for the information contained in the earlier monthly series.
4. Benchmarks were changed at 5-year intervals. Crop and livestock activity time-share were computed for each of the benchmarks, and these shares were used to allocate the actual farm labor series between the crop and livestock sectors. We believe that any error in this allocation will make only a slight difference to rates of growth agricultural productivity.
5. The USDA's procedure is unsatisfactory. First, as noted by the AAEA Task Force (USDA, 1980): "The fully gross approach has two practical benefits: (1) the data used to net out farm-produced feed are dubious in many respects, and (2) the fully gross measure facilitates growth accounting by

means of production functions or other methods." Also, the net approach seems particularly ill-suited to development of productivity indices at the state level. Productivity differences across states will be difficult to disentangle by an approach that obscures whether productivity improvements originate in the use of fertilizer and machine power to grow crops or in the development of specialized feedlots and the conversion of grain to animal weight.

6. Although the Evenson-Landau-Ballou data contain major adjustments for input quality, we know that the quality of the labor input differs across states in 1950, but other inputs should not differ significantly in quality across the states.

7. Further elaboration of the research variable is required. The public research variable incorporates three implicit deflators as well as a timing and spillin dimension. In constructing RPB, each type of commodity research is weighted by the production commodity shares, the estimated time-lag pattern is represented by the set (7,6,20), and the spillin weights from subregions and regions are represented by (.5,0) for crops and (1,1) for livestock research. For the spillin weights of crop research, crop research conducted in states located in similar subregions has a weight of one-half relative to a weight of one for a state's own research. Crop research in other states has a weight of zero. For livestock research, research conducted by a given state and by other states in the same subregion or region have the same weight (1).

8. The change that the public research system engages in "duplicative" field trials and too much state specific management can be indirectly examined

Table A.1 Output and Input Shares: U.S. Agriculture (42 States) 1950-1982

I. Selected Output Shares	1951-60	1961-70	1971-77	1978-82
A. Crop Production				
Tobacco	.059	.064	.050	.044
Cotton	.118	.081	.060	.052
Corn	.174	.160	.183	.197
Oats	.043	.029	.017	.013
Wheat	.146	.117	.132	.136
Soybeans	.040	.080	.121	.149
Tomatoes	.051	.053	.034	.024
Potatoes	.031	.034	.034	.029
B. Livestock Production				
Milk	.242	.247	.245	.263
Eggs	.101	.095	.075	.060
Broilers	.087	.084	.090	.102
Turkeys	.020	.019	.020	.021
Cattle and Calves	.346	.389	.410	.396
Hogs and Pigs	.147	.120	.124	.117
Sheep and Lambs	.027	.018	.011	.010
Other Livestock products	.029	.028	.025	.031
II. Input Shares				
A. Crop Production				
Fertilizer	.069	.087	.118	.111
Seeds	.035	.035	.051	.049
Land	.175	.221	.213	.213
Miscellaneous	.083	.113	.154	.200
Labor	.453	.357	.292	.235
Capital Services	.183	.187	.172	.193
B. Livestock Production				
Feed purchased	.272	.320	.352	.335
Feed Fed on Farm:				
Hay	.028	.032	.038	.041
Land	.133	.152	.136	.141
Miscellaneous	.055	.082	.112	.150
Labor	.311	.270	.219	.179
Capital	.026	.029	.023	.030

Table A.2 TFP Growth by Geo-climate Region

Region	Crop TFP Growth 1951-60	1961-70	1971-77	1978-82	Livestock TFP Growth 1951-60	1961-70	1971-77	1978-82
1. Northeast Dairy Region	1.32	2.68	-2.21	-.08	1.90	1.40	1.15	3.81
2. Middle Atlantic Coastal Plain	1.97	2.00	-2.43	2.34	3.06	2.41	2.09	2.82
3. Florida & Coastal Flatwoods	.92	2.61	1.19	.87	2.10	-1.13	2.89	.56
4. Southern Uplands	4.61	2.48	1.77	1.95	3.76	1.17	1.45	2.70
5. East-Central Uplands	3.40	1.47	2.27	2.47	2.31	1.71	.66	3.65
6. Midland Feed Region	3.30	1.45	3.00	1.93	1.23	1.07	.63	.69
7. Mississippi Delta	4.56	4.01	1.94	2.06	4.13	2.04	3.09	4.01
8. Northern Lake States	2.59	2.87	4.14	.31	1.36	1.59	2.51	.71
9. Northern Great Plains	1.70	1.81	2.76	3.18	2.68	.25	1.54	-.61
10. Winter Wheat & Grazing Region	4.82	.30	2.14	.29	1.67	.93	-.16	1.60
11. Coastal Prairies	4.61	2.35	3.19	-2.83	1.87	.78	1.37	1.83
12. Southern Plains	6.60	.06	4.29	-3.72	1.76	-.30	.39	.99
13. Grazing-Irrigated Region	.41	3.06	.26	.38	1.74	.20	.88	1.63
14. Pacific Northwest Wheat Region	-.57	3.61	1.22	2.09	2.77	.73	1.87	2.61
15. North Pacific Valleys	1.12	3.05	2.31	.76	2.05	1.10	.68	2.31
16. Dry Western Mild-Winter Region	2.48	2.18	3.55	-2.33	.09	.47	.05	.11

Table A.3 Annual crop and livestock MFP growth rates and efficiency index in 1950, by states, 1950-1982.

	MFP Growth 1950-82			Regional coef. of variation total (%)	Efficiency Index 1950		
	Crop	Live-stock	Aggre-gate		Crop	Live-stock	Aggre-gate
Northeast							
New York	-.10	1.45	.79		1.13	1.01	1.07
New Jersey	-.14	1.36	.68		1.91	.95	1.34
Pennsylvania	1.89	2.43	2.24		.84	.75	.79
Delaware	.87	3.60	2.45		1.36	1.58	1.54
Maryland	1.07	2.32	1.74		1.14	1.03	1.04
Region Total	.27	2.05	1.24	1.10			
Lake States							
Michigan	2.90	1.98	2.50		.88	.90	.90
Minnesota	3.33	1.12	2.22		.84	1.06	.97
Wisconsin	1.79	1.70	1.60		.80	1.04	.98
Region Total	2.34	1.52	1.77	1.16			
Corn Belt							
Ohio	2.09	1.47	2.01		1.17	.83	.96
Indiana	2.55	1.01	2.06		1.21	.98	1.08
Illinois	2.29	.03	1.69		1.38	1.03	1.88
Iowa	2.50	.01	1.26		1.25	1.17	1.21
Missouri	2.49	1.40	1.97		.86	1.00	.95
Region Total	2.07	.58	1.47	1.03			
Northern Plains							
North Dakota	2.41	1.26	2.24		.92	1.07	.96
South Dakota	2.52	.86	1.79		.73	1.02	.85
Nebraska	2.12	.46	1.59		1.09	1.02	1.05
Kansas	2.03	1.19	1.91		1.78	1.67	1.84
Region Total	2.05	.81	1.68	0.95			
Appalachia							
Virginia	1.37	2.65	1.99		.83	.79	.82
West Virginia	1.62	3.33	2.56		.36	.67	.54
Kentucky	2.57	3.54	3.05		.82	.72	.77
North Carolina	2.51	3.39	2.74		.78	.77	.77
Tennessee	2.67	2.30	2.50		.71	.85	.76
Region Total	2.11	3.09	2.49	0.92			
Southeast							
South Carolina	3.21	3.30	3.23		.53	.80	.56
Georgia	2.85	2.07	2.67		.69	1.23	.82
Florida	1.12	.60	.96		1.66	1.46	1.58
Alabama	3.51	2.89	3.29		.61	.98	.70
Region Total	2.56	2.11	2.43	1.05			
Delta States							
Mississippi	3.99	3.64	3.82		.54	.80	.59
Arkansas	3.14	3.56	3.37		.70	1.01	.77
Louisiana	2.98	2.76	2.89		.74	1.04	.80
Region Total	3.15	3.31	3.22	1.09			
Southern Plains							
Oklahoma	3.45	1.28	2.65		.54	1.19	.79
Texas	2.06	.51	1.58		.78	1.16	.90
Region Total	2.16	.63	1.70	1.38			
Mountain States							
Montana	.51	1.39	.89		.96	.97	.96
Idaho	1.14	1.26	1.25		1.37	1.05	1.25
Wyoming	1.14	.93	.79		.46	.76	.63
Colorado	1.95	1.20	1.73		.67	.99	.81
New Mexico	2.59	.39	1.54		.51	.68	.58
Arizona	.96	-.90	-.01		1.39	.69	1.11
Utah	-.43	1.15	.56		.99	1.07	1.05
Nevada	2.25	-.43	.24		.45	1.01	.82
Region Total	.99	.70	.89	0.54			
Pacific States							
Washington	1.53	2.26	1.88		1.62	.80	1.23
Oregon	2.00	1.50	1.79		1.11	1.03	1.07
California	2.10	.69	1.62		1.90	1.06	1.57
Region Total	1.74	1.08	1.55	0.99			