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Measuring the Costs and Returns to Agricultural Research:
Historical Perspective

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I. The Nature of Research

As an economist I find it helpful to view research as an investment
process which yields a capital good--a stock of knowledge relating in this
case to agriculture. Similar to the production of other capital goods such
as buildings or machines, the amount of knowledge produced during a given
period of time (K_t) depends on or is a function of the quantity of inputs
utilized. These inputs include scientific labor years along with the labor
of supporting personnel (L_t), various forms of capital such as test plots,
laboratory facilities, vehicles, computers, etc. (C_t), and other miscellaneous
inputs such as energy and supplies (I_t). Thus one can write a research
production function of the general form:

(1) $K_t = f(L_t, C_t, I_t)$

The quantity of research capital (K) which exists at any point in time
is equal to the summation of all previous years output, or import, of know-
ledge minus the proportion that has depreciated over time.

(2) $K = \sum_{t=0}^{T} (K_t - d_t K_t)$

where $0 \leq d_t \leq 1$

If d_t equals zero none of the knowledge produced in year t has depreciated;
if d_t equals one, 100 percent has depreciated. The reasons why knowledge
can depreciate will be discussed shortly.

Knowledge produced by agricultural research has value to society to
the extent that it improves the quality of conventional inputs such as labor,
seeds, or machines, or leads to the production of totally new inputs such

as chemicals or vaccines. The familiar increase in total factor productivity, i.e. the increase in this ratio of output over inputs, O/I, observed in the developed countries' agricultural sectors is due to quality improvements in conventional inputs, or to new inputs that are not measured perfectly for quality. The effects of higher quality inputs or of new inputs show up in the numerator as increased agricultural output but the higher quality is not accurately reflected as additional inputs in the denominator. Hence it appears that society is getting more output per unit of input. However, if all inputs were measured perfectly for quality, i.e. by their contribution to output, or VMP, the O/I ratio would remain stable. This is not to say that an observed increase in the O/I ratio is to be avoided. The main point here is that this ratio has increased over time because higher quality inputs have not been accurately measured, and that these quality improvements have come from research.

A. Similarities to Other Investment

Viewing research as an investment allows us to compare it with more conventional types of investment, and as a result enables one to gain a better understanding of the process.

1. A production activity. As indicated by equation (1) the output of knowledge in a given time period (K_t) depends on the amount of inputs utilized in its production. In principle this activity is no different from the production of any other capital or consumption good. Viewing research as a production activity which produces a capital good allows us to bring to bear our traditional economic tools and concepts such as rates of return, diminishing returns, economies and diseconomies of scale, etc. in our analysis of this investment.

2. Increases the productivity capacity of society. The total output of any society is governed by the quantity of inputs or resources at its disposal. Investment in capital increases the total inputs or resources of an economy and makes possible an increase in total and per capita output. There is still much to be learned about economic growth. But one thing is certain: there cannot be output without inputs nor can there be an increase in output without an increase in inputs. The same is true for agriculture. In the framework of an aggregate agricultural production function, total agricultural output during a given year (Q_t) is a function of land area (A_t), labor (L_t), capital (C_t) and intermediate inputs (I_t) such as fertilizer and herbicides.

$$(3) \quad Q_t = g(A_t, L_t, C_t, I_t)$$

As mentioned, agricultural research makes its contribution to output by increasing the quality of conventional inputs and/or by making possible the production of new, nonconventional inputs. Since X units of a higher quality input is more input than the same units of one of lower quality, the end result is an increase inputs and output, other things equal.

3. Depreciates over time. Two reasons are generally given for the depreciation of capital produced by research (K): 1. obsolescence and 2. changes in the environment. One might argue that research capital which made possible a new crop variety that was in turn replaced by a still newer variety has depreciated to zero. On the other hand, the knowledge that made possible the old variety may have facilitated the development of the new variety. Thus it is not clear whether the old knowledge has depreciated or not. Environmental changes, such as the appearance of new disease organisms which reduce yields of current crop varieties can also be viewed as a source of depreciation. But again the issue is not clear cut. Knowledge used to breed the current varieties may still be useful in developing newer, disease

resistant lines. The pattern and extent of depreciation of research capital
is still largely uncharted territory in this general area of inquiry.

B. Differences from Other Investment

1. Is not routine. Unlike the production of a structure or machine
where the builder can follow a detailed blueprint, research, by definition,
is something that has not been done before in exactly the same way. As a
consequence, the outcome of conventional investment is relatively certain
but the outcome of research is not. In 99.9 percent of the time, a finished
building or machine will look like and perform according to its specifications.
In the case of research the output of individual projects is virtually
impossible to predict. Perhaps the closest analogy is drilling for oil
where one or two holes out of each ten drilled turn out to be gushers.
Likewise one or two projects out of ten may yield new and useful information
that has commercial value. The upshot of this difference between research
and other investments is that it is very risky to evaluate the expected
returns to research at the individual project level. This risk increases
as one moves toward the more basic type of research.

Even if one assigns some expected probability of success to individual
projects, ex ante evaluation of individual projects will yield gross over-
estimates of the returns to the "dry holds" but will seriously underestimate
the returns to the "gushers". Ex ante evaluation is best performed on large
numbers of projects where the ratio of successful projects to failures is
relatively stable. Attempts to "manage" research by "outsiders" on the basis
of ex ante evaluation of individual projects is likely to have a negative
impact on the returns to research because of its bias against high risk
but potentially high payoff projects.

2. Output may not carry property rights. This difference is most critical to basic research which yields new understanding or ideas. The inability of private firms to patent or copywrite ideas, diminishes their incentive to carry on such research except on a token scale, or as a by-product of more applied endeavers. This characteristic of basic research serves as the main justification for public support of this investment.

3. Training component. Not all of the money spent on basic research is for research--part is for the training of future scientists. It is not clear, however, that the elimination of all graduate training from research institutions would result in a higher rate of return to research. There appears to be a range where graduate training and research are complementary (Pardey). That is, the presence of graduate students enhances the productivity of scientists. And research strengthens the teaching in graduate institutions. Unfortunately much of the agricultural research and graduate training in developing countries are conducted in different institutions, an organization which does not take advantage of this complementarity.

4. Output has value only when combined with other inputs. Investment which results in the production of buildings or machines yields a return through the contribution of these assets to production. However knowledge produced by investment in research can make a contribution to society's output only to the extent that it makes possible the production of entirely new inputs, or results in improved quality in conventional inputs. Thus the link between investment and the resulting increase in output is longer and less direct for research than most other investments. As a further consequence, the lag between research and the resulting increase in output is relatively long. In fact there are two lags: 1. the lag between

research inputs and the output of knowledge, and 2. the lag between the

output of knowledge and the utilization of this knowledge in the production

of new or improved inputs.

5. May not be subject to diminishing returns. Holding other inputs

constant, successive additions of an input will at some point lead to a

decrease in its contribution to output, i.e., diminishing returns set in.

To simplify the discussion, assume there are just two inputs or resources

in the research process--scientific effort and the potential stock of know-

ledge which remains to be discovered. Will future increases in scientific

activity eventually lead to diminishing returns to this input? At the

narrowest level of the individual project, the answer would seem to be

yes. But moving to broader levels of research such as all crops or all

livestock, to all agriculture, and finally to all science, the answer

becomes less and less obvious. If the potential stock of knowledge is

finite, diminishing returns to scientific effort must set in. However,

if the stock is infinite, diminishing returns is not inevitable. Unfor-

tunately this question is unanswerable because the potential stock of

knowledge is unmeasurable.

II. Measuring the Output of Agricultural Research

From a conceptual standpoint, measuring the output of research is rather

straightforward. Research is a production activity that produces additions to

the stock of capital, K_t, each time period. The problem begins when one tries

to place a value on this asset. For lack of an alternative measure, the

convention has been to measure the stock of capital by its cost of

production. This is commonly done for public goods that are not exchanged

in a market. The question then becomes, what is the rate of return on this

stock of capital? To yield a return, the capital must yield a flow of services

over a period of time. In the case of research capital, this flow of services is the improvement in quality of conventional inputs or creation of totally new inputs made possible by research. The value to society of the additional output, minus any increase in cost of producing the new inputs other than research costs, is the value of the service flow of research capital.

The value of the additional agricultural output stemming from agricultural research has been estimated using two general approaches: 1. the index number approach, and 2. the production function approach.

A. <u>Index number approach</u>. This approach, also referred to as the "consumer surplus" or "economic surplus" techniques, utilizes an increase in a productivity index to gauge the contribution of research. As mentioned, agricultural research has value only to the extent that inputs are improved in quality, or totally new inputs are created. If these new or improved inputs are not accurately measured, output will increase more than measured inputs causing the output/input ratio to increase over time.

The productivity or output/input ratio can be total or partial. In the total productivity index, output is divided by an aggregation of inputs utilized in its production. Partial productivity indexes reflect output usually divided by a single input. Examples include yield per acre, milk per cow, or output per hour of labor. In the case of partial productivity indexes, care must be taken to isolate productivity gains stemming from research from those gains attributable to other sources such as changes in relative factor prices not related to agricultural research. Information on changes in productivity indexes have been obtained from various sources including government statistics on the industry, and from experimental data. Experimental data usually yield partial productivity indexes.

1. Early studies. The first estimate of the social value of agri-
cultural research was made by T. W. Schultz in 1953 (Schultz). Using the
increase in the index of total factor productivity for U.S. agriculture
between 1910 and 1950, Schultz estimated that the saving in resources in
1950 alone over what would have been required with 1910 techniques was
greater than the total public investment in agricultural research from 1910
to 1950. The second study to evaluate the benefits of agricultural research
was conducted by Griliches on hybrid corn in the U.S. (Griliches, 1958)
In this study Griliches utilized evidence from experimental data which
suggested that hybrid corn yielded on the average about 15 percent more
than open pollinated varieties under similar conditions. Using this 15
percent gain in a partial productivity index, Griliches then estimated the
shift in the supply of corn due to the adoption of hybrid seed and the resulting
additional value of production. Matching the stream of benefits against
the public and private research costs, he obtained his famous 700 percent
rate of return on hybrid corn research. (This figure comes from a rather
unusual method of computing a rate of return and the result is not comparable
to figures obtained from the procedure most commonly used at the present).

The third study to measure the benefits of agricultural research also
was carried out by Griliches. However, this one utilized an aggregate pro-
duction function which will be discussed in the next section. Peterson's
poultry study appears to be the next after Griliches' hybrid corn study to
utilize the index number approach. (Peterson) In this study two productivity
indexes are constructed: 1. the increase in poultry output per unit of
feed, and 2. the decrease in poultry output price relative to a weighted
average of input prices. In regard to the first index it was argued that

the increase in feed efficiency represented a lower bound to the benefits
of poultry research. Benefits such as the saving in labor stemming from
more effective disease control, and more efficient housing also are the
result of research but are not reflected in feed efficiency. After the
Peterson poultry study, the majority of research evaluation studies at
leaast for the U.S. utilized what has come to be known as the production
function approach. In fact, the Peterson poultry study also utilized the
production function approach.

B. **Production Function Approach**. With this approach research expen-
ditures, usually some lagged value or values, are included in an agricultural
production function along with the conventional inputs. By and large, cross
section data are used, or panel data containing a pooling time series and
cross section. If the conventional inputs are not adjusted for quality, the
research variable picks up or explains the unexplained output or residual.
Two major advantages of the production function over the index number
technique are that the significance of the research variable can be tested
statistically, and the estimated contribution of research is a marginal as
opposed to an overall average return.

1. Early production function studies. As mentioned Griliches was
the first to utilize this technique, publishing the results in 1964 (Griliches
1964). Fitting an aggregate agricultural production to U.S. data, Griliches
included among the inputs public expenditures on agricultural research for
each state, actually per farm averages for each state. From the coefficient
on the research variable, he computed the marginal product of research
which turned out to be over $13 for each dollar of research. Reducing this
figure to take account of private research expenditures, and the surplus
of agricultural output at that time, he still reported a $3 marginal

product for each dollar of agricultural research. However this was not a 300 percent rate of return because no account is taken for the lag between research expenditure and the related output.

Evenson's aggregate production function study which took account of the lags between research and the related output reported estimated rates of return to research of 48 percent (Evenson). Another important contribution of the Evenson study was the estimation of the length of the lag between research and the related output of agricultural production. According to Evenson's results, the pay-off to agricultural research follows an inverted V, where the annual contribution of research increases for a time, reaches a maximum, and then declines. Evenson estimated that the length of time from the beginning to the end of the pay-off period was in the neighborhood of 12 to 14 years, with the peak pay-off occuring 6 to 7 years after the research was conducted.

C. Comparison of the Two Approaches

It has been demonstrated that the index number and production function approaches are comparable in that both measure the increase in output resulting from a research induced shift in supply (Davis, 1981) It should be pointed out, however, that in most studies using the index number approach, the results should be interpreted as an overall average rate of return to the research program from the time of inception to the point where the study ends. In the production function approach, the results yield a marginal product which can be converted to a marginal rate of return. Since economic decisions are made at the margin, the marginal rate of return should be preferred over the average. While the production function approach yields results which are economically more desirable, it does have the drawback of being more demanding of the data. To obtain reasonably accurate estimates using the

production function approach, cross section data having substantial

variation in the research variable are required. Of all the countries

of the world, the United States appears to be the most suitable for esti-

mating a coefficient on the research variable. It is a large country, and

there has been substantial variation in research expenditures between states.

In smaller countries, or in those with a smaller number of research

institutions, it may be necessary to use time series data. However,

estimates of production functions using time series data have not been very

satisfactory because of the high correlation of the variables over time.

In smaller countries, particularly in LDCs where data are not as complete,

it may be necessary to go back to the index number approach in order to

evaluate the returns to agricultural research. Another advantage of the

index number approach is that the evaluator is forced to sort out the

effects of research rather than mechanically gathering data and estimating

the functions. Consequently the results from the index number approach

may be more believable, at least to research administrators and policy

makers, than the other approach.

There is another problem with the production function approach; in most

of the studies using this approach, research expenditures from the current

year or some year in the recent past are used to represent the research

variable. However, we know that investment in research during a single year

does not represent the total stock of research capital. And the relevant

research variable is the stock of research capital, not changes in this stock.

The procedure that has been used is similar to using the purchase of new

tractors during a single year as a measure of the stock of tractors. Again we

know that it is the total stock of tractors which influences agricultural

output, rather than the purchase of new tractors during a single year. It

is not clear how this misspecification of the research variable biases the
results of production function studies.

    D. <u>Ex post results and allocative decisions</u>. By and large, the results
of ex post research evaluation studies have indicated that past investment
in agricultural research has yielded relatively high rates of return, esti-
mates of 40 to 50 percent are common (Ruttan). From these results, can a
person conclude that the rate of return to current and future investment
in research will also be high? The answer depends on whether there is a
stable relationship between research inputs and the output of new knowledge
over time. That is, is the research production function stable? The one
study which attempted to answer this question yielded inconclusive results
(Davis, 1979). The results of this study indicated that in the United States
the coefficient on the research variable started to decline in the late 1960s
and early 1970s. However, problems of measurement both of the research
variable and of the conventional inputs could have accounted for the downward
movement of the research coefficient. We are in the process of trying to
obtain a more definitive answer to this question.

    Another issue relates to the allocation of a given research budget
among competing ends. How much of the budget should go to crops and how
much to livestock? And within these categories how much should be spent
on each individual crop and livestock product? In an earlier study, Bredahl
and Peterson found that in the United States, the estimated rates of return
to research were highest on the largest crop and livestock outputs (Bredahl
and Peterson). In the context of a Cobb-Douglas production function, the
marginal product of research is equal to the coefficient on the research
variable times the average product of research, i.e. dollars of output per
dollar of research. Consequently, given the research coefficient, the higher

the average product, the higher the marginal product. The largest output

categories tend to have the largest average products of research, at least

in the U.S. This phenomenon is illustrated in the attached appendix tables.

These figures are the number of professional scientific personnel in U.S.

agricultural experiment stations working in agricultural economics, the crop

sciences, and the livestock sciences, in 10 year intervals from 1930 to 1980.

Substantial differences in average products exist within states. Equally

large differences exist between states within a given research category. In

general, the large agricultural states have higher average products of

research than the small ones. (See especially tables 8 and 9).

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Table 1

Numbers of Research, Teaching and Extension Personnel,

U.S. Colleges of Agriculture and Experiment Stations

Year	Agric. Economics		Plant Sciences[a]		Animal Sciences[b]	
	Res. & Teach	Ext.	Res. & Teach	Ext.	Res. & Teach.	Ext.
1930	299.7	95.3	1329.1	224.9	841.8	230.2
1940	366.8	225.2	1945.2	332.8	1095.2	248.8
1950	585.0	237.0	2639.4	404.6	1546.8	330.2
1960	826.4	363.6	3840.2	567.8	2372.0	402.0
1970	1127.2	504.0	5576.5	763.5	3516.4	515.6
1980	1245.0	537.0	6576.8	1045.2	4237.9	562.1

Source: U.S. Department of Agriculture, Professional Workers in State Agriculture
Experiment Stations, Misc. Pub. Series through 1949; Agric. Handbook No.
305 after 1949, 1930-1980 inclusive.

[a] Includes Agronomy, Entomology, Horticulture, Plant Pathology, and Soils.

[b] Includes Animal, Dairy, and Poultry Sciences, and Veterinary Medicine.

Table 2

Total Value of Agricultural Production,

U.S. Agriculture, $ mil., (Constant 1980 Prices).

Year	Crops	Livestock and Products	Total
1930	$19,790	$35,974	$55,764
1940	22,006	36,444	58,450
1950	30,153	43,423	73,567
1960	38,082	54,839	92,921
1970	46,893	65,420	112,313
1980	69,041	68,103	137,144

Source: U.S. Department of Agriculture, Agricultural Statistics, respective
years.

Value of crop production deflated by Index of Prices Received by Farmers
for all crops, and livestock deflated by Index of Prices Received by Farmers
for Livestock and Products, 1980 = 100.

Table 3

Dollars of Related Output per Research, Teaching, and
Extension Worker, $ mil., (Constant 1980 prices).

Year	Agricultural Economics	Plant Sciences	Animal Sciences
1930	$141	$12.7	$33.6
1940	99	9.7	27.1
1950	90	9.9	23.1
1960	78	8.6	19.8
1970	69	7.4	16.2
1980	77	9.1	14.2

Source: Tables 1 and 2

Agricultural economics is divided into total value of agricultural
production whereas numbers of workers in the plant and animal sciences
are divided into values of crop production and livestock production
respectively.

Table 4

Research and Teaching, and Extension Personnel in Agricultural Economics by State, 1930–1980.

ST	AETR30	AETR40	AETR50	AETR60	AETR70	AETR80	AEE30	AEE40	AEE50	AEE60	AEE70	AEE80
ME	5.0	6.0	9.0	10.0	11.2	12.7	1.0	5.0	5.0	2.0	7.8	4.3
H	3.0	5.0	6.0	3.5	1.5	5.0	1.0	1.0	1.0	3.5	5.5	1.0
	3.5	2.0	3.7	7.3	6.7	7.3	0.5	3.0	1.3	2.7	4.3	2.7
MA	10.0	5.0	9.0	7.3	14.0	11.7	2.0	5.0	4.0	10.7	4.0	5.3
RI	2.0	1.7	3.0	5.7	11.3	11.3	0.0	1.3	1.0	3.3	0.7	1.7
	6.0	3.3	8.0	8.7	10.3	10.5	3.0	2.7	4.0	4.3	2.7	2.5
NY	16.0	12.0	16.0	20.3	33.0	31.3	3.0	8.0	6.0	9.7	14.0	22.7
NJ	7.0	8.0	4.5	7.0	8.5	11.5	1.0	3.0	1.5	4.0	4.5	3.5
A	10.0	11.0	19.0	25.5	36.2	35.7	2.0	3.0	3.0	11.5	12.8	13.3
OH	8.5	11.5	18.0	27.7	45.5	47.7	7.5	6.5	9.0	18.3	7.5	9.3
IN	9.0	7.5	17.3	29.5	39.0	35.0	2.0	6.5	10.7	17.5	15.0	17.0
L	14.7	17.7	26.3	31.0	50.3	48.0	2.3	6.3	6.7	12.0	13.7	17.0
I	13.0	11.0	20.7	28.0	39.7	37.7	3.0	5.0	14.3	18.0	13.3	11.3
WI	10.0	11.7	20.0	21.7	33.0	31.7	3.0	7.3	7.0	6.3	9.0	11.3
MN	14.0	13.0	11.0	21.0	43.0	33.3	3.0	8.0	9.0	12.0	17.0	15.7
A	13.0	23.0	29.3	24.3	37.7	31.7	10.0	16.0	12.7	20.7	26.3	15.3
MO	5.0	7.0	11.0	22.0	34.0	34.3	2.0	3.0	10.0	13.0	18.0	16.7
ND	8.5	3.0	11.0	10.0	19.0	27.0	1.5	3.0	2.0	5.0	7.0	9.0
D	5.7	5.7	10.0	20.0	26.0	25.3	3.3	1.3	2.0	3.0	7.0	7.7
NE	5.0	5.0	10.0	16.5	18.5	21.3	3.0	7.0	4.0	5.5	8.5	9.7
KA	6.5	12.0	19.0	22.7	23.5	19.5	1.5	11.0	10.0	10.3	33.5	46.5
E	3.0	3.0	3.0	2.5	5.7	9.0	0.0	1.0	1.0	1.5	4.3	4.0
D	4.0	7.7	8.3	10.3	12.7	15.0	3.0	5.3	17.7	16.7	12.3	4.0
VA	5.7	7.7	8.0	17.7	13.0	22.5	1.3	5.3	6.0	11.3	11.0	10.5
V	4.5	5.0	7.0	9.0	11.0	22.5	0.5	2.0	1.0	2.0	1.0	2.5
	5.0	8.0	10.5	24.0	29.3	25.5	0.0	5.0	10.5	20.0	21.7	23.5
SC	3.7	7.0	13.0	28.0	27.5	24.7	3.3	10.0	8.0	8.0	5.5	13.3
GA	2.5	6.0	14.0	21.3	37.0	45.3	4.5	6.0	9.0	16.7	19.0	30.7
	7.0	8.7	15.7	25.7	36.5	47.0	0.0	5.3	3.3	4.3	14.5	16.0
KY	7.7	18.7	21.7	22.0	21.3	22.5	3.3	2.3	2.3	13.0	16.7	17.5
TE	3.0	10.0	14.7	17.0	33.0	38.5	1.0	9.0	7.3	4.0	7.0	9.5
	5.0	3.0	9.0	9.0	11.0	18.5	2.0	2.0	1.0	2.0	21.0	19.5
	4.0	3.0	11.7	12.0	19.0	28.5	3.0	11.0	3.3	4.0	13.0	6.5
AR	4.0	6.0	12.0	23.0	22.0	24.0	0.0	2.0	1.0	2.0	18.0	17.0
A	3.0	10.5	16.0	18.0	22.5	30.0	1.0	4.5	2.0	4.0	10.5	11.0
K	3.0	8.0	15.0	20.7	23.7	31.0	2.0	4.0	4.0	9.3	10.3	10.0
TX	15.0	26.0	25.0	33.0	36.5	47.0	1.0	9.0	4.0	7.0	25.5	32.0
MT	5.5	6.7	5.7	16.0	21.0	26.0	2.5	2.3	1.3	4.0	4.0	3.0
D	3.0	3.0	4.0	8.0	10.0	16.3	0.0	2.0	2.0	3.0	2.0	5.7
WY	1.0	2.0	3.0	10.0	8.7	8.3	0.0	3.0	1.0	3.0	3.3	4.7
CO	6.0	6.0	6.0	12.0	20.0	29.0	1.0	1.0	2.0	1.0	7.0	5.0
M	2.0	4.0	5.5	10.0	14.0	20.3	0.0	3.0	6.5	5.0	4.0	3.7
AZ	0.0	2.0	5.0	13.0	27.0	26.7	0.0	1.0	0.0	2.0	5.0	3.3
UT	4.0	5.7	9.7	12.0	26.7	23.7	0.0	1.3	1.3	2.0	2.3	5.3
V	5.0	3.0	3.0	6.0	9.2	6.5	0.0	2.0	0.0	1.0	3.8	2.5
A	4.0	3.0	17.0	19.0	29.0	24.0	2.0	3.0	3.0	3.0	9.0	10.0
OR	8.0	5.0	13.0	20.5	23.0	33.5	3.0	5.0	9.0	12.5	11.0	13.5
CA	9.0	6.0	27.0	37.0	35.0	49.7	5.0	5.0	5.0	8.0	10.0	9.3

Note: ST = state; AETR30 – AETR80 = teaching and research 1930–1980; AEE30-AEE80 = extension 1930–1980.

Table 5

Research and Teaching, and Extension Personnel in the Plant Sciences, by State, 1930-1980.

ST	PLTR30	PLTR40	PLTR50	PLTR60	PLTR70	PLTR80	PLE30	PLE40	PLE50	PLE60	PLE70	PLE80
ME	14.0	18.0	24.5	25.0	39.0	63.0	1.0	3.0	2.5	2.0	8.0	5.0
NH	13.5	18.0	17.8	16.0	30.0	42.0	1.5	2.0	2.2	4.0	3.0	6.0
VT	6.2	7.5	8.8	8.5	17.3	21.2	0.8	1.5	2.2	2.5	2.7	5.8
MA	40.0	49.5	56.0	48.5	42.2	34.5	5.0	7.5	7.0	9.5	12.8	13.5
RI	7.0	9.2	13.2	18.3	32.3	24.0	1.0	2.8	1.8	2.7	3.7	4.0
CN	21.5	29.3	44.0	45.7	63.5	44.7	2.5	5.7	6.0	5.3	8.5	7.3
NY	78.0	160.8	134.0	150.4	219.7	209.0	18.0	18.2	20.0	25.6	26.3	36.0
NJ	42.5	42.0	56.5	73.0	65.3	73.5	2.5	6.0	9.5	15.0	20.7	20.5
PA	40.5	49.5	70.0	90.0	129.7	139.0	7.5	10.5	11.0	14.0	14.3	12.0
OH	68.5	63.0	76.5	94.0	130.3	172.0	13.5	14.0	14.5	21.0	13.7	16.0
IN	31.5	42.5	58.7	106.3	148.0	162.7	7.5	10.5	17.3	19.7	19.0	16.0
IL	57.7	60.3	58.7	105.7	158.7	217.7	4.3	7.7	9.3	16.3	23.3	27.3
MI	49.0	52.5	81.1	109.2	138.5	145.7	16.0	14.5	17.9	18.8	16.5	24.3
WI	44.7	52.3	72.9	96.0	114.3	119.0	10.3	14.7	15.1	20.0	14.7	19.0
MN	49.7	65.7	68.8	112.0	143.0	161.0	5.3	7.3	9.2	11.0	20.0	23.0
IA	56.5	72.7	85.9	140.3	153.0	122.7	11.5	21.3	21.1	24.7	19.0	26.3
MO	24.0	39.0	42.7	67.0	105.0	123.7	6.0	9.0	8.3	11.0	19.0	23.0
ID	17.0	20.0	30.0	45.0	87.0	130.0	2.0	3.0	4.0	5.0	8.0	12.0
SD	13.0	11.0	35.0	59.0	87.0	99.7	3.0	3.0	5.0	11.0	12.0	10.3
NE	16.0	33.5	54.0	76.5	92.5	113.0	4.0	6.5	8.0	13.5	27.5	25.0
KA	44.5	43.0	54.0	90.0	136.3	148.0	7.5	8.0	11.0	10.0	19.7	30.0
DE	9.5	12.7	16.7	19.0	19.0	51.5	1.5	1.3	3.3	3.0	2.0	2.5
MD	21.7	27.0	33.7	42.3	78.5	86.0	9.3	14.0	12.3	22.7	20.5	16.0
VA	23.0	42.3	66.0	86.1	127.7	132.0	4.0	8.7	11.0	23.9	30.3	29.0
WV	15.7	24.7	26.7	26.0	52.5	71.3	5.3	7.3	5.3	6.0	5.5	4.7
NC	30.7	46.2	44.7	119.0	221.5	222.0	9.3	9.8	13.3	32.0	36.5	66.0
SC	17.3	37.0	47.0	63.0	82.0	119.7	5.7	8.0	11.0	9.0	18.0	26.0
GA	26.0	45.0	65.0	88.4	175.7	191.0	8.0	5.0	10.0	18.6	32.3	53.0
FL	38.0	54.7	110.0	187.3	321.0	438.0	1.0	2.3	5.0	14.7	26.0	31.0
KY	13.7	28.2	35.5	56.2	87.7	99.0	4.3	6.8	11.5	15.3	30.3	39.0
TE	20.0	47.0	49.3	56.5	99.5	116.7	2.0	5.0	11.7	8.5	12.5	22.3
AL	28.0	30.5	43.0	46.0	90.0	132.5	4.0	6.5	7.0	8.0	18.0	18.5
MS	19.7	30.0	55.7	65.0	118.5	158.0	2.3	4.0	7.3	9.0	13.5	39.0
AR	15.0	27.5	37.0	63.5	95.5	158.5	2.0	5.5	6.0	10.5	20.5	26.0
LA	27.0	40.0	59.5	86.5	141.5	215.0	4.0	7.0	10.5	12.5	10.5	18.0
OK	20.0	44.5	63.5	82.7	64.0	80.5	4.0	10.5	10.5	11.3	12.0	21.5
TX	45.0	91.0	132.8	197.3	316.0	315.0	3.0	8.0	11.2	17.7	49.0	118.0
MT	9.8	14.3	25.7	52.0	66.5	68.5	3.2	2.7	5.3	9.0	5.5	11.5
ID	14.3	18.3	25.0	55.0	56.3	83.0	5.7	5.7	5.0	9.0	7.7	13.0
WY	11.7	12.0	21.0	31.5	23.0	26.3	2.3	3.0	4.0	3.5	4.0	5.0
CO	23.0	29.0	40.0	62.0	121.7	159.3	2.0	6.0	5.0	6.0	9.3	7.0
NM	6.0	9.0	20.0	35.0	51.0	59.0	1.0	3.0	4.0	5.0	4.0	4.0
AZ	15.0	23.0	44.0	97.0	168.0	169.7	1.0	3.0	3.0	6.0	6.0	19.0
UT	13.0	26.0	42.5	49.0	81.0	111.7	1.0	2.0	3.5	5.0	5.0	9.0
NV	3.0	4.0	6.0	15.5	16.5	17.5	0.0	1.0	1.0	2.5	3.5	2.5
WA	20.0	35.0	93.0	143.0	163.0	169.3	3.0	3.0	5.0	8.0	14.0	13.0
OR	33.7	47.0	69.0	117.0	130.3	174.7	2.3	4.0	8.0	14.0	21.7	26.0
CA	74.0	160.0	224.0	312.0	476.0	580.0	3.0	3.0	11.0	24.0	33.0	35.0

Note: ST = state; PLTR30 - PLTR80 = teaching and research 1930-1980; PLE30 - PLE80 = extension, 1930-1980.

Table 6

Research and Teaching, and Extension Personnel in the Animal Sciences, by State, 1930-1980.

ST	ANTR30	ANTR40	ANTR50	ANTR60	ANTR70	ANTR80	ANE30	ANE40	ANE50	ANE60	ANE70	ANE80
	5.0	6.0	9.0	10.0	17.0	16.2	2.0	2.0	3.0	7.0	5.0	7.8
IH	10.0	13.0	13.5	15.2	15.0	14.7	2.0	2.0	2.5	3.8	2.0	3.3
T	7.5	8.0	7.0	7.1	15.5	13.3	2.5	2.0	3.0	3.9	2.5	3.7
	15.0	17.0	21.0	24.3	24.3	23.3	3.0	2.0	4.0	5.7	2.7	1.7
RI	2.5	2.8	7.7	10.0	21.0	8.2	1.5	1.2	1.3	2.0	2.0	1.8
N	5.0	21.7	40.0	37.0	76.5	35.7	5.0	5.3	5.0	6.0	8.5	6.3
	34.7	42.5	39.7	92.1	134.7	173.7	14.3	13.5	19.3	19.9	23.3	23.3
J	20.0	21.0	27.0	31.0	21.0	12.0	4.0	4.0	5.0	6.0	5.0	6.0
PA	30.5	43.5	56.0	63.5	88.0	47.7	6.5	5.5	8.0	9.5	10.0	9.3
	41.5	49.0	77.0	112.5	152.0	146.7	10.5	6.0	8.0	11.5	12.0	9.3
	33.7	38.5	54.7	83.3	120.0	109.3	9.3	9.5	13.3	12.7	13.0	15.7
IL	43.8	49.5	67.3	89.3	82.0	179.0	3.2	5.5	6.7	11.7	14.0	13.0
	36.5	47.0	65.0	111.0	168.7	269.0	10.5	10.0	11.0	14.0	16.3	18.0
	23.1	31.3	48.9	53.1	73.3	88.7	5.9	12.7	13.1	10.9	13.7	14.3
IN	22.5	35.0	55.5	95.0	136.5	142.7	5.5	6.0	5.5	6.0	8.5	12.3
	60.0	74.0	78.7	119.3	128.7	160.0	11.0	13.0	17.3	22.7	25.3	15.0
	25.0	31.0	46.0	69.0	96.0	89.5	7.0	5.0	8.0	9.0	10.0	13.5
ID	14.0	13.0	20.0	22.0	32.0	43.5	3.	3.0	2.0	5.0	6.0	4.5
SD	10.0	14.0	21.5	34.0	56.5	61.0	2.0	3.0	6.5	7.0	10.5	7.0
	18.0	18.0	28.0	44.0	60.0	84.5	6.0	7.0	7.0	11.0	25.0	18.5
	29.0	35.0	32.0	54.0	83.3	102.3	7.0	6.0	8.0	8.0	11.7	13.7
DE	5.0	6.5	10.0	10.3	17.3	28.0	1.0	0.5	2.0	1.7	2.7	1.0
	10.7	21.0	23.0	37.2	36.5	40.5	4.3	5.0	10.0	10.8	8.5	10.5
	8.0	11.5	21.5	47.1	56.3	73.5	8.0	9.5	12.5	17.9	22.7	22.5
V	15.0	11.0	19.0	20.0	27.0	33.3	4.0	6.0	7.0	6.0	8.0	2.7
C	16.7	20.2	23.0	57.7	74.0	100.7	7.3	10.8	12.0	20.3	25.0	33.3
	9.1	16.0	24.0	28.0	30.0	29.5	6.9	7.0	11.0	10.0	12.0	19.5
A	18.0	12.0	26.0	79.3	157.0	191.5	6.0	4.0	7.0	10.7	15.0	28.5
L	12.0	15.4	26.7	47.3	72.0	77.0	2.0	4.6	3.3	7.7	11.0	14.0
	14.2	21.2	35.3	43.3	50.3	61.0	8.8	8.8	9.7	12.7	22.7	21.0
	6.0	12.0	41.0	39.0	73.0	158.5	8.0	9.0	12.0	11.0	11.0	14.5
L	20.7	24.0	42.0	59.0	107.5	99.5	2.3	3.0	3.0	7.0	15.5	13.5
	10.7	17.0	21.0	35.0	52.0	60.5	6.3	5.0	10.0	8.0	10.0	12.5
	7.0	7.0	14.0	18.0	43.5	60.0	3.0	3.0	5.0	7.0	11.5	11.0
A	11.0	20.0	34.0	58.0	92.0	130.0	4.0	4.0	8.0	12.0	18.0	13.0
	16.0	24.0	32.5	69.7	80.3	104.0	6.0	5.0	6.5	9.3	6.7	14.0
	26.0	58.0	72.1	91.0	294.0	295.5	4.0	9.0	12.9	13.0	22.0	39.5
T	11.0	13.3	25.3	44.7	47.7	79.0	3.0	2.7	4.7	4.3	2.3	4.0
D	9.8	10.2	14.0	28.0	28.5	51.0	4.2	2.8	4.0	3.0	4.5	9.0
	10.0	10.0	9.0	32.0	41.5	49.7	2.0	2.0	4.0	4.0	4.5	4.3
	17.0	23.0	41.0	60.0	161.5	179.7	5.0	3.0	3.0	2.0	7.5	6.3
M	8.0	9.7	13.7	17.0	25.5	32.0	3.0	3.3	2.3	5.0	4.5	8.0
	7.0	9.0	12.0	24.0	46.5	48.7	2.0	3.0	3.0	3.0	3.5	5.3
	7.1	10.7	18.2	31.7	55.0	71.5	0.9	3.3	5.8	4.3	10.0	8.5
V	4.5	5.0	4.0	10.0	23.2	38.3	0.5	0.0	0.0	2.0	1.8	3.7
	17.0	26.0	46.0	69.0	53.0	51.7	1.0	3.0	5.0	5.0	8.0	4.3
	19.0	24.7	29.0	45.0	41.3	71.3	3.0	3.3	4.0	5.0	6.7	7.7
A	38.0	46.0	54.0	94.0	128.0	201.0	2.0	4.0	5.0	6.0	13.0	12.0

te: ST = state; ANTR30 - ANTR 80 = teaching and research 1930-1980, ANE30 - ANE80 = extension, 1930-1980.

Table 7

Dollars of Agricultural Production per Research and Teaching, and Extension Worker
in Agricultural Economics, by State, 1950-1980, $ mil., (Constant 1980 prices).

State	1950	1960	1970	1980
ME	30.092	47.770	30.506	25.318
NH	23.057	22.975	17.788	16.867
VT	55.019	35.512	33.214	38.750
MA	35.729	24.667	21.517	18.371
RI	14.292	6.369	4.018	2.515
CN	31.359	33.034	29.188	23.108
NY	92.785	78.769	53.814	45.328
NJ	122.187	73.763	44.585	29.013
PA	84.781	61.176	48.498	55.253
OH	85.486	60.148	57.555	66.132
.IN	89.181	65.497	66.076	87.167
IL	132.209	123.059	97.087	121.960
MI	47.392	43.383	39.325	55.651
WI	90.139	112.861	86.774	111.621
MN	152.760	119.661	76.639	129.171
IA	128.376	152.400	138.054	214.943
MO	127.076	88.637	68.443	81.412
ND	95.080	90.624	61.346	66.739
SD	106.913	71.934	68.762	77.718
NE	179.359	145.890	167.895	196.819
KA	89.505	98.557	70.072	89.632
DE	62.884	78.403	33.210	25.708
MD	22.914	28.371	35.773	47.958
VA	89.553	48.142	58.881	45.248
WV	48.091	32.242	22.438	10.320
NC	106.769	69.125	71.846	75.298
SC	40.533	28.434	31.550	28.566
GA	61.486	57.404	46.921	35.653
FL	64.142	65.469	57.973	60.657
KY	60.491	46.552	57.092	68.117
TE	57.764	71.989	41.716	37.210
AL	111.896	141.247	53.471	48.997
MS	91.435	106.072	66.091	62.060
AR	104.956	72.976	61.934	73.532
LA	49.173	46.584	46.001	40.661
OK	77.772	62.400	70.186	79.437
TX	183.048	151.089	115.151	113.929
MT	125.900	54.715	51.084	48.838
ID	125.993	104.060	128.203	91.714
WY	87.297	35.218	43.799	50.369
CO	157.306	132.146	97.770	94.318
NM	44.643	42.584	57.236	47.967
AZ	135.186	75.060	46.135	57.723
UT	34.978	31.564	17.559	18.334
NV	39.269	20.316	13.946	26.189
WA	62.911	68.755	48.924	80.515
OR	44.863	33.874	38.497	34.743
CA	171.661	182.089	229.203	229.949

Table 8

Dollars of Crop Production per Research and Teaching, and Extension Worker
in the Plant Sciences, by State, 1950-1980, $ mil., (Constant 1980 prices).

State	1950	1960	1970	1980
ME	6.7700	8.2475	4.7467	1.8706
NH	1.2326	1.4024	0.9668	0.5646
VT	3.8266	3.0155	1.9524	1.0556
MA	2.1226	2.6745	3.5714	3.8708
RI	0.9612	0.8246	0.6812	0.6857
CN	2.4512	2.9029	2.1329	2.3981
NY	3.6560	3.5560	2.9830	2.9571
NJ	3.7632	3.8636	4.2497	3.3000
PA	5.4838	5.0446	4.4362	4.9841
OH	7.5288	9.0159	9.3204	12.7170
IN	8.5863	8.6179	10.2752	15.6813
IL	23.7483	16.5474	18.4105	22.7963
MI	6.2673	6.6997	6.4424	9.4088
WI	3.4461	2.9941	4.4537	7.3594
MN	10.5635	7.7613	9.5004	16.3098
IA	8.8742	8.0621	14.9419	30.5805
MO	13.1099	12.9675	8.5004	13.1871
ND	22.7291	17.0927	10.4937	11.3197
SD	8.9302	5.3101	4.8485	6.8864
NE	12.4681	11.9675	11.3651	17.5406
KA	16.6905	14.9878	8.4417	14.2079
DE	1.9767	4.0909	5.5556	1.7944
MD	3.9838	3.6398	3.0519	2.8412
VA	7.3180	5.4169	4.1049	3.2683
WV	2.7180	2.5762	1.2315	0.9987
NC	28.2398	13.4114	8.7016	7.7087
SC	10.1283	9.4715	6.3571	4.5466
GA	10.5457	8.5434	5.0698	4.8668
FL	8.0344	6.7375	6.0121	6.0896
KY	13.0381	9.9289	8.5089	9.8116
TE	9.2223	10.4503	5.9970	6.2791
AL	12.5442	11.6531	4.7906	4.6808
MS	14.3337	12.3039	7.3773	6.4289
AR	19.9459	14.9242	10.5562	8.3124
LA	8.0731	5.8906	5.9038	5.1429
OK	7.2659	9.3565	7.4718	10.6500
TX	20.0323	14.9132	7.8284	8.7298
MT	14.3886	7.2291	6.4120	8.2787
ID	12.5736	9.2569	13.4301	12.0604
WY	2.5674	2.1603	3.1217	3.9625
CO	9.5711	8.8989	4.7328	5.7850
NM	7.6550	5.8232	3.9610	4.2873
AZ	9.1687	6.4812	3.7794	4.9915
UT	2.0273	1.5989	1.2016	1.1678
NV	1.7940	1.0027	1.7500	3.7700
WA	8.1324	5.9150	6.7797	10.1754
OR	6.5811	4.2562	4.6382	5.3667
CA	14.3177	13.9257	12.4353	15.2779

Table 9

Dollars of Livestock Production per Research and Teaching, and Extension Worker in the Animal Sciences, by State, 1950-1980, $ mil., (Constant 1980 prices).

State	1950	1960	1970	1980
ME	19.8750	20.6209	16.2055	12.6333
NH	8.5469	6.9883	5.4476	4.1167
VT	23.3000	29.2677	18.1290	21.1176
MA	13.2300	9.6296	7.0692	5.0600
RI	4.7500	3.3333	1.0302	1.3500
CN	5.6389	6.5439	2.6573	4.1833
NY	25.0551	15.5109	11.3635	8.7472
NJ	15.1484	12.7402	8.2358	6.9444
PA	22.2031	23.8204	17.7307	34.2947
OH	19.0941	13.9516	10.4162	8.8378
IN	27.1250	20.7552	13.9261	13.4296
IL	37.1351	32.4037	29.8211	12.1995
MI	13.6612	9.1044	5.8684	3.9282
WI	34.3629	43.9497	35.2874	36.7388
MN	36.5779	29.6452	21.0330	21.4735
IA	46.4922	33.9280	40.6846	31.6634
MO	37.0370	26.8056	23.6321	21.4903
ND	21.0568	18.6934	15.7265	16.5667
SD	33.0625	31.2873	26.7034	26.5765
NE	49.6571	38.7727	37.2864	34.8845
KA	37.7687	28.2841	28.1808	29.1957
DE	17.6667	18.6343	10.7717	8.1828
MD	12.5000	11.0301	13.1594	12.1843
VA	20.3015	12.3120	9.6780	10.0729
WV	11.4519	10.4701	5.6522	5.0583
NC	17.2643	13.0306	14.3347	10.9664
SC	7.5357	8.9912	9.6532	8.6061
GA	18.8864	14.0802	9.1456	6.9186
FL	9.8250	10.9646	10.4872	10.6038
KY	18.6444	16.3294	15.9649	16.7159
TE	13.3632	16.6500	11.8685	5.2792
AL	10.9278	14.0067	9.7048	10.2221
MS	15.1129	18.2946	18.4045	12.4055
AR	26.6711	28.8000	22.7787	20.8028
LA	7.6190	6.3095	5.6423	3.2783
OK	24.1026	12.5633	20.9020	18.3949
TX	28.5147	27.2810	13.5505	15.5833
MT	14.5083	13.3333	16.3087	9.0843
ID	21.0417	17.8136	20.5731	14.3317
WY	21.9231	10.6173	9.5936	9.7778
CO	18.8125	17.9480	11.9514	12.0468
NM	22.0000	18.4470	27.0797	22.0275
AZ	16.3333	16.9753	16.3739	14.5981
UT	12.1458	9.8765	6.2441	4.8800
NV	26.3125	10.3472	5.8522	3.8167
WA	9.0441	8.3709	10.8054	15.6321
OR	14.5530	11.2056	12.5815	7.0152
CA	36.0763	35.1500	27.7598	19.5826

Table 10

Scientific Labor Years and Dollars per Year, 1981.

ST	PSY	PSDY	ASY	ASDY	AEY	AEDY
ME	19.5	79.137	7.7	161.735	3.7	45.749
NH	6.4	90.431	7.1	131.725	2.2	60.608
VT	7.8	107.642	6.3	96.527	2.7	71.191
MA	17.9	92.841	7.5	125.828	3.2	146.811
RI	9.8	105.626	1.2	155.359	1.6	102.409
CN	4.3	102.508	12.4	92.359	5.4	53.493
NY	59.9	132.541	63.9	140.866	59.4	105.533
NJ	39.0	132.025	10.1	179.587	7.5	131.230
PA	53.9	107.674	31.2	134.203	21.3	68.763
OH	45.2	180.551	30.7	212.417	10.4	100.176
IN	65.0	126.714	50.9	176.791	15.9	105.979
IL	63.3	106.231	36.0	156.365	18.0	69.754
MI	54.0	126.420	37.9	102.469	17.0	89.710
WI	43.9	155.732	36.9	236.739	17.9	140.219
MN	60.1	153.491	41.4	194.181	15.8	124.958
IA	46.4	136.090	30.7	268.412	10.3	67.118
MO	32.2	177.960	27.4	194.414	9.1	199.685
ND	52.5	138.475	25.5	143.097	5.8	112.593
SD	30.8	91.665	43.8	59.468	3.7	51.947
NE	52.1	155.697	37.8	345.000	12.1	76.603
KA	97.9	107.109	58.1	163.435	12.7	58.461
DE	10.6	100.201	8.0	194.058	2.3	125.147
MD	31.7	90.803	22.2	118.751	2.8	70.331
VA	50.3	121.857	50.7	135.608	13.7	63.404
WV	12.0	99.358	8.2	214.502	5.1	68.990
NC	117.2	152.895	53.0	170.435	12.8	80.942
SC	47.3	127.316	15.5	241.443	6.5	106.468
GA	95.6	143.688	31.4	274.369	6.5	90.934
FL	219.4	103.333	59.0	158.451	16.2	88.978
KY	44.8	116.662	32.8	146.245	10.3	58.253
TE	46.9	107.240	39.3	208.931	9.9	72.368
AL	51.6	107.530	38.5	174.680	5.8	69.049
MS	86.6	128.874	42.9	137.028	8.4	96.737
AR	53.6	161.875	26.0	163.929	7.8	95.627
LA	112.8	105.724	44.4	178.392	11.1	83.440
OK	40.4	110.689	24.9	153.612	11.9	67.223
TX	180.4	94.555	78.1	133.350	17.2	78.349
MT	37.4	98.763	28.1	160.745	2.4	97.744
ID	31.6	137.073	10.4	269.218	3.7	152.932
WY	13.1	84.375	19.6	96.816	2.0	68.175
CO	45.6	103.078	61.3	153.338	17.8	73.411
NM	32.6	51.209	12.5	78.994	5.8	28.649
AZ	56.5	120.353	29.9	129.737	16.4	112.052
UT	16.3	118.836	28.0	144.066	17.2	35.165
NV	9.7	108.146	15.5	155.121	1.8	76.359
WA	70.7	163.212	18.0	185.103	8.4	85.312
OR	54.7	125.206	29.7	195.747	5.2	216.679
CA	223.0	176.483	62.2	178.797	44.0	145.283
US		120.123		167.134		91.583

Notes: See next page.

Notes to Table 10

ST: state
PSY: scientific labor years in the plant sciences
PSDY: cost per scientific labor year in the plant sciences ($1000).
ASY: scientific labor years in the animal sciences.
ASDY: costs per scientific labor year in the animal sciences ($1000).
AEY: scientific labor years in agricultural economics.
AEDY: cost per scientific labor year in agricultural economics ($1000).

Source: USDA CSRS Inventory of Agricultural Research, FY 1981, Vol. II,
         Table II-B.