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EVALUATING AGRICULTURAL RESEARCH AND PRODUCTIVITY IN AN ERA OF RESOURCE SCARCITY

Proceedings of a Symposium Sponsored by NC-208, "Impact Analysis and Decision Strategies for Agricultural Research" held at Orlando, Florida March 4, 1993

Proceedings compiled by
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THE FEDERAL CONTEXT FOR FUNDING AGRICULTURAL RESEARCH

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The views expressed are the author's alone and do not reflect those of OTA, the Technology Assessment Board, or the U.S. Congress.

The Federal Context for Funding Agricultural Research

Daryl E. Chubin
Office of Technology Assessment

Introduction

My presence at this symposium was requested to provide an "inside Washington--outside agriculture" perspective on issues of research funding and productivity. I come to paint agriculture on a canvas of Federal politics, and my palette favors funding as a "primary color." The fortunes of agricultural research will be shaped in the near term by the Federal funding climate and in the long term by goals, policies, and priorities determined nationally and locally.[1]

Priorities, of course, are "set" at various levels -- through the Federal budget process, across the agencies, within agency programs, and among projects. Different criteria and decisionmaking mechanisms may dominate each level of priority-setting. What seems rational and coordinated at each level, however, may never be consistent or effective in a "cross-cutting" way. Historically, research and development (R&D) priorities have been set in the U.S. through an ad hoc, pluralistic, and decentralized "system" of R&D missions pursued through various agencies.[2] Today, when budgets are severely constrained, outcomes are often confused with the process that precedes them.

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1 For an overarching discussion of "goals," see Carnegie Commission on Science, Technology, and Government, *Enabling the Future: Linking Science and Technology to Societal Goals* (New York, NY: September 1992).

2 Priority-setting and other issues are examined in the report I directed that forms the basis for my remarks: U.S. Congress, Office of Technology Assessment, *Federally Funded Research: Decisions for a Decade*, OTA-SET-490 (Washington, DC: U.S. Government Printing Office, May 1991).

Preparing the Canvas

Symposia such as this and the ongoing self-examination of research communities arise in part because, as noted by the American Association for the Advancement of Science:

> the S&T [science and technology] policy arena has entered a period of uncertainty and flux unparalleled since the Vannevar Bush report, *Science--The Endless Frontier*, in 1945.
>
> The reasons for this growing ferment have included the passing of the Cold War, growing international economic competition and the U.S.'s loss of clear economic superiority in many fields, mounting Federal deficits, and a creeping disillusionment with science and with academic institutions.[3] Evidence occurs in various forms, but one unmistakable indicator is the number and range of reports occurring recently on variations of the general theme: What should be the role of science and technology in the nation's future, and how should the Federal Government act to foster that role?
>
> An early indicator of the changing policy milieu for science was the Office of Technology Assessment's 1991 report, *Federally Funded Research: Decisions for a Decade*. . . . The report's tone and approach. . . reflects a policymaking perspective, asking what the nation needs from the research it supports, rather than asking what science needs in order to function smoothly--a view that did not endear it to certain segments of the scientific community.
>
> A more-or-less direct follow-on of the OTA report was a report on "The Health of Research," done by staff of the House Committee on Science, Space and Technology for its Chairman, George E. Brown, Jr. This report, released in September 1992, called for rethinking the basis of Federal support for research, and proposed that agencies' research programs be systematically evaluated in terms of their performance and contributions to national goals. It, too, has generated controversy within the scientific community. The report will spawn a series of hearings in the 103rd Congress on these and related issues, to be held by the subcommittee chaired by Representative Rick Boucher.[4]

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[3] For a perspective produced at the end of the Bush presidency on academic research performance, see the President's Council of Advisors on Science and Technology, *Renewing The Promise: Research-Intensive Universities and The Nation* (Washington, DC: U.S. Government Printing Office, December 1992). A companion volume is Office of Science and Technology Policy, *Trends in the Structure of Federal Science Support*, Report of the Federal Coordinating Council for Science, Engineering, and Technology Committee on Physical, Mathematical, and Engineering Sciences (Washington, DC: December 1992).

[4] Quote from Albert H. Teich et al., *Congressional Action on Research and Development in the FY 1993 Budget* (Washington, DC: American Association for the Advancement of Science, 1993), pp. 15-16.

As Chairman Brown recently observed:

> One of the more frequent pieces of advice that I hear from scientists goes something like this: 'The economy is a mess, our education system is a mess, our manufacturing system is a mess, our health system is a mess, but our research system is preeminent in the world, the envy of other nations. For goodness sake, don't try to fix the one thing that ain't broke.' Although I follow the logic of this argument, it does suggest a somewhat self-referential world view. Perhaps we need to expand our horizons.[5]

I would add that this world view also defies the logic of how a *system* works: the working parts are interrelated; what happens to one affects the others, and indeed, the operation of the entire system. This axiom seems lost on basic researchers who advocate for "curiosity-driven" science some protection or exemption from the rough-and-tumble of funding politics. Expenditures for *all* R&D, however, are tied together in the discretionary budget. When the executive branch proposes investments, they all are "on the table," vulnerable to increases, decreases, discontinuities, and misunderstandings. Then the legislative branch "disposes," sometimes reordering the President's priorities.

Agricultural research must be seen as embedded in the "Federal research system." The changing funding landscape currently tilts the system toward technology and therefore toward linking economic incentives and impacts of Federal policies. This may scramble, in the name of competitiveness, the order of the R&D agencies. The departments of Commerce and Labor will probably rise in importance and budget, spearheading the new administration's technology-industrial policy, while the most "basic" of research agencies, the National Science Foundation, stands in jeopardy of becoming second tier, i.e., not a primary site of action on either

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[5] Cong. George E. Brown, Jr., "The Objectivity Crisis: Rethinking the Role of Science in Society--Opening Remarks," Annual Meeting, American Association for the Advancement of Science, Boston, MA, Feb. 12, 1993, p. 3.

technology transfer or training issues. Megaprojects such as the Space Station and the Superconducting Super Collider will continue to cramp initiatives at National Aeronautics and Space Administration and the Department of Energy, respectively, as well as across a dozen or so smaller R&D agencies. The downsizing of the Defense budget may be accelerated, but civilian research may reap little benefit. The National Institutes of Health, an annual $10 billion Federal investment, is wracked by the demands to stifle AIDS and other dread diseases, to energize the biotechnology revolution, and in general to sustain both the health and the biomedical research missions of the nation.

Where, then, in this panoply of efforts to stimulate the economy and reduce the deficit, will agricultural research and the programs of USDA fit?[6] I see many comparative advantages: Traditionally connected to practical applications and local needs, agricultural research is not as dependent as other fields on Federal funding. Further, the land-grant universities are comfortable with block grants as a funding mechanism and are politically pragmatic with respect to earmarked appropriations. Research performance in the experiment station has long been multidisciplinary and team-oriented. Finally, agriculture's strong ties to industry represent a promising market not only for products (through patents and licenses), but also for a new generation of agricultural scientists trained in outreach as well as research.[7] Whether these advantages translate into larger budgets for USDA, or favored status on campus, remains to be seen.

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6 Some of the following is discussed in Daryl E. Chubin, "A Congressional Perspective on Peer Review, Pork, and Priorities in Agricultural Research," paper presented at the Agricultural Research Institute Symposium on the Dynamics and Performance of the U.S. Agricultural Research System, McLean, VA, Sept. 17-18, 1992. Also see "The Future of Agricultural Research" [letters], *Science*, vol. 259, Jan. 8, 1993, pp. 162-163.

7 For other, less optimistic perspectives, see Marcia Clemmitt, "Plant Science Job Horizon Dimmed by Lack of Funding," *The Scientist*, vol. 6, Sept. 14, 1992, pp. 1, 6-7; Scott Veggeberg, "Plant Science Field in Need of Healthier Funding Climate," *The Scientist*, vol. 6, Sept. 14, 1992, pp. 14, 18; and Elizabeth Bird and Chuck Hassebrook, "Report Card on USDA Research Policy," Special Report, Center for Rural Affairs, Walthill, NE, November 1992.

Displaying the Big Picture

In the following, the focus on agriculture research performance and funding sponsored by U.S. Department of Agriculture (USDA) is subordinated to the "big picture": context in which Federal policymaking occurs. I offer a collection of "exhibits" -- data and commentary -- that illustrate the policy context and illuminate the issues and choices that confront us all. The exhibits are self-explanatory. They have been sequenced to proceed from (i) an overview of the Federal research system, to (ii) a highlight of the Clinton Administration's R&D initiatives, (iii) a consideration of policies that concentrate and distribute research funds by State and institution, and (iv) strategies for making agriculture a research priority.

Finally, it is important to note the difficulty in measuring the returns on the Federal investment ($73 billion in fiscal year 1993) in R&D. Various characteristics of the portfolio remain elusive: balance, risk-taking, and performance are all relative terms. If viewed as a public good, certain expectations about returns, i.e., short-term financial benefits, are inappropriate.[8] But if the R&D portfolio is seen as a contribution to the nation's economic well-being, then R&D clearly competes with other missions. Indeed, R&D is deeply implicated in the mission of competitiveness. For better *and* worse (as it were), agriculture is on the cusp on that mission.

8 For reflections on this line of analysis, see Edwin Mansfield, "How Do We Measure What We Get When We 'Buy' Research," *The Scientist*, vol. 4, Aug. 19, 1991, pp. 11, 17; and Keith Pavitt, "What Makes Basic Research Economically Useful?" *Research Policy*, vol. 20, 1991, pp. 109-119.

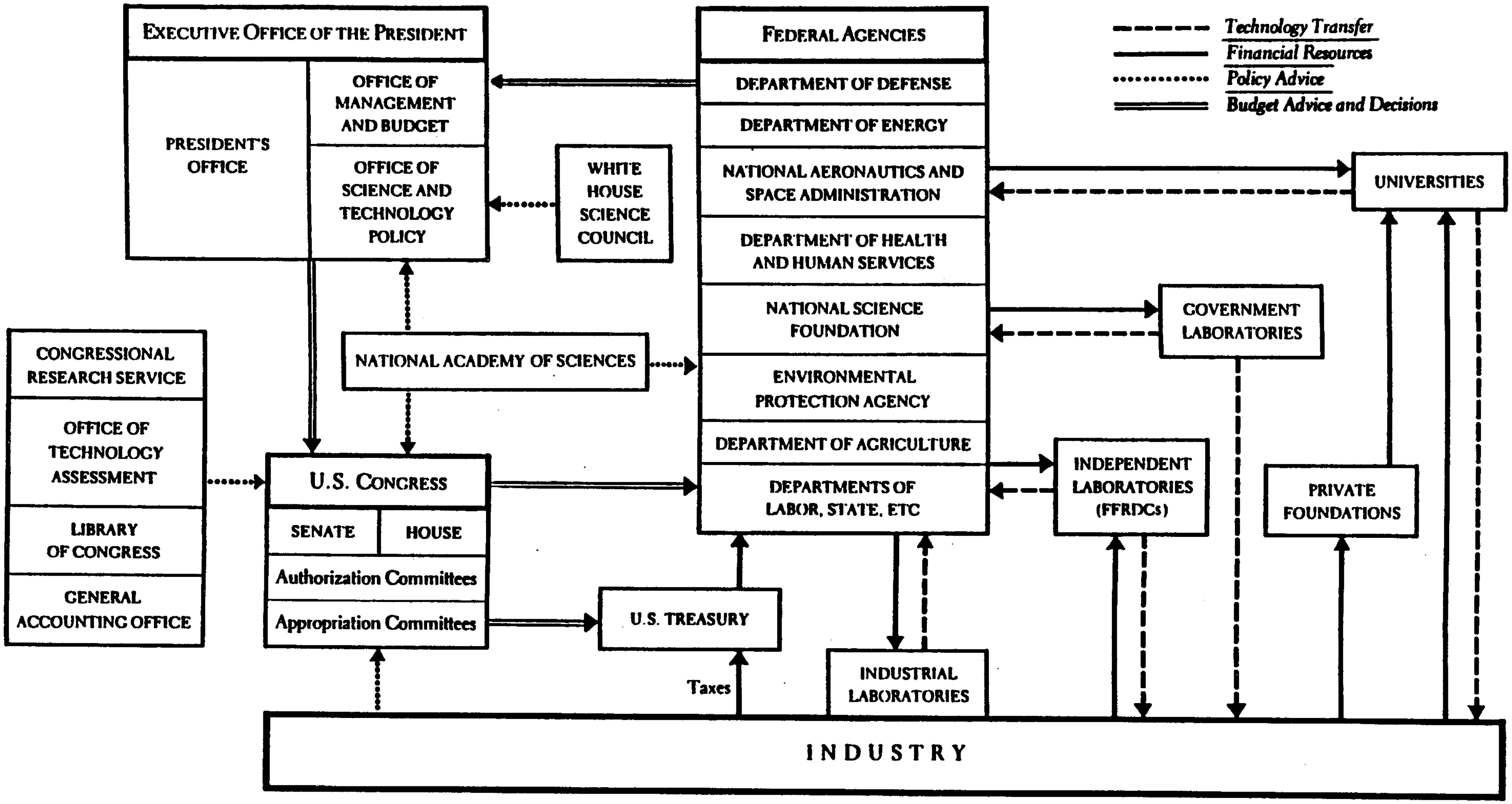


FIGURE 2: *The Organization of United States Science*

Source: David Dickson, THE NEW POLITICS OF SCIENCE, University of Chicago Press, 1988, p. 22.

EDITORIAL

A Changing Climate for Scientific Research

A confluence of factors has led to unusual uncertainty concerning support of scientific research. These factors include end of the Cold War, global economic competition, federal and state budget deficits, loss of faith in basic research as a key to prosperity, and diminished public esteem for academic research. The latter is due to publicity about fraud in science and a few instances of faulty bookkeeping of grant overhead charges.

The end of the Cold War, by diminishing funding in the defense industry, is causing major federal laboratories to scramble for support by undertaking civilian R&D. In response to the recession and global competition, many companies have engaged in "restructuring." This has often included a curtailment of efforts in basic research. Federal and state budgetary deficits, combined with diminished faith in basic research as the key to prosperity, have attenuated congressional enthusiasm for support of peer-reviewed research grants.

A significant recent development involves the Committee on Science, Space, and Technology of the House of Representatives. The committee's membership totals 53. George Brown, Jr., its chairman, has seniority and influence and is one of the few members having a degree in science. He has long been an advocate of federal support for basic research. That his position has evolved is evident in his favorable comments about a report* on the health of research prepared for him by the committee's staff. Some quotes from the report follow: "Research policy designed forty years ago may no longer be suitable..."; "...maintaining the world's preeminent (and most expensive) federal research system is not, in and of itself, adequate to insure economic vitality"; and "To create a more rigorous and socially-responsive science policy, a necessary first step is to define goals toward which the research should be expected to contribute."

Evolution of attitudes by others in Congress is evidenced by a huge expansion in non-peer-reviewed, pork-barrel facility legislation. A provision in the Senate bill for funding National Science Foundation (NSF) would have drastically modified its status and would in effect have placed NSF under senatorial micromanagement. Through intervention of George Brown and colleagues the onerous provisions were deleted in the House-Senate conference. Scuttlebutt has it that the current flurry of policy-review activities at NSF is a measure to create a line of defense in the 1994 congressional budget hearings. The NSF policy-makers should be steadfast in defending basic research. If they do so, they will be joined by influential allies in academia and industry.

For the foreseeable future, federal support of scientific research is likely to be conditioned by relevance to societal goals, with Congress having a major role in specifying the goals. Obviously one of these should be to maintain a viable academic capability to produce first-class scientists and engineers. They will be essential as problem-solvers in an unpredictable and dangerous future. Another goal should be to support highly competent investigators. Some function best as members of a team working toward a major objective. But others perform even more magnificently when permitted to follow the dictates of their own intuition and judgment.

As directors of research, congressmen in general have obvious limitations. In addition, they have a short time horizon—usually a few months to no more than 2 years. They are greatly influenced by the media, whose time horizon is even shorter—days to weeks. Many of the great problems that the world will encounter are long term (10 to 50 years). The R&D necessary to facilitate solutions for such problems also often will require steady support for a decade or more. There is need for a mechanism to help politicians to choose to provide steady support for important long-term goals.

A recent report† by a panel of the Carnegie Commission recognizes the need for such a mechanism and names 12 major long-term policy areas that should be part of a national agenda. Included are health and social welfare, economic performance, and energy supply and utilization. The report proposes creation of a long-lasting, nongovernmental forum that would interact with the political system. The membership in the forum would include a "broad based and diverse group of individuals who are critical and innovative who can examine societal goals and the ways in which science and technology can best contribute to their achievement."

Philip H. Abelson

*"Report of the task force on the health of research to the Committee on Science, Space, and Technology" (102nd Congress, 2nd session, Government Printing Office, Washington, DC, 1992). †"Enabling the future: Linking science and technology to societal goals" (Carnegie Commission on Science, Technology, and Government, New York, September 1992).

EXHIBIT 3

Table 1—Tensions in the Federal Research System

Centralization of Federal research planning	←→	Pluralistic, decentralized agencies
Concentrated excellence	←→	Regional and institutional development (to enlarge capacity)
"Market" forces to determine the shape of the system	←→	Political intervention (targeted by goal, agency, program, institution)
Continuity in funding of senior investigators	←→	Provisions for young investigators
Peer review-based allocation	←→	Other funding decision mechanisms (agency manager discretion, congressional earmarking)
Set-aside programs	←→	Mainstreaming criteria in addition to scientific merit (e.g., race/ethnicity, gender, principal investigator age, geographic region)
Conservatism in funding allocation	←→	Risk-taking
Perception of a "total research budget"	←→	Reality of disaggregated funding decisions
Dollars for facilities or training	←→	Dollars for research projects
Large-scale, multiyear, capital-intensive, high-cost, per-investigator initiatives	←→	Individual investigator and small-team, 1-5 year projects
Training more researchers and creating more competition for funds	←→	Training fewer researchers and easing competition for funds
Emulating mentors' career paths	←→	Encouraging a diversity of career paths
Relying on historic methods to build the research work force	←→	Broadening the participation of traditionally underrepresented groups

Source: Federally Funded Research, Decisions for a Decade, Summary. Congress of the US, OTA, 1991.

EXHIBIT 4

Some PCAST Dos and Don'ts

Universities SHOULD:

- Reemphasize teaching. This, PCAST warns, will often mean less research.
- Base faculty evaluation and rewards on a balance of both research and teaching.
- Collaborate more with other universities and industry and government labs, with the aim of conserving resources.

Federal agencies and Congress SHOULD:

- Pay all research costs, including all legitimate indirect costs.
- Create a temporary facilities fund, equally matched with university money, to rebuild crumbling university laboratories and buildings. Lest this program be taken over by pork-mongers, PCAST recommends that the projects be merit reviewed and available only to universities that pledge to forgo congressional earmarking.
- Establish a program of portable graduate fellowships and undergraduate scholarships in science and engineering in each congressional district, to ensure political support.
- Eliminate all federal, state, and local taxes on scholarships, fellowships, and stipends.
- Shift as much as possible the research conducted at government laboratories to universities, where research is generated in tandem with education and training.

Universities should NOT:

- Develop or implement research or education programs that would increase the net capacity of the system of research-intensive universities.
- Cut programs across the board. Rather, they should maintain those departments that are world class, and eliminate or cut back, if need be, the rest.
- Build facilities or programs without long-term prospects of sustaining them.

Federal agencies and Congress should NOT:

- Continue paying a portion of faculty salaries. That practice, PCAST argues, "artificially expands teaching faculties dependent on federal sources..."
- Encourage universities to embark on new research programs or building facilities where there is little long-term prospect of sustaining those programs.
- Continue recasting government labs, such as the national laboratories of the Department of Energy, as basic research labs in competition with universities. Government labs "have the benefit of superior resources, are not burdened by educational responsibilities, and are not subject to the same type of merit review that ensures high standards of academic research," the report complains.

Author: Christopher Anderson

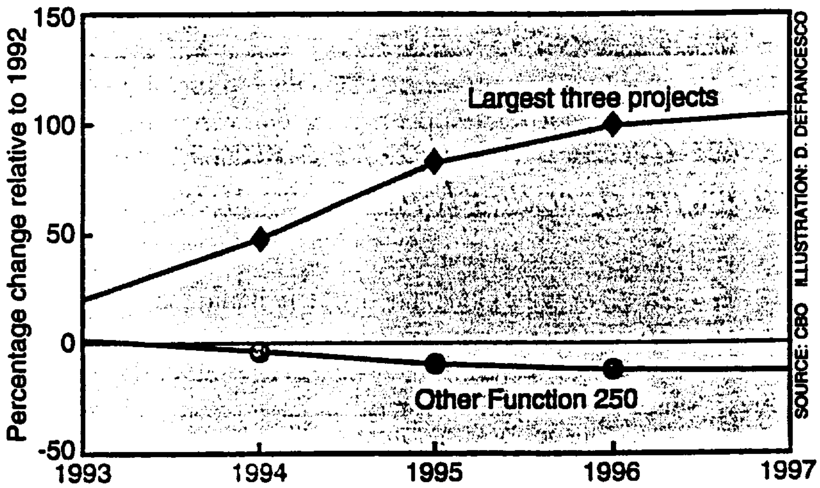
EXHIBIT 5

Funding of Big Science (or Megaprojects)

Are the SSC, Space Station, and the human Genome Project distortions of research priorities by effective lobbies, and therefore an expression of political will that should go unchallenged?

Or are such megaprojects a threat to the science base and the ability of the Federal Government to maintain a robust and balanced research portfolio?

Small Science Squeeze



If practitioners of "small science" are looking for confirmation of their fear that "big science" is threatening their livelihood, they will find it in a staff memorandum prepared by the Congressional Budget Office (CBO). CBO points out that the three biggest civilian science and technology projects—the space station, the Earth Observing System, and the Superconducting Super Collider—account for two-thirds of the Administration's proposed fiscal year 1993 increase in the budget category known as Function 250, which includes the National Science Foundation, much of the National Aeronautics and Space Administration, and the general science programs of the Department of Energy. What's worse for small science devotees is that this year's proposal may be only the thin end of the wedge. CBO projects that the annual budgetary needs of the three mammoth projects will double between 1992 and 1997—yet the Administration's budget assumes flat funding for Function 250 beyond 1993. If those projections turn out to be correct—a big if—the result isn't hard to figure: Small science gets squeezed (see chart). Some relief would come from allowing Function 250 to grow. But, as CBO points out, there will be increasing pressure to cut total government spending to hold down the ballooning federal deficit, with the result that "by 1995, the cumulative cuts will be so large that Function 250 is unlikely to escape without any reduction."

Source: Science 255:(20 March 1992), p. 1507.
Edited by Constance Holden.

EXHIBIT 7

Alternatives to Peer Review

A. *FORMULA FUNDING:* Formal, **non-merit** based review

B. *EARMARKING:* Formal, **non-peer** review

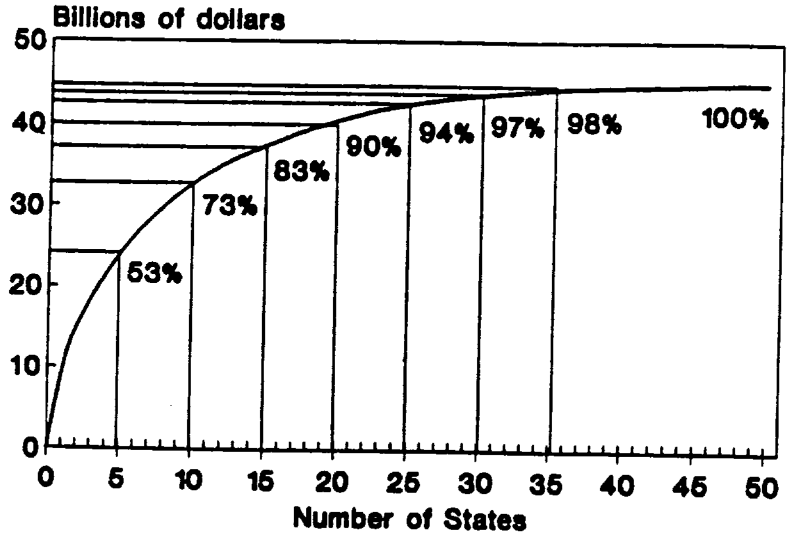
C. *"OLD BOYS" NETWORK:* Informal, peer-based **non-review**

D. *MANAGER'S DISCRETION:* Informal in-house review with **unknown** criteria and participants

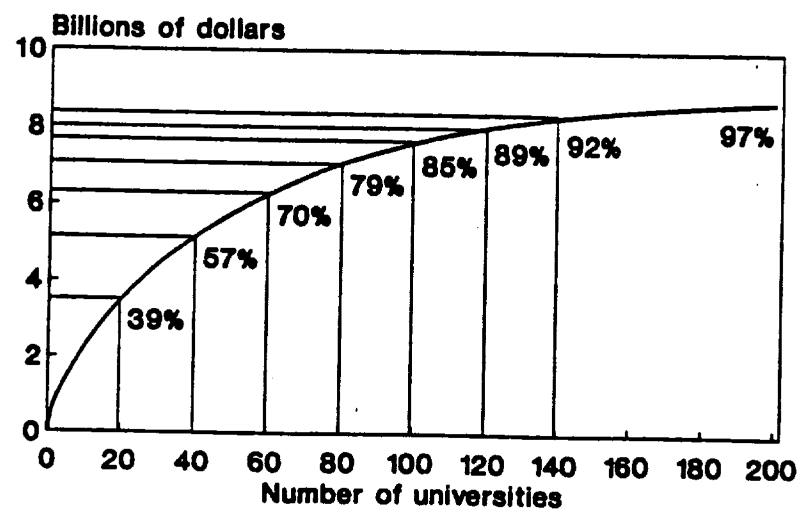
EXHIBIT 8

Figure 6—Federal R&D Obligations by State (1985) and at Universities and Colleges (1989)

Cumulative distribution of Federal R&D obligations by State: 1985



Cumulative distribution of Federal R&D expenditures at universities and colleges: 1989



SOURCE: National Science Foundation, *Geographic Patterns: R&D in the United States*, Final Report, NSF 90-316 (Washington, DC: 1990), table B-5; and National Science Foundation, *Selected Data on Academic Science/Engineering R&D Expenditures, Fiscal Year 1989*, NSF 90-321 (Washington, DC: October 1990), table B-35 and CASPAR database.

Source: Federally Funded Research: Decisions for a Decade, Summary, Congress of the US, OTA, 1991.

EXHIBIT 9

Table 4. States leading in R&D performance by sector and R&D as a percentage of gross state product: 1989

Rank	Total R&D[1] (in millions)		Largest 25 performers (ranked by size of R&D in sector) Industry	Universities & colleges[2]	Federal Government	R&D intensity of state economy Largest 25	R&D/GSP	GSP (in billions)
1	$30,881	California	California	California	Maryland	New Mexico	10.5%	$25.4
2	9,898	New York	Michigan	New York	California	Delaware	5.8	15.4
3	9,058	Michigan	New York	Texas	Ohio	Massachusetts	5.5	144.8
4	7,949	Massachusetts	New Jersey	Maryland	Virginia	Maryland	5.1	99.1
5	7,229	New Jersey	Massachusetts	Massachusetts	Florida	Michigan	5.0	181.8
6	6,581	Texas	Texas	Pennsylvania	New Mexico	California	4.4	697.4
7	5,791	Pennsylvania	Pennsylvania	Illinois	Alabama	Idaho	3.8	16.3
8	5,475	Ohio	Illinois	Michigan	Texas	New Jersey	3.6	203.4
9	5,305	Illinois	Ohio	North Carolina	New Jersey	Washington	3.4	96.2
10	5,091	Maryland	Washington	Georgia	Massachusetts	Connecticut	3.1	88.9
11	3,375	Florida	Connecticut	Ohio	Pennsylvania	Vermont	2.7	11.5
12	3,225	Washington	Missouri	Florida	Rhode Island	Missouri	2.7	100.1
13	2,745	Connecticut	Florida	Wisconsin	Georgia	Ohio	2.6	211.5
14	2,710	Missouri	Minnesota	Connecticut	Tennessee	Minnesota	2.6	93.6
15	2,680	New Mexico	Indiana	New Jersey	Mississippi	Pennsylvania	2.5	227.9
16	2,545	Virginia	North Carolina	Washington	Arizona	Colorado	2.5	66.2
17	2,399	Minnesota	Colorado	Virginia	Colorado	Rhode Island	2.3	18.8
18	2,120	Indiana	Virginia	Minnesota	Washington	New York	2.2	441.1
19	1,821	North Carolina	Maryland	Missouri	New York	Utah	2.2	28.1
20	1,649	Colorado	New Mexico	Indiana	Nevada	Illinois	2.1	256.5
21	1,399	Wisconsin	Wisconsin	Colorado	Indiana	Indiana	2.0	105.3
22	1,302	Georgia	Tennessee	Arizona	Michigan	Arizona	2.0	65.3
23	1,302	Tennessee	Arizona	Tennessee	Utah	Texas	1.9	340.1
24	1,293	Arizona	Delaware	Iowa	West Virginia	Virginia	1.9	136.5
25	1,226	Alabama	Georgia	Alabama	North Carolina	Alabama	1.8	67.9

[1] Includes in-state R&D performance of industry, universities, associated federally funded research and development centers (FFRDCs), and Federal agencies and the federally funded R&D performance of nonprofit institutions.

[2] Excludes R&D activities of university-administered FFRDCs located within these states.

KEY: GSP = gross state product

NOTES: Excludes R&D performance in the District of Columbia and R&D expenditures undistributed by state. States not listed had in-state R&D performance of less than $1 billion and an R&D/GSP ratio of 1.5 percent or less.

SOURCES: National Science Foundation/SRS, table B-17; and Bureau of Economic Analysis

Source: National Science Foundation, National Patterns of R & D Resources: 1992 by J. E. Jankowski, Jr., NSF 92-330, Washington, DC, 1992.

EXHIBIT 10

Academic Earmarking

Is the pursuit of pork barrel funding of facilities and equipment a result of inadequate Federal attention to these infrastructure needs?

Or is academic earmarking a crass debasement of principles of merit and competition in the name of "distributive politics"?

EXHIBIT 11

Summary of FY1992 Academic Earmarks, Distribution by Institution and Comparison with Federal R&D Funds for FY 1989

(total earmarked funds = $708 m)

N of recipient institutions of FY 92 earmarks	Cumulative % of earmarked funds	Cumulative n in top 100 Federal R&D funds received in FY89
10	32	6
30	61	19
50	78	26
75	88	35
100	95	42
167	100	51

source: based on James D. Savage, "The Distribution of Apparent Academic Earmarks in the Federal Government's FY 1992 Appropriations Bills," CRS Report for the Congress, Sept. 22, 1992, table 3.

EXHIBIT 11

TABLE 1

APPARENT FY 1992 ACADEMIC EARMARKS, BY APPROPRIATIONS SUBCOMMITTEE (HOUSE AND SENATE)

Subcommittee	Dollar Value	Percent of Total
Defense (PL 102-172)	$169,200,000	23.9%
VA, HUD, Ind. Ag. (PL 102-139)	151,016,000	21.3
Agriculture (PL 102-142)	146,368,000	20.7
Energy & Water (PL 102-104)	134,900,000	19.1
Commerce, Justice (PL 102-140)	60,413,000	8.5
Transportation (PL 102-143)	27,128,000	3.8
Interior (PL 102-154)	16,664,000	2.4
Labor, HHS, ED (PL 102-170)	2,300,000	.3
Total	$707,989,000	100.0%

SS&T | NEWS

EXHIBIT 11

COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
2320 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, D.C. 20515

EMBARGOED: For Release After 9 a.m. EST Friday, Feb. 12

Date: February 10, 1993
Contact: Robert Palmer (D), 202/225-4275
Dave Clement (R), 202/225-8772
Press: Rick Borchelt, 202/225-3359

HOUSE SCIENCE COMMITTEE STEPS UP PORK SCRUTINY; REP. BROWN ANNOUNCES HEARING SERIES, UNIVERSITY SURVEY

BOSTON -- Rep. George E. Brown, Jr. (D-CA), Chairman of the House Science, Space, and Technology Committee, today announced that the Committee will turn up the heat in its efforts to curb location-specific, unauthorized earmarks -- "pork" -- with a series of high-profile hearings and a survey of colleges and universities that accept unauthorized earmarks. The Chairman's remarks came during the annual meeting of the American Association for the Advancement of Science (AAAS) in Boston, Mass.

"Congressional porkbarrelling threatens many of the science and technology intiatives of the new Administration, which risk being sabotaged by parochial political interests," Rep. Brown told reporters at the AAAS meeting. **"Money that is diverted by Congress to fund earmarks comes out of the hide of other programs -- publicly debated, peer-reviewed, carefully scrutinized programs. This is not a legitimate way of funding science programs."**

Rep. Brown said that he would schedule within the next two months a series of high-visibility hearings on Capitol Hill to hear from college and university presidents, Members of Congress, and lobbyists who accept or help direct earmarked funds. **"With each of these groups of witnesses we will ask why they go the route of sidestepping merit review,"** he said.

As part of the investigation process, the Committee this week sent letters to 50 academic institutions across the United States which received pork from FY1993 appropriations bills. The letters ask the institutions to describe in detail how the money is being spent. The list of institutions is attached. The total earmarked for these 50 institutions totals $225 million.

50 Academic Pork-Barrel Projects

Following are the 50 academic institutions from which Rep. George E. Brown, Jr. requested detailed information on fiscal 1993 Congressional earmarks. The institutions, projects, and amounts appropriated are listed under the agencies that financed the projects.

AGRICULTURE DEPARTMENT

Michigan State U.: food-toxicology center; $4.6-million
Rutgers U.: plant-bioscience facility; $2.6-million
St. Joseph's U.: center for food marketing; $2.3-million
U. of Wisconsin at Madison: agricultural-biotechnology facility; $2.16-million
Wake Forest U.: center for nutrition research; $3.7-million

ENERGY AND INTERIOR DEPARTMENTS

Hahnemann U.: ambulatory-care and teaching center; $10-million
Indiana U.—Purdue U. at Indianapolis: cancer-treatment facility; $10-million
Louisiana State U.: center for energy and environmental resources; $10-million
Oregon Health Sciences U.: ambulatory-research and education building; $10-million
U. of Alabama: biomedical-research facility; $10-million
U. of Connecticut: advanced-technologies institute; $10-million
U. of Oklahoma: study of liquid natural gas for transportation; $1-million
U. of Oregon: industrialized housing; $1-million
Kansas State U., U. of Chicago, and Washington U. (consortium): plant-biotechnology research; $2.5-million

ENVIRONMENTAL PROTECTION AGENCY

Clark Atlanta U.: hazardous-substance—research center; $3-million
Columbia U.: environmental-health—research center; $10-million
Lamar U.—Beaumont: Gulf coast hazardous-substance—research center; $2.5-million
Tufts U.: center for environmental management; $3.2-million
U. of Detroit: polymer-research center; $1.2-million
U. of Georgia: ultraviolet-radiation—monitoring center; $700,000
U. of Maine: Maine quaternary-studies institute; $1-million
U. of New Orleans: urban-waste—management research; $700,000
U. of North Dakota: energy- and environmental-research center; $1.6-million
Arizona State U., New Mexico State U., Polytechnic Institute of New York, and San Diego State U. (consortium): environmental-research center; $2-million
North Carolina State U., U. of Miami, and U. of Michigan (consortium): Southern oxidants study; $3.5-million

INTERNATIONAL TRADE ADMINISTRATION

Iowa State U.: new materials center; $2.85-million
Auburn U. and Clemson U. (consortium): textile center; $7.48-million

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Delta College: science-learning center and planetarium; $8-million
Oregon State U.: distance-learning activity, marine-science center; $500,000
Saginaw Valley State U.: earth-science facility; $42-million
U. of Nebraska at Lincoln: earth-science research; $400,000
U. of Utah: science computation center; $10-million
Wheeling Jesuit College: classroom of the future; $2.8-million

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U. of New Hampshire: biological-sciences facility; $15-million
U. of South Carolina: estuary management; $672,000

TRANSPORTATION DEPARTMENT

Embry-Riddle Aeronautical U.: airway-science program; $11.5-million
Henderson State U.: airway-science program; $2.2-million
Middle Tennessee State U.: airway-science program; $556,000
U. of Alaska: airway-science program; $6.88-million
U. of California at San Diego: research on materials in bridge construction; $1.6-million
Florida International U. and U. of South Florida (consortium): research on intermodal-guideway—transportation systems; $3-million

EDITORIAL

Agricultural Research

At one time, agriculture was the principal research area funded by the federal government. But today the sums appropriated for R&D on it are tiny in comparison with those allocated to space or health. While appropriations for many agencies have expanded greatly since 1955, those for R&D in the U.S. Department of Agriculture (USDA) have remained at about $780 million in terms of constant dollars. Most of these funds have been spent intramurally by the Agricultural Research Service. Some have gone to state activities. The USDA did not initiate competitive grants activities until 1978. At that time, the appropriation for them was only $15 million. Annual appropriations grew slowly to about $44 million in 1988.

There is no question about the major contribution made by the R&D supported by USDA during the past hundred years. And for much of that time, U.S. agriculture enjoyed special advantages of fertile soil, innovation in farm machinery, and low-cost petroleum products. But today strong global competition is with us. Imports of food into the United States are increasing. Other countries, including developing nations, are successfully engaging in research. Advanced countries are devoting relatively more attention to agriculture than is the United States. The percentage of total R&D funds devoted to a category that included agriculture, forestry, and fishing in 1988 were: United States, 1.9; Japan, 6.5; Germany, 3.1; France, 4.6; and United Kingdom, 5.5. Yields of food grains in other countries often exceed those in the United States. In some countries labor or fertile land is cheaper than in the United States. If the United States is to maintain or increase its favorable balance of trade in agricultural products, it must enhance the quality of its agricultural products and increase production efficiency. To do this will require devoting a larger share of its creative talent to basic agricultural research. A means to this end would be to expand the USDA competitive grants program. A rationale for doing this and legislation authorizing it are already in place.

In 1989 the rationale for an enlarged competitive grants system was supplied by the Board on Agriculture of the National Research Council (NRC). It issued a report* that was unusually effective. The document won approval from the Bush administration and led to action under Public Law 101-624 to foster a National Competitive Research Initiative. Recommendations of the NRC were followed quite closely in the crafting of the legislation. The NRC report spotlighted six targets: plant systems; animal systems; nutrition; food quality and health; natural resources and the environment; engineering, products, and processes; and markets, trade, and policy. The legislation also targeted the six. Descriptions of the six targets were similar. In the legislation, the following appears specifying an area to be supported:

> Plant systems, including plant genome structure and function; molecular and cellular genetics and plant biotechnology; plant-pest interactions and biocontrol systems; crop plant response to environmental stresses; unproved nutrient qualities of plant products; and new food and industrial uses of plant products.

Equally broad scope characterized specifications of the other areas.

The legislation also specified, "in seeking proposals for grants...and in performing peer review evaluations of such proposals the Secretaries shall seek the widest participation of qualified scientists in the Federal Government, colleges and universities, State agricultural experiment stations, and the private sector." The legislation authorized appropriations of $150 million for fiscal year 1991, $275 million for 1992, $350 million for 1993, $400 million for 1994, and $500 million for 1995.

To date that schedule has not been met. The actual appropriation for 1991 was $73 million and for 1992 and 1993 it was set at $97.5 million. A cap of 14% for overhead has been set. Nevertheless, there have been so many proposals that only about 22% could be funded for an average slightly over $50,000 per year.

It is early to ask about accomplishments. However, as one example, the tools and methods that were developed by National Institutes of Health and National Science Foundation investigators are being rapidly and successfully applied to plant and animal genomes and to detection of disease processes in both plants and animals. Research in areas included in the USDA competitive grants program (NRICGP) should have high priority and corresponding increased federal support.

Philip H. Abelson

*"Investing in Research: A Proposal to Strengthen the Agricultural, Food, and Environmental System" (National Academy Press, Washington, DC, 1989).

EXHIBIT 13

Table 1. Total R&D by Agency

Congressional Action on R&D in the FY 1993 Budget (budget authority in millions of dollars)*

	FY 1992 Est.[1]	FY 1993 Request	FY 1993 Approved	Action by Congress: Change from Request Amount	Change from Request Percent	Change from FY 1992 Amount	Change from FY 1992 Percent
Defense (military)	37,776.5	40,083.8	39,165.8	-918.0	-2.3%	1,389.3	3.7%
National Aeronautics and Space Administration	8,543.2	9,308.4	8,842.5	-465.9	-5.0%	299.3	3.5%
Energy	8,247.9	8,070.9	7,385.1	-685.8	-8.5%	-862.8	-10.5%
Health and Human Services	10,283.7	10,664.6	10,558.1	-106.5	-1.0%	274.5	2.7%
(National Institutes of Health)	(9,638.4)	(10,138.6)	(9,923.2)	(-215.3)	(-2.1%)	(284.8)	(3.0%)
National Science Foundation	1,968.3	2,331.3	2,003.0	-328.2	-14.1%	34.7	1.8%
Agriculture	1,496.4	1,403.1	1,458.2	55.1	3.9%	-38.2	-2.6%
Interior	624.1	543.5	608.8	65.3	12.0%	-15.3	-2.5%
Transportation	473.3	518.4	497.1	-21.3	-4.1%	23.8	5.0%
Environmental Protection Agency	499.9	528.4	548.3	19.9	3.[illegible]%	48.3	9.7%
Commerce	610.2	654.7	708.6	53.9	8.2%	98.4	16.1%
Education	172.2	217.4	179.5	-37.9	-17.4%	7.3	4.2%
Agency for International Development	335.3	339.2	321.0	-18.2	-5.4%	-14.3	-4.3%
Department of Veterans Affairs	234.2	247.7	239.0	-8.7	-3.5%	4.8	2.0%
Nuclear Regulatory Commission	120.0	127.7	125.4	-2.3	-1.8%	5.4	4.5%
Smithsonian	107.0	125.0	118.8	-6.2	-4.9%	11.8	11.0%
Tennessee Valley Authority	92.7	55.0	85.9	30.9	56.2%	-6.8	-7.3%
Corps of Engineers	54.4	72.4	50.5	-21.9	-30.3%	-3.9	-7.2%
Labor	37.2	51.2	44.3	-6.9	-13.5%	7.1	19.1%
Housing and Urban Development	24.2	34.2	24.0	-10.2	-30.0%	-0.2	-1.0%
Justice	43.7	51.3	49.2	-2.1	-4.1%	5.5	12.6%
Treasury	16.6	18.6	16.0	-2.6	-14.2%	-0.6	-3.9%
TOTAL R&D	71,761.2	75,446.9	73,029.1	-2,417.8	-3.2%	1,268.0	1.8%

*Authors' estimates. Includes conduct of R&D and R&D facilities. Figures for FY 1992 and FY 1993 differ from those shown in AAAS Report XVII because of revisions to agency requests and technical corrections.

[1]Reflects the rescission of $1.4 billion in FY 1992.

Source: Teich, Albert H., et al. Congressional Action on the Research and Development Budget, American Association for the Advancement of Science, Washington, DC, 1993, p. 49.

EXHIBIT 13

Table 11. Department of Agriculture

Congressional Action on R&D in the FY 1993 Budget (budget authority in millions of dollars)*

	FY 1992 Est.[1]	FY 1993 Request	FY 1993 Approved	Action by Congress: Change from Request Amount	Change from Request Percent	Change from FY 1992 Amount	Change from FY 1992 Percent
Agricultural Research Service:							
Programs	668.4	694.3	666.0	-28.3	-4.1%	-2.4	-0.4%
Buildings and Facilities	50.6	27.3	34.5	7.2	26.4%	-16.1	-31.7%
TOTAL, ARS	718.9	721.6	700.5	-21.1	-2.9%	-18.4	-2.6%
Cooperative State Research Service:							
Programs	418.6	404.3	420.1	15.8	3.9%	1.5	0.4%
Buildings and Facilities	74.8	0.0	52.1	52.1	--	-22.7	-30.3%
TOTAL, CSRS	493.4	404.3	472.2	67.9	16.8%	-21.2	-4.3%
Forest Service	184.1	173.7	186.2	12.5	7.2%	2.1	1.1%
Economic Research Service	58.7	60.4	58.7	-1.7	-2.7%	0.0	0.0%
Agricultural Cooperative Service	3.5	3.1	3.5	0.4	12.0%	0.0	0.0%
Agricultural Marketing Service	4.7	4.3	4.5	0.2	5.5%	-0.2	-0.8%
International Cooperative Development	1.5	1.5	1.5	0.0	0.0%	-0.2	-3.5%
Human Nutrition Information Service	10.8	13.7	10.8	-2.9	-21.3%	0.0	0.0%
Nat'l Agricultural Statistics Service	3.4	3.4	3.3	-0.1	-2.4%	-0.1	-2.4%
Federal Grain Inspection Service	0.7	0.4	0.7	0.3	75.0%	0.0	0.0%
Animal and Plant Health Inspection Service	16.7	16.7	16.3	-0.4	-2.6%	-0.4	-2.6%
TOTAL, USDA R&D	1,496.4	1,403.1	1,458.2	55.1	3.9%	-38.2	-2.6%

*Authors' estimates. Includes conduct of R&D and R&D facilities.
[1]Reflects rescission of $1.3 million in FY 1992.

Source: Teich, Albert H., et al. Congressional Action on the Research and Development Budget, American Association for the Advancement of Science, Washington, DC, 1993, p. 66.

EXHIBIT 14

EXHIBIT B

Federal Agency Support of R&D (FY 93), by Discipline

discipline	agency DOE	NSF	NASA	DOD	HHS/NIH	USDA	EPA	ALL OTHER
Physics	X	X		X				X
Astronomy		X	X					
Atmos & Oceanic	X	X	X	X				X
Earth Sci.	X	X	X					X
Water Resources		X				X	X	X
Bio Sci.	X	X	X		X	X	X	X
Chemistry	X	X		X	X	X	X	X
Behav. & Soc. Res.		X		X	X			X
Math Sci.	X	X		X				
Comp. Sci.	X	X	X	X	X		X	X
Electrotech.	X	X	X	X				X
Chem. Eng.	X	X					X	
Materials Sci. & Eng.	X	X	X	X	X	X	X	X
Mech. Eng.	X	X	X	X			X	X

Source: "Disciplinary Analyses," in *Research and Development FY 1992,* AAAS Report XVII (Washington, DC: 1992), pp. 189-338.

EXHIBIT 15

Why an Nie?

Or How to Become a Priority in the Federal R&D Portfolio

1. Increased budget share (Lederman argument).

2. Priority-setting by a research community or professional society (e.g., astronomy, ecology, (FASEB), or by an agency division (e.g., Office of Energy Research at DOE).

3. Increased visibility through structural change within an existing agency (e.g., creation of an SBE Directorate at NSF).

4. Priority-setting across R&D agencies (e.g., OST/FCCSET Committee initiatives in high-performance computing, global change, education and human resources, etc.).

5. Other intra-agency action(e.g., strategic planning at NIH and NSF) and inter-agency coordination (e.g., to clarify support for neuroscience research by declaring the 1990s "Decade of the Brain").

6. Creation of a new agency.

AGRICULTURAL RESEARCH STRUCTURES IN A CHANGING WORLD*

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Agricultural Research Structures in a Changing World

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Abstract

Society's demands on the agricultural research system are evolving from preoccupation with the yield and cost of individual products to concern with safety, quality and variety on the one hand, and environmental implications of production processes on the other. The system's response to the demands will be profoundly affected by the revolutions in biotechnology, ecology and legal protection of agricultural research property rights. The scope of the public role, as exemplified in land grant universities, will be reduced in some areas, expanded in others. New incentives are created by opportunities to sell or license research products under patent protection. The managerial challenge for universities is to use these new incentives to improve overall research performance without compromising teaching, advising and other beneficial scholarly obligations with less direct financial rewards.

Agricultural Research Structures in a Changing World

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Public and private sectors in the United States have been major partners in an multibillion dollar agricultural research, development and extension effort that has made possible the impressive rate of technical change seen in the sector over this century. Despite a widely-acclaimed record of high rates of return to public investment (Ruttan 1982), the share of the public partners (USDA and state agricultural experiment stations) fell from 40 to 34 percent over the decade of the eighties (Huffman and Evenson 1993, Table 4.1), due to sporadic cuts in public support levels that are mainly traceable to exogenous budgetary pressures. Over the same period total expenditures increased, however, from 3.9 to 4.8 billion dollars (at 1984 value) due to an increase in private expenditures.

The budget cuts are the most obvious but not necessarily the most important forces for change. Other pressures for more fundamental changes in the nature of agricultural research structures is being engendered by qualitative changes in the social demands made on the agricultural research and extension system, in the scope and nature of scientific opportunities for discoveries, and in the potential rewards for researchers.

In this paper we consider the implications of these changes for the nature of public and private agricultural research. We focus on land grant institutions like U.C. Berkeley and their relations with the private sector in pursuing research and development. The questions include

- What changes should we want and/or expect in the public and private roles in agricultural research?
- What is the appropriate structure for public-private collaboration in modern agricultural research and extension?
- How should researchers be motivated and rewarded?

In what follows, we first consider the nature of the changes in demands on the agricultural research system. Then we review in Section 2 the reasons why both the public sector and the private sector have valid economic roles in the research and extension system. In Section 3 we consider public and private sector responses to the new research demands and opportunities. Then, focusing on the land grant universities, we consider in turn the implications for institutional structure (Section 4) and for the performance of the universities' roles in teaching, research and extension (Section 5). Conclusions follow.

1. The Evolution of Research Demands

Historically, the politically expressed demands on the agricultural research system have focused on efficiency in agricultural production and post-harvest activities, and the promotion of rural prosperity and parity with other sectors of the economy.[1] The cost-decreasing and/or yield-increasing innovations the system produced for farmers satisfied the supply requirements so effectively that market forces placed downward pressure on the equilibrium price of farm commodities (Cochrane 1958). This in turn led to effective political action by the farm lobby to obtain protection from price reductions via government intervention to support prices. On the other hand the distributional concern for relative prosperity of the rural population, featured so prominently in political rhetoric, has not been discernible among the major objectives of public agricultural research, which have remained focused on technical and economic efficiency. Improvements in efficiency clash with the achievement of rural prosperity when the induced increases in supply depress market prices so much as to reduce the net returns to rural suppliers of labor, land, and other inputs.

Now, however, society's effective political demands of the farm sector have become much more complex. Consumers wish to reduce the actual or perceived health risks of chemical residues in foods, and of herbicides and pesticides released into the environment by farmers. Other concerns include the effects of erosion on

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[1]Clear statements of the broad objectives of United States agricultural policies are surprisingly difficult to find. For our purposes, the following extract from the Hatch Act of 1955 is relevant:

> "Sec. 2. It is further the policy of the Congress to promote the efficient production, marketing, distribution, and utilization of products of the farm as essential to the health and welfare of our peoples and to promote a sound and prosperous agriculture and rural life as indispensable to the maintenance of maximum employment and national prosperity and security. It is also the intent of Congress to assure agriculture a position in research equal to that of industry, which will aid in maintaining and equitable balance between agriculture and other segments of our economy." (U.S. Congress, 1980, p. 18-22)

land and water quality, pollution by animal wastes and most recently the effects of methane emitted by belching ruminants on global warming. Standards for animal rights are being advocated for veal calves and poultry. Clearly the farming process itself is increasingly being subjected to direct social constraints, rather than being viewed as only indirectly socially relevant as the means to achieving a prosperous farm sector and a cheap and secure food supply. (See the accompanying chapter by Busch for more on this.)

At the same time, consumers with increasing incomes and no intention of eating or drinking more are looking for higher quality, novelty, variety and constant availability in their foods. These objectives are not obviously mutually consistent, especially if the research continues along the path that produced high yield and low costs.

Scientists and innovators are being asked to furnish production processes, and new products, that respond to these multiple social concerns, and there will be an increasing demand for products and services that can help management in this complex and dynamic environment. Indeed the multifaceted interactions that constitute an agricultural system will increasingly be the subject of analytical attention. Beyond biotechnology lies the challenge of ecologically appropriate agriculture. This is far more demanding than the more narrow, often organism-specific, focus seen in much of extensive research effort in modern medicine, for example, and also characteristic of that part of agriculture that has in the past achieved the greatest yield increase, the cultivation of a plant or animal species via the exclusion of competitive species by some artificial means. Fortunately these challenges come at a time when the research capacity is being transformed by the revolutions in biotechnology and information processing.

Besides improving the prospects for pursuit of the traditional productivity objectives, the new biological techniques make possible previously unimagined qualitative transformations of plants and animals. They seem to expand greatly the potential for satisfying the new demands for benign production processes, on the one hand, and an array of improved consumption characteristics on the other.

Already scientists have been able, for example, to transfer the pesticidal qualities of Bt into agricultural plants, which might help reduce chemical pesticide use. On the other hand genetic manipulation has also made possible delivery of better-ripened fruit, such as the Calgene tomato, with less damage and wastage. A slew of more impressive breakthroughs can be anticipated in the years ahead.[2]

Through biotechnology agriculture will expand to produce new higher-quality forms of existing products, and entirely new agricultural products, many of them beyond the traditional range of agricultural commodities. The term "pharming" refers to the use of plants as factories for biological and chemical products. The biological production of fine chemicals and fibers may offer a less costly alternative to the use of finite or ecologically sensitive environmental resources. Scientists have genetically engineered plants to manufacture a wide variety of materials, including human proteins

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[2]For an excellent overview of prospective applications of genetic engineeringõ of plants for control of insects, weeds, and diseases, of animals for growth promotion, animal health, reproduction technologies and creation of transgenic animals, and in food processing, see U.S. Congress, OTA (1992), and also parts of U.S. Department of Agriculture, Economic Research Service, (1992), especially Gibson (1992).

such as albumin and interferon, alpha-amylase, a bacterial enzyme that is widely used in the food processing industry and natural polymers, including a type of polyester (Moffat 1992).

The advent of the new biotechnological innovations has been fostered by new legal protections in the form of the Plant Variety Protection Certificate (PVPC), established in 1970 and extended in 1980, and subsequently the expansion of patent protection to life forms by the Supreme Court in Diamond v. Chakrabarty in 1980.[3] Similarly the market for software and databases has been sufficiently (if not optimally) developed under the evolving law regarding copyright protection that it has made the personal computer a productive and popular management tool for farmers and farm advisers.

However the legal system also poses new challenges for the modern biological products developed under its protection. The marketing of the Calgene Flavr-Savr tomato may be hindered by legal challenges or the threat thereof, or more generally by adverse publicity regarding the safety of foods containing new genetic material. Already its major backer, Campbell's, is backing away from plans to use this product.

In sum, the agricultural research system is faced with new challenges, but also with an exciting new array of opportunities. How should the agricultural research system be structured in this new environment?

[3]For an up-to-date discussion of relevant intellectual property protections, see Chapter 15 of U.S. Congress, Office of Technology Assessment, (1992).

2. Why Public Research and Extension?

2.1 General Arguments

As a preliminary, it is helpful to keep in mind the reasons why we have a public research system at all. After all, we rely on the private sector to produce other products, including food, with profits from private sales as the incentive. Public provision of research and extension has been justified by the argument that the private incentives for research and extension fall short of the public gains at the margin. Important "externalities", benefits (or costs) not captured in private profits, are associated with public research inputs, outputs, or the process itself. This argument has much greater force for some areas of effort than others.

It is widely accepted that pure knowledge, not embodied in any product, is a "public good", the benefits of which are properly made available free of charge because they are "non-rival"; use by one does not reduce the supply available to others. The product of successful basic research is of this type. The desirability of free provision is fortunate, for it is very difficult to exclude non-purchasers from acquiring such "disembodied" information, and since the information is often of quite general use the number of potential "free riders" is often very large. It follows that basic research is mostly produced in, or at least supported by, the public or non-profit sectors.

Basic research findings feed into the applied research areas, which tend to be more industry-specific. In many areas the fruits of applied research are at least partially capturable by its producer, for two quite different reasons. The creator of disembodied applied process discoveries reaps the benefits to the extent that it dominates the industry that uses the process. For example, an advance in irrigation-equipment manufacturing techniques would be likely to benefit a major manufacturer of such equipment. Furthermore, much applied research and development produces innovations that are embodied in products, such as machines or drugs, that can be sold for profit in private markets, and protected from copying by patents or secrecy. In these cases the derived private demand for applied research may well be adequate, if not optimal.

In agriculture, the producers of applied research have historically had little scope for capturing sufficient compensation from the market to justify their efforts. Most advances have been either yield-increasing or cost-reducing. Some of these advances are embodied in plants or animals that can reproduce, passing on the advances to later users, and spoiling the innovator's prospects for lucrative sales in the absence of effective legal protection. Others are process advances such as new techniques of crop cultivation that can be easily copied by diligent observers. Given the extremely competitive nature of agricultural production, the rewards accruing from use within the innovator's own farming operation are typically a tiny fraction of the full social value.

There are of course prominent exceptions to these generalizations. Private hybrid corn innovators have prospered because their product cannot be successfully reproduced by their customers. New hybrid chicken varieties are also produced privately. Mechanical and especially chemical farm inputs, originating in other sectors, have historically had patent protection. This has not always been very effective. Eli Whitney's (or was it Catherine Greene's? See Warrick 1992 pp. D3-D4) cotton gin, to take a famous example, was so widely copied, despite patent protection, that it was necessary to award him a prize to provide him, ex post, a significant return for his innovation.

Given the anticipated opportunities for innovation, on the one hand, and the lack of privately appropriable returns from many types of applied innovations on the other, the public sector role in supporting agricultural research has been unusually large, and has included the applied development and dissemination of techniques and products that in other sectors is left in the hands of the private sector. Thus the historical role of the public agricultural research complex covers the whole range from basic scientific investigation to the farmer's field. In the United States the land grant universities cover this span, in large part integrated within a college of agriculture and/or natural resources.

2.2 The Logic of the Land Grant System

Three aspects of the structure of the land grant agricultural research system suggest the types of externalities important to their mission. The first is that it is a decentralised system of vertically integrated individual institutions, dispersed across the states with substantial funding from state as well as federal sources. Second, its basic structure is program-oriented rather than project-oriented, in that its staffing is predominantly on a permanent basis. Third, the research mission is pursued in concert with an educational mission; researchers are also university teachers and students and others involved in public education.

Decentralization of research and extension to the state level has traditionally been rationalized by the argument that it reflects the fact that many applied research problems are locally specific. Pests, diseases, plant varieties and cultivation practices differ across states and even counties. An institution that is close to the problem is more likely to respond effectively. Thus dispersion of the applied research function makes sense. The dispersion of the basic researchers along with their applied colleagues, as in the land grant universities, allows both types to take advantage of the knowledge externalities available due to close informal contact. The experience of institutions set up with a more exclusively applied focus, such as the International Rice Research Institute, apparently has led them to an increasing appreciation of a permanent, in-house, more basic research capacity.

Concentration on local problems also reflects the fact that their solution receives the greatest political support from local agricultural interests. Yield increases and cost reductions supplied gratis to all producers in an industry tend to reduce output prices rather than increase profits. But to the extent that the effect is only on local producers, the price reduction response is muted, and the local benefits to the sector are more likely to be positive. Given productivity increases offer greater benefits if they occur on a national or international scale, but the benefits would tend to go to consumers, who have little influence on the system. The result is that local problems get the most attention, and the spatially decentralized research system is well suited to addressing them.

The permanence of the research and extension staffing means that there is an accumulation of institutional capacity in the form of knowledge and expertise to respond quickly and effectively to emergency problems, such as the poinsettia whitefly or the abruptly-apparent selenium toxicity to waterfowl at Kesterson reservoir in California, as they arise. This "option value" could be important to the extent that the same response cannot be had as efficiently from the private sector in the form of temporary consultants or contractors. When the whitefly struck California, would it have been better for each affected farmer to have sent out for bids from private fly-problem-solvers?

The argument for public provision of quick access to a standing capacity for flexible emergency response seems similar to the argument for a publicly supported standing army or fire brigade (granted some would argue against the latter). The argument has force if in-house performance incentives are more appropriate, if the externalities from easy contact with and access to basic researchers are important, and/or if it would be difficult to know what contractor to choose if the expertise were not already present in the public sector.

The association of research with teaching is a practice that is widespread across the academic spectrum. As Ruttan (1982, p. 110) reports, "Over time, a consensus seems to have emerged in the United States that research is highly complementary to graduate education, but less so to undergraduate teaching." But the interplay between functions is difficult to analyse and not well understood. Obviously class time competes with research time, for faculty and students. On the other hand the functions are complementary; in a sense each offers positive externalities to the other.

Students who learn how to apply their classroom learning by participating in real research in a critical environment under the supervision of their professors can reap educational and motivational rewards. Furthermore their work has an actual social contribution, in contrast to fictional educational exercises. Their experience might also help students make better and earlier choices about the direction of their careers. Such benefits would normally become more available as the student advances in his or her academic career.

For professors and other teachers, involvement with institutional research helps keep their teaching relevant to current problems. This is likely to be more important for advanced undergraduate and graduate classes where there is usually more discretion about choice of subject matter and teaching tends to be more focused on research challenges. As researchers, their involvement in teaching, especially in advanced courses, helps broaden their perspective beyond their currently pressing research challenges to comprehend current work in other corners of their academic field, and in related specializations. Since scientific progress often results from drawing links between lines of investigation, involvement in teaching can encourage faster progress in research.

The above discussion has focused on some rationales for the current structure of agricultural research, as seen in the land grant system in particular. The features noted have their drawbacks, of course. Decentralization means inevitable duplication of some research (especially basic research) and of teaching functions. Permanent employment on a program basis makes it possible for deadwood to accrue and for the institutional culture to tolerate sloth and lack of responsiveness to social demands in both education and research. Teaching demands can divert bright minds from vital research tasks, and, on the other hand, research demands are currently being blamed for neglect of undergraduate teaching in the universities and colleges in general.

The social optimality of the land grant approach to agricultural research in trading off the advantages and disadvantages of its institutional design has not been scientifically established, of course. But its contribution to American agricultural productivity is well recognized. (See, for example, Nelson and Wright, 1992, p. 1947.) The relevant question now is how the existing structure of public and private collaborative research will respond to changes in the social, institutional and scientific environment.

3. Private and Public Sector Responses to the New Environment

We have some evidence already about the private sector response to the new opportunities. There has been an explosion in the private creation of new varieties after they were covered by the PVPA (Evenson 1983), and this occurred with conventional technology; it was not caused by the new possibilities associated with genetic engineering (U.S. Congress, Office of Technology Assessment, 1992). One might have anticipated this private sector response from the history of successful private production and marketing of hybrid corn varieties, which had some natural protection from unauthorized duplication by customers.

New advances in biotechnology have opened up a whole new technological frontier, and patented life forms and other genetic engineering products are already being marketed to agricultural producers as well as to other industries including prominently those in the health sector. Furthermore there is a complementarity between the institutional and technological advances. Modern analysis of DNA is likely to make policing of life form patents more effective.

The ability to patent and copyright has also changed the marketing possibilities for public and non-profit research institutions and the researchers who are employed in them. Whereas previously they had few opportunities to sell their output (as distinct from their services as research inputs) the institutions, and their employees, now face very significant rewards for success in meeting market needs, the diversity of which is reflected in the fact that two of the most successful to date are the Cohen-Boyer gene-splicing patent and Gatorade. An agricultural example is the domination of the market for strawberry varieties by the University of California, Davis.

4. Implications for Institutional Structure

4.1 Vertical Integration of Public Agricultural Research

The new opportunities to sell the property rights to embodied research outputs will affect the public and private research structures in many dimensions. Perhaps the most obvious is that private for-profit applied research is more feasible for these new innovations, so that the public role need not be vertically integrated right down to the farm gate, as it has been for other agricultural innovations without capturable property rights. Somewhere between basic research and extension, an interface can develop between the public and private innovation institutions. The transfers will tend to be vertical, with the private party downstream. If the transfer happens at the pretechnology stage, before the knowledge is embodied in a marketable product, it is similar to the public provision of technology to farmers, in that the private party acquires a free good. In this case, though, it is an input to further (private) research and development, rather than directly to the production process itself. This distinction can be crucial.

The purchaser(s) of university research output are likely to be corporate entities with substantial market power, not competitive farmers. To the extent that the clientele of university research is dominated by large powerful firms, administrators of land-grant institutions may have a "potentially massive public relations problem" (Kenney et al 1982 p. 52).

As noted above, market power in the relevant final product is essential where developmental expenditures are significant and any results are not protected by patents. If a potential purchasing firm is unprotected by pre-existing market power, it might well be reluctant to invest in the development of the technology to the marketing stage, for fear that others equally free to acquire the public technology gratis might beat it to the punch, or even copy the technology if it is too applied to pass the novelty and non-obviousness tests required for patenting.

The more novel the innovation, the less likely the availability of pre-existing market power to protect it. This might explain why the Commonwealth Scientific and

Industrial Research Organisation in Australia found that they literally *could not give their technology away.* A policy of exclusive licensing was adopted to elicit greater interest in adoption of its discoveries by the private sector. Where this consideration is important, the public/private interface will tend to lie beyond the stage at which the first property right is acquired. Significant patenting will occur in the public part of the research sector. Private participation will replace some public efforts at the applied end of the research spectrum. This is already happening in other technological areas such as irrigation, where the dealers are the final agents of information transfer to farmers; a major part of extension ends at the dealer's yard. But substitution of private for public research will remain concentrated in the development stage, where further patenting is a possibility.

Another obstacle to direct technology transfer, found by Postlewait, Parker, and Zilberman in a survey, is the reluctance of in-house research departments to encourage the purchase of technologies that were not developed in the company itself. As a result , licenses to some of the most advanced technology developed in the U.S. have not been purchased by local companies. For example, a Stanford researcher invented an music chip for electronic keyboards. Despite the technology's obvious potential to revolutionize the industry, no American company wanted to license the chip, and eventually Yamaha licensed the technology and dominated the market.

Where the private innovator has market power, its research may, as mentioned above, extend up towards basic research, even without the legal protection of property rights. In this case the innovator may well be a large firm with a structure of bureaucracy possibly similar to that of a public institution.

Some other large firms take the opposite tack, acquiring technology by purchasing small companies that were developed around a certain innovation. Some large chemical companies lurk around trying to absorb promising innovative companies. In turn, these young companies need the marketing capacity of the big companies and they may seek an adopting parent. In effect some of the big companies are *marketing* organizations that rely on small R&D companies to develop a diversified product mix. They may also be potential customers for university research rights.

Increasingly, extension personnel are becoming more involved in giving policy advice to government and to public agencies, and in the facilitation of environmental management and controls. In these roles they extend knowledge produced by university research. As the downstream reach of extension is rolled back in some areas of technology, it is expanded in other areas to meet changing needs.

4.2 University Marketing Arrangements

The possibility of patenting research findings in a public institution such as a land grant university raises many issues, among which are:

- How will the rights be marketed?
- Who shares in the revenue?
- Should the university participate in development investment?

Answers to some of these questions already exist (at least provisionally) in the structure of the "Office of Technology Transfer" (OTT) or of the "Office of

Technology Licensing" (OTL), themselves institutional innovations seen in several universities.

The leader is Stanford, whose OTL is available for patenting and licensing the research of any faculty who wish to use it. The proceeds are divided as follows: After 15 percent is taken off the top to finance the OTL, net royalties are split into one-third shares for the inventor, one third for the inventor's department, and one-third for the university. In fiscal 1992, Stanford received $25.5 million in royalties and fees. (Barnum 1992)

The University of California has a similar systemwide office that awards university employees on a sliding scale, with 50 percent of the first $100,000 of net royalties, 35 percent of the next $400,000 and 20 percent of any higher amounts going to the inventor. Total revenues to the University from patents and royalties were $28.8 million in 1992 (Barnum 1992). In contrast to Stanford, faculty at the University of California, which has a central OTL, must use university services to patent university research. Some campuses, including Berkeley, are now developing their own campus-based OTL's to offer better service to their faculty.

Thus researchers at both public and private universities can stand to gain a substantial share of the realised value of their discoveries , and their departments and the whole institution also stand to gain. Paradoxically, *the explicit incentive appears greater in these public institutions than in the typical large private firm*, where the patents of employees are routinely assigned to the firm via prior contractual commitments and there is usually no significant explicit reward to the patent recipient.

What has been created is a monetary market for those types of innovation output that can obtain legal protection, within the context of the hierarchical bureaucratic structure of the university. Given the current popularity of markets as allocators of resources, the potential significance of this institutional innovation, for the university as well as for the researcher, should need little elaboration.

Some universities are now moving downstream again beyond patenting to financial participation in development of their patented technology, either directly or through a related institution to avoid legal problems of product liability. The University of California, for example, is considering the formation of California Technology Ventures Corporation to help commercialize the products of University research. It is time to question whether the university is an appropriate institution to handle the challenges and risks of participation in venture capital investment. Private inventors are notorious for having exaggerated views of the financial prospects of their brainchildren. In at least one case investment in venture capital has reportedly placed the financial health of a major private university at risk.

4.3 Beyond Patents to Partnerships?

The value of patent revenues in no way captures the contribution of university research to industry. Most of the important new biotechnology companies were created by university professors who linked up with venture capitalists to form new companies that developed and marketed new products. The founders of Genentech, Amgen, and Chiron, for example, include professors at Stanford, U.C. San Diego, U.C. Berkeley and U.C. San Francisco. Some of the top agricultural biotechnology companies have similar origins. The founders of Calgene and of Biosys include professors at U.C. Davis, and at U.C. Berkeley and Stanford, respectively. Generally the founders continue to be university professors while being involved with these companies.

One benefit of these companies is that, by their proximity and their personal links to the university, they are often good sources of employment for students and graduates. They also enable the university to continue to employ high-quality research professors while paying them less than the market value of their services.

But can the university design contracts that give it a greater share of the wealth which it helps to produce, off-campus, via its indirect contribution of prior research, expertise and other services? This is a challenge for the future, not unlike the challenge of optimal design of contracts for university research undertaken for the private sector. In both cases there are real pitfalls, including the danger of exposure of the university to legal actions (as seen previously in the tomato harvester case) and the danger of distortion of the university's research mission by private interest that "free ride" on university research efforts. (See Ulrich, Furtan and Schmitz (1986) for a discussion of free-riding by private-sector brewing companies on public research in Barley in Canada.)

5. Implications for University Performance

5.1 Research Efficiency

As noted, the frontier technologies we have been discussing happen to offer unusual opportunities for market returns due to patent and copyright protection. Patents and copyrights are very effective at encouraging the researcher to use his or her own information, informed by market pressures, to choose between research topics according to his or her capabilities, research costs, the probability of success, and the value if successful. Since research resource management is characterized by uncertainties and informational shortages, this utilization of the researcher's information and his or her market expectations is extremely important. The disclosure mandated under patent law also makes the information discovered more accessible for other members of society who can use it in further innovation efforts.

If instead a prize (money or promotion) is the reward for achieving a pre-specified goal, the researcher's information about the market value of success is unused unless an effective means of gathering it is found by the prize-setter. This does not matter if the latter has accurately identified an appropriate social goal. Some of the most important technical advances have occurred in response to prize incentives, including the technique of food preservation by canning, and the navigational chronometer. But in research an important part of the individual's skill is often the ability to know what questions to ask, what goals to set, given the economic environment and the technical possibilities, as set out in the (as yet incomplete) theory of induced innovation. (See for example Binswanger and Ruttan, 1978). Prizes for achievements defined ex ante do not reward such skills. If we assume the prize setter has similar skill and the latitude to use it, there may be no problem, but this is a big assumption.

On the other hand, if research contracts are awarded by competitive bids (an increasingly popular trend), private information about capabilities and success prospects is also lost to management. When the research process is managed by central direction of research inputs including personnel, all of the private information about capabilities costs, probabilities, and market returns may be neglected. (For more on this see Wright 1983, 1985.)

But patents, copyrights and similar awards have their problems as research motivators. The race to be first to patent may involve wasteful duplication of effort on similar projects by personnel within or between institutions, especially if the resources devoted to a given line of research are very responsive to economic incentives (Barzel, 1968, Wright 1985). Duplication is made more likely by the need for secrecy about research strategies in preserving a competitive advantage. Collaboration with complementary research colleagues may be discouraged for the same reason. This problem will be particularly severe in large teams such as a research laboratory where individual contributions are difficult to verify.

In addition the patent incentive might be too powerful in the sense that it distracts attention from other important tasks with less direct motivations. For university personnel, these could include teaching, advising and other institutional services, on the one hand, and research (such as more basic investigations) which yields non-patentable knowledge.

Similar kinds of objections to providing value-based rewards for innovation are increasingly expressed in the business management literature, largely influenced by recent Japanese thinking associated with the "Kaizen" (gradual improvement) system. They may also explain the observation that large private firms in the United States generally choose less high-powered, more implicit, rewards for their employees than the arrangements now becoming popular in research universities.

In the case of universities, it should be borne in mind that many of the problems with the new incentives, including duplication, envy, and misdirection of effort already exist in the system of rewards based on implicit criteria imposed ex post by deans and/or academic peers, from tenure and merit increases to general prizes such as the Nobel Prize, reflected in the adage "Publish or Perish." The advent of a parallel system of market-determined rewards might to some extent offset the distortions of the traditional implicit incentive structure. For example, the fact that researchers worry that the patent incentive biases research toward applications (Blumenthal et al. 1986 p. 1364) might be good news to those like Ed Schuh who claim that university research has lost a sense of relevance (Schuh 1986, 1991). In principal, this issue should be amenable to empirical resolution for specific cases.

5.2 Social Externalities

The market transfer of knowledge has been emphasized above. Two points are worth bearing in mind about the associated social contribution. First, an innovation, even if patented, usually transfers benefits to society greater than what the consumer pays. An innovator will often reduce, directly or indirectly, the price of some consumer goods, generating consumer surplus. Furthermore, the disclosure inherent in the patent process furnishes a knowledge externality, as mentioned above. In short, monetary returns do not necessary constitute adequate rewards for invention, even in some cases where a strong patent is obtained. In these cases, public employment of researchers, and/or other incentives such as prestige might be beneficial.

Second, it would be a grave mistake to conclude that without the recent innovation in biological research property rights the university research contribution to private research activity would be negligible. As Nelson (1986) concluded from a 1984 survey of research managers by Levin et al., the role of university research is especially important in biologically-based industries (p. 187). More generally, "university research rarely in itself generates new technology; rather it enhances technological opportunities and the productivity of private research and development, in a way that induces firms to spend more both in the industry in question and upstream" (p.188). This stimulation is at least partially local. As Jaffee (1989) and Acs et al. (1992) show, states with high university research expenditures also have more industry research expenditures, more patents, and more reported innovations. The locations of Silicon Valley, the Route 128 area near Boston, and the emerging biotechnology industries near Berkeley and Davis support this view. As argued above, the spread of university patenting of life forms should expand this complementarity, especially in biological applications including agriculture, while also increasing the direct role of universities in the generation of new technology

5.3 Cash Cows?

As we have seen, the sale of research products can be a multimillion dollar enterprise for universities. The funds can help retain productive researchers who might otherwise go to industry, and can also augment the university' resources. But one should keep a realistic view of the possibilities here. Stanford is singularly successful in this research marketing area. Yet Stanford gets only about 11 percent of its budget from industry (Postlewait, Parker and Zilberman).

6. Conclusions

The agricultural research system is facing fundamental changes in the nature and complexity of its challenges and its opportunities. We can expect that this will result in less vertical integration of public research in several areas including production of new plant varieties, leaving a greater role for the private sector in applied research.

In other areas, the role of university research and extension may well expand. Many of the coming social demands can be met only if complex innovations are achieved in institutions and policies. The university, in addition to furnishing new technologies, should facilitate the debate on options and help shape the necessary institutional adaptations. In informing people about alternative risky choices, for example pesticide versus irradiation to preserve foods, the university should exploit its educational role in teaching and extension, as well as its research capabilities.

The new opportunities bring with them new management challenges. The potential for private gains from research property rights must be handled carefully. Its introduction of market signals for researchers will be a very positive development if it is not allowed to distract them unduly from teaching, advising and collaborative research activities with a less direct financial reward. To ensure that the latter does not happen, careful research is warranted regarding the structure of license-sharing arrangements and the determination of relative research contributions from collaborative projects.

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PRIORITY SETTING IN A STATE AGRICULTURAL EXPERIMENT STATION: SHIFTING PARADIGMS

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"There are many interesting research problems.
Some of them are important."

Richard Bradfield
(Taken from introduction by Vernon W. Ruttan, in
Agricultural Research Policy.)

Introduction

When I was an undergraduate at Purdue University in the mid-1950s, I first met the director of an Agricultural Experiment Station (AES). I held several jobs to support myself and family. One of them was helping with research on forages and dairy cattle nutrition, both in the laboratory and in the field. On this particular summer day I was at the Purdue dairy center working in the field with dairy cows on an intensive experiment comparing forage management systems of continuous grazing, daily strip grazing and green chopping of forage. The project was co-led by Professor G. O. Mott of agronomy and Professor D. L. Hill of the dairy husbandry department. On this hot summer afternoon they had brought AES Director Norman J. Volk and a dairyman from Indiana to see the project in action. They even asked me, the lowly student worker, to tell what I was doing on the project. I learned some time later that they had a request in to Director Volk for additional funds for the project. Apparently Director Volk was favorably impressed by their proposal because he approved the request for funding. The project went on and I continued to have a job. This simple story suggests at least four things: (1) the AES Director was important; (2) he had control of funds; (3) he had the authority to act on his judgments; and (4) he was interested in the input of a farmer-user.

Let me point to another example of the former paradigm for priority setting, this one from proceedings of the 100th anniversary of the Wisconsin Agricultural Experiment Station: "The attitude here at Wisconsin was best expressed in the words of Professor E. B. Hart - that the station worker in cooperation with the station director take a practical farm problem of importance in a local region or state and then dig as deep as he can in science to find the answer to the problem." (emphasis mine) Let me hasten to add that I happen to believe that there is much merit in this philosophy. I hope that when translated into contemporary terms, it still can be the foundation of the AES process. However, much has changed from those simpler times.

Another example of priority setting is the PIPD, or Problem Identification, Program/Project Development system used effectively at some SAES. In this system the AES administrators and scientists seek input from clientele as well as extension workers and station scientists to get input for identifying high priority problems. Then, by sitting down together, they develop projects to address those problems. There is a risk associated with such a close linkage and implied immediacy of response. Caution should be used in entering into such a planning and program identification process unless you have control of the resources and are prepared to respond positively!

I am suggesting that in the new paradigm (which I'll discuss in some detail later) we go outside to learn real world problems and link that with a joint effort to seek help in attracting funds to address the problems.

This experiment station system, based largely on federal (Hatch and McIntire-Stennis) formula funds plus state funds, and near autonomy of the director, was very productive. However, the paradigm has shifted for some SAES, is shifting for many others, and likely will shift for all by the year 2000. In my view these shifts are not inherently either good or bad. They simply are reality and our challenge is to deal effectively with them to identify the high priority problems and assist in obtaining funds to address them.

With that hint of how I intend to approach my assignment, let me make just three introductory points:
1) I don't pretend to have the formula for setting priorities in State Agricultural Experiment Stations (SAES). Even the ideas I will be sharing with you certainly are not mine alone, but a composite of where I'm at in my synthesis and thinking process.
2) I will talk about some key components of a priority setting process which seem to me to be important wherever we may be.
3) Priority setting, in terms of both parameters and process, has changed and likely will be dramatically different tomorrow than it is today. I suggest that our challenge is to be prepared "to do the best of things in the worst of times."

Changes and Impacts

Of course many things have changed over the years. Here are just a few that come to mind:
- In the 1950s to 70s, AES funding was largely federal formula funds and state funds.
- Today more sources are involved and many of them priority setting implications.
- Funds directly to a Station are more limited and restricted.
- Directors have less "power" in the sense that funds controlled represents power.
- The priority setting process is more complex and there are many more stakeholders.
- SAES are not nearly as centrally managed (and funded) as are the USDA Agricultural Research Service (ARS) laboratories and international centers.
- Science has greatly advanced and has become much more sophisticated and expensive to conduct.
- An expanded, more diverse groups of stakeholders are asking questions, such as:
  - -is too much emphasis is being placed on research at the expense of teaching.
  - -what about public vs. private roles.
  - -is too much emphasis is being placed on "farming" at the expense of neglecting other increasingly visible areas related to our mission (and where our graduates go for employment!). Here I'm thinking of things like: diet and health; food safety; environment and water quality; waste management etc.

  Need to be cognizant of such concerns and to recognize that these priority issues must be evaluated as well.

  [There is something of a paradox here. Farming or production agriculture makes up less than 3% of the food and agricultural sector, but still has more "clout" than that in terms of getting things done.]

These changes have several impacts relevant to priority setting and implementation in SAESs today.

- Less ability to fully fund research projects out of resources controlled by the AES.
- More emphasis on using the limited flexible resources to "jump start" programs of new faculty members, provide start-up packages, and as matching requirements to get additional funds.
- Greater reliance on outside funds, which dampens any singular effort or plan to set priorities.

Priority Setting

Needs and opportunities always exist. Research is conducted on some topics and not on others. Priorities are always there; the question is who selects them. Without a well thought out timely plan, pressures are in charge and the present gets undue attention, not the future; fighting brush fires become the priority of the day; defense is the game, not offense; infighting rules, not meeting outside needs, threats and opportunities.

Levels of Priority Decision Making: At this point I'll simply introduce this topic, so we all can think about as we examine the process in more detail in the remainder of this paper.

- National level

The process of priority setting and establishing categories for funding tends to be more long-term considering impact and appropriation of funds. The SAES community expends considerable time and effort by in "tending" the system.

There have been some big payoffs for the efforts. For example, the start of the competitive grants program in 1977 and the influx of additional funds for biotechnology in 1985. This program was grown further with the initiation of the National Research Initiative (NRI) in 1991. The Water Quality Special grant is another example of the success of initiatives by the Land Grant Agriculture community. While there has been debate about whether emphasis should be placed on "formula funds" or "competitive grants", it is interesting to note that in recent years the only times there have been increases in formula funding was in those years where a major competitive grant program was started or "grown". Although arguments showing the importance of, and impressive returns from formula funds, Congress has favored research funding options where they have more control over the agenda.

- State and Local

Some states realized significant growth in state funding for AES during late 70s and early 80s

Unfortunately not all of it has "stuck" as states got into fiscal trouble.

However, it a very critical point today, whether to maintain what we have or in some cases to actually capture some growth.

- A simple outline of various kinds of funds used in AES programs is shown in Table 1: "Funding Sources and Uses"

Principal strategies

Next I would like to discuss some of the critical points for "priority setting" in these times of shifting paradigms.

Mission.

The first and foremost strategic decision which each SAES must make is determination of its purpose or mission. Failure to determine that and determine it well leaves the SAES with no focal point or central thrust for lining up the organization's energies and resources to accomplish the most desirable ends. We need to realize that an organization cannot really determine its mission or purpose in isolation; the client or "customer" makes this determination! Therefore, to be effective in developing our mission statements and subsequent strategies and tactics we must proceed from the outside (the client and the world in which we must operate) to the inside (management's response to the client's needs and wants). (McConkey, 1981)

To determine the mission of any organization it is necessary to carefully answer three major questions:

1. What is our present purpose?
2. How will the future impact on our present purpose if we make no changes?
3. What should our purpose become?

(Of these, number two is more important than number one and number three is the critical one.)

Infrastructure at the strategic level.

Where and how to allocate scarce, flexible resources, or base funding in the AES, is key. By this I mean faculty, facilities, and core operating budgets. Since most universities and SAES are in a re-allocation rather than in a growth mode, it is important to make such decisions at "targets of opportunity" when transitions can be least disruptive to the "losers."

Strategic Allocation of Faculty Positions:

- Faculty members (or AES scientists, if you prefer - I'll come back to this distinction later) comprise the "engine" which powers the entire system. Thus wise allocation of scarce faculty positions is critical.

Deciding which areas of expertise to capture in a faculty position is key area for strategic placement of resources. The impact is long-term because a faculty member (and the area of expertise carried with that person) may be with us for 25 years or more.

In our Purdue Agriculture system, all open positions created by retirements or persons leaving the university for any reason, revert to the Dean's office. To prepare for the strategic allocation of scarce faculty positions, departments have developed long-term (10-year) staffing plans and they are asked to update them periodically. Once (or in good times, perhaps twice) per year department heads are invited to submit their high priority requests for positions, along with justification. The Dean and Directors make decisions about which positions will be allocated. Occasionally, a very high priority position will be acted upon immediately upon learning of the (impending) vacancy, but that is rare. Any downsizing (rightsizing) that is to occur is accomplished by decreasing the number of positions in the pool, not by making such decisions on a position by position basis as the vacancy occurs. Thus, departments technically do not have "open positions" until a position is (re-) allocated to them. Also, they have not lost any specific positions; it may not have been requested, it may be a possibility for later consideration etc., but positions are not collapsed at the Department level by this system of allocating scarce faculty positions.

Now let us get on with factors involved in the process of deciding which positions are to be allocated. Areas of expertise needed for the teaching function may be the more important driver, or the aspect receiving first consideration today. Guidelines I use in evaluating the priority of the position for my input in terms of the priority of research component of a position (especially if more that 25% time assignment to research) include the following:

- Importance and likely impact of area.

- Needs of clientele and users.

- Opportunities in science and technology anticipated for the specific field.

- Availability of infrastructure - equipment, facilities, appropriate space (and start-up funds).

- Opportunity for outside support to develop and sustain a productive research program.

A more detailed version of this list in the format of an evaluation guide is shown in Table 2.

Selecting the individual faculty member.

- Some traits may be universally required, but many have to be specific to the position.
- Overall, priority is given to:
  - Excellence in their field.
  - Evidence of strong productivity
  - Communication abilities (and ability to relate their work to a variety of audiences).
  - Entrepreneur with a team spirit.
    - A self starter who can develop nationally recognized programs.
    - Yet, one who will work effectively as a team member for at least part of their research.
  - Ability to handle multiple responsibilities.
    - Education and research
    - More than one area at a time. (For example, to conduct basic and applied projects at the same time; individual project and a team project.)

A candidate for a faculty position in the plant sciences area that we were interviewing recently described the situation rather nicely. I had asked her a question about how she would select particular specific problems to work on. She responded, "There is a tendency for scientists, especially recent graduates or post-docs, to think, well I have these abilities, techniques, capabilities, let's see what problem I can find to use them on." She added that she believes it would be much better to go out and listen to what the problems (of farmers) are, and then design investigations to solve those problems.

She had the insight to add, "I'd better go out and tell people what I'm doing If people don't know what you're doing, they may think you're dispensable." I would simply add, that statement applies as well to research programs as it does to individual faculty members! More vigorous approaches to informing clientele and the general public about what we're accomplishing to help them are necessary. We need to capture and communicate the excitement and relevance of discovery.

Faculty members or Station Scientists?

There are significant differences in philosophies and operational models among the Land-grant colleges of Agriculture and each institution must address this issue in their own context. However, it is becoming much more common for an individual to carry responsibilities in two of the functional areas of teaching, research and extension. Or to put it another way, it is common for an individual to have responsibilities for both education and discovery.

Faculty members participating in the AES at Purdue (and I believe in most settings) must be "complete" faculty members in context of the definition appropriate for each of our respective universities. Most AES Scientists (i.e. faculty members with AES appointments) also have a responsibility to participate in education (classroom teaching and/or extension education). It is generally accepted that teaching is the fundamental function for a college or university. Over time, some so-called "research universities" developed a pattern where some faculty did not teach, spending all their time on research and related scholarly activities. On the other hand, most predominately teaching colleges and universities have expected their faculty members not only to teach, but also to be involved in some research or scholarly activity.

In the new paradigm, I believe that every faculty member - even those at research universities or with an AES appointment - will be expected to participate more fully in the education mission. It seems to me that this is an appropriate expectation. But, considering the purposes of this paper, I do not wish to digress into a discussion of the synergism between research and teaching.

Rather, I would like to focus on the unique research responsibilities of a faculty member with an AES appointment. Such a faculty member is expected to do more than simply "conduct research" and to obtain some funds to conduct research or engage in a scholarly activity of his/her choosing. The AES faculty member already has part of his/her salary paid and time assigned to conduct research. It is part of the contract for such an appointment. In addition, that research is to be directed to jointly determined thrusts. This is done not to stifle creativity, but to provide focus. Creativity should be encouraged and rewarded. Changes in the defined thrust can be made by means of revisions in the AES projects. I would suggest that the AES faculty members have fundamental responsibility for the kinds of research related activities listed here. Note, a specific faculty member may be involved in 1 and/or 2, and/or 3, but all will be expected to be involved in 4 and 5.

1) Mission oriented basic research
2) Applied research and site specific systems development.
3) Consumer-report type research activities.
4) Educating and training graduate students
5) Communicating to a variety of "publics" (and not just to colleagues).

Operating Resources.

The level of operating resources and funds to put around faculty members is another important component of infrastructure. Strategic decisions in this area also are critical. The funding process used at Purdue places most of the core or base funding in the departments. The department head has responsibility to allocate and manage those resources in the context of that departments research program as defined by their AES projects.

The cost of conducting research varies among the disciplines encompassed by agriculture. This needs to be taken into account when an AES Director evaluates the equity of funding provided to various departments. I have developed some estimates of costs by discipline/department, starting with expenditures data for several SAES and making some adjustments based on known anomalies. More precise estimates of the cost by discipline would be very helpful. Part of the charge I was given when invited to prepare this paper, was to identify areas where the NC-208 Regional Research committee could contribute to the priority setting process. Here is one example. We need better estimates of the cost of doing research in various disciplines and in department composites.

Another strategic decision which must be made is the allocation of scarce resources to faculty positions versus operating funds. Institutions vary in the flexibility that exists at the College or Station level. In situations where the College has significant flexibility in moving funds between positions and operating funds, a critical strategic question is, "At what point should some faculty positions be eliminated and the funds re-allocated to support programs and projects?" It was noted that faculty is the engine which drives the research machine, not only in terms of creativity and productivity, but also in getting grants! But at what point on the curve of shrinking resources available to put around faculty members to make them productive (and somewhat direct the research program) should the decision be made to decrease the size of the engine in order to fuel it for more effective operation? Not at all an easy decision, but one that is crucial!

Multi-State Programming.

Another strategy which needs to be considered is to build and expand on Regional research, developing innovative ways to enhance multi-state programming. Typically in regional research a topic or problem is identified and then the Stations divide up the effort for solving the problem. Regional research often involves most all of the states in the region and increasingly may involve Stations from other regions as well.

Alternative models for multi-state planning should be pursued. In terms of alternatives to regional research, there are (at least) two other kinds of Multi-State Planning needs, usually involving 2 to 4 contiguous states who may choose to get together and target areas to:

(1) Cooperate by picking different parts of the puzzle on which to work, OR

(2) Cooperate by agreeing to work on different puzzles.

Such bordering state coalitions require a shared vision for a need to get together and seriously consider how to do things more efficiently.

(1) Pursue, and ultimately agree on, problem and model to be pursued.

(2) Develop truly integrated efforts in specifically targeted areas. May involve both research and extension and perhaps teaching.

(3) The process often may start with discussions among Deans and /or Directors.

(4) Next need to get together with department heads. Keep faculty informed by each department head and invite input and ideas.

(5) Faculty planning and implementation (with appropriate administrators to facilitate and to uphold the pledge).

(6) Note, some of these activities could go the route of establishing regional research projects, but the appropriateness of keeping linkages from targeted states need to be met. It may be difficult under the formal regional research system to achieve some of the flexibility and speed of response required by the "virtual corporation".

NOTE, THE MODEL: the "Virtual Corporation", book by William H. Davidow and Michael S. Malone (1992) (Also highlighted in Business Week, February 8, 1993, cover story on pp. 98-103) The Virtual Corporation can be defined as a temporary network of companies that come together quickly to exploit fast-changing opportunities. It can be the ultimate in adaptability.

The key attributes of such an organization are: (1) Excellence; (2) Technology; (3) Opportunism (partnerships will be less permanent, less formal, and more opportunistic); (4) Trust (these relationships make companies far more reliant on each other and require far more trust than ever before); (5) No borders.

Capitalize on contemporary issues and concerns.

Agricultural research needs to be both forward looking (basic research) and also active in solving the important problems of the day (applied and adaptive research). Thus, it is obvious that the leaders and scientists have a responsibility to conduct research on problems of concern.

However, there is another reason to vigorously address contemporary issues and concerns. Agriculture no longer has the political clout it once had. To gain the public and political support necessary to achieve research funding, it is necessary to build coalitions with groups who have captured the imagination of large segments of the general population. Current high priority issues include the environment; food safety, diet and health; competitiveness; rural community and economic development; and upgrading skills of individual citizens. Most of the disciplines within Agricultural Experiment Stations can participate in productive research addressing these problems. It is especially critical that we build coalitions to develop plans to address these contemporary issues and concerns.

Building an Empowering a Constituency within the State.

The following discussion is based on a presentation I made to the New Directors' Workshop sponsored by USDA-CSRS in Washington, D.C. on April 22, 1992. I don't pretend to claim credit for the ideas and concepts described here. Rather, I'll relate principles and examples that I have observed and been associated with. Each institution has a structure and situation unique to their respective state. Specific plans, strategies and actions must be developed within the specific context. For purposes of this paper I will simply **outline** some of the important principles that seem to me to be fundamental to success in building and empowering a constituency.

I. What is the essence of building a constituency? Communicate:

- In the real estate business it is said that three things are important: Location, Location and Location.
- In advocacy efforts for a public entity such as an AES, three things are important: Communication, Communication and Communication. It is extremely important to remember that communication means, "- - the **interchange** of concerns, opinions, and information - -." Thus, communication must involve listening as much as talking.

1) Communication: Ask, learn, know the concerns of those we exist to serve and whose support we need.

In terms of both the "need to" and the "how to" of listening to our customers, I refer you to a paper written by John Gerber, while he was Assistant Director of the Illinois AES.

Tom Peters (of In Search of Excellence fame) writes, "to begin with, good listeners get out from behind the desk. Good listeners construct settings so as to maximize naive listening, the undistorted sort." Similarly we need to get out with our "customers" and listen to their interests and concerns.

2) Communication: Develop a crisp plan of how your group (AES) can be an important part of the solution to the problems they see.

3) Communication: Tell them clearly and simply what you propose to do and learn.

4) Communication: After you get the funds/support, inform them what you are doing. No, better yet, tell them what you are learning. Update often. Provide brief vignettes of what is being learned in appropriate AES newsletters and reports and as handouts at meetings around the state..

5) Communication: Inform them of what has been learned and how they can adapt the findings to their situation. (Even whether or not it might fit their situation.)

6) Communication: Continuous, although intensity may vary. It is very important to maintain contacts especially when you don't want them to do anything. One of the key reasons (Applies to legislators, their staffs, and to user or support groups.)

7) Opportunities can be created to keep clientele informed and seek their input on various relevant processes. For example, ESCOP has an elaborate planning process to develop research priorities (which are then inserted into the Joint Council and the USDA planning and budget development processes). The SAES directors vote to develop the final ranking for ESCOP each year. I have found it helpful to seek input from various groups in Indiana in terms of ranking these priorities.

II. Build trust and credibility:

- To be successful, an advocacy effort has to be built on trust and credibility.
- Be positive
- Don't over commit or promise more than can be delivered (for the dollars available/being asked for etc.). To do so essentially guarantees failure at some point in the future.
- Programs need to be relevant. Show what can be accomplished to help them; to solve problems and address issues of concern; to prepare them for future challenges.

  Note, many kinds of research are relevant, but it must be presented that way!
- Get back to people; let them know that things are happening

III. Empower others:

- Key actions: Identify, Listen, Energize.
- Build coalitions, not only with traditional clientele, but also with larger segments of society. (In most cases, it is no longer possible for a few university administrators to get agreement of the presidents of one or two farm organizations and then to be sure that good things will happen.)
- Building coalitions requires time, patience, and communication.

IV. Create a vision and develop a plan:

-Can one plan for an effective advocacy program by an empowered constituency?

-Yes, but I've saved that to last because my bias is that for a plan to be successful one must know the critical elements of the process you are about.

-Therefore, I chose not to approach this activity as a planning exercise, but rather to suggest some of the elements which in my judgment are critical.

-In the case of the "Crossroads 90" agricultural research and extension funding initiative in Indiana, Dean Thompson and key leaders of the "Coalition" of 45 organizations developed the "vision" and empowered many to "charge on."

Information Needed to Make the Priority Setting Process More Effective

Priority setting is never easy and much of it is subjective. The development of several kinds of information would enhance the objectivity of the process and make it more reliable. Several of the needs identified here could be developed by the NC-

208 Committee. Development of the benchmark data and estimates of the impacts as listed her would be very useful.

Support costs

It would be useful to have reliable estimates (median and range) of the costs of conducting research by discipline and/or department. It would be most useful to have such data presented both as total costs and then also as total support costs minus faculty salaries, all on a research FTE basis. Presenting these as index values, or per cent of the overall mean would be most useful. Data classifications should include "hard funds" (state and federal formula); grant and contract; and other; as well as total for all sources.

Access to reliable data of costs of doing research by discipline would provide one index to aid Directors in the equitable allocation of scarce resources ("hard funds") among departments in the AES. Furthermore, it would provide a more objective means of measuring the relative degree of success in getting outside funds by discipline or department. CRIS data from the USDA system could be a useful source for arriving at some of the information (raw data) needed to calculate the index costs of doing research. Additional specific data might be obtained by surveying SAES Directors.

Alternate funding sources

It would be helpful to have benchmark data on what sources of outside funds are typically available to faculty in various disciplines. The data should include the average size "grant" and the total outside funds per research FTE, by discipline.

Accomplishments

Individual Stations and the total agricultural research system need to improve their effectiveness in communicating with many audiences concerning what was accomplished with the investment in agricultural research. Too often the "annual reports" of AES research tell what was done rather than what was learned. And, the reports often are too detailed for most audiences. There is a great need to develop crisp, readable vignettes of what was learned or accomplished from research projects.

Impacts

This committee should be in an ideal position to lead an effort to further develop methodology for making ex ante impact assessments of doing particular kinds of research. The assessments should include social and environmental as well as economic impacts.

Furthermore, it would be valuable to provide estimates of economic impact of NOT doing the research in U.S. (vs. doing it). Agricultural economists can provide estimates of the impact of doing or not doing specific kinds of research. Some real examples should be studied and should include the impacts of learning new principles that lead to practices and/or technologies, as well as ultimate technologies.

SOME SUGGESTED READINGS

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TABLE 1

AGRICULTURAL RESEARCH FUNDING CATEGORIES AND USES

Federal formula (Hatch, McIntire-Stennis, Animal Health) **and State match:**
- Infrastructure and core competencies of expertise.
- Project funds for priority state, regional and national needs (Shrinking!)

Federal Competitive Grants (eg, USDA-NRI, NSF, NIH)
- Targeted basic research

State Special Lines:
- High priority state problems;
- Systems; Cost reducing; Site specific etc.

Federal Special Grants:
- High priority regional and national problems

Industry Grants and Contracts:
- Usually product oriented
- Often linked in terms of moving discoveries (of public and private sectors) to users.
- Consumer Reports type function

Commodity Market Development and Research programs ("Check-Off"):
- High priority needs perceived by producer community
- Often product, new use, and market oriented (Sometimes forbid "production" research)

TABLE 2

CRITERIA FOR DETERMINING LONG-RANGE STAFFING PRIORITIES FROM A RESEARCH PERSPECTIVE

EVALUATING STRENGTHS AND WEAKNESSES OF SPECIFIC RESEARCH AREAS
(an aid in targeting areas for future growth)

FACTOR	Evaluative Criteria	Rating Categories
RESOURCES	Faculty expertise	Exceptional, Strong, Adequate,Weak
	Quality of graduate students	High, Medium, Low
	Availability of graduate students	Good, Poor
	Quality of equipment & facilities	Excellent, Adequate, Insufficient
	Quantity of equipment & facilities	Excellent, Adequate, Insufficient
IMPORTANCE	Centrality of mission	Yes, No
	Importance to users	High, Medium, Low
	Progress potential	High, Medium, Low
	Demand for graduates	High, Medium, Low
	Contribution to graduate education	High, Medium, Low
	Comparative advantage	Yes, No
FUNDING	Cost of this research	Low, Medium, High
	Cross-disciplinary potential	High, Low
	Grant funding potential	Good, Adequate, Poor
	Industry funding potential	Good, Adequate, Poor
	Priority for reallocated funds	High, Low
	Likelihood for new State funds	High, Low
	Other sources of funding	(Listing)

Structure, Management, and Funding of Agricultural Research in the United States: Current Directions and Likely Impact

By Wallace E. Huffman and Richard E. Just*

In the United States, the public and private sectors are major institutions in the agricultural research and development system. This is in contrast to developing countries where private R&D is almost nonexistent. Huffman and Evenson (1993, Table 4.1) estimate that U.S. total public and private agricultural research and development expenditures were $3.9 billion in 1980 (in 1984 research dollars) with 40 percent due to public research activities. In 1990, total public and private agricultural R&D expenditures had grown to $4.8 billion (in 1984 research dollars) with only 34 percent in the public sector. Thus, even before the most recent economic hard times of land-grant universities, the relative importance of public R&D in total U.S. agricultural R&D had fallen significantly. Although the early 1980s was also a period of general economic hard times in agricultural states, total state agricultural experiment station (SAES) expenditures on agricultural research were 13 percent higher in real terms in 1988 than in 1980. Since then a decline in total real SAES funds has occurred.

Although the U.S. public agricultural research and extension system has faced periodic scrutiny and criticism since the 1970s (e.g., Hightower 1973; Office of Technology Assessment 1981; Rockefeller Foundation 1982), new concerns about structure, management, and funding have been raised recently (Office of Technology Assessment 1992; Chubin 1992) which suggest possible new

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*** The authors are professors at Iowa State University and the University of Maryland, respectively.** **Helpful comments were made by Peter Orazem as well as participants in a session on this topic at the 1992 AAEA meetings in Baltimore. We thank Larry Busch and Bill Lacy for kindly making data available from a late 1970s survey of public sector agricultural scientists and Ann Judd, Yale University, for carrying out the statistical analysis.**

directions in SAES research. Environmental and food safety concerns have surfaced with greater intensity. The decline in the number of farms and farm population slowed during the 1970s, but they declined sharply again during the 1980s. Production of agricultural commodities has become increasingly concentrated regionally and in specialized farming units that are much larger and run by increasingly sophisticated farm businesses.

Within the agricultural economics profession, concerns have been expressed that SAES research has become too "disciplinary" and needs to return to more effective linkages between research, extension, and teaching (Bonnen 1983; Schuh 1986). Numerous studies have confirmed good overall rates of return to public agricultural research expenditures (e.g., Ruttan 1982), but significant problems have been demonstrated with the allocation between pretechnology and applied sciences and between plant and animal oriented research (see Huffman and Evenson 1993, Table 9.1). With the economic recession starting in 1990 followed by a slow recovery and reduced real expenditures by state governments on SAES research and extension and by the federal government on extension, deans of colleges of agriculture and directors of agricultural experiment stations and cooperative extension services have turned to generally tighter central control with more emphasis on setting priorities, review of proposals, and management (also see Office of Technology Assessment 1991). Some land-grant institutions have reorganized their structures to separate administration of extension from teaching/research or of extension/research from teaching in order to enhance direct relationships with the field. At the same time, federal funding of the land-grant system has tended to shift to competitive grants and contracts, and administrators have shifted from resistance to encouraging pursuit of both public and private grant and contract funds. These changes raise a number of issues about the future of agricultural research and extension in the United States.

In an earlier paper, Just and Huffman (1992) presented some principles dealing with the structure and management of U.S. agricultural research and education. This paper extends the examination of new economic and political incentives facing land-grant administrators and agricultural scientists and presents econometric evidence about the effects of current changes in structure and management of public agricultural research on U.S. agriculture. First, some important issues facing land-grant agricultural research and extension are examined and then hypotheses are formulated. Second, evidence is presented showing selected organizational and structural characteristics of SAES research and then econometric evidence is presented showing what determines structure and management of SAES research and how structure, management, and funding of SAES research affect state agricultural multifactor productivity. While measures of performance other than multifactor agricultural productivity may be important and of interest (e.g., number of scientists trained, effects on environmental quality), we leave those areas of inquiry to future investigations.

Some Important Issues

Vertical Integration of Science

Bonnen (1986), Schuh (1986), and others have argued that the land-grant system has become unresponsive and SAES research has become "too disciplinary" in its orientation. They argue that the activities in each of the fields or departments supported by colleges of agriculture and agricultural experiment stations have become increasingly focused on output indicators and rewards cherished by the respective scientific societies, e.g., journals of the American Agricultural Economics Association, American Society of Agronomy, etc. These arguments focus on horizontal linkage of the applied agricultural disciplines, including activities in teaching, research, and extension.[1]

From another perspective, the agricultural disciplines may be viewed as inadequately linked vertically. That is, U.S. agricultural R&D is part of a much larger public and private R&D system. Strong upstream linkages to the general sciences and the parent disciplines which produce the knowledge that fuels pretechnology sciences and downstream technology development in agriculture may be needed.[2] Huffman and Evenson (1993) argue that these vertical linkages among disciplines need strengthening. When applied agricultural sciences become disconnected from pretechnology sciences, the flow of new innovations dries up rapidly. For example, weak ties of SAES research to general and pretechnology sciences was a barrier in the early 1980s to applications of biotechnology to agriculture. Both vertical and horizontal linkages appear to be required in order to have a long-term successful science and technology system. In order to identify changes that enhance the organization of the public system, perspective is needed on how the general R&D system functions and how public agricultural research fits into this larger system.

Hypothesis 1. Integration of pretechnology and applied sciences and extension activities does not enhance public agricultural research productivity.

Formulas, Grants, and Earmarks: Allocations of Federal Funds

Arguments for and against both formula and competitive grant funding of SAES research have been made for many years (Rockefeller Foundation 1982; National Research Council 1989; Office of Technology Assessment 1991). Issues raised by federal earmarked funding of research have surfaced largely during the 1980s (Office of Technology Assessment 1991, p. 86-93). Anticipating the political-economic incentives of different funding mechanisms is more slippery than most writers acknowledge. Formula funding is a type of categorical or block-grant disbursement of federal funds to States, which has considerable discretion in use. In federal formula-supported research, typically a state government employee (SAES director, department chair, or scientist) decides the exact nature of the research that is to be undertaken subject to broad guidelines of the enabling legislation. The

Hatch Act provided for the first formula-funded state research. It is sometimes argued that formula-funded research has weak ties to science and produces too much duplicative and pedantic activity (e.g., Rockefeller Foundation 1982; Office of Technology Assessment 1992). Other evidence shows higher output rates of human capital (doctorates) and some types of publications (Office of Technology Assessment 1992, p. 423).

Competitive grant funding through a merit or peer review process is usually a multistage activity. Institutions that have funds to allocate solicit proposals from scientists and then reviews of the proposals from scientific experts. The experts are generally asked to evaluate the scientific merit of the proposals and the competency of the researcher(s). Next, the proposals and the reviews are evaluated and competing proposals are compared and ranked by a panel of experts. This ranking guides the disbursement of research funds. Because almost all institutions receive proposals for using more funds than are available, the process is competitive because only the most highly ranked projects are funded. The primary examples of large merit or peer-review research programs in the United States are those of the National Science Foundation and National Institutes of Health (Office of Technology Assessment 1991). The National Research Initiative of the USDA-CSRS is also a peer-review program.

The merit or peer-review system has several characteristics argued to be advantages and others that are disadvantages. Proponents claim that (1) experts used in the reviewing and ranking process are highly knowledgeable and make good absolute and relative judgements about the scientific merit and competency of principal investigators, (2) only high quality proposals and competent researchers are funded, and (3) research funds can easily be channeled into new areas. However, the merit or peer review process also appears to have disadvantages. First, the disbursement of federal research funds supporting peer-review programs is concentrated in relatively few institutions and states (Office of Technology Assessment 1991, p. 125-26). Second, Chubin and Hackett (1990) have documented that peer-review processes are burdened with many hidden and major conflicts of interest that tend to subvert the process and make it political. Experts and review panels make evaluations that cannot be refuted by principal investigators, panels tend to take narrow views of acceptable procedures and rank too highly proposals of "friends and associates." Third, the proposal writing and evaluating process consumes large amounts of scientists' time that could be allocated to other productive activities.

Academic earmarking, sometimes called pork-barrel funding, provides funds for particular research projects directly allocated by Congress, are not subjected to peer review, and are not competitively awarded (Office of Technology Assessment 1991, p. 87). These funds have grown rapidly since 1980 and apparently have been used by universities to build major new research facilities, to undertake large research projects than otherwise would not have been undertaken, and to add significantly to research capacity in new areas or regions. Academic earmarks are a channel by which some institutions and states may be able to expand their research capacity quickly and ultimately become more competitive in peer reviewed proposals (e.g., the Soil Tilth Center at Iowa State University, the Soybean Laboratory at the University of Illinois). Some groups see disadvantages of earmarks from politizing science, reducing the average quality of research, and diverting research funds away from federal peer-review or formula research programs (Office of Technology Assessment 1991, p. 88).

In reality, all mechanisms for allocating federal research funds suffer from political considerations whereby characteristics other than scientific merit matter (Chubin 1992); and formula, competitive, and earmarked funding each contain some good and some bad incentives. The net advantages of a federal competitive-grants system of agricultural funding, however, may be exaggerated. First, the competitive-grant process places a major burden on agricultural scientists for conducting the reviews upon which granting decisions are made. Bredahl, Bryant, and Ruttan (1982) note that the cost of entreprenuring and managing competitive grants falls mostly on the researchers compared to the cost of entreprenuring and managing formula funds that falls mostly on administrators. Second, less than 50 percent of all written proposals (e.g., in the National Research Initiative) are awarded funds, and some of the time spent on these activities represent socially wasted resources. Third, the size of awarded grants is almost always significantly less than the marginal cost of a project, which means that resources from other sources must be used to complete the project (e.g., from time otherwise allocated to other research projects, teaching, or leisure). Fourth, projects are funded for short duration (often for one year, and never more than five years) although some projects take 10 years or longer to complete, e.g., crop rotation and beef-cattle crossbreeding experiments. This causes inefficiency when successful research requires a long-term sustained effort or a group of scientists with specialized skills. Fifth, institutions must generally carry out-dated scientists on teaching appointments and new scientists on "star" scientists' projects, e.g. as post-doctoral researchers or research associates. Terminating tenured university (and government) scientists is just as difficult with competitive-grant funding as with formula-funded research. Sixth, the criteria for allocating federal research funds have a political (or nonscientific) factor which reduces the claimed advantages for competitive-grant funded agricultural research. Thus, the issue of whether to fund research with competitive grants, formula funds, or earmarked funds is difficult to answer. The answer may depend on the particular circumstances.

> Hypothesis 2. Competitive grant funding and earmarked funding of agricultural land-grant research is no more productive than traditional formula funding.

Managed Public Research

The production of scientific discoveries is an area where implicit contracts rather than elaborate formal written contracts dominate. Short, formal written contracts generally accompany inter-institution transfers of funds for research. These contracts usually state in general terms that some type of advance in knowledge is to be attempted and that a written report summarizing the activity will be prepared at the end of the project. Detailed contracts are almost always impractical because they are unenforceable.

Defining contracts is a common labor-management problem, and managers of firms in the private sector have found the most efficient way to deal with labor contacts is to have implicit contracts that create incentives for "good performance," [e.g., rewards by promotion to a position with more responsibility and higher rate of pay (Elliott 1991; Goldin 1990, p. 114-115)].[3] Such contracts represent an application of Adam Smith's "invisible hand" to R&D. Application of this principle by public research administrators suggests developing incentive schemes to insure diligence and productivity toward long-term objectives. Given the somewhat unspecified nature of most scientific tasks, public research administrators may enhance research productivity by establishing clear economic incentives for their scientists by defining expectations about the quantity and quality of outputs from the R&D activity but leaving the exact choice and specification of the problems, choice of methods, and timing of work to the scientists (Schultz 1985).

This principle goes against the top-down administration of scientists, at least for discoveries in the general and pretechnology sciences. It also suggests that elaborate research priority setting activities are likely to be unproductive because they are both used and misused as instruments of top-down research management. In applied research and technology development, on the other hand, the final product is more clearly defined, so administrators at this level might be more effective in top down management. Heretofore, however, empirical evidence has not shown that one system is definitely better than another.

> Hypothesis 3. Top-down management of land-grant research and development is no less productive than competitive choice of problems and methods by scientists in response to financial and professional incentives.

Administrative Structure

The administrative structure in the SAES system is quite different from the USDA. Both systems have been in place, although changing, for over 100 years. The USDA's research agencies primarily have one large national research agenda and receive almost all of their research funds from the federal government. In contrast, the SAES system has more than 50 different research plans associated with about 50 separate agricultural experiment stations at land-grant universities (exceptions are the New Haven station and others in the U.S. Territories). Although all SAESs receive significant CSRS-administered funds (so-called regular federal funds), are monitored by CSRS, and frequently cooperate with USDA research agencies, the SAES system is mostly a state-run system with more than 50% of funding from state government appropriations. In contrast to criticisms of Schuh (1986; 1992), Bonnen (1986), Rockefeller Foundation (1982) and others of the SAES system, Schultz (1985, p. 15-17), Ruttan (1982), and Huffman and Evenson (1993) conclude that the SAES system has been a relatively successful system and the future looks promising.

The primary reason for success of the SAES system appears to be its decentralized nature which provides sufficient flexibility and incentives to adapt to local or state needs. Specific reasons are: (1) agricultural technology and agricultural problems are frequently geoclimatic-specific so each state has somewhat unique needs which can be addressed only by scientists working locally (Griliches 1960; Evenson 1992), (2) SAES researchers are close enough to local problems that their research can help to solve local problems, (3) the SAES research is located in almost all cases in the center of a scientific community where advances in science are occurring regularly, and (4) SAES research, training of new scientists, and graduate education are conducted as complementary activities that facilitate inter-field and inter-layer scientific information exchange (Huffman and Evenson 1993, Ch. 3).

The SAES in every state, as well as the land-grant university and all other public institutions in a democratic society, are continually facing competing social-political-economic pressures (Weimer and Vining 1992). Some of these pressures come from the federal government, some from local and national clientele groups, and some from their staff. This is not a new phenomena facing state agricultural experiment stations or land-grant universities, which have responded to such pressures over a 100 year tradition (Huffman and Evenson 1993, Ch. 1 and 9). One perspective is that public institutions like the SAES can survive over the long term only by responding along lines suggested by interest group theories of behavior (see Becker 1983; Reid 1977; Evenson and Rose-Ackerman 1985). However, institutions should be structured so social-political-economic markets do not fail due to public good characteristics of scientific knowledge or due to diversion of public resources to private wealth enhancement of public employees and officials. Because political and administrative careers are short relative to the length of time over which research outputs have their impacts, the political process can significantly underinvest in general and pretechnology science relative to applied science and other more immediate goods and services.

These considerations also give rise to an interaction between public research funding and the research agenda. These are reasons why federal formula, competitive-grant and earmarked funding; private sector funding; selling new innovations for profit; and including clientele groups directly into agenda setting are burning issues in the SAES system today. Methods and sources of research funds invariably affect the incentives for particular types of work. Also, the environment in which scientists work undoubtedly affects their creativity (Price 1986; Schultz 1985; Berry 1980; Bonnen 1986).[4]

Hypothesis 4. The administrative structure does not directly affect productivity of public research and extension.

Hypothesis 5. Administrative structure does not affect problem choice and the allocation of research funds.

Empirical Evidence

Before presenting statistical analysis, we first present some variables used to measure structure, management, and funding of SAES research. The empirical evidence is then presented investigating the five hypotheses given above.

Data Characterizing SAES Structure, Management, and Funding

Structure. Table 1 contains information on administrative structures for agricultural research, teaching, and extension in land-grant universities. Thirty-four states have traditional administrative structures where departmental administrators report to a single agricultural college administrator (see column 2). Nine states have structures where extension is administered separately. Seven states have administrative structures where unit administrators report along competing administrative lines to an agricultural administrator (e.g., Vice President for Agriculture) and a non-agricultural administrator (e.g., Academic Vice President).

Also, thirty six states have a traditional budget type where agricultural research, teaching and extension budgets are coordinated. Only eight states have budgets for all three functions that are separate. Thirty eight states have a traditional supervisory type where agricultural research, teaching, and extension functions are under a single agricultural supervisor. Eight states have agricultural teaching and research under a single agricultural supervisor and extension under a separate supervisor.

Management. In doing research, the selection of research problems and projects are key decisions. Busch and Lacy (1983) conducted a survey of 1,876 SAES and USDA scientists in 1978 regarding research procedures and problem selection. Table 1 transforms their data for individual scientists' responses to influences on choice of research problems into station averages. Two types of indexes are created, one for influence of department chairs and SAES directors and another dealing with more general external versus internal control over research problems.

The role of department chairs and experiment station directors in choosing research projects of scientists is reflected in the two far righthand columns of Table 1. Department chairs and directors represent a larger share of total research personnel in smaller stations, and in general, their influence is greater in smaller stations (e.g., CT, NH, WY, OK, NM, NV, MT). Exceptions are Florida, Georgia, and Vermont. Furthermore, department chairs (or heads) were generally rated as having more influence than the SAES director (or director of the institute) (exceptions are HI, ID, IL, RI, and SC).

The rating by SAES scientists for degree of influence (7 point scale) by immediate supervisor in their choice of research problem represents the influence of department chairs (SD). The average index for degree of influence by an institute director represents the influence of SAES directors (SAD). An average index of "external downstream" influences on scientists' choice of research problems was derived from responses to eight questions (7 point scales). An average index of "internal influences" or "own preferences matter" in research problem choice was derived from responses to seven related questions.[5] Then, an index of relative external downstream influences on scientists' research problem choice was derived as the ratio of external to internal influences (E/I).

This index of relative external downstream influences on research problem choice shows that California, Wisconsin, and several other stations that have a reputation for scholarly research programs have low external downstream influence ratings. That is, the scientists' preferences or assessments matter relatively strongly in research problem choice relative to external downstream influences. In these stations, the administrators are also a smaller share of total research personnel than in small stations which might contribute directly to reduced influences. Stations known for diverse outputs and tendencies toward central control, e.g., Oklahoma, Florida, and most smaller stations, show relatively high external influence on scientists' research problem choices. Many stations, however, have E/I values that are relatively close to the mean; 32 are within one standard deviation.

Funding. Agricultural experiment stations differ significantly in the relative importance of alternative funding sources. Table 2 presents information on the share of funds received from (1) all USDA contracts, grants, and cooperative agreements, (2) other federal contract and grant funds, (3) contract and grant funds from private business, commodity groups, and other nongovernmental sources, and (4) state government appropriations. The average share is computed by summing relevant totals for 1970, 1975, and 1980 before dividing.

For all states, the largest share of SAES funds comes from state government appropriations. Several SAESs have an average share from state government appropriations that is less than forty percent (e.g., Indiana, Louisiana, Nebraska, New Hampshire, Rhode Island, and Tennessee). Even before the 1980s, several states had moved heavily into contract and grant funding of SAES research. On average, the share from federal contract and grant funds outside the USDA (e.g., Environmental Protection Agency, National Institutes of Health, National Science Foundation) was larger than the share obtained from the USDA. These federal contracts and grants from outside the USDA accounted for more than 12 percent of the SAES funds in Colorado (25%), Rhode Island (22%), Oregon (20%), Wisconsin (18%), New York (15%), Indiana (15%), California (14%), and Tennessee (13%). On the other hand, the states that received the largest share of SAES funds from USDA contracts, grants, and cooperative agreements were Maine (8%), Iowa (7%), Nebraska (7%), Arizona (6%), Colorado (6%), New Mexico (6%), and Utah (6%) (see Table 3).

Statistical Evidence

We now examine the hypothesis that structure, management, and funding sources of public agricultural research affect the productivity of agricultural research as reflected in state level multifactor productivity statistics. Subsequently, we consider whether structure, management, and the federal grant share of funding are exogenous. Testing exogeneity is important for easing concerns about direction of causality. The productivity data and standard explanatory variables are taken from Huffman and Evenson's (1993) state aggregate data for 42 U.S. states, 1973-82. The New England States, Alaska, and Hawaii are excluded from the data set.

Although the Huffman and Evenson data set covers 1950-1982, we use only the 1973-1982 because (1) the Busch and Lacy (1983) data represent influences on problem choice during the mid-1970s and no other survey of this type exists for other years, (2) a 10-year period provides a large enough sample size to provide confidence in the empirical results, and (3) the Huffman and Evenson data set does not extend beyond 1982. While many land-grant universities have been re-evaluating their administrative structures, some have been making changes and scientists in institutions change, these measurement errors are likely minor compared to variations among states so that results are not greatly affected. All of the variables used in the analysis are described briefly in Table 4.

Productivity. Our major interest is in how the structure, management, and funding of agricultural research affects the productivity of agricultural research as agricultural research and other public polices impact multifactor productivity. For this investigation, we modify the Huffman and Evenson (1992; 1993) model. In their model, state multifactor productivity is expressed as a three equation model. The three equations are for multifactor productivity in the U.S. crop sector, livestock sector, and aggregate agricultural sector. To provide empirical evidence about the effects of structure, management, and funding of public agricultural research, the variables in Tables 1-3 were added to the Huffman and Evenson model (1992; 1993).

Selected regression results from fitting the multiple-equation model to state multifactor productivity data for 1973-82 are reported in Table 4. The results show that the productivity of the scientific discovery and technology development processes are affected by the organization of agricultural research. First, other things equal, a larger average share of SAES funds received from federal contracts, grants, and cooperative agreements uniformly reduces agricultural productivity in all sectors. This result is highly significant and implies rejection of Hypothesis 2. Alternatively, the results suggest inefficiencies associated with public contract and grant funding and earmarked funding compared to formula funding. It also may reflect problems associated with redirecting SAES research away from state needs.[6] A larger share of nongovernment contract and grant funds, on the other hand, increases crop sector productivity, but reduces livestock sector and aggregate productivity. One possibility is that nongovernment contracts and grants involve considerably lower transactions costs on scientists' time (e.g., reviewing activities) than federal grants and contracts. Another possibility is that private sector crop research and some forms of SAES testing of crop varieties and pesticides are highly complementary activities. Thus, private funding of SAES crop research may raise local agricultural productivity because of geoclimatic specificity of crop technology. Similar localized benefits and complementarities with private research are apparently much less important for livestock production.

Second, the results in Table 4 suggest that traditional administrative structures which do not separate agricultural research, extension, and teaching in some way are more effective for enhancing local agricultural productivity. However, the results are not statistically significant except marginally for livestock. Thus, Hypothesis 4 is not rejected. The coefficient of DB2 (1 for nontraditional type) is far from significantly different from zero in the crop sector and aggregate productivity equations. Thus, this evidence does not suggest that the administrative type is a major research efficiency factor, except possibly in the livestock sector.[7]

This paper argues that scientific discovery is an abstract, human capital intensive, creative process that is difficult to routinize and most likely thrives in a decentralized but supportive environment with economic incentives that promote diligence, cooperation, and creativity. While the results show that the administrative structure does not matter greatly, different channels of influence on scientists' choice of research problems are important. Apparently, alternative administrative structures can be both used effectively and misused.

The results show that greater administrative influence on choice of scientists' research problems raises the productivity of public applied research but reduces the productivity of public pretechnology science research. These conclusions are based on the signs of the coefficients of the interaction terms for ln (SD x SAD) with ln APP and ln SC. The direction of the effect is the same in all three productivity equations. Thus, moving from applied to pretechnology and general scientific research, the comparative advantage of administrators for "directing" problem choice appears to decrease. These results are all highly significant in the sector specific results. Thus, Hypothesis 3 is firmly rejected with respect to pretechnology science but is not rejected with respect to applied research.

The second type of influence on problem choice is the index of relative downstream influence (E/I). Roughly, scientists can be viewed as choosing projects because of downstream influences such as issues raised by clientele and feedback from extension personnel, or because they are important in their own assessment (to their own professional career or to the development of innovations). The results suggest that greater relative external influence on scientists' research problems reduces the productivity of public applied research but increases the productivity of public pretechnology science research. These results suggest that applied scientists tend to be sufficiently familiar with needs in the field to choose where their productivity is greatest on the basis of scientific discoveries available in pretechnology sciences in absence of interest group pressures. However, for research of the pretechnology type, the results suggests that research is more productive when scientists have a "sense of importance" that can be obtained from considering external downstream influences. Scientists doing pretechnology research can in principle undertake any of a huge range of scientific investigations, but many of them will not lead to discoveries that are useful for enhancing local agricultural productivity. Recall that the E/I index is much more comprehensive and subtle than the direct measures of administrative influence SD and SAD. Taken together, the result that greater external influence reduces applied research productivity but increases pretechnology research productivity implies that overall research productivity is enhanced by greater vertical integration of the sciences.[8] Furthermore, these results are all significant beyond the 1 percent level and thus lead to rejection of Hypothesis 1 that vertical integration is unimportant. These results offer empirical support for the land-grant philosophy that productivity follows from communication among general pretechnology sciences, applied sciences, and application activities in the field.

The importance of integration of the land-grant activities is further suggested by the interaction terms, ln APP x ln SC and ln APP x ln EXTG. The coefficients of these terms imply that applied and pretechnology sciences are significantly complementary for crop research and that applied research and extension activities are highly complementary for livestock research. The lack of complementarity among applied research and extension for crops may suggest that much of the benefits of new technology for crops are embodied in inputs and accompanying information provided by private marketers. Conversely, the lack of complementarity between pretechnology and applied sciences for livestock may be due to the fact that most advances in livestock productivity over the past two decades have not had strong roots in pretechnology sciences and (perhaps as a consequence) productivity growth for livestock has been comparatively weak (Huffman and Evenson, 1993).[9]

Exogeneity. To investigate the validity of the results in Table 4, exogeneity tests were performed on the variables representing structure, management, and funding. As is well known, endogeneity can cause simultaneous equations bias in coefficient estimation. Thus, we consider the possibility that structure, management, and funding are jointly determined with (or caused by) productivity First, we examine the index of relative external downstream influences on scientists' research problem choices (E/I). Geoclimatic conditions and distance from central markets have a major impact on the geographical location of agricultural production (USDA 1957; Huffman and Evenson 1993). Thus, variables representing the share of each state's land area included in 16 major geoclimatic regions might be an important determinant of the management of agricultural research. These variables capture much of the effects of geoclimatic conditions and distance to markets. Also, the SAES administrative structure (DB2) might impact research problem choices. Column (1), Table 6, presents some econometric evidence on the determinants of E/I.

These results show that administrative structure, as represented by a dummy variable DB2 for nontraditional land-grant administrative type, does not affect E/I. Furthermore, we find only weak evidence that geoclimatic variables impact E/I. In particular, we cannot reject the null hypothesis that the coefficients of DB2 and all the geoclimatic region variables are jointly equal to zero. Under the null hypothesis, the sample F-value is 1.79, but the critical F-value is 2.03 at the 5 percent significance level. Thus, we conclude that the index of relative external influences on scientists' problem choices (E/I) is relatively exogenous.[10]

A related issue is whether the land-grant administrative structure (DB2) is affected by scientists' research orientation (as represented in E/I) and geoclimatic variables. If the E/I index is really exogenous, then scientists might change the administrative structure to a form that is most productive for them. In Table 5, column 2, evidence is presented on this issue. Although the estimated coefficient of E/I is positive, suggesting that relatively strong external influences increase the likelihood of nontraditional administrative structure, the coefficient is not significantly different from zero at the 5 percent level. Furthermore, the geoclimatic region variables do not have much power for explaining DB2. In particular, we cannot reject the null hypothesis that the coefficients of E/I and all of the geoclimatic region variables are jointly equal to zero. The sample value of the F statistic is 0.67, but the critical value of the F statistic is 2.03 at the 5 percent significance level. Thus, we conclude that structure, as represented by DB2, is relatively exogenous.

Currently, the share of SAES funds that comes from federal grants, contracts, and cooperative agreements (SHFD), or so-called federal nonformula funds, are receiving attention as the National Research Council exerts pressure on Congress and Office of Management and Budget against formula funding of agricultural research (National Research Council 1989). In the previous section, we showed that SHFD contains relatively large variation across the states and over time. What might be some of the reasons? In the past, SAES directors and department chairs have frequently expressed negative opinions about these research funds because they feel some loss of local control over the direction of research or that state funds for agricultural research are diverted to research of little local value (i.e., little local geoclimatic specificity) as a result of taking federal nonformula research funds (see discussion in Huffman and Evenson 1993). Also, it seems likely that geoclimatic and locational factors are important in competing for these funds. Thus, we examine the relationship between SHFD and the index of influence of departmental chairs (SD), SAES directors (SAD), and relative external influences on scientists' research problem choices (E/I) and the geoclimatic region variables.

These results are reported in Table 5, column 3. The results show that larger relative external downstream influences or stronger influence by department chairs or directors on scientists' problem choices is associated with a statistically significant reduction in the average share of federal grant, contract, and cooperative agreement funds for SAES research. One can interpret these results as suggesting that external downstream and local administrative influences are biased against nonformula federal research funds. Also, many of the geoclimatic region variables are individually significantly different from zero at the 5 percent level and are highly positive for regions 8 and 15 and highly negative for regions 11 and 14.[11]

The hypothesis that the regression equation for SHFD has no explanatory power is rejected. The sample value of the F statistic under the null hypothesis is 34.1 whereas the critical value of the F statistic is 1.67 at the 5 percent level. Thus, evidence suggests that SHFD is not totally exogenous. Accordingly, caution is suggested for interpretation of the SHFD coefficient in the multifactor productivity analysis of Table 4.

While the results of Table 4 do not suggest a strong productivity effect of administrative structure, the final results of Table 5 suggest that administrative structure affects the allocation of funds. In the fourth column of Table 5, the share of the stock of public applied crop and livestock research in the total stock of public agricultural research is regressed on E/I, SD, SAD, DB2, SHFD, SHPR, and 15 geoclimatic region variables. The most interesting result is that the share of applied research is reduced when extension is administered separately from agricultural teaching and research functions (DB2 has a negative effect with t-ratio 6.8). This result lends credibility to the argument that a combined land-grant administrative structure promotes integration of research and extension and helps to keep research activities relevant.

Conclusions

During the 1990s, U.S. public agricultural research, extension, and higher education have been hit again with economic hard times. Land-grant administrators are looking for new sources of funds and prioritizing research which leads to tighter control over research projects undertaken. As the extension and research problems of agriculture and rural areas have expanded beyond traditional agricultural interests, the administrative structure in land-grant universities has been modified in many states. The administration of extension in a number of states has moved to a university official above the dean of agriculture. Similar changes in administration of experiment stations have occurred in some states as directors have struggled to gain access to biotechnology expertise in other colleges. As a result, simple traditional administrative lines have been modified in a way that most likely weakens the incentives for cooperation across traditional teaching, research and extension activities.

Our work suggests some economic and political consequences of changing the structure, management, and funding of agricultural research in land-grant universities. Tighter control over research problem choice may enhance applied research productivity but significantly reduces productivity from pretechnology science research. While modifications of general administrative structures within the land-grant universities do not appear to have major direct impacts on the overall productivity of agricultural research and extension, administrative separation of land-grant activities can cause research efforts to be directed away from applied work. The current trend toward competitive grant and earmarked funding, as opposed to formula funding from federal sources, apparently reduces productivity of research expenditures and/or shifts the focus of scientific inquiries and technology developments away from innovations that raise local agricultural productivity. In the long term, this type of change in focus can be expected to erode local political support for SAES research. It might, however, increase politcal support for national funding of agricultural research.

The results of this paper emphasize the importance of maintaining a vertically integrated agricultural science establishment. In the short run, pretechnology sciences and applied sciences may be somewhat independent, but in the long term progress can only occur when vertical linkages exist and function well. Pretechnology scientists are more productive when they are aware of practical needs, and applied scientists are more productive when they are informed and literate in the parent sciences. Historically, the applied sciences in agriculture have tended to become disconnected from the parent sciences due to increasing sophistication. As a result, agricultural faculties of land-grant universities have been poorly prepared to assimilate new scientific developments, for example, in biotechnology.

The results of this paper also emphasize the importance of scientist directed research at least in the pretechnology sciences. Prediction of advances in most areas of science and technology is difficult. This means that micro-management of R&D is most likely an unproductive activity, and research management approaches that follow a research priority setting methodology are likely to fail because they ignore the realities of the scientific discovery process. Although the production of scientific discoveries is uncertain, it is unreasonable to assume an equally likely probability of a discovery in all areas. Working scientists are most likely the best judge of their own ability to make a breakthrough. Research administrators, recognizing these realities, can effectively "direct" the use of research funds by setting appropriate incentives for useful outputs and the "riskiness" of the research enterprise.

Previous work has not examined quantitatively the implications of alternative land-grant funding mechanisms, management, and administrative structures. The work reported in this paper represents only a beginning to this area of inquiry that contains many unanswered questions. However, the results suggest that several current directions may be counter-productive and deserve further examination.

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ENDNOTES

1. For example, Bonnen (1986) and Schuh (1986) have charged that incentives in land-grant universities have been far too skewed in favor of refereed journal articles. This is apparently an untested proposition.

2. In the Huffman and Evenson (1993) R&D system for agriculture, the general sciences consist of mathematics, probability and statistics, atmospherical and meterological sciences, chemistry, geological sciences, physics, bacteriology, biochemistry, botany, ecology, genetics, microbiology, molecular biology, zoology, economics and psychology. The pretechnology sciences consist of applied math, applied physics, engineering, computer science, climatology, soil physics and chemistry, hydrology and water resources, plant physiology, plant genetics, phytopathology, environmental sciences, animal and human physiology, animal and human genetics, animal pathology, nutrition, applied economics, statistics and econometrics, political science, and sociology. The applied agriculture sciences consist of agricultural engineering and design, mechanics, computer design, agricultural chemistry, soils and soil sciences, irrigation and water methods, agronomy, horticulture, plant breeding, applied plant pathology, integrated pest management, animal and poultry science, animal breeding, animal and human nutrition, veterinary medicine, farm management and marketing, resource economics, rural sociology, public policy studies, and human ecology. The pretechnology sciences are unique in their upstream ties to general science and downstream to applied agricultural sciences.

3. In fact, it is illegal to have a labor contract that extends for more than one year into the future. Furthermore, labor contracts have generally been interpreted in a one-sided fashion by obligating the employer but not the employee to stated terms of performance.

4. See Johnson (1987) and Beattie (1983) for additional discussion of advantages and disadvantages of different administrative structures.

5. Items used to approximate the importance of external (E) downstream influence on scientists' problem choice were (1) potential marketability of the final product, (2) publication probability in a farm and/or industry journal, (3) evaluation of research by scientists in your field, (4) colleagues' approval, (5) credibility of other investigators doing similar research, (6) demands by clientele, (7) feedback from extension personnel, and (8) priorities of the research organization. For internal influences, (I) the rated items were (1) potential contribution to scientific theory, (2) likelihood of clear empirical results, (3) publication probability in professional journals, (4) currently a "hot" topic, (5) enjoys doing this kind of research, (6) scientific curiosity, and (7) client needs as assessed by you.

6. Recall that the coefficient of SHFD might contain simultaneous equation bias. Thus, conclusions for this coefficient should be viewed with some caution.

7. The administrative structure variable, however, only represents an approximation of the actual administrative structure over the time period of the analysis. Nevertheless, regressor problems caused by measurement error and proxy-variables are generally not large enough to reverse the signs of estimated coefficients (Greene 1990, p. 293-98).

8. While no question in the survey measured upstream influence on applied researcher's problem choice, reason suggests that greater downstream influence comes at the expense of less upstream influence.

9. All of the productivity elasticities for the research variables are positive when evaluated at the sample mean, except for applied livestock research. See Huffman and Evenson 1993 (Ch. 7 and 9) for a discussion of reasons why this is true.

10. We have only one set of values for DB2, and this is the reason why only 42 observations are used in fitting this equation.

11. Note that dummies are associated with regions as follows: 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. The Dry Western Mild-Winter Region is represented in the constant term.

Table 1. Indicators of influence on choice of research problems by SAES scientists.

SAES	No. Ph.D. Scientists[a/]	Administrative structure for research, teaching and extension[b/]	Index of external vs. own preferences matter most[c/]			Administrative role[d/]	
			Downstream Influences Matter (E)	Own Preferences Matter (I)	E/I	Immediate Supervisor (SD)	Director of Research Institution (SAD)
Alabama	197	3	3.608	4.819	0.749	1.611	0.889
Arizona	203	1	3.700	4.857	0.762	2.133	0.467
Arkansas	175	3	3.726	5.034	0.740	1.870	1.043
California	824	4	3.419	4.979	0.687	1.082	1.017
Colorado	146	1	3.607	4.789	0.753	1.435	0.783
Connecticut	113	1	3.125	4.619	0.677	3.571	1.429
Delaware	62	1	4.403	5.175	0.851	1.444	0.778
Florida	514	1	4.043	5.032	0.803	3.000	2.422
Georgia	277	1	3.746	4.724	0.793	2.972	1.806
Hawaii	135	1	3.929	4.714	0.833	2.125	2.125
Idaho	143	1	3.923	5.027	0.780	1.952	2.286
Illinois	292	1	3.515	4.739	0.742	1.000	1.250
Indiana	338	1	3.088	4.595	0.672	1.567	0.733
Iowa	244	2	3.375	4.750	0.711	2.034	1.276
Kansas	306	1	3.859	5.050	0.764	2.185	1.926
Kentucky	170	1	3.732	5.088	0.733	1.682	1.227
Louisiana	240	3	4.136	4.857	0.852	2.115	1.462
Maine	110	2	4.000	4.619	0.866	1.500	1.333
Maryland	141	3	4.346	5.033	0.864	2.929	2.286
Massachusetts	114	1	3.338	5.043	0.662	1.417	1.083
Michigan	355	1	3.371	4.806	0.701	1.333	1.152
Minnesota	348	1	3.398	4.630	0.734	1.286	0.964
Mississippi	221	1	3.783	4.692	0.806	2.318	1.000
Missouri	241	2	3.933	4.781	0.823	0.800	0.667
Montana	122	1	4.389	5.444	0.806	2.889	0.889
Nebraska	213	1	4.028	5.127	0.786	1.667	1.444
Nevada	62	1	3.859	4.482	0.861	2.500	1.000
New Hampshire	59	2	3.792	5.095	0.744	3.000	2.500
New Jersey	176	1	3.772	4.739	0.796	2.000	1.579
New Mexico	99	1	4.425	4.571	0.968	2.833	2.667

Table 1. (continued)

SAES	No. Ph.D. Scientists[a/]	Administrative structure for research, teaching and extension[b/]	Index of external vs. own preferences matter most[c/] Downstream Influences Matter (E)	Own Preferences Matter (I)	E/I	Administrative role[d/] Immediate Supervisor (SD)	Director of Research Institution (SAD)
New York	560	1	3.538	4.606	0.768	1.949	1.373
North Carolina	422	1	3.573	4.585	0.779	2.368	1.184
North Dakota	153	2	4.427	4.583	0.966	2.538	1.692
Ohio	345	1	3.708	4.800	0.773	2.313	1.000
Oklahoma	172	1	4.195	4.839	0.867	3.294	1.059
Oregon	307	1	4.028	4.614	0.873	2.385	1.269
Pennsylvania	243	1	3.952	4.844	0.816	2.308	1.000
Rhode Island	44	1	3.675	4.343	0.846	1.667	1.833
South Carolina	162	1	3.992	4.952	0.806	2.176	2.235
South Dakota	111	1	3.847	4.571	0.842	2.000	1.778
Tennessee	140	3	4.464	5.153	0.866	2.933	2.133
Texas	462	3	3.489	5.134	0.680	1.750	1.556
Utah	154	2	3.472	5.111	0.679	1.909	1.364
Vermont	57	1	3.979	4.929	0.807	1.833	0.500
Virginia	263	1	3.767	4.896	0.769	1.957	1.174
Washington	302	1	3.522	4.893	0.720	1.655	0.586
West Virginia	73	2	3.990	4.736	0.842	2.818	2.091
Wisconsin	333	2	3.105	4.484	0.692	0.978	0.891
Wyoming	69	1	4.047	4.482	0.903	3.750	1.500

a/ Data are taken from the Handbook of Professional Workers in Agricultural Experiment Station, USDA-CSRS, 1980.

b/ Administrative Structure:
1. Standard form with SAES, CES, and instruction reporting to an agricultural administrator.
2. Separate extension administration with SAES and instruction reporting to a campus agricultural administrator.
3. A competing administrative line model where departments report both to agricultural administrators and campus administrators.
4. The California model with system wide agricultural administration but, in effect, a type 1 structure on campus.

c/ The indexes of "downstream influence" and "own preferences" over research problem choice were defined as follows. The index of downstream influence is defined as the mean over all respondents in an SAES (or USDA research) unit to 8 rated statements designated with a "E" on the page 279 in Busch and Lacy (1983). The index of own preference is defined in an analogous way for the 7 statements designated with an "I" in the following table appearing on page 279 in Busch and Lacy (1983). Scientists were asked to rate each statement on a scale of 1-7 with a 1 being "not important."

d/ The influence of "immediate supervisor" and "director of research institute" on choice of research problem are defined as the mean over all respondents in an SAES (or USDA research unit) to the following statements: In choosing your research during the last 5 years, in what ways did (1) your immediate supervisor or (2) the director of your research facility influence your choice of research problems. The degree of influence was indicated by giving a rating of 1-7, with 7 denoting most important. See Busch and Lacy (1983), pp. 280-81.

Table 2. Average share (%) of SAES funds from major sources: average over 1970, 1975, and 1980.

State	All USDA Contracts, Grants and Coop Agreements	Fed. (but not USDA) Contracts and Grants	Private Bus., Commodity Group and other non-govt. sources	State Government Appropriations
Alabama	2.39	3.66	2.72	42.79
Alaska	1.31	0.38	0.00	61.75
Arizona	6.14	6.63	5.18	61.94
Arkansas	2.88	2.33	3.24	57.11
California	3.40	14.46	6.22	69.32
Colorado	6.26	25.14	0.50	43.94
Connecticut	0.53	6.58	0.84	65.38
Delaware	1.96	2.55	4.21	44.56
Florida	2.46	4.09	4.91	76.83
Georgia	3.35	1.47	2.62	68.51
Hawaii	2.53	6.40	2.89	72.99
Idaho	3.18	2.30	8.95	55.45
Illinois	3.02	7.23	5.75	47.85
Indiana	4.20	14.95	6.82	38.09
Iowa	6.90	8.51	16.29	40.44
Kansas	2.03	5.87	11.45	49.51
Kentucky	0.50	0.24	0.04	66.45
Louisiana	1.60	1.87	2.52	74.39
Maine	8.03	2.63	6.78	37.24
Maryland	0.63	3.20	0.79	63.31
Massachusetts	3.05	3.22	5.09	48.05
Michigan	5.13	12.78	9.03	49.24
Minnesota	4.96	5.33	4.24	65.91
Mississippi	4.06	2.77	2.37	50.92
Missouri	5.10	6.23	3.00	46.55
Montana	2.82	6.58	6.83	40.07
Nebraska	6.78	3.71	3.03	37.23
Nevada	4.21	3.51	2.14	51.04
New Hampshire	1.90	0.13	0.13	36.34
New Jersey	2.11	6.44	9.05	63.70
New Mexico	6.19	2.75	6.20	50.39
New York	3.77	14.87	3.90	50.27
North Carolina	3.70	8.24	3.33	59.53
North Dakota	2.33	2.58	4.69	64.23
Ohio	2.59	1.73	0.00	74.18
Oklahoma	4.15	8.31	4.20	53.84
Oregon	2.65	20.14	5.03	47.59
Pennsylvania	4.19	4.87	5.95	52.30
Rhode Island	0.69	21.56	1.59	34.34
South Carolina	1.50	0.00	0.00	73.08
South Dakota	2.10	1.49	3.18	57.17
Tennessee	0.91	13.09	2.59	36.53
Texas	4.54	3.11	13.28	55.04
Utah	6.13	12.33	4.01	45.92
Vermont	2.73	2.65	5.62	44.25
Virginia	4.22	10.37	6.68	49.78
Washington	3.80	8.55	8.93	51.76
West Virginia	1.89	2.82	1.78	43.94
Wisconsin	3.70	18.04	7.51	48.39
Wyoming	0.70	3.19	1.02	54.37

Source: USDA, Inventory of Ag. Res., Table IV-F.

Table 3. Definition of Variables.

Variable	Definition
MFP	Multi-factor productivity: Divisia output index divided by Divisia input index, 1.00 for national mean 1949-52. (Crop, livestock, and aggregate)
APP	Stock of public applied research in 1984 dol, total lag of 33 years, trapezoidal shape weights 7 rising + 6 constant + 20 declining. Research spillins from similar subregions and regions are included. (Crop, livestock)
SC	Stock of public pre-technology science research in 1984 dol. Lag pattern and spillin as in APP. (Crop, livestock)
SHFD	Average share (1970, 1975, 1980) of SAES funds received from grants, contracts, and cooperative agreements with the federal government.
SHPR	Average share (1970, 1975, 1980) of SAES funds received from grants and contracts with private business, commodity groups, and other nongovernmental sources.
DB2	Dummy variable taking a value of 1 for nontraditional administrative type for agriculture research, teaching, and extension, i.e., administrative types 2 and 3 (Table 2), and a zero otherwise.
SD	Average rating by SAES scientists for degree of influence by immediate supervisor in their choice of research problems (Busch and Lacy 1983; also, see Table 3).
SAD	Average rating by SAES scientists for degree of influence by director of research institute (or SAES) in their choice of research problems (Busch and Lacy 1983; also see Table 3).
E/I	Index of relative external downstream influences on SAES scientists in choice of research problems (see discussion in text and Table 3).
EXTG	Public extension stock having a commodity focus in days per year, total time lag of 3 years (.5, .25, .25), adjusted for number of geoclimatic subregions. (Crop, livestock)
SCH	Schooling of farmers: average years of schooling completed by rural males 15-65 years of age (interpolated between census years).
PRIVG	Private agricultural research stock in 1984 dol, total lag of 33 years, trapezoidal shape 7 + 6 + 20, adjusted for the number of geoclimatic subregions. (Crop, livestock)
ST	Ratio of the number of private agricultural and extension staff to the number of public staff in 1970.
DROUGHT	Drought dummy variable: equals 1 if rainfall is less than 1 standard deviation above normal, and 0 otherwise.
PREPLANT	Cumulative rainfall, Feb. - July.
WAGEMG	Real wage rate for production workers in manufacturing.
NPSUPPORT	Government crop price support: weighted ratio of support price to market price for crops.
NPSUPMLK	Government milk price support: weighted ratio of milk support price to milk market price.
NDVERSION	Government crop diversion payments: equivalent price ratio of direct government crop acreage payments.
TIME	Trend
D_r	Share of a state's agricultural land classified in each of 16 geoclimatic regions.

Table 4. Selected Regression Results Examining Effects of Sources of Funds, Administration Type, and Choice of Research on SAES Problems Multifactor Productivity: 42 U.S. States, 1973-82 (t-ratios in parentheses) [a/]

Variable	Crop Sector	Livestock Sector	Aggregate Agriculture	
SHFD	-.014 (5.7)	-.006 (3.3)	-.007 (5.0)	
SHPR	.011 (2.7)	-.009 (2.6)	-.005 (2.0)	
DB2	.007 (0.2)	.051 (1.9)	.008 (0.4)	
ln APP	-.454 (2.8)	-1.227 (9.9)	b/	
ln SC	.528 (3.3)	1.377 (10.7)	b/	
ln APP x ln SC	.005 (2.9)	-.005 (3.1)	b/	
ln APP x ln EXTG	-.003 (0.6)	.014 (3.0)	b/	
ln (SD x SAD) x ln APP	.372 (5.3)	.353 (6.1)	.063 (0.8)	.404 (6.5)
ln (SD x SAD) x ln SC	-.394 (5.4)	-.362 (6.2)	-.054 (0.7)	-.426 (6.8)
ln (E/I) x ln APP	-1.421 (2.9)	-2.851 (7.7)	-1.787 (3.7)	-3.065 (8.1)
ln (E/I) x ln SC	1.464 (2.9)	2.817 (7.4)	1.724 (3.5)	3.144 (8.0)

a/ Each equation contains additional variables including 15 geoclimatic region variables and annual trend and trend squared. The set of 3 equations was estimated by Zellner's seemingly unrelated method with some cross-equation equality restrictions between crop (livestock) sector equation and the aggregate sector. The weighted R^2 for the system is.83.

b/ In the equation for aggregate productivity, all the variables with sector-specific designations were multiplied by the appropriate sector output share. Then these parameters for the aggregate equation were constrained to be the same as on similar variables in the sector equations.

Table 5. Evidence investigating exogeneity of structure and management of public agricultural research (t-ratios are in parentheses).

Variables	E/I (1)	DB2 (2)	SHF (3)	Applied Research Share (4)
E/I		.445	-27.38	-.008
		(0.3)	(5.8)	(0.3)
SD			-1.12	.006
			(2.2)	(2.6)
SAD			-1.69	-.015
			(3.2)	(5.9)
SHFD				.001
				(6.0)
SHPR				.002
				(4.2)
DB2	.007			-.018
	(0.3)			(6.8)
D1	.083	.049	1.60	-.136
	(1.2)	(0.1)	(1.1)	(20.3)
D2	.123	.181	-4.15	.058
	(1.9)	(0.3)	(1.42)	(8.6)
D3	.120	-.427	2.49	.184
	(1.0)	(0.4)	(0.8)	(13.0)
D4	.070	.361	-8.51	.105
	(1.1)	(0.7)	(6.2)	(14.9)
D5	.068	.525	-4.02	-.052
	(1.1)	(1.1)	(3.0)	(7.7)
D6	.023	.292	-3.30	-.149
	(0.4)	(0.7)	(2.8)	(26.5)
D7	.195	.763	.67	.112
	(1.8)	(0.9)	(0.3)	(10.9)
D8	-.768	4.378	157.07	-1.763
	(0.7)	(0.5)	(6.2)	(14.2)
D9	.196	.269	-3.39	-.099
	(3.1)	(0.5)	(2.2)	(13.3)
D10	.050	-.165	7.53	-.013
	(0.6)	(0.3)	(4.8)	(1.8)
D11	-1.643	9.528	-77.06	.252
	(2.0)	(1.5)	(3.9)	(2.6)
D12	.397	-.237	.21	.123
	(2.1)	(0.1)	(0.1)	(5.7)
D13	.099	.314	1.17	.104
	(1.5)	(0.6)	(0.8)	(16.0)
D14	-.335	-.697	-25.28	.119
	(1.2)	(0.3)	(6.0)	(5.7)
D15	.827	.249	94.95	-.058
	(1.9)	(0.1)	(9.1)	(1.1)
Constant	.709	-.347	38.20	.586
R^2	.53	.30	.60	.97
N	42	42	420	420
F (H_0: no explanatory power)	1.79	.67	34.1	538.3
F (critical value)	2.03	2.03	1.67	1.60

Impact of Changing Intellectual Property Rights on U.S. Plant Breeding R&D

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I. Introduction

The Plant Variety Protection Act (PVPA) and the application of utility patents (UPs) to plants are currently the topic of considerable controversy among plant breeders, business people, environmentalists and others. The primary goal of the seed industry is eliminate "farmers rights" to sell protected varieties. Seed firms feel they are losing money because seed firms posing as farmers are selling protected varieties without permission from or royalties to the owner. A second goal of the seed industry is to strengthen the rights of variety owners by disallowing certificates for varieties that have only minor changes. This goal is embodied in the clause on "essentially derived" varieties in the 1991 UPOV treaty.

Public sector scientists and some private firms are concerned that the application of utility patents to plants will have a negative impact on the exchange of information and germplasm between scientists within the U.S. and world wide.

In order to decide whether the U.S. should strengthen or weaken current intellectual property rights on plants, policy makers need information on the impact of IPRs on public and private research. This paper attempts to measure the impact of recent changes in IPRs on the amount and direction of U.S. private R&D.

II. Model of R&D by Private Firms

To place IPRs in their proper perspective it is important to remember that they are only one factor a firm considers when investing in a research program. In fact, the primary factors in many early models of R&D, which were based on the work of Schumpeter, were firm size and market power. In these models the larger the firm the more research it conducts both in absolute terms and as a percentage of sales or other measures of firm size. Many of the early empirical studies in this literature found an inverted U shaped relationship between R&D and firm size, with small and large firms spending less R&D per sales than the medium size firms.

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[1]From Rutgers University, University of Michigan and Rutgers University, respectively. This research was funded by the USDA Economic Research Service and the New Jersey Agricultural Experiment Station.

The role of demand in influencing investment in R&D was emphasized by Schmookler (1966) in several important studies in the 1960s. He tried to show that the growth in demand in an industry stimulated R&D with a certain time lag.

More recent studies have incorporated Schmookler's ideas on the role of demand and have divided the Schumpeterian emphasis on industry structure into two factors: appropriability and technological opportunity. Thus, the three main factors influencing a private firm's investment in research to develop new products are: (1) the expected demand for the products; (2) the technological opportunity for developing new products through research and (3) the ability of the firm to appropriate some of the benefits which users of the new products receive (see Griliches 1984).

The demand for new varieties of crops is a derived demand based on the expected demand for the crop and the productivity of the new variety. The quantity demanded is also influenced by farmers' ability to reproduce seed of the crop. Some crops like alfalfa are virtually impossible for farmers in many regions to produce themselves while other seeds such as wheat and rice are easy to reproduce and store.

The technological opportunity for firms to develop new varieties depends on the costs of the research inputs, the skill and level of technology used by their plant breeders, and the germplasm and information available from public research, from other private research and abroad. The major change in technological opportunity in recent years is the application of molecular biology to plant breeding. This has increased the productivity of conventional plant breeding and led to the production of transgenic plants with genes from other species and even from bacteria and animals. Technological opportunity can also be changed by changes in the spillovers of information from other firms and the public sector due to changes in intellectual property rights. The more easily germplasm and information are available from other firms and government research programs, the more research a firm will do ceteris paribus.

Appropriability is a function of the firm's ability to keep other seed companies and farmers from duplicating or making close substitutes for their variety. It is thus a function of the technical characteristic of the variety, the structure of the seed industry, and intellectual property rights. Firms have greater appropriability in crops in which hybrid varieties are used[2]. Firms can, with careful management, keep the parental lines of hybrids secret, and farmers and other seed companies can not

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[2] Primarily crops that are naturally cross pollinated such as maize, sorghum, pearl millet and sunflower.

produce hybrid seed by simply multiplying hybrid material purchased from the owners of the hybrid. Without intellectual property rights firms have little appropriability of new pure line varieties[3]. Farmers and seed companies can easily reproduce such new varieties.

Intellectual property rights provide firms the right to exclude other firms and farmers from reproducing the varieties which they develop. This gives the firm a temporary monopoly on the sale of the protected variety which allows the firm to charge higher prices for seeds of the variety than if other firms are also selling the variety. In this way the firms profit from the research they used to produce the new variety.

The concept of patents contains a built in contradiction. Spillovers stimulate research because they increase the productivity of each firm's research - in other words they increase technological opportunity. However, more spillover means less appropriability and this may discourage research. This is precisely the debate that is going on between scientists over whether plants should be patentable under the utility patent law. Those who oppose it fear that the spillovers allowed under PVPA will be eliminated since there is no explicit research exemption in utility patent law. Economic theory provides little help. Thus, empirical research is necessary to determine the impact.

III. IPR Laws Covering Plants

A Legislation

The Plant Patent Act (PPA) when passed in 1930 was the first legislation to provide intellectual property rights in plants. It covered new and distinct asexually propagated varieties excluding tuber-propagated plants such as potatoes. Application forms are straight forward and can be filled out by breeders. More than 80 percent of the applications are approved. Table 1 presents a summary of the coverage and characteristics of different types of IPRs.

The U.S. Plant Variety Protection Act (PVPA), which was passed in 1970, provides owners with the exclusive rights for 18 years to novel, sexually propagated varieties and inbred lines of hybrids. The U.S. Department of Agriculture (USDA), which administers PVPA, checks applications against the descriptions of varieties in its data bank. If the variety is assessed to be different, a certificate is issued. PVPA has two explicit exemptions from protection. First, farmers can reproduce seed for themselves and sell seed as long as seed sales are less than 50 percent of total production of that variety on their farm. Second, the owners of a

[3] Pure line varieties are normally produced in naturally self-pollinated crops, such as wheat and rice.

variety can not prevent researchers from other companies or public agencies from using that variety to produce a new variety.

Like Plant Patents PVPA application forms are straight forward and can be filled in by breeders. About 90 percent of PVPA applications are approved.

Plant varieties, engineered genes, and hybrid varieties have been subject to utility patents since the *Ex parte Hibberd* ruling by the Patent and Trademark Office's Board of Patent Appeals and Interferences in 1985. UPs provides exclusive rights for 17 years for inventions that are novel, nonobvious to others in the field and useful. Protection can be much broader than under PVPC or Plant Patents. It can include a group of varieties that all have the patented characteristics while only individual varieties could be patented under PVPA. No explicit research or farmers exemptions exist in UPs. Farmers can not sell seed and theoretically farmers must pay royalties to the holder of the UP if they plant the variety as second year using their own saved seed. Scientists who use a patented variety to produce another commercial variety could either be prevented from selling the second variety or would have to pay a royalty to the owner of the first variety.

Patents are unlike Plant Patents and PVPA in several key aspects. They require enabling disclosure of the inventions so that other can use the knowledge to make other inventions. The U.S. Patent Office requires a deposit of seed, if a variety is being patented and this seed must be made available to others for research use. Patent applications are different in that they usually require lawyers to fill out the forms which increases the cost of applying considerably. Of the applications which include claims on plants 22 percent have been granted. In addition it takes several years to grant patents while only a few months are required for PPs and PVPCs.

There is no explicit research exemption in UP law. However, the courts recognize the right of legitimate research who are not attempting to produce a commercial product with their research to use patented products in research. In addition since a patent case takes about four years and costs about $1 million a year few companies will take researchers to court unless they think the researchers will seriously cut into their market.

Trade secrets are the fourth type of IPR that are used to protect plants. Trade secrets are governed by state laws, but they go back to the English common law tradition. They provide protection for an invention as long as the secret is not disclosed in a nonconfidential manner. They have primarily been used to protect F1 hybrids in which the inbreds lines are kept secret.

Table 1. Comparison of IPRs of Plants

	PPA	PVPA	Utility Patents	Trade Secret
Coverage				
Asexually Propagated Variety[1]	Yes	No	If large inventive	No
Sexually Propagated Variety	No	Yes	If large inventive step	No
Hybrid Variety	No	No	Yes	Yes
Engineered Gene	In protected Variety		Yes	Until Disclosed
Phenotypic characteristic in different varieties or crops	No	No	Yes	No
Cost of application	Low	Low	High	---
Percent of applications accepted	84	90	22	---

1. Excludes tuber propagated crops

B. Case Law

Case law and rulings by the patent system have evolved to help define the protection offered to plant breeders. To enforce the U.S. PVPA firms must identify violators and bring them to court to seek injunctions against further infringement, royalties and punitive fines. Adherence to the law has varied over time. When the law was passed, firms ran a publicity campaign to educate farmers and other firms about the provision of the law. In most cases when companies discovered violations, they just needed to write the farmers or cooperatives informing them about the provisions of law and the violations stopped. Adherence to the law weakened gradually. Specific cases defined farmers rights more broadly than most companies wished. For example, Asgrow vs. Kunkle 1987 found that even very large sales by farmers were legal as long as the farmer sold less than 50% of his crop as seed for reproductive purposes. The weakness of the law were emphasized recently by Pioneer Hi-Bred's well publicized closure of its hard red winter and hard red spring wheat program (Newlin).

In contrast to the self pollinated crops, property rights for corn and other hybrids and potatoes were strengthened during the 1980s. Firms speculated that the plants could be covered by Utility Patents immediately after the Chakravarty case in 1980. A number of firms sent applications to the patent office in the early 1980s. The ex Parte Hibbard ruling officially gave firms the ability to patent plants for the first time in 1985. At the same time the use of trade secrets to protect inbreds to be used to produce hybrid corn was validated in the courts for the first time in the 1987. (Pioneer Hi-bred Int'l v. Holden Foundation Seeds, Inc. No. 81-60-E, slip op. (S.D. Iowa, Oct.29, 1987)).

C. Proposed Changes

The top priority of the American Seed Trade Association (ASTA) is to eliminate the current farmers' exemption in PVPA. ASTA members are not opposed to farmers saving their own seed, but they do oppose the farmer's right to sell seed. The other change currently under consideration is to amend PVPA so that it conforms with the 1991 UPOV Convention. Varieties that are "essentially derived" from a protected variety would also be owned by the breeder of the protected variety. Depending on how essentially derived is defined, acceptance of this provision could reduce the scope of the research exemption and increase appropriability considerably. A series of committees within ASTA is working to develop an acceptable definition of "essential derived."

The most likely changes in U.S. utility patent legislation are changes that would bring the U.S. in line with the rest of the world. Specifically, the rule on priority of patent claims might change from "first to invent" to "first to file" which is the rule in most of the rest of the world. This would reduce patent litigation in the U.S. because much litigation centers on who and when a new product or process was invented.

At a recent meeting in Washington[4] some public sector scientists have suggested that plants should not be subject to patents or that there should be a research exemption in the utility patents for plants. However, little support was expressed for this position by representatives of the private sector. Those who supported this position seem to have been in the minority.

IV. Previous Evidence of Impact of IPRs

Two surveys of seed companies were conducted in the early

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4. Meeting on "Intellectual Property Rights: Protection of Plant Material" was sponsored by the Crop Science Society of America, the American Society of Horticultural Science, and American Society of Agronomy and the Soil Science Society of America. 26-28 January 1993, Washington, DC.

1980s to answer the question of the impact of PVPA (Perrin et.al.1983 & Butler and Marion 1985). Figure 1 shows R&D expenditure divided by the value of the crop which holds demand constant in order to show the impact of appropriability. As expected, the ratios of self pollinated crops like wheat and soybeans increased about the time PVPA was passed. In addition crops in which hybrid seeds are widely used such as maize and sorghum have higher research: value ratios than self pollinated crops. This is due to property rights in the form of trade secrets and greater demand for the seed of these crops because hybrids can not be reproduced by farmers. Both Perrin et al and Butler and Marion conclude that PVPA had a positive effect on private plant breeding for small grains and soybeans, but were puzzled why small grains breeding increased before the PVPA was passed 1970.

Recent research indicates that the increase in small grains research documented in Figure 1 was only partially due to PVPA. Most of the research on small grains was on wheat. The history of hybrid wheat by Knudson (1990) indicates that most wheat breeding in the 1960s and 1970s was undertaken with the expectation that hybrid wheat would be successful. As firms gave up on hybrid wheat they tried to market improved wheat varieties protected by PVPA. When they could not make profits on varieties most firms stopped breeding hard red wheat entirely. Thus, the increase in cereals R&D was largely due to the expectation of increased appropriability due to hybrids rather than PVPA.

There have been no empirical studies of the impact of utility patents on plant breeding. In 1987 OTA surveyed 39 seed firms, biotechnology firms, universities and USDA about their views on the different types of IPRs. On the basis of this survey OTA concluded that utility patents were important in stimulating biotechnology firms to do research on plants (OTA 1989:85), but less important for the other types of firms or the public sector.

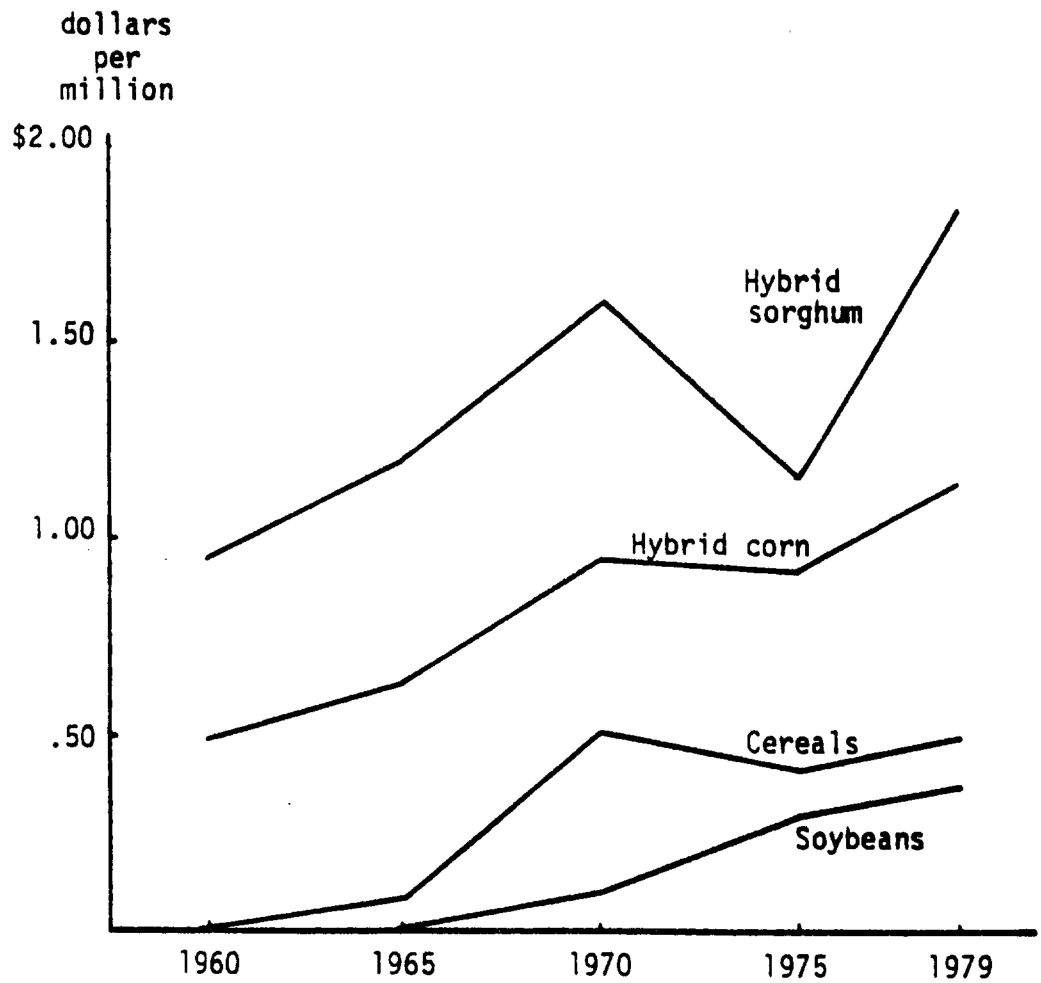


Figure 1. Crop Breeding Research Expenditures (59 Firms) Per Million Dollars of Annual U.S. Crop Value in the Preceding Five Years.

V. Empirical Evidence on Impact of IPRs

A. Survey of Private Research

To measure the impact of IPRs on private research since 1980 we conducted a survey similar to the one conducted by Perrin et al (1983). The first part of the survey requested R&D expenditures and sales by crop. The second part asked about the impact of PVPA and utility patents on profits, R&D, spillovers from public to private research and spillovers between private firms. The survey was sent to 564 companies who were active members of the American Seed Trade Association as of March 1, 1991. An additional 90 surveys were sent out to non-ASTA members. In total 654 firms were sent questionnaires and 237 responded. 121 stated that they did not have plant breeding programs. 90 of the responses were from firms with plant breeding programs who completed the entire questionnaire. 5 firms with breeding programs chose not to provide sales and R&D data, but completed the second part of the survey. 4 of the surveys were returned with a note that the firm had undergone a merger or acquisition and 17 of the surveys were classified as undeliverable.

In 1990 the 84 participating firms reported seed sales of approximately $ 1.8 billion and R&D of $137 million (Table 2). R&D as a percentage of sales (research intensity) was around 8 per cent. This is larger than the 59 firms that replied to the Perrin et al. survey. It is less than the 157 firms that replied to a short questionnaire sent out by three private sector scientists (Kalton, Richardson and Frey 1989. That survey asked only about number of scientists, broad classes of R&D expenditure and no information on sales. Kalton et al do make a rough estimate of total R&D expenditure in 1989 of $272 million. If Kalton et al are correct, our study includes about half of the private seed research conducted in the U.S. The share of R&D of different crops is similar to Kalton except for wheat and other cereals which appear to be underrepresented in out survey. The information on PVPCs (below Table 4) suggests this sample underestimates wheat and soybeans.

Table 2. Sales, R&D and IPRs for Participating Firms by Crop in 1990.

Crop	#firms	Sales ($ millions)	R&D ($ millions)	R&D/Sales	PVPCs	UPs
Hybrid Corn	42	1008	67	.07	133	25
Hybrid Sorghum	9	30	4	.13	4	0
Soybeans	23	208	16	.08	105	2
Vegetables	20	214	24	.11	252	4
Forage	12	111	7	.06	45	0
Wheat	7	35	4	.11	20	1
Cotton	5	2	1	.65	11	0
Grasses	9	102	2	.02	94	0
Other[1]	21	50	12	.24	55	4
Total	84	1761	137	.08	719	36

Source: Survey.
1 Includes crops for which the number of respondents was less than five.

B. Impact of IPRs on R&D

This section first examines trends in the determinants of R&D. These trends are broken down by crop when possible. Then it looks at the trends in R&D and R&D divided by sales for the main crops.

1. IPRs and Other Factors that Influence Appropriability

Tables 3, 4, and 5 show the use of Plant Patents, PVPA and utility patents for all firms not just those in our survey. Plant patents continue to be extensively used for asexually propagated flower and fruit varieties (Table 3). Table 4 shows the number plant variety certificates. Figure 2 shows the PVPCs of the four most important field crops which are held by the private sector. One of the most significant changes between the 1970s and the 1980s is increase in certificates for corn varieties. Table 5 shows the distribution of the utility patents issued in 1985 through 1988. In contrast to PVPCs the most utility patents were issued for two crops in which the commercial seed is primarily F1 hybrids - corn and sunflowers.

Table 3. Plant Patents Issued.						
	Number granted between					
Crop[5]	1931-62	1963-68	1969-73	1974-78	1979-83	1984-87
African violet	9	0	12	45	54	49
Almond	6	15	9	11	15	7
Apple	55	22	17	36	33	17
Azalea	49	40	34	27	7	4
Begonia	4	0	7	28	7	4
Camellia	38	5	4	1	0	1
Carnation	50	6	11	33	10	83
Chrysan-themum	133	38	68	155	99	128
Fuchsia	27	3	0	0	0	1
Gladiolus	30	53	8	6	0	0
Grape	10	8	5	9	16	14
Kalanchoe	0	0	5	33	14	30
Nectarine	59	14	25	29	17	23
Peach	151	29	29	30	34	30
Plum	25	18	6	16	14	31
Poinsettia	13	14	17	22	0	15
Rose	1,061	232	141	239	232	201
Strawberry	30	8	13	18	21	14
Annual average	53	108	111	189	162	227
Total	2,207	647	556	946	808	907

Sources: American Association of Nurserymen, Plant Patents with Common Names, 1931-1962; 1963-1968; 1969-1973; 1974-1978 (Washington, DC: American Association of Nurserymen, 1963; 1969; 1974; 1981).

[5]Partial listing of most common plants, representing from 70 to 79 percent of plant patents for the time period.

Table 4. Number of Certificates in Force Dec.31,1990 by Crop

Soybean	486	Fescue	90
Wheat	234	Ryegrass	86
Pea	195	Lettuce	85
Cotton	176	Alfalfa	71
Corn	162	Barley	42
Garden Beans	139	Bluegrass	40

Source: USDA Plant Variety Protection Office Official Journal Vol. 18, December 1990.

Table 5. Number of Utility Patents Issued for Plants by Crop

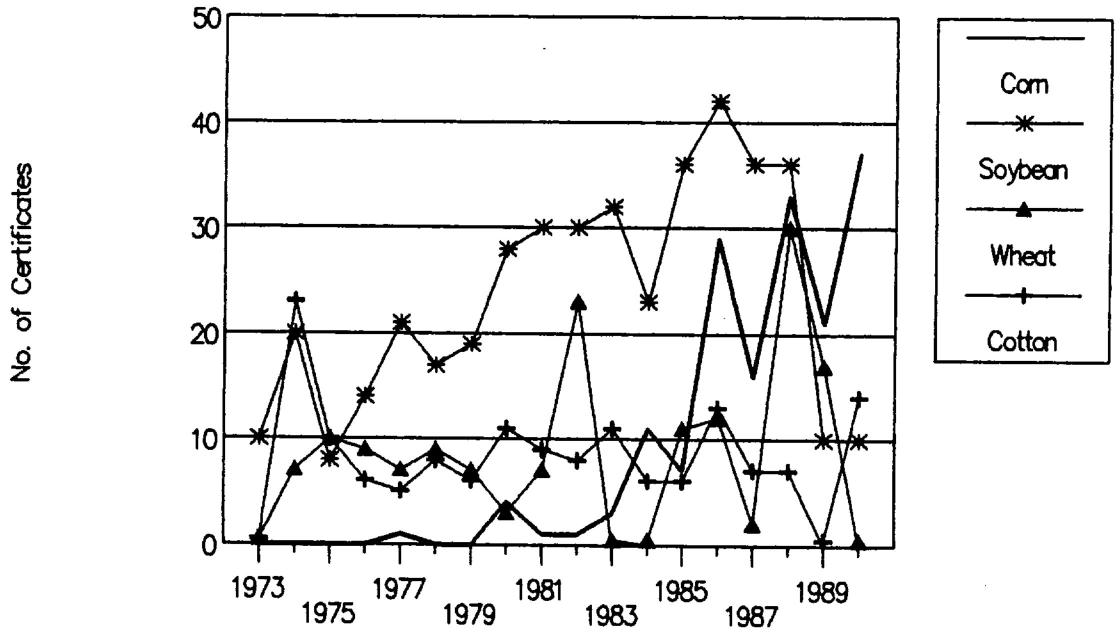
Corn	11
Sunflowers	6
Soybeans	5
Wheat	5
Others	17
Total	42

Source: OTA 1989.

Most firms in our sample believed it was in their interest to use PVPA. 51 firms held at least one PVPC. Only 11 firms held a utility patent on a plant or plant part. To find out more about firms' perception of PVPA and UPs, the survey included questions about the impact of intellectual property rights on R&D, profitability and on spillover. Firms perception of the impact of PVPA and UPs is shown in Table 6. Firms were asked to rate the impact of PVPA and UPs on types of spillovers and on profits from plant breeding on a scale from -3 to 3. The table below reports both the mean score and the number of firms that rate the impact as positive, negative or none.

PVPA appears to have increased the flows of information and perhaps germplasm from government R&D and from other private firms. Of the firms that thought PVPA did have an impact 25

Figure 2. No. of PVPCs of Wheat, Soybean, Cotton & Corn



thought the impact on information from the government was positive and only 9 thought it was negative. Regarding information from other firms, 34 thought PVPA had a positive impact compared to 17 that thought the impact was negative. Firms were about evenly divided about the impact on germplasm movement.

In contrast, utility patents may have decreased the spillover of germplasm while they were neutral on information exchange. 30 firms (38%) felt that the effect of utility patents on exchange with the public sector was negative, 14 thought it was positive, and 36 felt there was no impact. This finding is quite worrying, although as the public sector becomes more familiar with patents this may become less of a problem. Regarding spillovers within the private sector, 28 firms (35%) felt that UPs limited germplasm exchange between private companies, 17 felt this effect to be positive, and 35 reported that there was no impact.

If IPR's positive impact on a firms' ability to appropriate the gains from research outweighed the negative impact of reduced spillovers, firms profits from R&D should increase and R&D should increase. 67 firms reported that the PVPA increased their ability to profit from breeding new varieties, while 24 reported that it had no impact and only one reported a perceived negative impact on profitability. Firms were less sure about the impacts of utility patents - 43 said utility patents increased profitability, while 8 reported a negative impact.

Since there is data to analyze the impact of PVPA on breeding but it may be too early to estimate the impact of the Hibberd ruling of 1985 which permitted UPs on plants, the survey asked firms about the impact of UPs on research. Firms reported that the extension of utility patent protection to plants had little effect on breeding efforts. Only 6 reported that the availability of utility patent protection increased their research expenditures and one more commented that they had increased research before 1985 in anticipation of the ruling. Eight firms reported a decrease in R&D, with 76 firms reporting no change total expenditures. In addition 14 firms reported that research priorities changed after 1985 due to the availability of UPs.

Table 6. Impact of PVPA and Patents on R&D Number of Firms

	Impact of PVPA				Impact of UPs			
	Mean	+	No	-	Mean	+	No	-
Info from Govt. R&D	.27	25	58	9	-.18	15	46	19
Germplasm from Govt. R&D	.18	24	49	19	-.16	14	36	30
Info from Other Firms	.08	34	41	17	-.51	20	40	20
Germplasm from other firms	.08	24	49	19	-.33	17	35	28
Ability to Profit	1.43	67	24	1	.89	43	31	8
More or Less R&D due to ex parte Hibbard						6	69	0

Source: Survey

Firms' perception of increased profits from breeding due to PVPA and utility patents seems to outweigh their concern about reduced spillovers. Even for utility patents only 8 firms stated that the profits will go down despite the fact that 30 thought there was less spillovers from the government and 28 thought there was less spillover form other private firms.

Intellectual property rights for hybrids increasing during the 1980s due to ex parte Hibbard and the court ruling on trade secrets. Property rights in some self pollinated crops such as wheat and cotton in some areas were declining because of the ease with which farmers could reproduce seed and court rulings that specified the extent of the farmers right to sell seed. Thus, R&D and R&D/sales should be increasing in hybrids and declining in some self pollinated crops.

Different types of seed firms may have quite different research expenditure patterns due to different levels of appropriability that they face. Table 7 shows the different levels of R&D and R&D/sales for several different types of seed firms. These differences could be due to the structure of the industry -

vegetable varieties may be easier to control because there are a small number of seed companies and a small number of growers (Foster and Perrin 1990). Their research expenditure may also be different at different stages in the life cycle of the firms. When the firm is just starting up, it will invest money in research but have little or no sales. Finally, certain types of firms are primarily research firms. Foundation seed companies will have very high research intensity because they have low seeds sales and some of their research is essentially contract research for other firms.

2. Changes in Technological Opportunity and Demand

In addition to the changes in intellectual property rights the other major variable that changed since 1980 was technology opportunity due to advances in molecular biology. Many firms and government institutions have applied biotechnology techniques such tissue culture and genetic mapping to plant breeding in the mid 1980s. Using these techniques they are improving the efficiency of plant breeding and producing varieties resistant to pests and herbicides. The public and private sectors are also working on transgenic plants some 300+ of which are in field trials. So far no transgenic crop varieties are available commercially.

The extent of biotechnologies impact on private plant breeding is indicated by the 1989 study by Kalton et al. They found 252 PhDs working on biotechnology related to plant breeding compared to 580 PhDs working on conventional breeding. The pattern of biotechnology research by seed firms is shown in Table 8. Corn biotechnology attracted three times the research resources of any other individual crops and twice as much resources as all vegetables together. This pattern reflects the size of the market for various types of seed and firms' perception of intellectual property as well as differences in technological opportunity between crops.

The other factor that our model suggests would influence R&D is demand for seed. Firms should do more research in crops which have rising seed prices and quantity demanded is rising. Table 9 shows the value of seeds planted and Figure 3 the trends in seed prices and quantity demanded of the major crops. Corn was by far the most important crop in terms of value of sales and it also led in growth of value between 1974 and the present. Figure 3 shows that the value of seeds sold of corn, sorghum and soybeans grew rapidly between 1974 and 1985 and then declined or levelled off. The value of cotton seed sale grew until 1981 and then declined. Wheat is only one of these crops that declined in the 1970s and 1980s and ended with its value in nominal dollars in 1990 lower than in 1974.

Table 7. Sales, R&D, and IPR's by Type of Firm for 1990.

Type	# Firms	Sales	R&D	R&D/Sales	PVPCs	Patents
			(Million $)			
Field Crops						
Vertically[6] Integrated	4	972.6	52.9	.05	183	15
Regional[7]	30	317.5	22.3	.07	67	2
Foundation[8] & Start-ups[9]	30	132.4	37.2	.28	74	18
Sub-Total	65	1387.5	105.4	.08	324	35
Other Crops[10]						
Vegetables	17	210.1	19.9	.09	207	1
Flowers & Grasses	9	128.5	4.8	.04	133	0
Sub-Total	26	338.6	24.7	.07	340	1
Total	91	1726.1	130.1	.08	664	36

Source: Survey

[6]Firms that specialize in field crops and had seed sales greater than $50 million a year in 1990.

[7]Firms that specialize in field crops and had seed sales less than $50 million a year in 1990.

[8]Firms that specialize in the production of foundation seed.

[9]Firms that were established or entered the seed business after 1980.

[10]Firms that specialized in the production of the following groups of crops. A few start-up companies are included in these categories.

Table 8 Number of Companies and Scientist Involved in Biotechnology Research Related to Plant Breeding

Crop	Companies	PhD	Other Scientist & Technicians
Corn	19	90.1	168.2
Vegetables	17	31.4	90.6
Soybeans	6	17.3	29.0
Cotton	5	7.15	16.8
Sugar beets	3	6.5	9.0
Canola	3	9.5	27.0
Alfalfa	2	2.1	10.4
Sunflower	2	1.0	6.0
Wheat	2	1.1	2.3
Other small grains	1	.5	1
Rice	1	.25	0
Turf grasses	1	0	.9
Forage grasses	1	0	.1
Undifferentiated by crop	2	85.0	55.0
Total		251.9	411.8

Source: Kalton, Richardson and Frey 1989.

3. Trends in R&D

During the 1980s one would expect corn R&D to grow the most rapidly of the five main crops because IPRs of corn and sorghum were strengthen the most, the value of seed grew the most and the most biotechnology R&D was conducted on corn. Wheat should do the worst in the 1980s because IPRs were weakened, hybrid wheat turned out to be commercially impractical, and the value of wheat seed purchased by farmers declined. R&D by the other three crops should be somewhere in between possibly led by sorghum, then soybeans and cotton.

Table 10 shows that hybrid corn accounted for the largest share of total R&D in 1990, followed by the class of vegetable crops, soybeans, forage crops, hybrid sorghum and wheat. Hybrid corn was also the individual crop for which firms held the most Plant Variety Protection Certificates (PVPCs) and was again

Table 9. Quantity, Price and Sales of Seed of Five Crops

	Tons Planted (1,000s)	Price per ton $s	Value of Seed Planted Million $s	Percent Purchased	Value of Seed Purchased Million $s
			1985		
Corn	493.64	2872.00	1417.73	95.00	1346.84
Wheat	2348.22	227.70	534.69	35.00	187.14
Soybeans	1623.34	444.30	721.25	60.00	432.75
Cotton	119.25	1079.68	128.75	50.00	64.38
Sorghum	63.02	1480.64	93.31	95.00	88.64
			1991		
Corn	439.46	3276.00	1439.67	95.00	1367.68
Wheat	2401.82	216.72	520.52	35.00	182.18
Soybeans	1486.29	477.87	710.25	60.00	426.15
Cotton	138.39	1303.68	180.42	50.00	90.21
Sorghum	36.19	1594.88	57.71	95.00	54.83

Sources: Area planted, seed rate and price from USDA _ Agricultural Statistics 1991 Washington:GPO 1991. Percent purchased from Butler and Marion 1985.

followed by soybeans. Firms held 252 certificates for vegetables, which is nearly equal to the total for the major grain crops. Thus, PVPCs were primarily used to protect innovations in corn, vegetables, and soybeans. Two-thirds of the utility patents were used to protect corn varieties or characteristics. The rest were scattered among a number of crops.

Seed research in total has grown rapidly since 1979 or 1980 (Table 10). Perrin's estimate of $54 million (1982 $s) for 1979 R&D is probably closer to the industry total than our estimate of $35 million (1982 $s) for 1980.[11] Using either estimate real research expenditure in some crops grew very rapidly. Corn research grew rapidly as expected - at least doubling in real terms. Cereals which includes wheat declined as expected.

11. Firms that went out of business between 1980 and 1990 would not have been included in our sample. 1980 research by firms that merged may also not have been reported by the new firm. Also some firms who report having R&D programs in 1980 only provide R&D data for 1990 and/or 1985.

Figure 3 Indices of Seed Sales

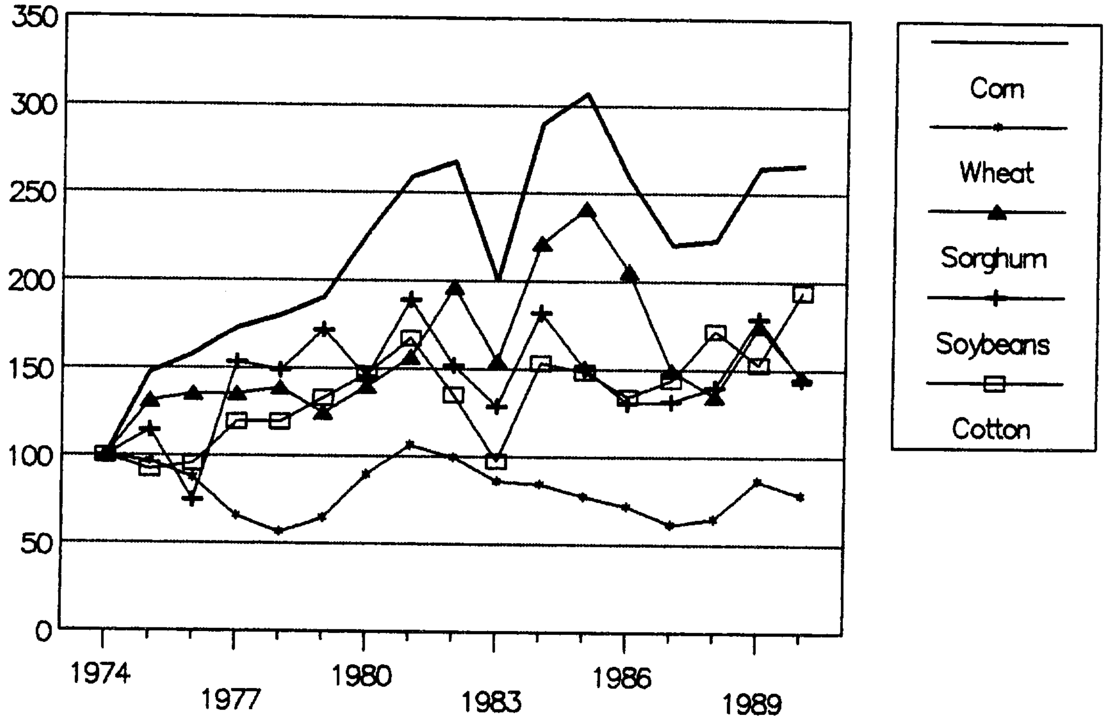


Table 10. R&D Expenditures by Crop, 1979-1990.[1]

Crop		1979[2]	1980	1985	1990
		(Thousands of 1982 dollars)			
Hybrid Corn	R&D	25121	21544	35029	51249
	R&D/Sales	.038	.033	.056	.067
		(32)	(26)	(32)	(42)
Hybrid Sorghum	R&D	3622	1902	2513	3095
	R&D/Sales	.043	.078	.073	.133
		(18)	(5)	(7)	(9)
Soybeans	R&D	5465	3060	5676	12435
	R&D/Sales	.041	.052	.051	.078
		(21)	(14)	(18)	(23)
Cereals	R&D	9564	1204	3485	4241
	R&D/Sales	.208	.276	.255	.139
		(9)	(1)	(4)	(11)
Vegetables	R&D	5506	3110	6811	17956
	R&D/Sales	.048	.055	.104	.110
		(16)	(7)	(15)	(20)
Forage and turfgrasses	R&D	3879	3727	4563	6537
	R&D/Sales	.017	.036	.037	.040
		(16)	(10)	(15)	(19)
Other	R&D	1117	893	3669	6708
	R&D/Sales	.010	.120	.188	.236
		(11)	(5)	(11)	(16)
Total	R&D	54274	35440	61746	102221
	R&D/Sales	.038	.041	.063	.078
		(59)	(43)	(63)	(84)

Source: 1980 - 1990 Survey.
1979 Perrin, et.al., "Some Effects of the U.S. Plant Variety Protection Act of 1970," Economic Research Report No. 46 (Raleigh, North Carolina: Dept. of Economics and Business, North Carolina State University, 1983) p. 25.

[1] Numbers in parentheses are the number of firms with active plant breeding programs.

Soybean research between 1979 and 1990 grew 228 percent, which was more than corn and more than expected. Sorghum did not grow much. R&D on vegetable grew by 326 percent.

B.2. Regression analysis

Regression analysis was used to try to sort out the relative influence of these different factors on private R&D. Two dependent variables were used. First, R&D by firm was regressed on demand, IPR variables, spillover variables and characteristics of the firms. Second, R&D by crop and firm was regressed on the public R&D by crop, IPR variables and industry demand variables. The results are shown in Table 11.

None of the industry demand variables, such as growth in value of sales of seeds by crop in the previous five years, were significant. Public sector plant breeding R&D by crop of five major crops from 1972 to 1988 from USDA CRIS was also insignificant in all specifications.

The sales variables is consistently positive and sales squared is negative in different specifications and with both the firm and crop R&D as dependent variables. This indicates the inverted U type relationship between research intensity and size of firm found in the early empirical tests of the Schumpeterian theory. Hybrids are positive and significant at the ten percent level in the crop R&D equations. When hybrids are used as a dummy variable in the firm R&D equations, they are negative but insignificant. In the firm R&D analysis specification 3 they are positive and significant in interaction with sales. The positive sign on the interaction term seems plausible because larger firms make more money from hybrids because they have the legal departments or the resources to hire the lawyers needed to enforce trade secrets and apply for and enforce utility patents.

Various dummies were used to try to capture the impact of utility patents with mixed results. In both data sets the dummy for 1985 and 1990 was positive and significant at the 5 or 10 percent level which provides some support for the hypothesis that utility patents increased R&D. The impact of utility patents was also estimated by the using the firms' responses on the questionnaire on whether they though UPs increased their profits from plant breeding. The firms that thought UPs increased profits had higher levels of R&D than other firms using both firm and crop R&D. In the third specification in Table 11 the time dummies were 1 for 1980 and 1 for 1985. Thus, they were expected to have a negative effect if firms were gradually convinced of the increased importance of utility patents. In interaction with sales they do have a negative and significant impact on R&D which implies that the slope of the sales variable is higher in the later years after utility patents became an accepted tool for increasing appropriability.

Table 11. OLS Regression Analysis of Firm R&D Data

	R&D Expenditure by Firm			R&D Expenditure by Crop	
Constant	-398.7	-1154.3	138.1	-277.8	-280.5
Sales	.078 (.006)	.073 (.009)	.046 (.011)	0.069 (0.005)	0.068 (0.005)
$Sales^2$	-1.02E-07 (1.0E-08)	-9.6E-08 (2.0E-08)	-1.62E-07 (1.0E-08)	-9.46E-08 (1.2E-08)	-9.4E-08 (-1.2E-08)
Hybrids	-2.08 (185.9)	-308.7 (229)	-580.1 (185.8)	319.65 (168.1)	347.37 (167.5)
D85-90	455.1 (208.7)	418.9 (206.6)		295.15 (176.1)	
Exp.Profits from UPs	339.6 (181.3)	334.3 (181.9)	524.4 (160.9)		160.27 (80.15)
Integrated Firms		1861 (729)			
Regional Firms		857 (375)			
Foundation Seed Firms		2223 (569)			
Start up Firms		1104 (380)			
Vegetable Seed firms		881 (379)			
Flower seed Firms		890 (593)			
HYB*Sales			.068 (.012)		
1980*Sales			-.026 (.003)		
1985*Sales			-.014 (.004)		
R Squared	.75	.774	.813	.649	.657

The dummies for some types of firms shown in Table 7 were significant. Foundation seed firms and the large integrated firms had to largest increases in R&D over grass seed firms which were represented by 0. They were significant at the 5 percent level as were the other industry dummies except flower seed.

The regression indicates that some of variables used to represent utility patents and firms perceptions of utility patents did have a positive impact on R&D. Firm size has a positive impact and certain types of firms - foundation seed firms and large integrated firms - also had a positive impact. However, several other variables which we believe affect R&D - public R&D and growth in demand - did not have significant impacts probably due to the fact that they were crop level variables rather than firm level variables.

Conclusions

The data on private research suggests that private firms and were induced to conduct more research on the crops in which intellectual property rights were strengthened most. PVPA did not, however, cause as much increase in R&D as earlier studies suggested because they had neglected to correct for the firms' mistaken belief that hybrid wheat would be profitable. Firms did not find that germplasm exchange or information was reduced by PVPA.

About 38% of the firms surveyed felt UPs hampered their exchange of germplasm with the public sector and 35% said it reduced the exchange of germplasm between firms. This problem may decline as firms and universities get more experience with UPs, but at the moment there does appear to be a decline in information and germplasm exchange. However, over half of the firms indicated that UPs would increase the profitability of plant breeding while less than 10 percent thought the impact would be negative. This suggests that overall the firms felt utility patents were a good thing.

The trends in R&D expenditure by crop were generally consistent with trends in IPRs, demand and technological opportunity. Corn research grew rapidly as expected - at least doubling in real terms. Cereals which includes wheat declined as expected. Soybean research between 1979 and 1990 grew 228 percent, which was more than corn and more than expected. Sorghum did not grow.

The regression analysis suggests that UPs did stimulate research by seed firms as well as by new biotechnology firms. Those firms that stated UPs had increased profits from breeding did do more R&D than those who thought it was neutral. Other dummies such as time and hybrid dummies also indicate the stronger property rights lead to more R&D.

In conclusion, it appears that stronger intellectual property rights in the form of utility patents and trade secrets have increased the amount of R&D in the U.S. despite the concerns about declining spillovers. In addition firms confirmed the findings of earlier studies that PVPA did have a positive impact on profits from R&D on plant breeding. These findings provide preliminary evidence that the strengthening property rights further through measures such as eliminating farmers rights to sell seed and adopting UPOVs convention on essentially derived varieties would increase R&D. More study is needed to answer the question of the impact of more private R&D on farmers.

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A NEW LOOK AT STATE-LEVEL PRODUCTIVITY

GROWTH IN U.S. AGRICULTURE

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A NEW LOOK AT STATE LEVEL PRODUCTIVITY GROWTH IN U.S. AGRICULTURE

There is a large body of empirical evidence suggesting the rates of return to investments in public-sector research for U.S. agriculture have been very high, typically in excess of 30% per annum. Consistent with this view are the studies by Ball (1985), Capalbo and Vo (1988), Jorgenson and Gallop (1992), Huffman and Evenson (1993) and others reporting rates of *total* factor productivity (*TFP*) growth for U.S. agriculture in the 1.84% to 1.34% per annum range for the post-war period. But these high rates of return to U.S. agricultural research have not gone unchallenged (see, for example, Pasour and Johnson 1982). There are real difficulties in measuring and modeling the contribution of research to the stock of knowledge in use and the subsequent productivity or growth consequences of this changing knowledge stock.[1] And there is a suspicion that by not carefully accounting for those quality changes in "conventional" inputs that are not the direct consequence of public research and extension investments, the technical change effects of these public investments could be seriously mismeasured. Systematic attempts to adjust for these quality changes would give us more confidence, for example, that the growth consequences of increased human capital inputs or improved durable inputs (where the quality improvements arise largely from private research) are not spuriously being attributed to public research and extension efforts.

This paper is a report of our efforts to construct new, state-level output, input, and *TFP* measures for U.S. agriculture over the 1949-85 period. In compiling these data we have taken

[1]The recent studies by Pardey and Craig (1989) and Cox and Chavas (1992) raise some serious questions about the common parameterizations used to estimate the productivity effects of research.

on-board many (but by no means all) the measurement issues raised by Griliches (1960), AAEA (1980), Shumway (1988 and others. The work is in the spirit of Griliches' (1963) attempt to provide an explicit and "full" accounting of the sources of growth in U.S. agriculture and by so doing "whittle down" the measured *TFP* residual. After briefly describing pertinent data and measurement issues we highlight the substantial differences between our national and state-level results and the previously published work in this area.

Measurement Methodology

Partial factor productivity measures, that express output per unit of an input (e.g., land, labor, or fertilizer) are affected not only by advances in the state of technology, which enable increased levels of output to be produced per unit of measured input, but also by changes in the quantities of other inputs used in production. If the goal is to distinguish between those changes in output due to technical changes arising from research (or any other productivity-enhancing factor) and those arising as a consequence of changes in the mix of inputs and outputs due to shifts in their relative prices, then a more general concept of productivity is required. Aggregate total factor productivity (*TFP*) can be defined as

$$TFP = \frac{Q}{X}, \qquad (1)$$

where *TFP* expresses an *output aggregate*, Q, produced per unit of an *input aggregate*, X, for a given state of technology. Obviously some suitable means of aggregating across different types of outputs and inputs is required when calculating a *TFP* no matter how small the unit of production under analysis. Unfortunately we encounter the inevitable index number problems.

Changing relative prices will cause optimizing producers to alter their mix of inputs and outputs and, unless steps are taken to mitigate these effects, such responses to prices can result in a change in measured *TFP* even in the absence of technical change.

The method commonly used to minimize the impact of relative price changes when forming aggregate quantity indices is to use a *Divisia* indexing procedure. As Richter (1966) and Hulten (1973) describe, the Divisia index is desirable because of its invariance property; if nothing real has changed (e.g., the only input quantity changes involve movements around an unchanged isoquant) the index itself is unchanged. The formula for an index of aggregate inputs is

$$XI_t^D = XI_b^D \exp \int_b^t \frac{W_s' \Delta X_s}{W_s' X_s} ds \tag{2}$$

where XI_b^D is the index value of the base period, b.

If the economy of interest—measured at either the sector, industry or even farm level—is moving along an unchanged transformation surface, the changes in inputs, ΔX, weighted by current factor prices, W, will be approximately zero; the index will be unchanged. If the economy's transformation surface is shifting, current price-weighted changes will be different from zero leading to changes in the index value. This invariance property is, one should note, dependent upon a maintained assumption of optimizing agents.

Unfortunately, the calculation of a Divisia index requires continuous measurement of input prices and quantities. In any discrete approximation, some information is lost, but the advantage of using a chained index always reduces to the notion that recent quantity changes are weighted by the most recently observed prices. Intuitively, these indices are attempting to evaluate current behavior in the light of current prices. In proceeding from the base period to some distant period t, the small steps are chained together, to minimize the measurement error that is possible when only base-period prices, and period t prices, are used to evaluate real input quantity changes.

There are, of course, many possible discrete approximations to the Divisia index. We have chosen to use the *Törnqvist-Theil* approximation that uses both current and lagged cost shares in weighting quantity changes yielding

$$XI_t^{DT} = XI_{t-1}^{DT} \prod_{i=1}^{m} \left[\frac{X_{it}}{X_{it-1}}\right]^{\bar{w}_{it}} \quad \text{where } \bar{w}_{it} = \frac{1}{2}\left[S_{it} + S_{it-1}\right] \tag{3}$$

and where the input cost shares, in any particular period t, are given by

$$S_{it} = \frac{X_{it}W_{it}}{\sum_{j=1}^{m} X_{jt}W_{jt}} \tag{4}$$

The Törnqvist-Theil approximation in growth rate form involves weighted sums of quantity changes, and can be written as

$$\ln(XI_t^{DT}/XI_{t-1}^{DT}) = \frac{1}{2}\sum_{i=1}^{m} (S_{it} + S_{it-1}) \ln(X_{it}/X_{it-1}), \tag{5}$$

An input series index is formed by scaling the series so as to set $XI_b^{DT} = 1.0$ for any arbitrarily chosen base year b, and accumulating the measure forward (and if necessary backward) in time according to equation (3) or by compounding the period-to-period growth rates calculated in equation (5).

An output quantity index can be formed in a symmetric way using growth rates calculated according to equation (6).

$$\ln\left(QI_t^{DT}/QI_{t-1}^{DT}\right) = \frac{1}{2}\sum_{j=1}^{n}(s_{jt} + s_{jt-1})\ln\left(Q_{jt}/Q_{jt-1}\right) \tag{6}$$

Here QI_t^{DT} is a Törnqvist output quantity index and the output revenue shares in any particular period t are given by

$$s_{jt} = \frac{Q_{jt}P_{jt}}{\sum_{i=1}^{n} Q_{it}P_{it}} \tag{7}$$

From equation (1) it follows directly that the growth rate in *TFP*, *tfp*, is the difference between the growth rate in output, q, and that of inputs, x, i.e.,

$$tfp_t = q_t - x_t$$

$$\text{where} \quad tfp_t = \frac{dTFP_t}{dt}\frac{1}{TFP_t}, \quad q_t = \frac{dQ_t}{dt}\frac{1}{Q_t}, \quad x_t = \frac{dX_t}{dt}\frac{1}{X_t} \tag{8}$$

For relatively small changes in a variable, Z, proportionate rates of change (e.g., dZ_t/Z_t) are approximately equal to logarithmic differences, $(\ln Z_t - \ln Z_{t-1}) = \ln(Z_t/Z_{t-1})$, so a discrete approximation of equation 8 is given by

$$tfp_t \simeq \ln\frac{TFP_t}{TFP_{t-1}} = \ln\frac{QI_t^{DT}}{QI_{t-1}^{DT}} - \ln\frac{XI_t^{DT}}{XI_{t-1}^{DT}}$$

Data

The primary data include annual observations on inputs and outputs for the 48 contiguous states (excluding Alaska and Hawaii) covering the period 1949-85. To minimize the possibility of confounding substitution effects with real changes in *aggregate* output and *aggregate* input we collected the output and input variables to a much higher degree of disaggregation than is found in previous studies. In this regard we gave particular emphasis to finding state-level prices for both outputs and inputs since the economic rationale for using Divisia price indices is based on the idea that input and output mixes change in response to changes in the relative prices actually faced by producers.[2] A special effort was made in the construction of the labor, capital, and land variables to account for the substantial but spatially uneven changes in these primary inputs since 1949. To avoid biased indices, we avoided using any preaggregated measures of either output or input if an alternative was available.[3] The aggregate output measure reported here is a Törnqvist-Theil Divisia index that includes 15 field crops, 9 livestock products, 24 horticultural (fruit and vegetable) crops, plus a greenhouse and nursery marketings aggregate. The quantity components of the index represent state-level quantities produced and these are weighted using state-specific prices received by farmers.[4]

To measure labor in agriculture and account for quality change in the labor input, we

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[2]Using the same output data set described here, Craig and Pardey (1990) showed that state-level growth rates were significantly lower when state-level output indices were formed using national price weights instead of local ones. Drechsler (1973) advocated the use of *characteristic* prices on the grounds that one should use the price weights most specific to the economic activity being measured.

[3]If quantities and/or prices of different items within an input category such as labor do not move in parallel, there will be aggregation bias. For example, if rates of change in higher quality labor exceeds rates of change in lower quality labor, the rate of growth of the labor aggregate is biased downward relative to an index treating high and low quality items as separate components (Star 1974).

[4]Alternative output aggregates are possible. These same data can be used to form a Divisia output price index that, together with state-level farm marketings data (suitably adjusted for home consumption, change in farmer-owned inventories and, if desired, government payments), can be used to derive a broader, implicit Divisia measure of agricultural output. To the extent that producers commit resources (especially set-aside acres) to "farm government programs" this output measure may be of analytical interest.

constructed measures of hours worked and implicit wage series for each of 32 distinct types of labor within each state. We differentiated between hours worked by hired workers, family members, and 30 classes of farm operators with different age and education profiles. *Census of Agriculture* data on the age characteristics of farm operators was used in conjunction with state-level *Census of Population* data on the number and earnings characteristics of rural males in various age-education classes to construct opportunity cost measures of the earnings profiles for farm operators within each state. We also incorporated data from the *Agricultural Census* on days worked off-farm by farm operators to take into account the substantial but uneven shift toward part-time farming.[5] *Farm Labor* data were used to measure hours of family labor. An implicit quantity measure of hired labor was derived from ERS data tapes reporting state-level expenses for hired labor. The state-specific price for hired and family workers is a wage rate for hired workers reported in *Farm Labor*.

To measure capital's contribution to agricultural inputs we had to deal with the usual problem of inferring service flows from measured stocks of capital on farms as well as accounting for the heterogeneity of capital within each of nine capital classes.[6] To handle both problems we relied heavily on market values as reflections of the relative effectiveness of different types of capital within each capital class and as indicators of the rental values of capital. As a first step, we derived estimates of depreciation and lifespan parameters for a numeraire machine type in each capital class using blue book values of new and used machines.

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[5]The data indicate that, for many states, the number of days worked off-farm actually declined for a temporary period during the mid-1970s.

[6]Our nine capital classes consist of trucks, autos, tractors, combines, forage equipment, buildings, cows, ewes, and sows. For a more complete description of the data and measurement procedures we used to construct capital inputs see Craig, Pardey and Deininger (1993).

These parameter values were combined with information about the average age and quality of capital within each class to adjust published stock figures and to construct rental series for each capital class.

When working with *Agricultural Census* data on physical counts of undifferentiated capital of a given capital class, we converted the published numbers to counts of a new numeraire type assumed to be of constant quality over the sample. When no information was available about the mix of types within a class -- as was the case for biological capital, cars, trucks, and forage equipment -- the published figure was taken to be an accurate count of the used numeraire capital type of the likely average age. Using the parameter of depreciation for the class, these counts were then discounted to arrive at counts of new numeraire machines.

For tractors and combines a more sophisticated quality adjustment was possible. After 1963, unpublished data from FIEI on state-level purchases of tractors of 21 horsepower types and combines of 8 different types made it possible to form a much more accurate measure of the average age and type of tractor and combine in use in each state. Prior to 1964, the average horsepower of tractors in use for the country as a whole was used along with an assumed average age to convert census counts to new numeraire equivalents for both tractors and combines.

When working with the total current market value of a capital class, as in the case of buildings, we constructed physical quantities by dividing the total value by the market value of the typical used structure. The latter price series was based on a price series of a typical farm structure and an assumed pattern of depreciation of buildings.

To impute rents for the numeraire within each capital class, we used the relationship between market values and rents. For all capital classes we employed the same constant real discount rate. But the factor of proportionality that was used to convert market values of new numeraire capital types into rents differed across capital classes with different rates of depreciation or lifespans.

The land input is the service flow from land of three basic types: pasture or rangeland, nonirrigated cropland, and irrigated cropland. The measure we used differs from the land in farms figure commonly used by others in that ours excludes non-grazed forest and woodlands, which are land in farms but not in agriculture. Our measure also includes tracts of federally-owned (e.g., Bureau of Land Management) land that was rented or leased for rangeland grazing purposes. The price weights used in aggregation were annual, state-level, cash rents. When missing observations made it necessary, imputed rents were calculated using the correspondence between observed rents and land values. By separating land into the three types and constructing a different rental series for each, we hope to have a more accurate measure of the quantity and quality of land in agriculture.

There are nine broad classes of purchased inputs used in this study. They include fertilizers (further disaggregated into elemental nitrogen, phosphorus and potash), a preaggregated pesticides, herbicides and fungicides category, purchased seed, purchased feed, fuels and oils, electricity, repairs, machine hire, and a miscellaneous input category that preaggregates a long list of disparate inputs such as fencing, veterinary services, insurance costs and so on.

Output and Input Trends

A useful way to assess a new data series is to compare it with previously available estimates that purportedly measure the same thing.[7] But often this is not a wholly satisfactory exercise. Inevitably there are variations in data coverage, quality, methods of construction, and aggregation, that can make it difficult to interpret the similarities and differences so revealed. With these caveats in mind we follow with some selected comparisons of our series with previously published estimates.

Aggregate output

The national output aggregate formed with state-level prices and quantities grew by 1.78% per annum during the 1949-85 period. Underlying this figure there is considerable regional variation. Output increased by 2.94% annually in the South East, but decreased in the smaller northeastern states.[8] States with average annual output growth at or above 3% are Florida, Delaware, Georgia, California, and Arkansas. By contrast, output decreased over this period in Connecticut, Massachusetts, New Hampshire, New Jersey, and West Virginia. In the aggregate, our rate of growth in output is higher than the 1.44% obtained by Capalbo and Vo (1988) for 1948-83, but lower than the 2.38%, 1.92%, and 1.98% annual growth rates, obtained by Huffman and Evenson (1993), Jorgenson and Gollop (1992), and Ball (1985), respectively.[9]

Input Aggregates

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[7]Gardner (1992) recently reminds us that appearances can be deceiving in this respect.

[8]See table 8 for a grouping of states into 11 production regions.

[9] Huffman and Evenson's estimates are from 1950-82, Jorgenson and Gollop's from 1947-85, and Ball's from 1948-78.

Labor: According to Ball's (1985) estimates the value share of labor in U.S. agriculture was around 54.6% in 1948 and declined to 20.8% by 1979. This represents an annual rate of decline in labor use of 3.17%. Capalbo and Vo (1988) report a 1949 labor share figure of 36%, declining to 9.5% by 1983. By contrast, our data suggest a much more modest long-run contraction in quality-adjusted labor shares down to 27.2% in 1985 from a 1949 figure of 44.7% (table 2). And, according to our estimates, quality-adjusted labor shares actually rose during the 1981-85 period. Apparently the increase in labor quality over the post-war period has partially offset the decline in total hours in agriculture.

Capital: Our data have the share of quality-adjusted capital services (including services from mechanical inputs, service structures, and biological capital) in U.S. agriculture at around 11.4% in 1949 growing to 14.4% in 1985 (table 3). This translates into a relatively small increase of 0.59% per annum, which contrasts with other studies such as Ball (1985) whose capital share almost doubles from 13.2% in 1949 to 25.9% in 1979. Our estimates of the rate of increase in capital use in U.S. agriculture are in line with Capalbo and Vo's more modest growth from 23.7% in 1949 to 27.7% in 1983.[10] For our data the largest increase in capital services occurred in the Delta, Appalachian, and Southeastern states.

Land: Using a land in farms measure, Capalbo and Vo report a steep increase in the

[10]In Ball's case these capital inputs represent durable equipment (excluding service structures) and farm-produced durables and for Capalbo and Vo they represent durable equipment, nonresidential structures and animal stock.

land share from less than 6% in 1950 to more than 40% in 1981. Ball's real property (i.e., land and structures) share is quite volatile, ranging from 2.9% in 1949 to 31% in 1973, 9.3% in 1975, and 17.6% in 1979. In our case the cost share of quality-adjusted land services at the national level is remarkably stable over time ranging from 18.3% to 19.7% (table 4). But this stability at the national level masks a good deal of cross-state variability. The Mountain states have land-intensive farms with cost shares around 30% while less than 7% of the farming costs in the Northeastern states go to land services. Moreover, land shares decreased over time in the Appalachian and Southeastern states but grew a little in the Corn Belt, Mountain, and Pacific regions.

Purchased Inputs: While Capalbo and Vo report a decline in the share of purchased inputs from 37.2% in 1948 to 26.9% in 1983, our data has this cost share increasing from 25.7% to 40.7% between 1949 and 1985. These trends are consistent with Ball's estimates that show an increase from 23.3% in 1948 to 35.7% in 1979. Our data show the largest increase was in the southern states (i.e., the Southeast, Delta, Southern Plains and Pacific states) while the use of purchased inputs actually decreased in the smaller Northeastern states.

Total Inputs: A summary measure of the real inputs used in agriculture is given in table 5. Taking the U.S. as a whole, aggregate input use declined marginally for all sub-periods except during the latter half of the 1970s when it grew by 2.4% per annum. On balance aggregate input use since 1949 grew by 0.18% per annum at the national level, 1.2% per annum in the Pacific region, and contracted in the smaller Northeastern states as well as the Appalachian and Delta regions.

Productivity Growth

National estimates: The TFP estimates presented in table 6 (and graphically in figure 1) give a rough indication of the quantitative differences in the most widely used series. These series are not strictly comparable since the Ball and Capalbo and Vo figures were derived using national aggregate data while the other two series were formed using state-level data. But, they do indicate that the rate of growth of measured TFP may differ substantially depending on methods used and commodity coverage. The growth in TFP calculated using our data is higher than Capalbo and Vo's estimate but some 14% below those of other studies. One feature to note is that, despite historically high rates of growth in real output during the late 1970s, measured TFP actually contracted during this period given the commensurately large increase in input (particularly purchased inputs and capital services) use. The rather large productivity gains in the early 1970s and early 1980s came from increases in real output coupled with a decline in aggregate inputs.

Regional and state estimates: The state- and regional-level data display large spatial variations in input, output and measured productivity trends since 1949. For the Northeastern states measured TFP actually increased because the decline in aggregate inputs was even more rapid than the decline in aggregate outputs. In the mid-western states moderate productivity growth was brought about by increases in both inputs and outputs. In the Southeast and Delta regions, aggregate input use for some states such as Alabama and Mississippi declined markedly, resulting in high rates of growth in measured TFP despite slower growth in aggregate output. By contrast, Florida had the largest increase in aggregate output of any of the contiguous 48 states but this was offset by a relatively large increase in inputs so that the measured growth in TFP was not so dramatic. Regional comparisons of measured TFP are given in table 7.

The Evenson, Landau and Ballou (1987) series (as used by Huffman and Evenson 1993) provide the only other published estimates of state-level TFPs for U.S. agriculture. We compared these state-level TFP estimates with our own, and -- with the exception of seven states (Arizona, Florida, Georgia, Idaho, Nevada, New York and Utah) -- found their rates of TFP growth were much higher than our own estimates. Table 8 gives a summary indication of the differences between the two TFP series.

Final Comments

The data reported here represent our efforts to construct a highly disaggregated series of state-level output, input, and TFP measures that give special attention to accounting for quality changes. One of our ultimate objectives is to revisit the rates of return to public research (and extension) issue. But to do so we felt it necessary to compile data that lowers the risk of attributing output or productivity gains to these public investments that in fact have their origins elsewhere. Our first look at these data reveal substantial quantitative and qualitative differences with previous studies. Disaggregating the data to the state-level introduces a good deal of variation that offers the prospect of a much richer understanding of the nature and sources of technical change in U.S. agriculture and may also minimize our appeals to a residual measure of ignorance in order to account for observed growth in agricultural output.

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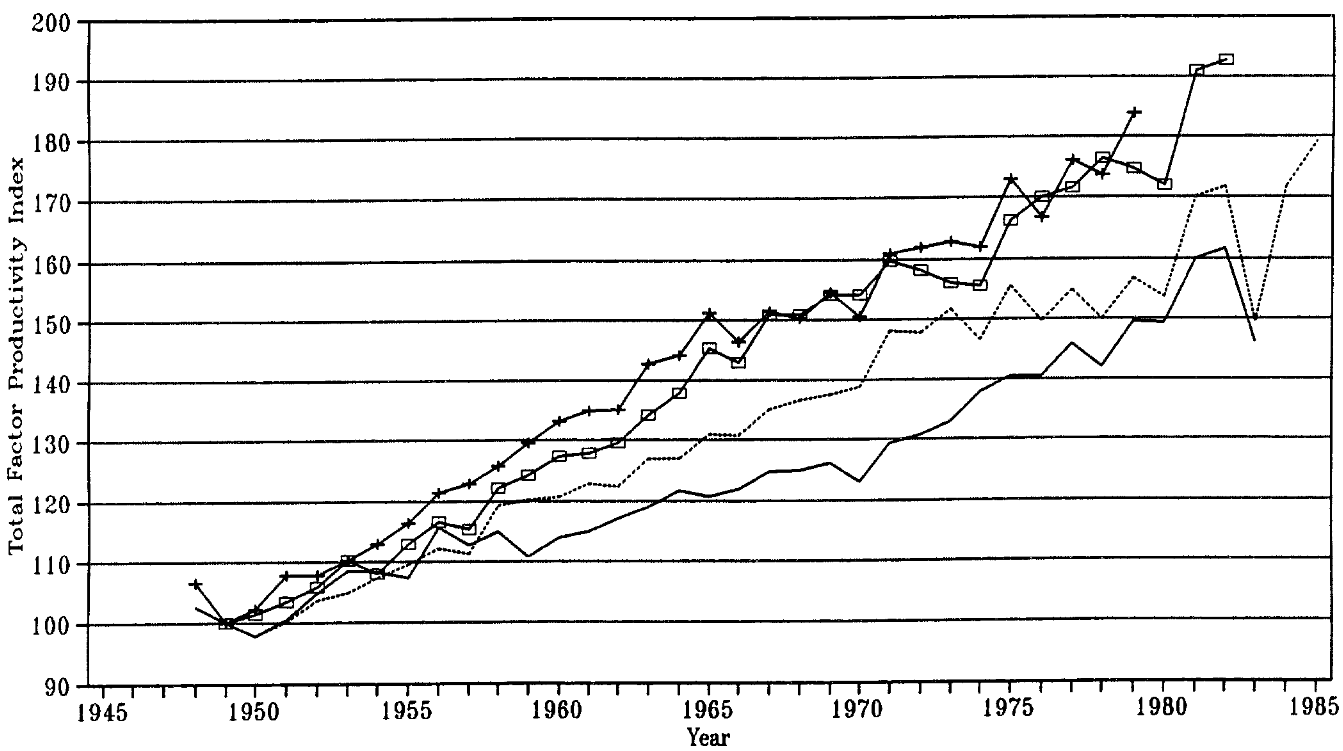
Figure 1: *Total factor productivity indices, 1949 = 100*



Legend : —+— Ball (1985); —— C&V (1988); —⊟— H&E (1993); ------ PC&D (1994).

Note : In the absence of relevant quantity data the Ball (1985) and Capalbo and Vo (1988) indices were simple rescaled (rather than rebased) from a 1977 to a 1949 = 100 "base".

Table 1: *Tornqvist-Theil Aggregate Output Quantity Indexes, 1949 = 100*

Year	North East 1	North East 2	Corn Belt	Lake States	Northern Plains	Appalachian States	South East	Delta States	Southern Plains	Mountain States	Pacific States	National
Indexes												
1950	102.31	102.02	97.76	96.85	111.50	97.14	97.14	92.28	75.88	101.16	101.48	97.32
1955	107.58	109.22	109.58	112.61	111.74	105.72	133.88	122.12	82.89	121.24	122.39	109.96
1960	103.06	114.16	118.07	117.43	144.32	108.71	142.21	119.63	103.24	130.30	137.91	120.37
1965	103.81	117.21	127.53	118.87	150.35	112.26	174.38	154.38	112.47	145.17	157.48	130.32
1970	103.67	117.10	129.00	126.74	170.61	121.66	201.33	178.91	126.06	168.26	169.46	140.09
1975	100.29	122.14	145.92	132.48	181.88	132.87	250.60	195.09	144.96	182.71	211.74	155.10
1980	101.46	136.44	163.80	166.05	201.00	138.16	285.18	201.16	151.08	208.38	249.13	172.78
1985	98.99	165.98	178.17	182.63	251.15	152.26	291.65	240.17	167.31	214.09	273.03	191.87
Average annual rates of growth (percentages)												
1949-55	1.23	1.48	1.54	2.00	1.87	0.93	4.98	3.39	-3.08	3.26	3.42	1.73
1955-60	-0.86	0.89	1.50	0.84	5.25	0.56	1.22	-0.41	4.49	1.45	2.42	1.83
1960-65	0.15	0.53	1.55	0.24	0.82	0.64	4.16	5.23	1.73	2.18	2.69	1.60
1965-70	-0.03	-0.02	0.23	1.29	2.56	1.62	2.92	2.99	2.31	3.00	1.47	1.28
1970-75	-0.66	0.85	2.50	0.89	1.29	1.78	4.48	1.74	2.83	1.66	4.56	1.23
1975-80	0.23	2.24	2.34	4.62	2.02	0.78	2.62	0.61	0.83	2.66	3.31	2.18
1980-85	-0.49	4.00	1.70	1.92	4.56	1.96	0.45	3.61	2.06	0.54	1.85	2.12
1949-85	*-0.03*	*1.38*	*1.57*	*1.64*	*2.52*	*1.14*	*2.94*	*2.40*	*1.40*	*2.08*	*2.75*	*1.78*

Note: All regional and national indexes are formed using state-level prices and quantities. All growth rates are average annual compound growth rates.

Table 2: *Labor Share in Total Factor Costs, 1949-85*

Year	North East 1	North East 2	Corn Belt	Lake States	Northern Plains	Appalachian States	South East	Delta States	Southern Plains	Mountain States	Pacific States	National
Share	%	%	%	%	%	%	%	%	%	%	%	%
1949	44.61	44.67	39.74	47.06	38.83	53.23	55.86	57.09	44.63	35.06	38.40	44.66
1955	41.91	41.12	34.87	43.14	33.89	50.54	49.56	50.76	37.51	31.72	32.71	39.64
1960	40.30	39.68	32.12	39.68	31.94	46.65	41.57	42.20	33.46	29.08	30.94	36.04
1965	42.26	40.00	31.87	40.26	31.28	46.45	39.42	37.11	32.20	28.41	29.81	35.20
1970	39.53	39.15	30.59	39.48	30.24	44.64	35.79	32.40	31.47	26.57	31.63	33.73
1975	35.32	36.29	25.14	33.97	24.53	39.82	31.86	29.00	26.43	21.11	28.45	28.72
1980	32.81	30.62	21.47	29.17	21.10	33.57	27.06	24.28	22.53	17.44	23.97	24.36
1985	35.38	32.00	24.77	30.89	23.68	36.10	30.74	27.36	27.22	20.30	25.81	27.21
Average annual rates of growth (percentages)												
1949-55	-0.96	-1.12	-1.73	-1.25	-1.70	-0.71	-1.89	-1.77	-2.25	-0.83	-1.68	-1.55
1955-60	-0.94	-0.85	-1.54	-1.64	-1.39	-1.66	-3.34	-3.45	-2.42	-1.73	-1.38	-1.93
1960-65	0.77	-0.06	-0.44	0.16	-0.53	-0.12	-1.31	-2.84	-0.79	-0.46	-0.49	-0.60
1965-70	-0.97	-0.23	-0.53	-0.26	-0.41	-0.71	-1.58	-2.19	-0.35	-1.60	0.71	-0.72
1970-75	-2.75	-1.72	-3.72	-2.87	-3.93	-2.40	-2.77	-2.71	-3.81	-4.00	-2.24	-3.21
1975-80	-0.75	-2.82	-3.12	-3.02	-2.96	-3.10	-2.67	-3.02	-2.37	-3.21	-2.48	-2.91
1980-85	0.83	0.07	1.70	0.26	1.26	0.94	1.93	1.80	2.73	1.46	0.98	1.30
1949-85	*-0.68*	*-0.94*	*-1.33*	*-1.20*	*-1.36*	*-1.07*	*-1.63*	*-1.98*	*-1.33*	*-1.44*	*-0.94*	*-1.35*

Note: See table 1 notes.

Table 3: *Capital Service Share in Total Factor Costs, 1949-85*

Year	North East 1	North East 2	Corn Belt	Lake States	Northern Plains	Appalachian States	South East	Delta States	Southern Plains	Mountain States	Pacific States	National
Share	%	%	%	%	%	%	%	%	%	%	%	%
1949	12.68	12.80	11.80	13.31	12.55	9.77	8.95	8.59	12.82	12.03	8.95	11.39
1955	12.89	13.99	14.07	15.25	14.89	11.79	11.10	11.60	13.27	12.45	9.75	13.12
1960	13.77	16.17	14.05	16.89	14.88	13.44	12.46	13.59	13.91	12.97	9.71	13.90
1965	12.74	15.80	13.86	16.32	14.03	13.81	12.10	13.54	12.87	12.01	9.18	13.42
1970	13.60	15.93	13.68	15.79	13.20	13.96	12.38	14.04	13.02	11.80	9.02	13.28
1975	13.64	15.62	12.69	14.84	12.11	14.51	13.15	14.01	12.43	10.17	10.58	12.79
1980	15.71	17.14	14.38	16.44	13.27	17.36	14.51	16.33	13.97	11.50	10.91	14.31
1985	19.42	17.19	13.19	15.12	13.42	18.15	15.25	16.54	16.86	12.34	10.94	14.41
Average annual rates of growth (percentages)												
1949-55	0.50	1.63	2.50	2.11	2.22	2.38	2.86	4.24	0.28	0.37	1.56	2.00
1955-60	1.23	2.88	0.39	2.17	0.75	2.65	2.24	3.13	0.54	1.41	0.16	1.38
1960-65	-1.43	-0.45	-0.26	-0.66	-1.22	0.64	-0.36	0.39	-1.01	-1.35	-1.02	-0.58
1965-70	1.36	-0.05	-0.47	-0.94	-1.58	0.23	0.52	0.33	-0.16	-1.37	-0.64	-0.51
1970-75	-0.41	-0.22	-1.15	-1.23	-0.99	0.92	1.00	-0.18	-0.11	-1.19	3.21	-0.35
1975-80	3.16	1.71	2.35	2.41	1.34	3.38	1.84	3.21	1.66	1.39	1.16	2.06
1980-85	2.53	-0.26	-1.45	-1.32	0.21	0.58	0.81	0.46	2.99	0.89	0.36	0.05
1949-85	*0.94*	*0.76*	*0.32*	*0.39*	*0.15*	*1.51*	*1.28*	*1.66*	*0.57*	*0.02*	*0.68*	*0.59*

Note: See table 1 notes.

Table 4: *Land Share in Total Factor Costs, 1949-85*

Year	North East 1	North East 2	Corn Belt	Lake States	Northern Plains	Appalachian States	South East	Delta States	Southern Plains	Mountain States	Pacific States	National
Share	%	%	%	%	%	%	%	%	%	%	%	%
1949	7.06	6.86	21.89	15.00	25.50	18.73	11.76	15.60	18.07	27.79	18.19	18.25
1955	5.92	6.80	21.84	14.58	25.78	15.94	8.99	13.61	21.02	27.66	21.63	18.36
1960	5.56	6.75	24.24	15.36	26.51	15.68	10.09	14.92	20.39	26.28	20.67	19.12
1965	4.79	6.92	22.98	14.97	26.16	14.32	9.57	15.83	20.21	27.17	21.89	18.97
1970	4.96	7.01	23.25	14.40	25.09	13.38	9.49	16.29	19.13	28.16	19.93	18.79
1975	3.92	6.47	24.51	15.26	26.30	12.35	8.83	16.32	18.93	33.05	18.36	19.62
1980	3.77	6.65	26.35	15.47	23.69	11.27	8.13	15.55	16.05	34.28	20.00	19.74
1985	3.80	6.83	24.44	14.08	23.08	9.73	7.65	15.21	16.57	31.45	21.58	18.82
Average annual rates of growth (percentages)												
1949-55	-2.24	0.08	0.00	-0.31	0.61	-2.00	-2.68	-1.16	2.05	0.23	1.95	0.24
1955-60	-1.32	0.24	1.23	0.32	0.17	-0.50	1.43	0.71	0.05	-1.60	-0.83	0.38
1960-65	-2.67	0.46	-0.51	-0.05	-0.15	-1.80	-0.75	1.62	-0.25	0.74	0.22	0.01
1965-70	0.37	1.02	0.39	-0.79	-0.65	-0.74	0.22	0.34	-1.45	1.64	-0.63	0.15
1970-75	-4.25	-2.62	0.80	1.01	0.37	-2.27	-1.85	-0.31	-0.84	1.58	-1.00	0.33
1975-80	-0.93	0.64	1.73	0.53	-1.56	-1.42	-1.36	-0.31	-2.85	1.15	0.34	0.29
1980-85	0.07	-0.51	-0.66	-1.05	-0.02	-2.08	-0.78	-0.88	0.89	-1.20	0.08	-0.57
1949-85	*-1.55*	*-0.10*	*0.40*	*-0.06*	*-0.15*	*-1.52*	*-0.86*	*-0.03*	*-0.28*	*0.34*	*0.07*	*0.12*

Note: See table 1 notes.

Table 5: *Tornqvist-Theil Aggregate Input Quantity Index, 1949 = 100*

Year	North East 1	North East 2	Corn Belt	Lake States	Northern Plains	Appalachian States	South East	Delta States	Southern Plains	Mountain States	Pacific States	National
Indexes												
1950	96.71	97.61	100.42	100.20	100.30	98.49	99.17	99.81	98.77	101.06	101.13	99.56
1955	90.89	98.76	107.35	104.95	106.59	95.50	99.26	95.28	98.03	106.41	109.47	100.42
1960	86.48	95.36	107.32	103.77	107.45	88.45	99.61	87.34	97.87	113.56	120.24	99.79
1965	76.23	87.66	107.94	99.07	110.05	84.37	100.52	89.41	105.90	117.98	123.86	99.46
1970	69.47	84.37	114.06	96.37	116.22	81.72	109.77	92.50	116.13	125.71	125.98	100.85
1975	65.14	83.21	113.83	97.96	115.81	76.86	106.58	85.80	108.80	124.17	135.12	99.77
1980	73.65	95.74	123.90	111.94	132.24	86.93	130.52	98.16	126.88	142.96	155.35	112.45
1985	70.81	94.39	114.40	110.00	126.94	83.11	123.79	93.16	120.66	140.41	155.52	107.00
Average annual rates of growth (percentages)												
1950-55	-1.58	-0.21	1.19	0.81	1.07	-0.77	-0.12	-0.80	-0.33	1.04	1.52	-0.06
1955-60	-0.99	-0.70	-0.01	-0.22	0.16	-1.52	0.07	-1.72	-0.03	1.31	1.89	-0.13
1960-65	-2.49	-1.67	0.12	-0.92	0.48	-0.94	0.18	0.47	1.59	0.77	0.59	-0.07
1965-70	-1.84	-0.76	1.11	-0.55	1.10	-0.64	1.78	0.68	1.86	1.28	0.34	0.28
1970-75	-1.27	-0.28	-0.04	0.33	-0.07	-1.22	-0.59	-1.49	-1.30	-0.25	1.41	-0.22
1975-80	2.49	2.85	1.71	2.70	2.69	2.49	4.14	2.73	3.12	2.86	2.83	2.42
1980-85	-0.78	-0.28	-1.58	-0.35	-0.81	-0.89	-1.05	-1.04	-1.00	-0.36	0.02	-0.99
1949-85	*-0.93*	*-0.16*	*0.36*	*0.26*	*0.65*	*-0.50*	*0.58*	*-0.19*	*0.51*	*0.92*	*1.20*	*0.18*

Note: See table 1 notes.

Table 6: *Total Factor Productivity Growth Rates for U.S. Agriculture*

Period	Ball	Capalbo & Vo[a]	Huffman & Evenson[b]	Pardey, Craig, & Deininger
	%	%	%	%
1949-55	2.56	1.18	2.04	1.79
1955-60	2.75	1.19	2.46	1.95
1960-65	2.54	1.16	2.66	1.67
1965-70	-0.07	0.42	1.18	1.00
1970-75	2.83	2.69	1.53	2.46
1975-80	1.52	1.21	0.66	-0.23
1980-85		-0.71	2.13	3.14
1949-85[c]	*1.86*	*1.34*	*1.84*	*1.59*

Note: Huffman and Evenson figures are simple averages of the state-level TFP estimates while the Pardey, Craig and Deininger figures are calculated using state-level prices and quantities.

[a]Designated by Capalbo and Vo (1988) as the Capalbo, Vo and Wade or CVW series.
[b]As reported by Evenson, Landau and Ballou (1987).
[c]For Ball the relevant period is 1949-79, for Capalbo and Vo it is 1949-83 and for Huffman and Evenson it is 1949-82.

Table 7: *Regional Total Factor Productivity Estimates, 1949-85 (1949 = 100)*

Year	North East 1	North East 2	Corn Belt	Lake States	Northern Plains	Appalachian States	South East	Delta States	Southern Plains	Mountain States	Pacific States	National
Total Factor Productivity												
1950	105.79	104.51	97.35	96.66	111.16	98.62	97.95	92.45	76.82	100.10	100.34	97.76
1955	118.36	110.60	102.08	107.30	104.83	110.70	134.88	128.18	84.55	113.94	111.79	109.51
1960	119.16	119.71	110.01	113.16	134.31	122.91	142.77	136.97	105.49	114.74	114.70	120.63
1965	136.19	133.70	118.14	119.99	136.62	133.06	173.48	172.68	106.20	123.04	127.15	131.02
1970	149.22	138.78	113.10	131.51	146.80	148.87	183.42	193.41	108.55	133.84	134.51	138.91
1975	153.95	146.78	128.19	135.23	157.05	172.87	235.14	227.37	133.24	147.15	156.70	155.45
1980	137.76	142.51	132.21	148.34	151.99	158.94	218.50	204.94	119.08	145.76	160.37	153.65
1985	139.80	175.83	155.75	166.03	197.84	183.21	235.60	257.79	138.66	152.47	175.56	179.33
Average annual rates of growth (percentages)												
1949-55	2.85	1.69	0.34	1.18	0.79	1.71	5.11	4.22	-2.76	2.20	1.88	1.79
1955-60	0.14	1.60	1.51	1.07	5.08	2.11	1.14	1.33	4.52	0.14	0.51	1.95
1960-65	2.71	2.23	1.44	1.18	0.34	1.60	3.97	4.74	0.13	1.41	2.08	1.67
1965-70	1.85	0.75	-0.87	1.85	1.45	2.27	1.12	2.29	0.44	1.70	1.13	1.00
1970-75	0.63	1.13	2.54	0.56	1.36	3.03	5.09	3.29	4.18	1.91	3.10	2.46
1975-80	-2.20	-0.59	0.62	1.87	-0.65	-1.67	-1.46	-2.06	-2.22	-0.19	0.46	-0.23
1980-85	0.29	4.29	3.33	2.28	5.41	2.88	1.52	4.70	3.09	0.91	1.83	3.14
1949-85	*0.91*	*1.54*	*1.20*	*1.38*	*1.86*	*1.65*	*2.34*	*2.59*	*0.89*	*1.15*	*1.53*	*1.59*

Note: See table 1 notes.

Table 8: *Comparison of 1982 State-Level TFP Indices (1949=100)*

Region/State	Huffman & Evenson	Pardey, Craig, & Deininger	$(TFP_{82}-TFP_{49})^{HE}/(TFP_{82}-TFP_{49})^{PCD}$
Northeast 1	%	%	
Connecticut		124.27	
Maine		190.96	
Massachusetts		112.06	
New Hampshire		140.00	
Rhode Island		180.51	
Vermont		126.90	
Northeast 2			
Delaware	227.5	217.10	1.05
Maryland	181.7	166.69	1.09
New Jersey	136.6	97.12	1.41
New York	133.6	142.08	0.94
Pennsylvania	202.9	162.00	1.25
Corn Belt			
Illinois	165.9	146.05	1.14
Indiana	187.2	149.87	1.25
Iowa	148.9	138.35	1.08
Missouri	184.4	137.73	1.34
Ohio	182.3	142.45	1.28
Lake States			
Michigan	220.3	166.41	1.32
Minnesota	194.0	167.72	1.16
Wisconsin	164.8	140.93	1.17
Northern Plains			
Kansas	212.3	175.43	1.21
Nebraska	202.2	183.56	1.10
North Dakota	237.9	181.67	1.31
South Dakota	187.4	182.36	1.03
Appalachian			
Kentucky	224.5	169.42	1.33
North Carolina	263.2	220.45	1.19
Tennessee	208.3	187.98	1.11
Virginia	186.3	147.39	1.26
West Virginia	186.3	140.11	1.33
Southeast			
Alabama	288.6	271.73	1.06
Florida	127.5	176.44	0.72
Georgia	277.3	294.75	0.94
South Carolina	249.3	226.58	1.10

Table 8: *Comparison of 1982 State-Level TFP Indices (1949=100)*

Region/State	Huffman & Evenson	Pardey, Craig, & Deininger	$(TFP_{82}-TFP_{49})^{HE}/(TFP_{82}-TFP_{49})^{PCD}$
Delta			
Arkansas	284.0	255.32	1.11
Louisiana	217.5	212.56	1.02
Mississippi	340.1	318.14	1.07
Southern Plains			
Oklahoma	207.8	160.19	1.30
Texas	158.3	132.60	1.19
Mountain			
Arizona	100.7	132.78	0.76
Colorado	162.9	130.25	1.25
Idaho	162.9	183.51	0.89
Montana	173.0	172.62	1.00
Nevada	101.2	135.23	0.75
New Mexico	141.9	133.58	1.06
Utah	115.4	147.28	0.78
Wyoming	130.3	127.99	1.02
Pacific			
California	186.2	170.85	1.09
Oregon	199.5	153.14	1.30
Washington	231.8	138.48	1.67

MEASURING AGRICULTURAL PRODUCTIVITY IN U.S. AGRICULTURE

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1. Introduction

The U.S. Department of Agriculture (USDA) has long been concerned with sectoral productivity growth. The content of the USDA's *Production and Efficiency Statistics* can be traced to the pioneering work of Glen Barton. His paper with Martin Cooper was one of the first to publish multifactor productivity indexes for U.S. agriculture (Barton and Cooper [1948]).

An early innovator, the USDA was for more than two decades the sole government agency to regularly compile and publish multifactor productivity indexes. Other agencies, in particular the Department of Labor, have continued to emphasize the much less useful, and theoretically less palatable, partial factor productivity indexes. For its innovativeness, the USDA is to be commended.

Although innovative in many ways, the USDA has been resistant to change in others. Soon after the USDA began publishing productivity indexes, Griliches (1960) challenged the quality of some of the data and a number of procedures used by the USDA to measure agricultural productivity. Since that time, others have criticized specific aspects of the productivity series and its statistical underpinnings (e.g., Christensen [1975]; Brown [1978]; Ball [1984, 1985]; Shumway [1988]). Few of the suggested changes have been implemented.

The purpose of this paper is to address concerns regarding the USDA productivity series. In doing so, we will draw on the report of the American Agricultural Economics Association (AAEA) task force on productivity measurement which synthesized needed improvements perceived by Griliches and others (USDA [1980]).

2. The Divisia Index of Productivity

Suppose that at each point in time t we have a production function $f(x_1, \cdots x_n, t)$ showing the quantity of output obtainable from inputs $x_1, \cdots, x_n$. Total differentiation of

(1) $$y(t) = f(x_1(t), \cdots, x_n(t), t)$$

with respect to time yields.

(2) $$\frac{dy(t)}{dt} = \sum_{j=1}^{n} \frac{\partial f}{\partial x_j} \frac{dx_j}{dt} + \frac{\partial f}{\partial t}$$

Dividing both sides by y and rearranging terms, we obtain

(3) $$\frac{\partial \ln f}{\partial t} = \frac{d \ln y}{dt} - \sum_{j=1}^{n} \epsilon_j \frac{d \ln x_j}{dt}.$$

If we assume profit maximization, the output elasticities ϵ_j equal input shares in total revenue, and (3) becomes

$$(4) \qquad \dot{T} = \frac{\partial \ln f}{\partial t} - \sum_{j=1}^{n} \frac{w_j x_j}{Py} \frac{d \ln x_j}{dt} .$$

Equation (4) measures productivity growth by subtracting from the rate of change in output a weighted sum of the rates of change in inputs. If all prices and quantities are observed, $\dot{T}$ can be calculated without estimation of the production function. However, this result only applies exactly to data generated continuously. And since economic data come in discreet observations, (4) can only be approximated. A common approximation is

$$(5) \qquad \hat{T} = \ln y_t - \ln y_{t-1} - \frac{1}{2}\sum_{j=1}^{n} (S_{j,t} + S_{j,t-1})(\ln x_{j,t} - \ln x_{j,t-1}) ,$$

where $S_{j,t}$ is the ratio of the cost of input j to the revenue at time t. As the time interval approaches zero, (5) approaches (4).

The second term on the right-hand side of (4) is the familiar Divisia input index, whereas the second term on the right-hand side of (5) is the Tornqvist approximation to the Divisia index. This observation suggests immediately a reasonable approach when there are many outputs. Let R_{it} be the ratio of the revenue associated with output i to the total revenue at time t. Then the Tornqvist approximation to the Divisia output index is

$$(6) \qquad \hat{y} = \frac{1}{2}\sum_{i=1}^{m} (R_{i,t} + R_{i,t-1}) \; (\ln y_{it} - \ln y_{i,t-1}) .$$

The productivity index presented here is constructed as the ratio of the Tornqvist index of aggregate output to the Tornqvist index of aggregate input.

3. Labor Input

Prior to 1985, the USDA data on hours worked were not derived from surveys of actual hours of labor committed to agricultural production. Rather, the labor input was calculated on a "requirements" basis using estimated quantities of labor required to perform various production activities. Beginning in 1985, estimates of hours worked were survey based.

It is important not only to to have an accurate count of hours worked, but also to consider the attributes of individual workers. Griliches (1960) argued that the labor input had been underestimated because of changing level of formal eduation in the farm labor force. The AAEA task force concurred and suggested that labor quality has also been affected by changes in such characteristics as age, sex and employment status--employee and self-employed. None of these factors are considered in the USDA labor series.

Griliches (1960) attempted an early adjustment of the labor series based on sex and years of schooling. Gollop and Jorgenson (1980) undertook a much more involved analysis of labor quality in many sectors, including agriculture, covering the period 1947-73. In a recent working paper, Jorgenson extended this series to 1985. The series reflects changes over time in demographic charcteristics and employment status.

For each of 37 sectors of the economy, they tabulated data on wages and quantities of labor input cross-classified by the two sexes, eight age groups and five educational groups for both hired and self-employed and unpaid family workers. Annual data on hours worked and average labor compensation per hour are required for 160 components of the work force in each industry. For this purpose employment, hours, weeks, and labor compensation within each sector are allocated on the basis of available cross-classifications. This approach makes it possible to exploit all the published detail on labor input from the decennial Census of Population and the Current Population Survey.

The value of labor compensation is equal to wages paid plus the imputed wage to self-employed and unpaid family labor. We impute to this class of workers the mean wage of workers with same demographic characteristics.

4. Capital Input

Our first task is to construct estimates of capital stock for each asset type. We employ the perpetual inventory method to estimate the stock of depreciable capital assets. The stock of capital assets is equal to a weighted sum of past investments where the weights are the sequence of relative efficiencies of assets of different ages. For land and inventories, the estimates are implicit quantities constructed from balance-sheet data.

Next we construct estimates of rental prices for each type of asset. We derive implicit rental prices based on an assumed relationship between the purchase price of an asset and the discounted value of future service flows derived from that asset.

For this study, depreciable capital assets include nonresidential structures, motor vehicles, farm tractors, and other equipment. Data on investment are obtained from the Bureau of Economic Analysis' (BEA) *Fixed Reproducible Tangible Wealth in the United*

States. The Bureau of Labor Statistics (BLS) producer price indexes for passenger autos, motor trucks, wheel-type farm tractors and agricultural machinery excluding tractors are employed as investment deflators. This is because BLS collects price information for machines of constant quality rather than pricing machines with options farmers typically purchase, as is the USDA practice. For nonresidential structures, we use the implicit price deflator for nonresidential structures in the National Income And Product Accounts.

4.1 Capital Stock

The perpetual inventory method is employed to cumulate annual investment into a measure of capital stock. In this method, the sequence of relative efficiencies of capital goods of different ages enables us to represent the capital stock at the end of each period, say K_t, as a weighted sum of past investments:

$$K_t = \sum_{\tau=0}^{\infty} S(\tau) I_{t-\tau}, \tag{7}$$

where $I_{t-\tau}$ is investment in period $t-\tau$ and the weights are given by the sequence of relative efficiencies.

Capital goods decline in efficiency at each point in time, generating the need for replacement of productive capacity. The proportion of investment to be replaced at age τ, say m_τ, is equal to the decline in efficiecny from age $\tau-1$ to age τ:

$$m_\tau = -(s_\tau - s_{\tau-1}), \quad \tau = 1, \dots, T. \tag{8}$$

These proportions are mortality rates for capital goods of different ages.

Replacement in period t corresponding to the mortality distribution m_τ is given by:

(9)
$$R_t = \sum_{\tau=1}^{\infty} m_\tau \, I_{t-\tau}$$

Efficiency loss is assumed to be a function of age. The sequence of relative efficiencies of capital assets of different ages is given by the hyperbolic fucntion:

(10)
$$S(\tau) = \frac{(L-\tau)}{(L-\beta\tau)}, \quad 0 \le \tau \le L$$
$$S(\tau) = 0, \quad \tau > L$$

where L is the service life of the asset and β is a curvature or decay parameter. The calculated value of this function gives the productive capacity of an asset τ years after the purchase date expressed as a proportion of the original invstment. Subtracting this value form unity yields the proportion of accumulated physical depreciation t years after the purcahse date.

This function incorporates many of the of the commonly used forms of depreciation as special cases. The upper limit on β is 1. This corresponds to the "one-hoss shay" form of depreciation where an asset is fully productive until it reaches the end of its service life, at which point it productivity falls to zero. As the value of β approaches zero, decay occurs at an increasing rate over time. If β is zero, the function corresponds to the formula for straight line depreciation where physical decay occurs in even increments over the life of the asset. Finally, if β is negative, decay occurs more rapidly in the early years of service corresponding to accelerated forms of depreciation such as the geometric or declining balance patterns.

Problems arise as to the value that should be chosen for β in order to accurately reflect efficiency loss. Little empirical evidence is available to suggest a precise value. Much of the justification for assuming an accelerated form of depreciation is based on studies which detail the resale of used assets in secondary markets. Typically, these studies find that the value of an asset does decline most rapidly in the early years of service. However, these studies fail to distinguish between physical depreciation and the decline in the value of an asset. To illustrate this point, consider the example of a light bulb. If we expect no decline in output (illumination) over a given period, say 1000 hours, the relative efficiency follows a one-hoss shay pattern. Yet the value, assuming a zero rate of discount, is proportional to the hours in service. That is, after 100 hours in service, the replacement value of the light bulb is nine-tenths of its original value. Therefore, if we look at economic depreciation, the maximum value of β is zero. If there is a positive discount rate and future capital services are discounted to the present, we find that the value of the asset declines exponentially. Thus, the empirical evidence does support the theory that the value of an asset declines at an accelerated rate.

However, there is no justification for extending this argument to conclude that efficiency also declines at an accelerated rate. On the contrary, there are both technological and economic arguments that support the theory that efficiency decay occurs more rapidly in the later years of service. If one observes a capital asset in use it appears that efficiency is uniformly high in the early years of service. Only after some time does the asset begin to deteriorate. Expenditures for repairs and maintenance are required to maintain efficiency. As the asset ages, greater efficiency loss occurs and required expenditures for repairs and maintenance reach such a level that many are foregone, and the efficiency of the asset declines to the point where the asset is scrapped or sold.

In this study, repairs and maintenance expenditures are defined to be of a minor or nature. They do not include major repairs which both increase the efficiency of an asset and extend the useful life. This is consistent with the accounting practice of treating minor repairs as current expense and major repairs as as capital expenditures.

Two studies provide evidence that firms attempt to maintain efficiency until such time as technological obsolescence or efficiency decay warrent a decision to scrape the asset. At that point, the asset is allowed to decay with little effort to maintain efficiency. Utilizing data on. Utilizing data on expenditures for repairs and maintenance of 745 farm tractors covering the period 1958-74, Penson, Hughes and Nelson (1977) found that the loss of efficiency was very small in the early years and increased rapidly as the end of the asset's service life approached.

More recently, Romain, Penson and Lambert (1987) compared the explanatory power of alternative capacity depreciation patterns for farm tractors in a model of investment behavior that also included the price of capital services. They found that the concave depreciation pattern better reflects actual investment decisions.

Given the above discussion, it seems appropriate to restrict the value of β to lie between zero and one. It was assumed that the efficiency of structures declines slowly over most of their service life until the point is reached where the cost of major repairs exceeds the discounted value of the increased service flows derived form the reapirs. At this point, structures were assumed to deteriorate rapidly. In the case of machinery, the efficiency loss was assumed to occur over a larger proportion of the service life. The final values chosen for β were 0.50 for machinery and equipment and 0.75 for structures.

Each type of asset consists of a homogenous group of assets for which the service lives differ due to quality differences, maintenance schedules, etc. For each asset, there exists some mean service life $\bar{L}$ around which there exists some distribution of actual service lives. In order to determine the amount of capital available for production the actual service lives and their frequency of occurence must be determined. It was assumed that this distribution could accurately be depicted by the normal distribution.

One problem in using the normal distribution to calculate the frequence of occurence of each of the service lives is that the distribution extends infinitely in either direction from the mean. Without some adjustment, the distribution would yield cases where assets were discarded prior to the initial investment date or assets with unrealistically long service lives. To eliminate these extremes, the distribution was truncated at a point two standard deviations before and after the mean. Two standard deviations correspond to 0.98 times the assumed mean service life. This dispersion parameter was chosen to conform to the observation that assets are occasionally found that are considerable older than the mean service life and that a few assets are accidently damaged when new. The area under the truncated normal curve was then adjusted upward within the allowed range of asset lives. Asset service lives correspond to 85 percent of *Bulletin F* lives.

Once the frequence of occurence of a particular service life was determined, the efficiency function for that service life was calculated using the assumed value of β. This process was repeated for all possible service lives. An efficiency function for the investment cohort was then constructed as a weighted sum of the individual efficiency functions using as weights the frequency of occurence. This function not only reflects changes in efficiency, but also the discard distribution around the mean service life of the asset.

We construct the stock of land in farms as an implicit quantity index using as prices land values (excluding buildings) per acre. In an effort to obtain a constant quality land series, we compiled data on land area and land values for each Crop Reporting District in each state. Acres of cropland, pasture and other land were handled separately in the 17 Western States, as was irrigated/nonirrigated land. The acreage of the components is reported in the Census of Agriculture; USDA compiles annual estimates of total land in farms. The distribution of land in each use category was interpolated between the censuses.

The stock of producer-owned inventories is constructed in a similar manner. The number and average value of animals on farms at the beginning of the year are available from annual surveys. Data on stocks of grains and oilseeds are also available. However, no distinction is made between producer-owned and commercially held stocks. We estimated producer-owned stocks at yearend 1978 as the quantities stored on the farm plus producer-owned stocks stored off the farm; quantities of commodities used as collateral for outstanding Commodity Credit Corporation loans were subtracted. Stocks were then moved forward to 1989 by adding, and back to 1960 by subtracting, the estimated annual changes in stocks. Yearend stocks were valued at the average price received by farmers during the month of December.

4.2 Retail Prices of Capital Services.

We assume that firms will add to the capital stock so long as the present value of the net revenue generated by an additional unit of capital exceeds the purchase price of the asset. This can be stated algebraically as (Coen 1975):

$$\sum_{t=1}^{\infty} \left(P\frac{\partial Y}{\partial K} - q\frac{\partial R_t}{\partial K} \right) (1+r)^{-t} > q, \tag{11}$$

where P is the price of output, Y is the real output, q is the price of an additional unit of capital and r is the real discount rate.

To maximize net present value, firms should add to the capital stock until this equation holds as an equality. This requires that

$$\begin{aligned} P\left(\frac{\partial Y}{\partial K}\right) &= r\sum_{t=1}^{\infty} q\left(\frac{\partial R_t}{\partial K}\right) (1+r)^{-t} + rq \\ &= c, \end{aligned} \tag{12}$$

The expression for c is the implicit rental price of capital for a particular mortality distribution m. The rental price consists of two components. The first term, qr, represents the opportunity cost of invested funds. The second term,

$$r\sum_{t=1}^{\infty} q\left(\frac{\partial R_t}{\partial K}\right) (1+r)^{-t}, \tag{13}$$

is the discounted value of all future replacement required to maintain the productive capacity of the capital stock.

Following Coen (1975), we define F as the present value of the stream of capacity depreciation on one unit of capital according to the mortality distribution m; that is:

(14) $$F = \sum_{t=1}^{\infty} m_t (1+r)^{-t}.$$

Since replacement at time t is equal to capacity depreciation at time t:

(15) $$\sum_{t=1}^{\infty} \left(\frac{\partial R_t}{\partial K}\right) (1+r)^{-t} = \sum_{t=1}^{\infty} = \frac{F}{(1-F)}$$

and

(16) $$c = \frac{qr}{(1-F)}.$$

The real rate of return r in the above expression was calculated as the nominal yield on corporate bonds less the rate of inflation as measured by the producer price index for gross domestic product. An *ex ante* rate was obtained by expressing observed real rates as an ARIMA process. We then calculated F keeping this *ex ante* real rate constant for each vintage of capital goods.

5.1 Output

The data on crop output consist of quantities sold (including unredeemed Commodity Credit Corporation loans) plus additions to farmer-owned inventories and the quantity consumed in farm households during the calendar year. The USDA collects annual data on quantities of crops sold. However, the accounting period often differs from the calendar year. When this occurs, we use data on the monthly distribution of sales to distribute quantities sold during the crop year to the calendar year. In the case of livestock, the measure is the estimated weight gained on farms and in feedlots.

The value of farm output reflects the value to the producing sector; that is, subsidies are added and indirect taxes are subtracted form the market value. Prices received by farmers, as reported in USDA's *Agricultural Prices*, include an allowance for net Commodity Credit Corporation loans and purchases by the Government valued at the average loan rate. However, direct payments under Federal commodity programs are not reflected in the data. Average prices for wool, mohair, and program crops are constructed as ratios of cash receipts plus subsidies to quantities sold; dairy assessments are subtracted from receipts. We then calculate the value of output by multiplying adjusted prices by the output quantities.

5.2 Intermediate Inputs

Intermediate inputs comprise all goods (other than fixed capital) and services consumed by the sector. Goods which were produced within the sector are recorded as intermediate input only if they have also been recorded as output. Feed crops produced and consumed on the farm are excluded from both output and intermediate input. In the case of livestock, only the costs incurred in the transaction are recorded as intermediate input. This accounting procedure is designed to prevent the full value of a live animal being included as both output and intermediate input every time it moves from one farm to another.

5.2.1 Feed, Seed, and Livestock

Expenditure data for livestock feeds are available from the Census of Agriculture and annual surveys. In an effort to measure the nonfarm value added, the USDA uses Census of Manufacturing data to estimate the margin between the farm value of feed crops and the value of manufactured feeds. The margin is intended to capture the value of salt, minerals, and other additives, as well as processing and transportation services added in the nonfarm sector. An estimate of the nonfarm value added in constant prices is obtained by dividing by the prices paid index for livestock feeds. The farm value of purchased livestock feeds is subtracted from the measure of sectoral output.

For seeds, the nonfarm valued added is based on the difference between prices paid for seed and prices received for crops, while the nonfarm valued added in livestock purchases is the difference between purchases from hatcheries and receipts for hatching eggs.

The AAEA task force rejected the value added measure advancing arguments similar to those outlined above. Instead, the AAEA recommended that feed crops consumed on the farm, as well as purchased livestock feeds, be included in the measure of intermediate input. Gross production of feed crops would be included in output from the sector. An objection is that this approach counts feed crops twice--once as crop production and again as embodied in livestock output.

The approach adopted here is to include the full value of purchased feed and seed. We construct Tornqvist price indexes as deflators. Livestock purchases consist of imports of live animals.

5.2.2 Agricultural Chemicals

For fertilizer and lime, the basic data are annual estimates of the tonnage consumed of nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O) as reported in *Commercial Fertilizer Consumption*. Consumption of lime was obtained from the National Lime Institute. To aggregate the plant nutrients, we use estimates of the prices of plant nutrients consumed in the form of bulk materials (fertilizer materials that contain a high concentration of a single plant nutrient). Several nitrogenous materials are available. A weighted average price for a ton of nitrogen is constructed using as weights the quantities of nitrogen supplied by each material. Prices for the two remaining plant nutrients are derived from the prices for concentrated super phosphates (46 percent P_2O_5) and muriate of potash (60 percent K_2O). The measure of pesticides is based upon current expenditures as estimated by the USDA. Estimated expenditures are deflated by a Tornqvist price index constructed from data provided by the U.S. Environmental Protection Agency.

5.2.3 Petroleum Fuels, Natural Gas, and Electricity

Data on fuel consumption in agriculture by type of fuel and agricultural sector are taken from the *National Energy Accounts: Energy Flows in the United States* compiled by the Office of Business Analysis, U.S. Department of Commerce. Data are reported for the years 1947, 1954, and 1958-85. For succeeding years, we estimate fuel consumption based on expenditure and price data taken from annual issues of *Farm Production Expenditures* and *Agricultural Prices*, respectively. For the intervening years, fuel consumption is estimated as the sum of fitted values for consumption in both crop and livestock sectors. Consumption of natural gas and liquified petroleum gas was a function of specific production activities, including grain drying, irrigation, and livestock brooding. Consumption of gasoline and diesel fuel was regressed on stocks of gasoline and diesel tractors, stocks of gasoline and diesel self-propelled harvesting equipment, and time.

We estimate electricity consumption by dividing expenditures for electricity by the average price per kilowatt hour provided by the Rural Electrification Administration.

5.2.4 Other Purchased Inputs

There remains several purchased inputs that account for a relatively small share in total intermediate input expense. Included are expenditures for contract labor, purchased machine services, machine and building repairs and maintenance, transportation services, irrigation fees paid to public sellers of water, and purchases of farm supplies such as small hand tools, baling twine, etc. The deflator for contract labor expenditures is the piece rate reported by the USDA. For purchased machine services, we construct a Tornqvist price index of rental rates for durable equipment, petroleum fuels, and the wage paid to hired farm workers. Expenditures for transportation services are deflated using the implicit price deflator for the trucking and wharehousing industry (SIC 42). The Consumer Price Index (CPI) for automobile repairs is used to obtain the series on machinery repairs in constant prices; the CPI for building repairs and maintenance is used to measure expenditures for building repairs and maintenance in constant prices. The index of operating and maintenance costs computed by Bureau of Reclamation is used to deflate irrigation expense. Finally, expenditures for farm supplies are deflated by the Consumer Price Index for hardware items.

6. Total Factor Productivity

Using equations (5) and (6), we compute indexes of total output, total factor input and productivity for U.S. agriculture and for selected states. The indexes are reported for the period 1900-89 along with average rates of growth for the 1960-89 period and intermediate periods. These correspond to peaks in business cycles.

Looking first at the results at the national level, we see that total output from the sector grew at a 2 percent annual rate. All of the increase in output was accounted for by increases in productivity. Total factor input actually declined modestly over the 1960-89 period.

Two intermediate periods are of particular interest. The first period is that spanning the years 1973-79. Total output grew at an annual rate of 2.4 percent. Growth in input use accounted for most of the growth in output with productivity growth stagnant. This period is bracketed by the two oil embargoes which resulted in dramatic increases in energy prices and prices of other purchased inputs.

The second is the period 1979-89. Growth in total output slowed during this period. however, this relatively modest rate of growth in output was sustained while total input use actually declined at a 1.5 percent annual rate. Growth in total factor productivity was almost 3 percent per annum.

A comparison with the nonfarm sector, done by Jorgenson, Gollop and Fraumeni (1987), found only the communications industry achieved greater rates of productivity growth than agriculture.

Also presented are results for selected states. The regional disparities in growth of the agricultural sector is striking. For the five states where data are complete, the annual growth rates ranged from a low of 1.8 percent in Illinois to 3.35 percent in Colorado. Productivity growth, while clearly cyclical, exceeded the annual rate for the U.S. in each of the five states. With the exception of California, productivity growth rates exceeded 2 percent annually. Productivity increases exceeded 4 percent annually in Nebraska.

Summary and Conclusion

Measures of total output, total factor input and productivity are constructed for the United States and selected individual states for the period 1960-89. The rate of growth in total output exceeded 2 percent per annum. All of the growth in output was accounted for by growth in productivity. The index of total input declined modestly.

Regional disparities in growth rates of total output were striking. These ranged from a low of 1.8 percent annually in Illinois to a high of 3.35 percent annually in Colorado. Differences in rates of growth of productivity were similarly striking. This underscores the need to develop regionally disaggregated production accounts.

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--------------------UNITED STATES-----------------

	QOUTPUT	QINPUT	TFP
1960	0.59838	0.91743	0.65223
1961	0.61179	0.90124	0.67883
1962	0.62094	0.90066	0.68943
1963	0.64825	0.90363	0.71738
1964	0.63802	0.89526	0.71267
1965	0.67367	0.89779	0.75037
1966	0.65597	0.88824	0.73851
1967	0.69793	0.90413	0.77194
1968	0.69468	0.92154	0.75383
1969	0.71871	0.93274	0.77054
1970	0.69950	0.93117	0.75121
1971	0.76536	0.93409	0.81937
1972	0.77302	0.92597	0.83482
1973	0.81525	0.92091	0.88527
1974	0.76921	0.96420	0.79778
1975	0.81909	0.96151	0.85188
1976	0.82270	0.98365	0.83637
1977	0.88219	0.96435	0.91481
1978	0.88083	1.03025	0.85497
1979	0.94273	1.05898	0.89022
1980	0.90618	1.06115	0.85397
1981	1.00893	1.03354	0.97619
1982	1.00000	1.00000	1.00000
1983	0.82755	0.97123	0.85207
1984	1.02008	0.99149	1.02884
1985	1.06551	0.94929	1.12244
1986	1.03115	0.92494	1.11483
1987	1.04219	0.90662	1.14953
1988	0.97351	0.89018	1.09361
1989	1.07608	0.91231	1.17951

RATES OF GROWTH

1960-66	.0153	-.0054	.0207
1966-69	.0304	.0163	.0142
1969-73	.0315	-.0044	.0347
1973-79	.0242	.0233	.0009
1979-89	.0132	-.0149	.0281
1960-89	.0202	-.0002	.0204

CALIFORNIA

	QOUTPUT	QINPUT	TFP
1960	0.53351	0.96233	0.55439
1961	0.52131	0.93959	0.55483
1962	0.53996	0.95316	0.56650
1963	0.56029	0.93063	0.60205
1964	0.58325	0.90351	0.64554
1965	0.55987	0.93819	0.59676
1966	0.59562	0.91556	0.65055
1967	0.54642	0.89241	0.61230
1968	0.60186	0.91278	0.65937
1969	0.63175	0.91380	0.69135
1970	0.64122	0.93349	0.68691
1971	0.66065	0.94037	0.70254
1972	0.67555	0.93524	0.72233
1973	0.72112	0.92856	0.77661
1974	0.72957	1.02176	0.71403
1975	0.76746	1.07397	0.71460
1976	0.80795	1.06571	0.75813
1977	0.81624	1.01349	0.80538
1978	0.80128	1.01909	0.78627
1979	0.87442	1.07977	0.80981
1980	0.95618	1.03207	0.92647
1981	0.96667	1.03540	0.93362
1982	1.00000	1.00000	1.00000
1983	0.92374	0.97577	0.94668
1984	1.01461	1.00288	1.01169
1985	1.02574	0.96782	1.05984
1986	1.03623	0.95792	1.08174
1987	1.13816	0.94115	1.20933
1988	1.14901	0.95068	1.20862
1989	1.09975	1.01433	1.08421

RATES OF GROWTH

	QOUTPUT	QINPUT	TFP
1960-66	.0183	-.0083	.0266
1966-69	.0196	-.0006	.0202
1969-73	.0331	.0040	.0289
1973-79	.0321	.0251	.0069
1979-89	.0249	.0018	.0231

COLORADO

	QOUTPUT	QINPUT	TFP
1960	0.43538	0.73468	0.59261
1961	0.44396	0.74488	0.59602
1962	0.43575	0.78280	0.55666
1963	0.43595	0.77135	0.56518
1964	0.47467	0.75202	0.63119
1965	0.56302	0.80853	0.69635
1966	0.56730	0.82761	0.68546
1967	0.59734	0.90591	0.65938
1968	0.69552	0.90545	0.76814
1969	0.68811	0.99762	0.68975
1970	0.67856	1.05497	0.64320
1971	0.66464	1.16533	0.57034
1972	0.76464	1.17988	0.64807
1973	0.86741	1.02032	0.85013
1974	0.83862	1.01184	0.82880
1975	0.81540	0.99728	0.81762
1976	0.74507	1.00486	0.74147
1977	0.88709	1.06412	0.83364
1978	0.99637	1.17633	0.84702
1979	0.91161	1.10555	0.82457
1980	1.09363	1.10602	0.98880
1981	1.01221	1.03045	0.98231
1982	1.00000	1.00000	1.00000
1983	1.03001	1.01172	1.01807
1984	1.08101	1.01511	1.06492
1985	1.08466	1.05072	1.03230
1986	1.08557	1.04754	1.03630
1987	1.21008	1.07613	1.12447
1988	1.06082	1.06014	1.00064
1989	1.15167	1.01985	1.12925

RATES OF GROWTH

	QOUTPUT	QINPUT	TFP
1960-66	.0441	.0198	.0242
1966-69	.0643	.0622	.0020
1969-73	.0578	.0056	.0522
1973-79	.0083	.0133	-.0051
1979-89	.0233	-.0081	.0314
1960-89	.0335	.0113	.0222

ILLINOIS

	QOUTPUT	QINPUT	TFP
1960	0.59971	1.04301	0.57498
1961	0.62364	0.99961	0.62389
1962	0.63358	1.04020	0.60909
1963	0.68306	1.03136	0.66229
1964	0.64068	1.02628	0.62428
1965	0.72899	1.02422	0.71175
1966	0.66853	1.05205	0.63546
1967	0.77589	1.05311	0.73676
1968	0.70580	1.04910	0.67277
1969	0.73601	1.03130	0.71367
1970	0.64498	0.99837	0.64603
1971	0.79648	0.98023	0.81254
1972	0.77995	0.97935	0.79640
1973	0.78698	0.98924	0.79554
1974	0.65373	1.01964	0.64114
1975	0.91530	1.05779	0.86530
1976	0.84698	1.14788	0.73787
1977	0.89250	1.13368	0.78726
1978	0.87808	1.10941	0.79149
1979	0.99408	1.13962	0.87229
1980	0.84040	1.12374	0.74785
1981	1.01504	1.06906	0.94947
1982	1.00000	1.00000	1.00000
1983	0.61021	0.97500	0.62586
1984	0.92521	0.98234	0.94185
1985	1.10660	0.96067	1.15190
1986	1.04012	1.02376	1.01598
1987	0.96675	0.92930	1.04031
1988	0.72376	0.90890	0.79630
1989	1.02054	0.90367	1.12933

RATES OF GROWTH

1960-66	.0181	.0014	.0167
1966-69	.0334	-.0066	.0387
1969-73	.0167	-.0104	.0271
1973-79	.0389	.0227	.0153
1979-89	.0026	-.0231	.0258
1960-89	.0183	-.0049	.0233

FLORIDA

	QOUTPUT	QINPUT	TFP
1960	0.42157	0.72118	0.58455
1961	0.39571	0.71303	0.55497
1962	0.41018	0.72968	0.56213
1963	0.40636	0.73724	0.55120
1964	0.41812	0.75772	0.55181
1965	0.43049	0.78934	0.54537
1966	0.43883	0.81049	0.54143
1967	0.49171	0.88023	0.55862
1968	0.45865	0.87236	0.52575
1969	0.47481	0.88956	0.53376
1970	0.49601	0.94090	0.52717
1971	0.49869	0.93251	0.53478
1972	0.52093	0.90311	0.57681
1973	0.59966	0.90121	0.66539
1974	0.72198	0.78526	0.91942
1975	0.73194	0.82681	0.88526
1976	0.74647	0.86694	0.86105
1977	0.73931	0.87031	0.84948
1978	0.73503	0.97755	0.75191
1979	0.73430	1.04801	0.70066
1980	1.07655	1.01617	1.05941
1981	0.98333	0.98728	0.99600
1982	1.00000	1.00000	1.00000
1983	1.00561	0.98124	1.02483
1984	1.00916	1.03754	0.97264
1985	0.97656	0.93399	1.04558
1986	0.98306	0.92549	1.06221
1987	1.05516	0.95489	1.10500
1988	1.03983	0.91437	1.13721
1989	1.15731	0.91406	1.26612

RATES OF GROWTH

	QOUTPUT	QINPUT	TFP
1960-66	.0067	.0194	-.0128
1966-69	.0263	.0310	-.0047
1969-73	.0584	.0032	.0551
1973-79	.0338	.0251	.0086
1979-89	.0454	-.0136	.0591
1960-89	.0348	.0081	.0266

NEBRASKA

	QOUTPUT	QINPUT	TFP
1960	0.52517	1.42671	0.36810
1961	0.47802	1.37711	0.34712
1962	0.50448	1.37265	0.36752
1963	0.50135	1.27709	0.39257
1964	0.49559	1.23115	0.40254
1965	0.50916	1.23046	0.41380
1966	0.61110	1.17668	0.51934
1967	0.59467	1.12935	0.52656
1968	0.57676	1.10348	0.52268
1969	0.66700	1.09163	0.61101
1970	0.63632	1.08410	0.58696
1971	0.71869	1.09497	0.65636
1972	0.75240	1.14570	0.65672
1973	0.75670	1.16357	0.65033
1974	0.65542	1.30778	0.50117
1975	0.76680	1.30670	0.58682
1976	0.78110	1.32878	0.58783
1977	0.89656	1.13385	0.79073
1978	0.86942	1.21202	0.71733
1979	0.96192	1.15257	0.83459
1980	0.86738	1.17119	0.74059
1981	1.05001	1.09252	0.96109
1982	1.00000	1.00000	1.00000
1983	0.79722	0.91744	0.86896
1984	1.04395	1.07430	0.97175
1985	1.20626	1.12087	1.07619
1986	1.15701	0.99052	1.16808
1987	1.13508	0.95626	1.18700
1988	1.13734	0.94770	1.20010
1989	1.17924	0.96232	1.22541

RATES OF GROWTH

1960-66	.0252	-.0321	.0573
1966-69	.0291	-.0250	.0541
1969-73	.0315	.0159	.0156
1973-79	.0399	-.0016	.0416
1979-89	.0204	-.0180	.0384
1960-89	.0279	-.0135	.0414