FINANCING AGRICULTURAL RESEARCH IN A FEDERAL SYSTEM OF GOVERNMENT: OPTIMAL COST-SHARING FOR STATE AND NATIONAL INVESTMENTS

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ABSTRACT

FINANCING AGRICULTURAL RESEARCH IN A FEDERAL SYSTEM OF GOVERNMENT: OPTIMAL COST-SHARING FOR STATE AND NATIONAL INVESTMENTS

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David Brian Schweikhardt

This dissertation examines the federal-state cost-sharing arrangements necessary to provide a nationally optimal level of state agricultural research investment. Agricultural research is a good that provides benefits that spill across state boundaries. Unless the states are provided compensation for the research benefits they create, research investment may be sub-optimal from a national perspective.

Public finance theory indicates that an open-ended matching grant (i.e., the grantor matches each dollar spent by the recipient on the spillover-generating good with a fixed number of grantor dollars) is the least-cost method of financing public goods that create benefit spillovers (such as agricultural research). Each state will provide a nationally optimal level of agricultural research when the federal matching rate is established at a level that (a) equates the share of the marginal benefit of research retained by each state with that state's share of the marginal cost of research and (b) equates the share of the marginal benefit of research that accrues outside the state with the federal government's share of the marginal cost of research.

David Brian Schweikhardt

To estimate the optimal matching rates for financing agricultural research in the United States, Cobb-Douglas production functions were fitted to state-level cross-section data for the years 1964, 1969, 1974, 1978, and 1982. Conventional inputs, research investment in the state and other relevant states, state extension investment, and weather were included as the independent variables. Six spillover patterns were used to examine the sensitivity of the estimated matching rates to the assumed spillover pattern. The marginal benefit of research that accrued inside and outside each state was then estimated, and the optimal matching rates for financing agricultural research in each state were then calculated.

The average estimated optimal federal matching rates ranged from 0.40 to 1.54 federal dollars per state dollar. These results suggest that the 1.00 matching rate used to allocate Hatch Act funds may be appropriate, but that the closed-ended nature of the Hatch system could be preventing the states from providing a nationally optimal level of research. Since the matching rates of individual states appear sensitive to the spillover specification, future work should focus on improved specification of spillover patterns.

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Jim Bonnen served as my major professor during both my M.S. and Ph.D. programs. He suggested the research topic, provided encouragement, and dealt with all the problems that arose. No one could ask for more from a major professor. I have said it elsewhere, but it bears repeating that any student who has worked with Dr. Bonnen knows that the following quote, written about a nineteenth century agricultural educator, describes precisely his contribution to his students' work:

> His patience in listening to our crude papers and in flooding with light our ignorant discussions was heroic, not to say fairly sublime; while his delicacy and tact in concealing our imperfections from ourselves and stimulating us to higher attainments were as beautiful as they were helpful (Woodward and Waller, p. 17).

Warren Samuels, Stan Thompson, and Al Schmid made numerous comments that improved the final product. Their insistence on recognizing the limitations of the analysis resulted in a more complete, coherent, and accurate product.

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Knudson--thanks for everything. Mary Procopio deserves special thanks; never a friend in need, you were always a friend indeed.

Finally, thanks must go to my parents, Richard and Emma Schweikhardt, who sent three sons away to college and got back one veterinarian and two economists. Liberty Hyde Bailey knew them well:

> I think of the father and mother, what it means to them to have sent those boys...away to school. It had not been simple or easy.... I have known them to work for years to the one end, unfalteringly and tirelessly (Dorf, p. 142).

As did Alfred Marshall:

> The heroic sacrifices which some middle-class parents make for the sake of their children's education are instances of the latent romance of modern life (Marshall, volume 2, p. 311).

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INTRODUCTION

> "I am convinced that the plan which we are now discussing, namely, that of joint Federal and State support, is far ahead of any other known system in its possibilities of providing for stable support and proper local appreciation of, and interest in, agricultural research."
>
> R.W. Thatcher, Former Director, Minnesota Agricultural Experiment Station (p. 105)

> "There is and can be no final solution to the allocation of financial resources in a federal system. There can only be adjustments and reallocations in the light of changing conditions. What a federal government needs, therefore, is machinery adequate to make these adjustments."
>
> Kenneth C. Wheare, Political Scientist (quoted in Oates, p. 145)

Problem Setting

The U.S. agricultural research system is a continually-evolving partnership between the federal government and the states. Over the past century, this evolution has been an ongoing search for balance between the needs expressed in the quotes that preface this chapter. On the one hand, policymakers have sought to maintain a stable federal-state relationship in support of agricultural research. On the other, they have occasionally sought to make adjustments in resource allocations as changing conditions arose.

The U.S. may be approaching the next stage in the evolution of this partnership. Change may be imminent because the existing system suffers from political tensions that exist both within the system and between the system and the larger scientific community.

These tensions involve at least four issues that raise fundamental questions about the responsibilities of the federal government and the states in financing agricultural research. First, some within the system view the Hatch Act formula, which allocates federal agricultural research funds to the states based on their farm and rural populations, as outdated or biased against those states with a predominance of large farms (Hodgson; U.S. Congress, 1986, p. 200).

Second, internal tension has arisen because the federal government has failed to maintain its share of the real resources committed to agricultural research. The federal share of the agricultural research funds spent at the state agricultural experiment stations declined from 38% in 1966 to 29% in 1987, leaving an increasing share of the burden of U.S. agricultural research funding on the states (U.S. Office of Technology Assessment, p. 206, U.S. Department of Agriculture, 1988, p. 117). As a result, the federal-state partnership that has governed agricultural research for the past century is suffering an erosion of commitment that threatens its capacity to respond to research problems in a coherent manner (Bonnen, 1986, p. 1060).

A third source of tension arises from the ongoing debate over the use of formula funds and competitive grants in financing agricultural research. Advocates of competitive grants insist that such a system ensures scientific quality and permits greater flexibility in allocating research resources. Proponents of formula funding contend that a formula system provides a stable system of funding and permits long-term planning of research (Eliot Marshall, 1979a; Strobel; Johnson and Wittwer, pp. 8-9; Ruttan, 1982a, pp. 215-236). This debate, conducted both within the agricultural research system and between the system and its critics in the larger scientific community, has thus far been conducted without reference to the economic rationale for either method of financing research.

Finally, the system has long been believed to suffer from a persistent problem of underinvestment. The high rates of return on public agricultural research investments, estimated to range from 30 to 70 percent annually, have led economists to suggest that the United States persistently underinvests in public agricultural research (Ruttan, 1982a, pp. 237-59). The most commonly accepted explanation of this problem is that the existence of research benefits that spill across state lines inhibits individual states from providing a nationally optimal level of investment in agricultural research. The existence of spillovers indicates that individual states may underinvest in agricultural research because they cannot capture the full benefits of their investment in research

(Ruttan, 1982a, p. 254-58; Latimer and Paarlberg; Bredahl and Peterson; Evenson, et al., 1979; Ziemer, et al.; Havlicek and White, 1983a; Lyu and White; Garren and White). The persistence of the underinvestment problem suggests that the present Hatch Act formula provides inadequate compensation to the states for the research benefit spillovers they create.

Given the tensions that are currently impacting the system, economists, research administrators, and legislators have questioned whether the existing Hatch Act system is the appropriate mechanism for financing agricultural research (Ruttan, 1982a, p. 256; Havlicek and White, 1983a; Hodgson; U.S. Congress, 1984, p. 215; U.S. Congress, 1986, p. 200). The existing system of subsidies, provided as Hatch Act funds, distributes federal agricultural research funds to the states by using a formula based on each state's share of the national farm and rural population. The Hatch provisions also require that states match federal Hatch funds on a one-to-one basis with state funds.

If the present system is inadequate, how should the federal-state agricultural research partnership be redefined? What system of state and federal financing would yield a more optimal level of investment in agricultural research? Within this system, what should be the relative responsibilities of the federal government and the states in financing agricultural research? Similarly, under what conditions are formula funding and competitive grants the appropriate policy tools for financing agricultural research?

This research examines these questions within a theoretical framework that, while clearly relevant to the issues at hand, has not yet been applied adequately by economists to the problems associated with public financing of agricultural research. Adopted from a branch of public finance literature, this framework addresses the problem of financing public goods in a federal (i.e., multi-level) system of government. In particular, this framework--known in the public finance literature as the theory of intergovernmental grants--is intended to identify the conditions under which two levels of government can design an optimal cost-sharing arrangement for financing public goods that create benefits for persons outside the jurisdictional boundaries of the lower level of government. As such, it is particularly relevant to the policy issues facing the agricultural research system.

By providing intergovernmental grants to the states, the federal government can compensate the states for the benefit spillovers they create and promote a more efficient allocation of resources to agricultural research. To do so, however, the subsidies provided by the federal government must be designed to reflect accurately the benefit spillovers generated by agricultural research. This research provides an indication of the system of intergovernmental grants needed to finance an optimal level of agricultural research investment in each state in the presence of research benefit spillovers. In addition, the framework also sheds light on the present institutional barriers to achieving an optimal level of research investment, the adequacy of the existing Hatch Act formula funding system, and the economic rationale for using formula funding or competitive grants in financing agricultural research.

The History of Federal-State Relations in Financing Agricultural Research

The creation and maintenance of economic institutions are fundamental responsibilities of government. Accordingly, the political structure and philosophy of the government are reflected in the structure of its economic institutions. This is true of the institutions in the United States' federal system of government. To understand the evolution of the institutional structure of the U.S. agricultural research system, it is necessary to understand the philosophical foundations of a federal system of government (Schweikhardt).

A federal system of government, according to Riker, has three characteristics. First, "two levels of government rule the same land and people." Second, "each level has at least one area of action in which it is autonomous." And third, "there is some guarantee (even though merely a statement in the constitution) of the autonomy of each government in its own sphere" (Riker, p. 11). The appropriate areas of responsibility for each level of government in this system have long been a matter of debate in the United States.

Elazar has characterized the eighteenth and nineteenth century debate over the proper roles of the national and state governments as a debate over "dualism." In a dual federal system, "the dual sovereignties--federal and state--were to exist side by side, each virtually independent of the other in its own sphere" (Elazar, 1962, p. 11). On the one hand, Thomas Jefferson envisioned a dual system of government in which the states dominated in the conduct of domestic affairs, including economic development, and the federal government exercised authority in foreign affairs, the supervision of the militia, and a limited number of domestic matters arising between states (Elazar, p. 12).

Government, insisted Jefferson, must be based on a "sacred principle, that though the will of the majority is in all cases to prevail, that will, to be rightful, must be reasonable; that the minority possess their equal rights, which equal laws must protect, and to violate which would be oppression" (Koch, p. 54). The system of government that would best prevent such oppression, according to the Jeffersonian view, is a decentralized system of government that allows political minorities the maximum opportunity to express their preferences and permits the states to fit political decisions to the peculiarities of their regions and citizens. Thus, Jefferson viewed a dual federal system with the maximum power residing with the states as the most appropriate system for guaranteeing both individual and national improvement.

A second view of dualism, expressed by Alexander Hamilton, favored a strong national government. The national government, according to Hamilton, "like that of each State, must be able to address itself immediately to the hopes and fears of individuals; and to attract to its support those passions which have the strongest influence upon the human heart" (Hamilton, p. 108). In such a government, the power to address the common interests of the citizens of the states must be held by the national government. Indeed, the Constitution permitted the national government to establish national copyright laws, a patent system, and postal roads, thereby reflecting the Hamiltonian dualist view that, in the realm of economic development, "Nothing which tends to facilitate the intercourse between the States can be deemed unworthy of the public care" (Madison, p. 293).

Reviewing the policies of the nineteenth century, however, Elazar observes that, while the rhetoric of the debate may have focused on the appropriate form of dualism, the political practice was one of cooperative federalism. Under a system of cooperative federalism, the national and state governments of the United States "developed a broadly institutionalized system of collaboration, based on the implicit premise that virtually all functions of government must be shared by virtually all governments in order to fulfill the demands of American democracy for both public service and private access" (Elazar, p. 297). Thus, while dualism implicitly viewed the total amount of political power as a constant, which one level of government could only gain at the expense of the other, cooperative federalism recognizes that government power is a dynamic concept with both levels of government often sharing power in a given area of public policy (Elazar, p. 310; Leach, p. 26).

Cooperative federalism often sought to capture the best aspects of both Hamiltonian and Jeffersonian federalism. While the power of the national government was called upon to address the common needs of citizens, administration of that power often resided with state governments, thereby tailoring programs to local needs. This arrangement was used during the nineteenth century to promote the economic development of the United States through the cooperative support of primary and secondary education, road construction, railroad development, canal and river development, and forest management (Elazar, pp. 25-30, 102-33; Graves, pp. 932-68). Corwin (p. 19) emphasized the pragmatic nature of such efforts at cooperative federalism:

> According to this conception, the National Government and the States are mutually complementary parts of a <u>single</u> governmental mechanism all of whose powers are intended to realize the current purposes of government according to their applicability to the problem in hand (italics in original).

The land-grant college system was created in this spirit of cooperative federalism. More impressive, perhaps, is that the land-grant college system often provided the prototype for later cooperative efforts such as road construction, health care, and revenue sharing (Graves, pp. 934-68; Walker, pp. 208-209). The land-grant colleges, for example, were established by the Morrill Act of 1862. This legislation, which followed an earlier pattern of providing grants of land

to the states to support a specific function, established a precedent by providing the grants uniformly (30,000 acres of land per senator and representative) and simultaneously to all states. Moreover, while this legislation did not require direct matching of the federal effort by the states, it did require the states to fund all building construction at the colleges, thereby establishing the principle that the states should share the burden of providing public services (Elazar, pp. 219-24).

The Hatch Act of 1887, which established federal support for agricultural research at the land-grant colleges, was the first modern intergovernmental grant. As such, it abandoned the use of land grants, which had previously been used when land was more plentiful than cash, and introduced the use of cash grants (which were earlier believed to be unconstitutional) that would be provided to the states on a continuing basis (Elazar, p. 230). Moreover, the Hatch Act established the principle that, while the institution would be financed in part by the federal government, administrative control would reside primarily with the states.

These innovations signaled the emergence of a new form of cooperative federalism. The historical significance of this step in the evolution of intergovernmental relations was explained by E. W. Allen, Chief of the USDA's Office of Experiment Stations, at the semicentennial celebration of the Connecticut Experiment Station:

> This nation-wide subsidizing of research in agriculture was evidence of change which had come

> in the conception of the relationship of the Federal Government and the states. It was a recognition of a joint responsibility in developing the industry of agriculture on a high stage of efficiency, and it was a new expression of what the general Government may do under the Constitution for the promotion of public welfare (True, p. 130).

It is important to note, in this regard, the difference between the Morrill Act of 1862 and the Hatch Act of 1887. Being a one-time grant, the Morrill Act shifted control of the colleges of agriculture to the states once the grant was made. Since the Hatch funds were appropriated annually, however, closer federal supervision of the funds was possible. As J. W. Holcombe, Chief Clerk of the U.S. Bureau of Education, observed in 1892:

> A great and radical step beyond previous legislation must be recognized here. The land-grant of 1862 amounted to an absolute gift. If the institutions established did not teach agriculture or military tactics (and some of them did not do so for years) the President and his Cabinet and the entire judiciary of the United States might whistle to the wind for redress. But this last act establishes, to put it plainly, Federal control and supervision over the use of the fund created. If any dangers, therefore, lurk in the possibility of Federal interference and Federal dictation, the beneficiaries of this last Congressional grant are liable thereto....The cordial acceptance of such a measure by the legislatures indicates that there is no real danger from Federal interference and that jealousy of the Federal power on that score has disappeared (Holcombe, pp. 114-15).

Agricultural research continues to be supported cooperatively by the federal government and the states (True; Ball, pp. 4-11; Conover; Knoblauch, et al.; Marcus; Bonnen, 1962; Schweikhardt). Table 1 summarizes the provisions of the legislation that has provided federal support to the state

Table 1. Provisions of Legislation Providing Intergovernmental Support of Agricultural Research

Legislation	Allocation Formula	Matching Requirements
Hatch Act (1887)	Equal	None
Adams Act (1906)	Equal	None
Purnell Act (1925)	Equal	None
Bankhead-Jones Act (1935)	Rural Population	One state dollar per federal dollar
Agricultural Marketing Act (1946)	20% equally, 26% by rural population, 26% by farm population, 25% for regional projects, 3% for administration	One state dollar per federal dollar
Hatch Consolidation Act (1955)	20% equally, 26% by rural population, 26% by farm population, 25% for regional projects, 3% for administration.	None on first $90,000. One state dollar for each additional federal dollar.

Source: Compiled by author from Knoblauch, et al., pp. 219-235.

agricultural experiment stations. Under the terms of the original Hatch Act, the federal government provided $15,000 per year for each state to support the newly-created state agricultural experiment stations. While some states did provide additional support for the stations, states were not required to match the federal funding effort. Federal support for the experiment stations was increased by the Adams Act of 1906 and Purnell Act of 1925. The Adams Act provided an additional $30,000 per year for each state, and the Purnell Act added another $60,000 per year for each state.

The concept of a formal matching requirement was introduced by the Smith-Lever Act of 1914, the organic legislation of the Cooperative Extension Service. Again, agriculture provided the prototype which many later programs would follow. The Bankhead-Jones Act of 1935 marked the introduction of a state matching requirement for agricultural research funding. To receive Bankhead-Jones funds, each state was required to allocate funds for agricultural research equal to the federal funds provided to the state. The Bankhead-Jones Act also introduced a federal funding formula to allocate federal agricultural research funds among the states based on their share of the total rural population. This formula was adopted "on the assumption that it reflects the need for the service involved, particularly when use has been made of classes of the population to which the aided service is directed" (Key, p. 322). Although a population-based formula has been used in subsequent legislation, it was recognized immediately as discriminating against states with a highly diversified agriculture that may require relatively more support than those states with a more homogeneous farm sector (Key, pp. 320-21).

The Agricultural Marketing Act of 1946 amended the Bankhead-Jones Act to provide a more complex system of funding. Twenty percent of the funds were to be allocated equally among the states. Fifty-two percent were allocated according to a formula based on each state's share of the national farm and rural population. As before, each state was required to match the federal effort with its own funds. Twenty-five percent of the funds were available for the Secretary of Agriculture to allocate to regional research projects, and 3 percent were designated for administrative costs.

The present allocation system is the product of the Hatch Consolidation Act of 1955. This legislation consolidated all previous funding and distributes these funds on an equal basis among the states. All additional funding is distributed according to the formula in the 1946 Act (that is, each state is allocated funds based on its share of the national farm and rural population). The states were required to match all but the first $90,000 of their allocation.

Attention must be paid to the political forces that have influenced the evolution of the agricultural research system. The population-based formula used to allocate federal funds for agricultural research originated in the Smith-Lever Act of 1914, the legislation that established the Cooperative Extension Service. During the debate on the Smith-Lever bill, congressmen from the South, who dominated the House and Senate agriculture committees, proposed that extension funds be allocated according to each state's share of the national rural population. Midwestern and western congressmen attempted to amend the bill by allocating the funds according to each state's share of land in farms or value of production, a formula that would have increased funding for western and midwestern states. Arguing that the purpose of extension was to educate people and that the total cost of education was a function of the number of people served, a coalition of southern and eastern congressmen defeated the amendment and established the precedent of a population-based formula (U. S. Congress, 1914, pp. 2579-83, 2655-58, 2736-44).

This precedent, combined with the continuing power of southerners on congressional agriculture committees, may account for the population-based formula used to allocate federal research funds in the Bankhead-Jones Act of 1935. The Agricultural Marketing Act of 1946, which established the present-day formula based on each state's share of national farm population and rural population (where rural population referred to those persons living in towns of 2,500 or less), resulted in a further shift in funding in favor of the southern states, mostly at the expense of eastern and midwestern states (with the notable exceptions of Iowa, Wisconsin, and Minnesota, which gained funds under the new formula) (U. S. Congress, 1946, p. 9027). Again, this may be due in part to the political power exerted by southerners.

The history of the federal-state partnership in financing agricultural research may confirm Martin Feldstein's observation, regarding the intergovernmental support of local education, that "the actual development of formula matching grants reflects history, legislative compromise, and accident rather than empirical analysis and economic logic" (Feldstein, p. 80). While such political decisions must also be based on factors other than economic logic, the generally recognized need to consider a revision of the Hatch formula provides an opportunity to apply such logic and analysis to a new and needed area of work. This dissertation is intended to contribute to such policy decisions by applying public finance theory to the problem of financing public agricultural research.

Research Objectives and Dissertation Organization

This research has three specific objectives:

1. The development of a public finance model designed to provide the optimal method (expressed as an optimal matching rate) of financing public investments that produce benefit spillovers across governmental boundaries;
2. The development of an econometric model designed to measure the size and geographic distribution of agricultural research benefit spillovers across state boundaries;

3. The calculation of an optimal system of federal agricultural research subsidies (i.e., matching rates for federal payments to each state) based on the results of the models developed under objectives 1 and 2.

These objectives will be accomplished in three stages. The first stage of this research, the development of a public finance model to compensate governmental units for benefit spillovers, draws on public finance theory to specify a mathematical model that maximizes national research benefits. It should be noted that this model could be applied to any public investment that produces benefit spillovers and is not limited to agricultural research.

The public finance model maximizes national research benefits by compensating states for the marginal research benefits that spill across state lines. National research benefits will be maximized when two conditions are met: (1) when each state equates its share of the marginal benefit that it retains from its own research with its share of the marginal cost of that research, and (2) when the share of the marginal benefit of research that spills outside the investing state equals the federal government's share of the marginal cost of research conducted in that state (i.e., when the federal matching rate, defined as the number of dollars the federal government provides to a state for each dollar the state spends on agricultural research, compensates each state for the marginal research benefit spillover produced by that state).

The second stage of this research, the measurement of agricultural research benefit spillovers, will draw extensively from the existing economic literature on returns to agricultural research. Two methods have been used to measure research spillovers. The first estimates a production function that includes research investment as a production input. The marginal benefit of research can be derived from the estimated equations and, if the equations are properly identified and the data are sufficiently accurate, the research benefit spillovers can be measured.

The second method of estimating the returns to agricultural research calculates the producer and consumer welfare gains that result from public investments in agricultural research. By estimating the change in supply that results from agricultural research, changes in the price and quantity of farm products can be estimated and the resulting gains to farmers and consumers can be measured. Again, if the estimated equations are properly specified, benefit spillovers can be measured.

While these two methods have been used to measure research benefit spillovers, neither has been used to determine an optimal federal matching rate because the estimates have been made on a regional or national basis and the necessary breakdown of spillovers by states have not been calculated. To make such calculations, state-level estimates of research spillovers must be made. This research will employ the production function method to estimate the state-level research benefit spillovers necessary to make such calculations. Since little is known about the pattern of research spillovers that prevails in the U.S., six assumed spillover patterns will be used to estimate these production functions. The optimal matching rates will then be estimated for each of these six spillover scenarios.

The final stage of this research will introduce the research benefit spillover estimates from stage two into the public finance model developed in stage one to determine the optimal federal matching rate for each state. To achieve this, the results of the production function model estimated in the second stage of this research will be used to calculate (1) the marginal product of research spending that accrues to a given state as a result of agricultural research conducted in that state, and (2) the marginal product of research that accrues to all other states as a result of agricultural research conducted in the given state. These estimates will then be used to calculate the share of the total marginal product of research that spills outside the funding state. This share will be used in the public finance model to estimate the optimal federal matching rate for financing agricultural research in the each state under each of the six spillover scenarios.

This dissertation is organized around the three stages of the research. Chapter II reviews the problem of financing public goods in a federal system of government. It then reviews the theory of intergovernmental grants and the use of intergovernmental grants as a means of promoting optimal investments in public goods in the presence of spillovers. Next, the economic literature on the measurement of agricultural research benefits and the measurement of benefit spillovers is reviewed. Finally, the case for a joint system of federal and state investments in agricultural research is considered.

Chapter III develops a public finance model of optimal cost-sharing for federal and state investments in public goods that create benefit spillovers across state lines. It then presents a production function model designed to measure research benefit spillovers and describes the data used to estimate this function under six assumed spillover patterns. Chapter IV presents the empirical results of the production function models described in Chapter III. Chapter V uses the production function estimates reported in Chapter IV to calculate research benefit spillovers. These results are then incorporated into the public finance model to determine an optimal federal matching rate for each state under each spillover scenario. Chapter VI summarizes the research, discusses the limitations of the research method, and examines the policy implications of the results for federal-state relations in funding agricultural research.

A Preface to Economic Policy Analysis

This research is an exercise in economic policy analysis. In order to interpret such analysis correctly, it is necessary to recognize its nature and limitations. It is particularly important to recognize four essential characteristics of economic policy.

First, economic policy is concerned with the institutional structure of the economy. An institution, as defined by Commons (p. 69), is collective action in control of individual action. The institutional structure of the economy defines each persons' rights and responsibilities or, more simply, what persons may do, may not do, and must do (Clark, p. 203; Mitchell, p. 19; Commons, p. 71). All policy, according to Ostrom (p. 126), must "fashion appropriate structures for the allocation, exercise and control of decision-making capabilities among people....Decision structures establish the 'rig' to the games of life. Designing and altering the 'rig' of real-life games is the work of political artisans." He traces this view to Alexander Hamilton, James Madison, and Alexis de Toqueville, who all viewed the political process as a means of biasing selfish human behavior toward politically-chosen ends (Ostrom, p. 7).

It must be recognized that economies are always and everywhere an "instituted process" (Polanyi, p. 248), and that economic policy ultimately deals with the creation, modification, and destruction of institutions (Bonn, p. 337). That is, the choice of an institutional structure determines the production, consumption, and distribution incentives that exist in the economy (Bonn, p. 333), which in turn determine the distribution of income, wealth, and power in the economy. A change in this incentive structure can lead to a change in individual behavior and a change in the level, composition, or distribution of the output of the economy (Stigler, 1975, p. 33; Samuels, 1978, p. 103).

The choice of an institutional structure for the economy is an inevitable duty of government (Bonn, p. 335). As Brinkmann (p. 331) observed, the problem of determining policy "raises everywhere and at all times the question of as to how economic incentives underlie social behavior," and, furthermore, "it is unrealistic to think of any age or community as exempt from this economic predetermination." The inevitable need to make such choices is also reflected in Knight's observation (1951, pp. 8-15) that all economies must solve five fundamental problems: (1) the fixing of standards of value, (2) the organization of production, (3) the distribution of production, (4) the promotion of economic growth, and (5) the adjustment of consumption to production.

This admission of the instituted nature of the economy does not bias policy analysis toward any particular institutional structure (Buchanan, 1964, p. 222; Knight, 1951, pp. 7-14; Robbins, p. 50). Instead, it simply recognizes that the economy is a man-made system, reflecting an "artificial harmony of interests" established by the participants in the system (Mitchell, p. 13; Samuels, 1966, p. 4; Commons, p. 6). Economic policy can only establish this artificial harmony by determining whose interests the economy will serve.

The second characteristic of economic policy is that it is necessarily prescriptive in nature. The policy process must organize knowledge in order to guide the evolution of institutions (Mitchell, p. 36). Like any decision, an economic policy decision must be a prescription--a statement of what ought to be done. All prescriptions must be based on two types of knowledge: normative knowledge (about values--i.e., about the goodness or badness of conditions, situations, or things) and positive knowledge (about characteristics other than the goodness or badness of conditions, situations, or things) (Glenn Johnson, 1986b, pp. 16-20).

As Glenn Johnson has also emphasized, decisions require, in addition to knowledge, the use of both decision rules and power. Decision rules (e.g., the maximization of good, minimization of bad, majority voting, etc.) determine the standard by which policy alternatives are judged. Power enters the decision process in at least four ways. First, as Paarlberg (pp. 158-59) observed, the power to place problems and alternative solutions on the political agenda is "the most potent of all powers," since focusing attention on a problem is "an absolutely necessary first step" in the decision process. Second, the possession of knowledge is itself a form of power, since the knowledge that is considered by policymakers will affect the policy alternative chosen (Glenn Johnson, 1986b, p. 230). The ability to provide information in the decision process or to convince policymakers to focus on a certain type of information can be used to influence the outcome of policy decisions (Bartlett, pp. 31-34, 56, 132-37). Third, the institutional structure of society is only viable when it is enforced by the power of the state, particularly against the challenges of those who disagree with the policy (Bonn, p. 334; Clark, p. 15; Commons, p. 713; Robinson, p. 124; Knight, 1960, p. 113, and 1953, p. 278; Mitchell, p. 19; Robbins, pp. 34-36; Buchanan, 1964, p. 220). Fourth, power is both an input and an output of the policy process. The establishment of an institutional structure produces a power structure that allows individuals to influence decisions beyond the issue at hand; as mentioned earlier, it grants the power to determine the production, consumption, and distribution patterns in the economy.

A third characteristic of economic policy is that it is necessarily predictive in nature. All policy prescriptions must be based on a comparison of the continuation of the existing institutional structure with a modification of that structure. To make such comparisons, the analyst must consider the economic incentives under each alternative structure, predict the behavior of individuals under each structure, and assess the success of each policy alternative in achieving the objective chosen (Knight, 1953, p. 282, and 1960, pp. 21, 29, 111, and 146; Tinbergen, pp. 50-53;

Lindblom, 1965, p. 138; Ostrom, p. 9). Without such predictions, no economic policy--including a continuation of the status quo--can be justified.

The fourth characteristic of economic policy is that it is necessarily normative in nature on several levels. On the first level, the act of making a policy decision presumes that a problem--defined as a divergence between existing and desired conditions--has been identified and agreed upon as requiring collective action. The assessment of existing and potential conditions involves normative judgments. These judgments must include what conditions do exist, what conditions could exist, the goodness or badness of these conditions, and who benefits or is damaged by current and potential conditions.

On the second level, an economic policy decision involves a decision to make a decision. As Dahl and Lindblom (p. 64) have observed, policymakers must first make a rational calculation whether to make a rational policy calculation. Paarlberg (p. 158-59) points out that the resources devoted to political decision-making (in the form of time, capital, and human comprehension) are limited. Thus, he concludes, an agenda is required to provide order in the political process. The decision to place a select number of policy problems and alternatives on the agenda also involves normative judgments. Knight (1960, p. 133) insisted that the most critical question of the policy process is "What questions are worth discussing?" and called the laws regulating the discussion of this question "the most important of our laws." This level of decision-making, which Paarlberg refers to as the control of the policy agenda, possesses its own distribution of power, its own normative premises, and its own decision rules.

On the third level, an economic policy decision involves a choice of ends as well as means. According to Knight, the most important and difficult stage of the policy process is the selection of the economic ends that will be pursued (Knight, 1952, p. 54; 1951, p. 4 and 1960, p. 152). The selection of ends, whether chosen by the economic analyst or imposed on the analyst by the political process, is an indispensible part of the policy process and of policy analysis, ultimately depending on normative judgments and an assumed or real distribution of power (Rothbard, p. 38; Mitchell, p.35; Myint, p. 230; Lindblom, 1958, p. 533).

On the fourth level, any economic policy decision based on a maximizing or minimizing calculus must presume an institutional structure for the economy and, therefore, must make normative assumptions about that structure (Rothbard, pp. 36-38; Buchanan, 1962, p. 342, and 1964, p. 216; Clark, p. 108; Knight, 1935, p. 137; Samuels, 1978, pp. 100-113, and 1980, pp. 181-83). Simply put, any policy proposal that intends to maximize or minimize some target measure must first define which factors (such as various benefits and costs) will be included in the optimizing calculus. As emphasized earlier, the institutional structure of the economy defines which benefits and costs will be included in such calculus. Only after these normative judgments have been made can any form of optimization proceed.

To summarize, economic policy determines the economic structure of an economy, thereby determining the behavior its participants. All policy--including a continuation of the status quo--is prescriptive and depends on positive knowledge, normative knowledge, numerous decision rules, and a distribution of power. The prescriptive validity of any policy analysis is determined by the accuracy of the knowledge upon which it is based. Given the many normative premises involved in policy decisions, accurate policy analysis must make such premises as explicit as possible (Knight, 1953, p. 278; Samuels, 1978, p. 100). Chapter III identifies several such premises underlying this analysis. In Chapter VI, a companion to this section, "A Postscript to Economic Policy Analysis," will examine the implications of these assumptions and the limitations they impose on the results of this research.

CHAPTER II

REVIEW OF LITERATURE

This research applies the principles of public finance theory to the problem of resource allocation in agricultural research. This chapter begins the research by examining the relevant economic literature in three areas. First, the problem of financing public goods is examined, with special emphasis on the problems of providing public goods in a federal system of government. Second, the use of intergovernmental grants to finance public goods is examined. Third, the measurement of benefit spillovers in agricultural research is examined and the role of intergovernmental grants in financing agricultural research is considered.

Financing Public Goods in a Federal System of Government

While earlier authors recognized the existence of public goods, the work of A. C. Pigou provided the foundation of modern public finance theory.[1] Pigou differentiated between the marginal private net product of an investment and its marginal social net product. The marginal private net product of an investment, by Pigou's definition, "is that part of the total net product of physical things or objective services due to the marginal increment of resources in any given use or place which accrues in the first instance--i.e., prior to sale--to the person responsible for investing resources there," while the marginal social net product "is the total net product of physical things or objective services due to the marginal increment of resources in any given use or place, no matter to whom any part of this product may accrue" (Pigou, 1946, pp. 134-35).

Private investors, argued Pigou, will allocate their resources in such a manner that, allowing for transaction costs, the money value of the marginal private net products are equal across all investment opportunities. In doing so, investors will contribute to the maximization of national money income (Pigou, 1946, pp. 136-41). This process of equalization will not yield the maximum national welfare, however, if the marginal net private product does not equal the marginal net social product, a condition that occurs when "a part of the product of a unit of resources consists of something, which, instead of coming in the first instance to the person who invests the unit, comes instead, in the first instance (i.e., prior to sale if sale takes place), as a positive or negative item, to other people" (Pigou, 1946, p. 174).

Three groups of people were identified by Pigou as potential recipients of these positive or negative effects:

1. "The owners of durable instruments of production, of which the investor is a tenant;
2. Persons who are not producers of the commodity in which the investor is investing; and

3. Persons who are producers of the commodity" (Pigou, 1946, p. 174).

While Pigou saw all three cases as potentially requiring corrective government action, the concern here is with only the second case.

In the second case, according to Pigou, "the essence of the matter is that one person A, in the course of rendering some service, for which payment is made, to a second person B, incidentally also renders services or disservices to other persons (not producers of like services) of such a sort that payment cannot be extracted from the benefited parties or compensation enforced on behalf of the injured parties" (Pigou, 1946, p. 183). Pigou's examples of such disservices included factory smoke, automobile pollution, and added congestion due the erection of high rise buildings in crowded urban areas. His examples of such services included lighthouses, roads, city parks, and,

> Lastly and most important of all, it is true of resources devoted alike to the fundamental problems of scientific research, out of which, in unexpected ways, discoveries of high practical utility often grow, and also to the perfecting of inventions and improvements in industrial processes. These latter are often of such a nature that they can neither be patented nor kept secret, and, therefore, the whole of the extra reward, which they first bring to their inventor, is very quickly transferred from him to the general public in the form of reduced prices (Pigou, 1946,pp. 184-85).[2]

When such divergences between the marginal private net product and the marginal social net product occur, Pigou argued, the welfare of society could be increased by establishing taxes and subsidies that equate the two. In the case of a disservice, the marginal private net product exceeds the marginal social net product, and overinvestment (as viewed from a social perspective) occurs in the industry producing the disservice. Such overinvestment can be avoided if a tax is imposed on producers that brings their marginal private net product into alignment with the marginal social net product.

In the case of a service, the marginal private net product is less than the marginal social net product, and underinvestment (as viewed from a social perspective) occurs in the industry providing the service. A socially optimal level of investment can be reached if the government provides a subsidy to producers equal to the difference between the marginal social net product and the marginal private net product.[3] It is notable that Pigou had such subsidies in mind for agricultural research and extension:

> This type of bounty is also not infrequently given upon the work of spreading information about improved processes of production in occupations where, owing to lack of appreciation on the part of potential beneficiaries, it would be difficult to collect a fee for undertaking that task. Thus the Canadian Government has established a system, "by means of which any farmer can make inquiry, without even the cost of postage, about any matter relating to his business"; and the Department of Interior also sometimes provides, for a time, actual instruction in farming....In the United Kingdom the various Agricultural Organization Societies are voluntary organizations, providing a kindred type of bounty at their subscribers' expense. An important part of their purpose is, in Sir Horace Plunkett's words, to bring freely "to the help of those whose life is passed in the quiet of the field the experience, which belongs to wider opportunities of observation and a larger acquaintance with commercial and industrial affairs." The Development Act of 1909, with its provision for grants towards

> scientific research, instruction, and experiment in agricultural science, follows the same lines (Pigou, 1946, pp. 193-94).[4]

This Pigouvian view of the public good nature of research was later developed mathematically by McCain (pp. 182-95) and O'Connell (1978; 1982, pp. 96-99). Both demonstrated that profit-maximizing competitive firms would underinvest in research when a portion of the benefits of research investments are captured by firms other than the inventor.

Samuelson (1954, 1955, 1958) cast the underinvestment problem in terms of his version of the "new welfare economics." In his version, a pure public good is any good that is common to all consumers in the sense that the consumption of that good by one individual does not reduce the quantity of that good available for consumption by any other individual (Samuelson, 1954, p. 387). Said another way, whatever level of consumption is chosen by one person is also the level available for consumption by all other persons.

Given his definition of a public good, which assumes a high cost of excluding users of the good, Samuelson found three conditions that are necessary for optimal investment in private and public goods: (1) each person's marginal rate of substitution between each pair of private goods in the economy must equal the marginal rate of transformation between those two goods; (2) the marginal utility of each private good must be equal across all consumers of that good; and (3) the sum of all persons' marginal rate of substitution between the public good and each private good in the economy must equal the marginal rate of transformation between those two goods. The last of these conditions leads to what Samuelson called the "impossibility of decentralized spontaneous solution" (1954, pp. 388-89).

The third condition implies that each individual receives utility from both the quantity of a public good that he has purchased and from the sum of the quantities of the good purchased by all other individuals. Thus, in this process of summation, each individual may attempt to avoid purchasing the public good in the hope that others will provide a sufficient quantity of the good. If each person adopts such a strategy, however, the net result will be an underinvestment in the public good, since it will be in each person's interest to attempt to "free ride" on the purchases of others. Even if various voting methods are used to determine the level of public goods provided, it will still be in the individual's best interest to hide his true preference for public goods and underinvestment will still result (Samuelson, 1954, pp. 388-89; Bowen).

While Samuelson dealt only with public goods that are used for final consumption, Kaizuka extended the Samuelson model to address the problem of public goods that serve as inputs to the production of consumption goods, such as "weather broadcasts for commercial farmers, or research the fruits of which any firm is free to use" (Kaizuka, p. 118). Like Samuelson, Kaizuka concluded that users of such a public good will have an incentive to conceal their demand for the good in hopes of shifting the cost of the good to others and, without some form of government subsidy, underinvestment in the public good may persist.[5]

Albert Breton (p. 177) redefined the problem as not simply a matter of whether government should provide public goods, but also which unit of government should do so. Economic goods, he argued, can rarely be classified into the polar cases of pure private or public goods. Instead, there are a number of "non-private" goods whose services are available to individuals in unequal amounts (as opposed to a pure public good which must be available to all individuals in an equal amount). The problem of underinvestment in non-private goods is further complicated when such goods are provided by a federal (i.e., multi-level) system of government. In particular, a problem of "imperfect mapping" may arise.

If the benefits of a good are perfectly mapped, that is, if the benefits of a good accrue strictly within the boundaries of the unit of government financing the good, then the government of that jurisdiction will provide the optimal quantity of the good to its citizens (assuming it has overcome the problem of ascertaining accurately the preferences of its citizens). On the other hand, if the benefits of the good are imperfectly mapped, or spill across the jurisdictional boundaries of the financing government, the investing government, like the investing individual in Pigou's analysis, will underinvest in the good. A higher level of government could provide a subsidy to the lower level unit of government to induce it to invest in the socially optimal quantity of the good (Breton, pp. 180-82).

As Weisbrod (pp. 131-32) would later point out, both spillouts and spillins can lead to underinvestment. The former, as Breton had written, because the investing government cannot capture the full benefits of its investment. The latter, according to Weisbrod, because spilled-in goods can displace internally-financed goods if the recipient of spillins overestimates the benefits it will receive from other jurisdictions. Similarly, McKinney used a Stackelberg model of duopoly behavior to demonstrate that both spillouts and spillins would cause society to suffer welfare losses from underinvestment when units of government attempt to engage in strategic behavior and "free ride" on the purchases of others.

Drawing on the welfare economics of Samuelson and the public finance economics of Breton, Oates examined the problem of underinvestment in public goods when benefits spill across jurisdictional boundaries. Assuming a world of two goods and two jurisdictions (the results can be generalized to many goods and jurisdictions), the optimal allocation for each community in the absence of spillovers can be defined as:

(2.1) $MRT_1 = MRS_1$

(2.2) $MRT_2 = MRS_2$, where:

MRT_i = the marginal rate of transformation between goods X and Y for community i;

MRS_i = the marginal rate of substitution of community i between good X (a private good consumed by the citizens of community i) and good Y (a public good provided by the government of community i), which is, as Samuelson showed earlier, the sum of the marginal rates of substitution of all individuals in community i.

Thus, if there are no losses of benefits across jurisdictional boundaries, each community will invest in the level of public good Y that is optimal for its citizens. Again, this assumes the problem of preference revelation has been solved within each community (i.e., each jurisdiction has solved the problems of determining how much of the public good is optimal for its citizens and how the cost of the public good should be shared by its citizens).

If some portion of the benefits of good Y spill across the boundaries of the communities, such spillovers must be taken into account when determining the socially optimal level of good Y. The socially optimal level of consumption now becomes:

(2.3) $MRT_1 = MRS_1 + a_2 * MRS_2$

(2.4) $MRT_2 = MRS_2 + a_1 * MRS_1$, where:

a_1 = the increase in consumption of public good Y that occurs in community 1 as a result of a one unit increase in the consumption of Y by community 2;

a_2 = the increase in consumption of public good Y that occurs in community 2 as a result of a one unit increase in the consumption of Y by community 1, and

$0 \le a_1, a_2 \le 1$.

It is now possible to consider a broad range of spillover combinations and their implications for public investment decisions:

1. If $a_1 = a_2 = 0$, no spillovers will be generated, and each community will provide the socially optimal quantity of Y for its citizens.
2. If $a_1 = a_2 = 1$, the good is a pure Samuelsonian public good and must be provided by a higher level of government than the two community governments if an optimal level of investment is to be reached (this is analogous to Samuelson's "impossibility of decentralized spontaneous solution" for a pair of individuals).
3. If $0 < a_1, a_2 < 1$, there will be spillovers generated between the communities and, in the absence of a system of compensating subsidies, the quantity of good Y provided by each jurisdiction will less than the socially optimal quantity of Y (Oates, pp. 95-99).

To summarize, underinvestment in a good may result when some portion of the benefits of that good accrue to individuals other than the original investor (where, in this case, the investor is a unit of government). A socially optimal level of investment can be obtained through the use of government subsidies. In a federal system of government, a socially optimal level of investment in public goods that create benefit spillovers across jurisdictional boundaries (such as agricultural research) can be achieved through a system of intergovernmental subsidies (e.g., from the federal government to the states).

The Use of Intergovernmental Grants in Achieving Optimal Investment in Public Goods

Before considering the use of intergovernmental grants to correct the problem of underinvestment in public goods, it is necessary to examine the use of other policy tools to correct the problem. The first alternative is the reapportionment of jurisdictional boundaries. It is theoretically possible to redefine the boundaries of units of government in such a way that all benefit spillovers would be internalized to the decision process and, as a result, a socially optimal level of investment would be reached (Musgrave and Musgrave, pp. 597-602). Using a spatial model of public goods, McMillan demonstrated that an optimal level of investment could be reached through the use of both grants and reapportionment of jurisdictions. Breton and Scott (1977) reached a similar result using a transaction cost minimization model.

To rely solely on reapportionment, however, would require a unique set of boundaries for each good that creates benefit spillovers. This alternative would require a large number of jurisdictions to cover all the goods that might create spillovers (Break, 1980a, p. 77). More important, while economists may judge the existing boundaries of government to be inefficient, such boundaries can only be changed at high political cost (Schultze, p. 185). Thus, while changes in jurisdictional boundaries are a possible solution to the underinvestment problem, they are unlikely to succeed if institutional rigidities prove impossible to overcome.

A second possible solution to the underinvestment problem would be the granting of taxing authority to the investing jurisdiction, thereby permitting it to tax the recipients of benefit spillovers. Such taxes may either be levied directly on outside citizens by the investing jurisdiction, or the investing jurisdiction may impose taxes on its own firms and citizens which, when the burden is shifted to outside citizens, compensate the jurisdiction for the spillover benefits it has created (Musgrave, p.115; Ellickson).

As with reapportionment, however, this option may create an large number of taxing authorities and raise the transaction costs of collecting the appropriate taxes. The establishment of taxes, the share of whose burden on outside citizens equals the share of benefits that spill across jurisdictional boundaries, may be an equally difficult and costly task. If this cannot be performed at the lower level of government, a central taxing authority may better serve to correct the underinvestment problem. Finally, as Stigler

(1957, p. 214) observed, a central taxing authority may be necessary when the taxed parties can escape their financial obligation by migrating beyond the boundaries of lower level governments.

A final option would simply be the negotiation of appropriate subsidies between units of government that create and receive benefit spillovers (Coase, pp. 28-42). While such an approach may succeed when the number of units is small, it becomes increasingly difficult as the number of units involved in the negotiation process increases, and thus the transaction costs associated with such negotiations rise (Oates, p. 68; Wellisz, p. 361; Regan, p. 436-37; Stigler, 1966, pp. 113-14; Mishan, p. 31; Baumol, 1972, p. 308; Ellickson, pp.97-100). It must also be noted that Pigou (1946, pp. 183-84) recognized the self-correcting nature of the small-numbers case and only advocated intervention in those cases where the large number of parties involved makes it "technically difficult to exact payment."[6]

If none of the options discussed above will succeed in promoting a socially optimal level of investment in public goods, the use of intergovernmental grants may be the most feasible option. The problem remains, however, to design a system of grants that will encourage an optimal level of investment. As discussed earlier, a simple Pigouvian subsidy will compensate the investing government for the difference between the total marginal benefits received by all citizens and the marginal benefits received by citizens of the investing jurisdiction. Such a subsidy is shown in Figure 1.

If jurisdiction i invests in a spillover-generating public good (Y), the optimal quantity for it to provide will be the quantity that equates the marginal cost to jurisdiction i (MC_Y) and the marginal benefits received by the citizens of i (MB_{Yi}). Thus, the optimal quantity for jurisdiction i to provide for its citizens would be Q_{Yi} in Figure 1.

By providing good Y, jurisdiction i also provides benefits to citizens outside its boundaries. These external benefits are equal to MB_{Ys} (the marginal social benefit, including all benefits that accrue inside or outside jurisdiction i) minus MB_{Yi}. The socially optimal quantity of good Y is the quantity that equates the marginal social cost (MC_Y) with the marginal social benefit (MB_{Ys}), or the quantity Q_{Ys}. To achieve this level of investment in Y, jurisdiction i should receive a subsidy (S_i) equal to the difference between the marginal social benefit (MB_{Ys}) and the marginal benefit that accrues to the citizens of jurisdiction i (MB_{Yi}). As will be discussed, this subsidy may come from either a higher level of government or from the government whose citizens receive benefits from jurisdiction i.

Returning to Oates' more general solution, a set of subsidies that encourage an optimal level of investment in the spillover-generating good can be designed (Oates, pp. 99-104). The optimal conditions for each community were

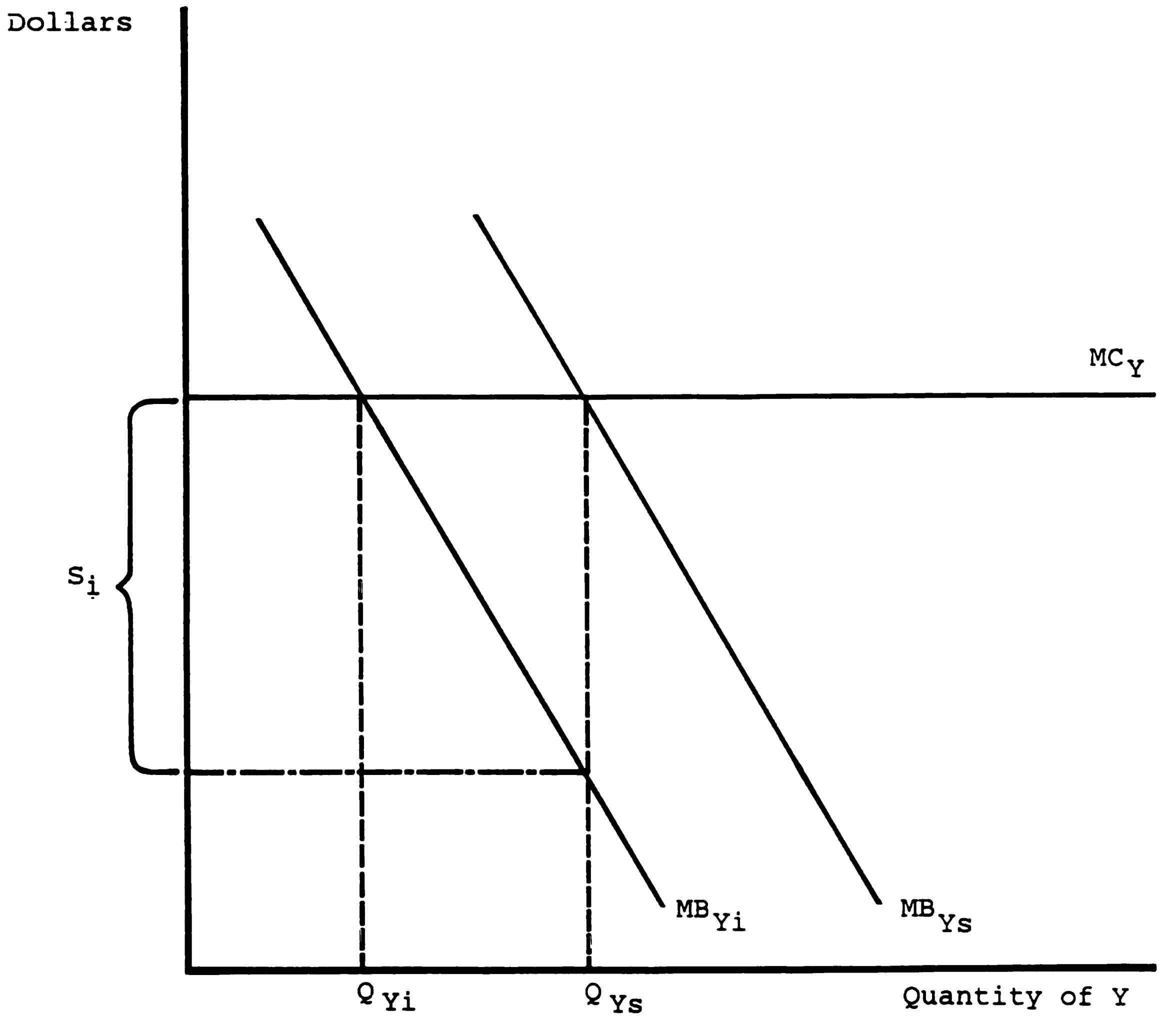

Figure 1: Use of a Pigouvian Grant to Achieve a Socially Optimal Investment in a Spillover-Generating Good

Source: Oates, p. 67.

established in the previous section of this chapter as:

(2.3) $MRT_1 = MRS_1 + a_2{*}MRS_2$

(2.4) $MRT_2 = MRS_2 + a_1{*}MRS_1$.

If a_1 and a_2 are both non-zero (i.e., there are reciprocal spillovers), then both governments will receive a subsidy. To find the optimal subsidy for each, a system of equations must be solved:

(2.5) $MRS_1 = MRT - S_1$

(2.6) $MRS_2 = MRT - S_2$

(2.7) $MRT = MRS_1 + a_2{*}MRS_2$

(2.8) $MRT = a_1{*}MRS_1 + MRS_2$, where

MRT = the marginal rate of transformation between private good X and a spillover-generating public good Y;

MRS_i = the marginal rate of substitution between good X and good Y for jurisdiction i;

a_1 = the increase in the consumption of good Y that occurs in jurisdiction 1 as a result of the consumption of an additional unit of good Y by jurisdiction 2 ($0 \leq a_1 \leq 1$);

a_2 = the increase in the consumption of good Y that occurs in jurisdiction 2 as a result of the consumption of an additional unit of good Y by jurisdiction 1 ($0 \leq a_2, \leq 1$);

S_i = the subsidy paid to jurisdiction i, expressed in units of good X.

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The simultaneous solution of equations (2.5) through (2.8) provides the optimal subsidy for each jurisdiction:

(2.9) $S_1 = (a_2*(1 - a_1)/(1 - a_1*a_2))*$ MRT

(2.10) $S_2 = (a_1*(1 - a_2)/(1 - a_1*a_2))*$ MRT.

This result suggests some important implications for designing intergovernmental subsidies. As shown by equation (2.9), given a_1, a larger value for a_2 (i.e., a larger share of benefits that spill from 1 into 2) will yield a larger subsidy paid to jurisdiction 1. Similarly, for a given level of a_2 in equation (2.10), a larger value for a_1 (i.e., a larger share of benefits that spill from 2 into 1) will yield a larger subsidy paid to jurisdiction 2.

Accepting that intergovernmental grants may be necessary to promote an optimal level of investment in public goods that create benefit spillovers, the question now turns to what form such grants should take. An analysis of alternative grant forms is shown in Figure 2 (Scott, pp. 377-94; Wilde 1968, pp. 340-57 and 1971, pp. 143-55; Boadway and Wildasin pp. 518-29).[7] The jurisdiction is assumed to allocate its resources between the consumption of a public good Y that creates benefit spillovers in other jurisdictions and all other goods. It should be noted that these other goods may be private goods consumed by the citizens of the jurisdiction or public goods that create no benefits outside the funding jurisdiction (Waldauer, p. 215).

The jurisdiction can be assumed to have an initial budget AA' that is allocated between the spillover-generating public

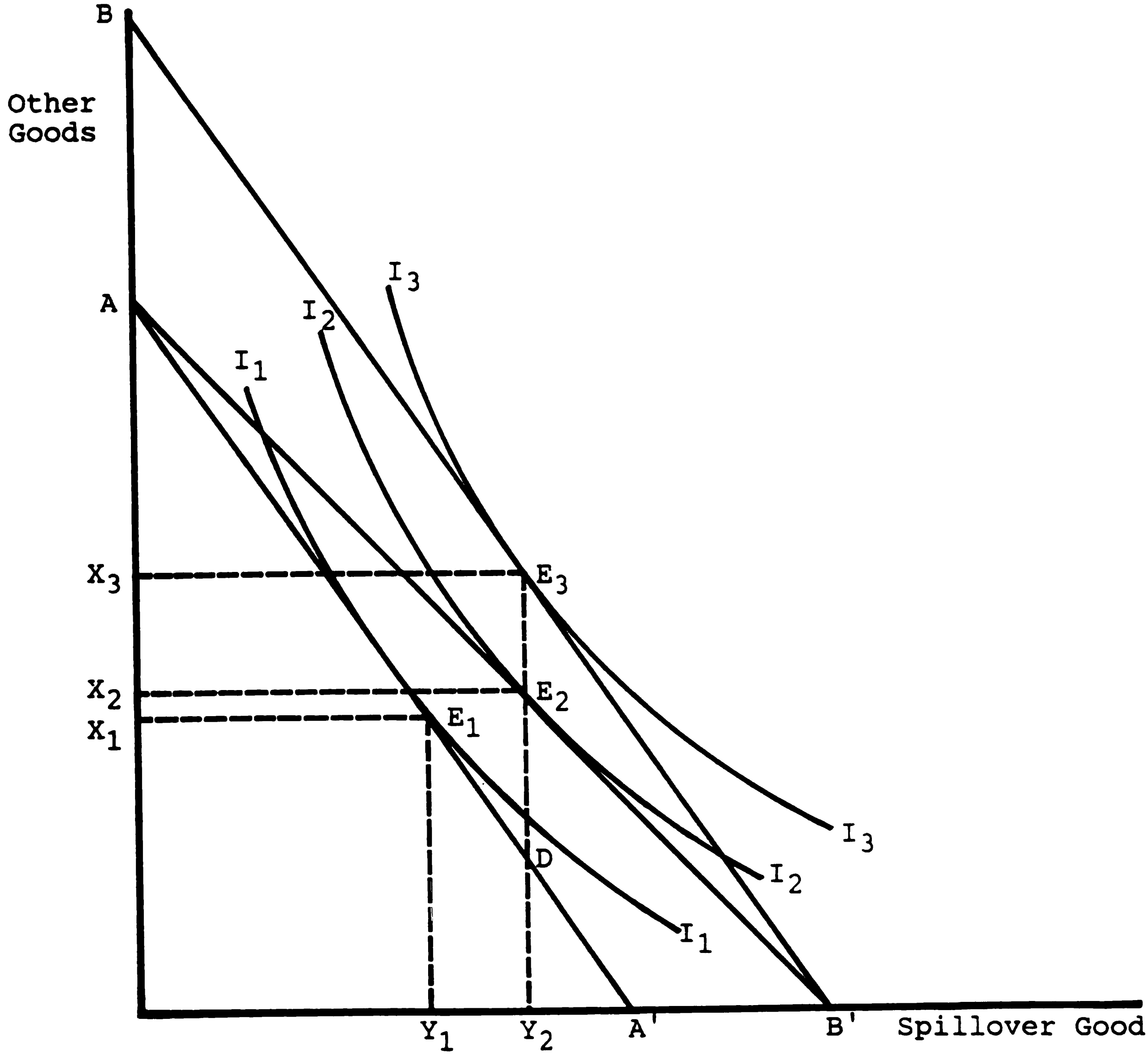

Figure 2: Comparison of an Unconditional Lump-Sum Grant and a Conditional Matching Grant

Source: Boadway and Wildasin, p. 520.

good and all other goods. The community indifference curve I_1 indicates that community welfare is maximized at point E_1, and the optimal quantities purchased will be Y_1 and X_1. Assuming that another unit of government (either another unit of government at the same level acting directly--as among two states--or a higher level of government acting on behalf of other lower level governments--as between the federal government and a state government) provides a subsidy to the community to compensate it for the benefits that spill across its boundaries, what form should such a subsidy take?

It may take the form of an unconditional, lump-sum grant. Such a grant has no restrictions on its use and may be allocated by the recipient for any purpose. Thus, some of the grant may be allocated to the spillover-generating public good, and some of it may be allocated to private goods (via a reduction in taxes in the recipient community) or to public goods that do not create spillovers. Such a grant is shown in Figure 2 as a shift in the recipient's budget line from AA' to BB'. The recipient's new allocation, located at point E_3 tangent to the community indifference curve I_3, will be Y_2 of the spillover-generating good and X_3 of all other goods.

As an alternative to a lump-sum grant, the grant may take the form of a conditional matching grant. In this case, the grant will only be received if the recipient satisfies two conditions. First, the recipient must use the grant for production of the spillover-generating good. Second, the

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recipient must match the grant at a specified rate with its own funds.

Assuming the original slope of the budget line is h and that the matching rate implies that s is the share of the cost of good Y paid by the grantor, the new budget line will have a slope of h*(1 - s) and will rotate from AA' to AB'. The new allocation of the recipient will be X_2 and Y_2. If Y_2 is the socially optimal level of the public good, Figure 2 demonstrates that it can be achieved at least cost to the grantor by use of a conditional matching grant. As shown in Figure 2, the grantor's cost of achieving output Y_2 is DE_3 if a lump-sum grant is used, but only DE_2 if a matching grant is used. This result arises because the lump-sum grant produces only an income effect, while the matching grant reduces the recipient's price of the spillover-generating good, thereby combining the income effect with a price effect to provide a more powerful incentive for the recipient to increase its spending on the spillover-generating good. A number of studies of intergovernmental grant programs have confirmed that recipient jurisdictions do respond to such price effects and, as a result, the recipient's spending on the spillover-generating good is stimulated more by a matching grant than by a lump-sum grant of equal size (Gramlich, pp. 222-35).[8]

In comparing the cost efficiency of these two types of grants, it should be reiterated that the choice of grant form is determined by the objective of the grant program. This choice of objectives has important distributional consequences for both the grantor and the recipient. While it is true that the recipient would prefer the lump-sum grant (since it would be on the preferred indifference curve I_3), it must be emphasized that the purpose of the grant is not the maximization of the recipient's welfare. Instead, it is assumed in this analysis that the purpose of the grant is only to compensate the recipient for spillovers and induce the socially optimal level of investment in the public good at the minimum cost to the grantor. This objective can best be accomplished with a matching grant.

If the grantor agrees to provide matching funds for each dollar invested by the recipient, the grant is an open-ended matching grant and will achieve the socially optimal level of investment in the spillover-generating good. Open-ended grants are rarely used, however, since such grants would expose the grantor to an undetermined future budget obligation and would make budget planning difficult for the grantor.

To overcome this problem, most matching grants are closed-ended grants that impose a limit on the size of the grant provided by the grantor. Such a closed-ended matching grant is shown in Figure 3. Once again, the recipient community has a pre-grant equilibrium at a point along the budget line AA'. If a closed-ended matching grant is offered to it, the budget line will shift to ABC, where point B represents the limit on matching funds imposed by the grantor. The slope of the budget line is $h*(1 - s)$ along the segment

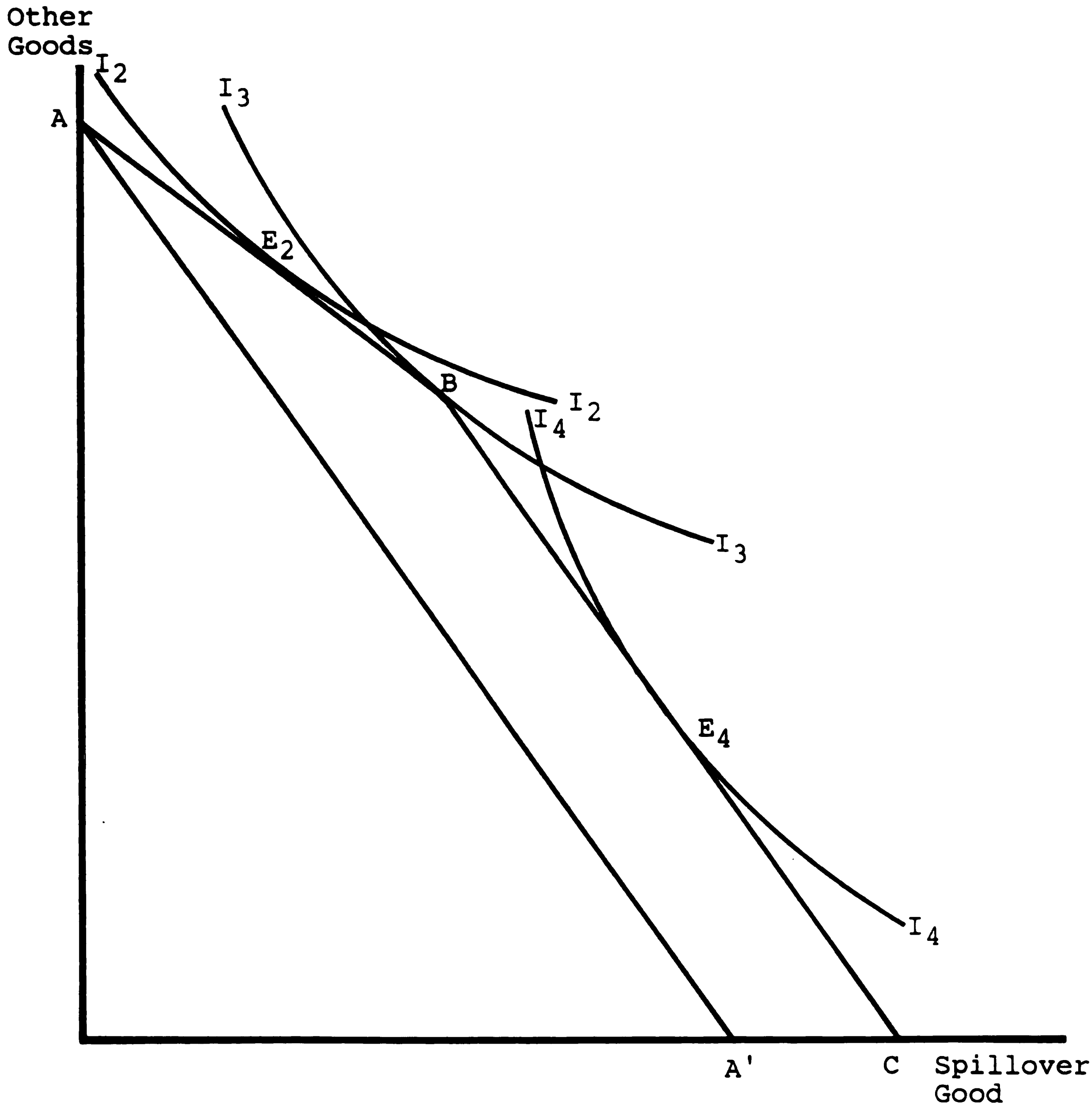

Figure 3: Impact of a Closed-Ended Matching Grant on the Budget of the Recipient Jurisdiction

Source: Boadway and Wildasin, p. 528.

AB, reflecting the matching funds provided by the grantor, and returns to h along the segment BC, since matching funds are not provided in this range.

A closed-ended matching grant may have three different outcomes, depending on the preferences of the recipient. If the recipient's preferences are such that its indifference curve is tangent to the budget line at a point along the segment AB (such as at point E_2 on the indifference curve I_2), the recipient is adequately compensated for the spillovers it has created and will provide a socially optimal level of the public good. In this range, the price effect and the income effect are the same as for an open-ended matching grant.

There is no price effect in the BC segment of the budget line, however, and while the quantity of the spillover-generating good is greater than in the pre-grant situation, it is still not the socially optimal quantity. That is, because the funds provided to the recipient are limited by the grantor, the recipient still is not compensated fully for the spillovers it has generated and is still underinvesting in the spillover-generating good. For example, if the recipient jurisdiction's preferences are represented by the indifference curve I_4 rather than I_2, then the recipient would provide more of the spillover-generating good if an open-ended grant were available. Given the limit imposed by the grantor, however, the recipient still does not have an incentive to provide a socially optimal level of the spillover-generating good.

Point B represents an indeterminate corner solution. If the recipient allocates its resources at this point (i.e., if its preferences are represented by the indifference curve I_3), the allocation may represent a socially optimal allocation (the recipient happens to achieve a socially optimal allocation at the end of the AB segment and would not allocate more resources to the spillover good even if more grantor funds were available), or B may represent a socially sub-optimal allocation (the recipient allocates its resources at the end of the BC segment and would allocate more resources to the spillover good if the grant was open-ended (Boadway and Wildasin, pp. 518-29).

This leads to an important observation. If the recipient provides less funds than required to receive the maximum matching grant (i.e., it is located along AB on the budget line), then it is providing the socially optimal level of the public good. If it provides more funds than are required to reach the limit (i.e., the recipient is along BC on the budget line), then it is not providing the socially optimal level of the public good. This is particularly relevant for judging the efficiency of the existing system of agricultural research funding in the United States. States have traditionally provided far more funds than are required to receive their matching Hatch Act funds from the federal government (U.S. Office of Technology Assessment, p. 206; U.S. General Accounting Office, 1983, pp. 37-38). In 1987, for example, the states appropriated an average of 5.68 dollars of state agricultural research funds for each dollar of federal Hatch funds (U.S. Department of Agriculture, 1988, p. 117). This suggests the existing system of closed-ended Hatch Act grants fails to provide adequate compensation to the states for the benefit spillovers they create, thereby resulting in a nationally sub-optimal level of investment in agricultural research.

A final consideration is the impact of benefit spillins on the provision of public goods. Figure 4 shows a jurisdiction, in the absence of grants and spillins, with an equilibrium position of E_1 along its budget line AA' (it is, of course, ignoring any benefit spillovers it may be creating). If it receives benefit spillovers because another jurisdiction provides some quantity of the spillover-generating good, then the budget line of the recipient jurisdiction will shift from AA' to ABB', where A'B' represents the quantity of benefit spillins received. An important result should be noted here: spillovers that are received from another jurisdiction have only an income effect for the recipient, not a price effect. Therefore, receiving spillovers will not induce the recipient jurisdiction to produce the socially optimal level of the spillover-generating good. Thus, even if a jurisdiction produces and receives spillovers, a system of intergovernmental grants may still be required if a socially optimal level of investment in the spillover-generating good is to be achieved (Oates, pp. 97-98).

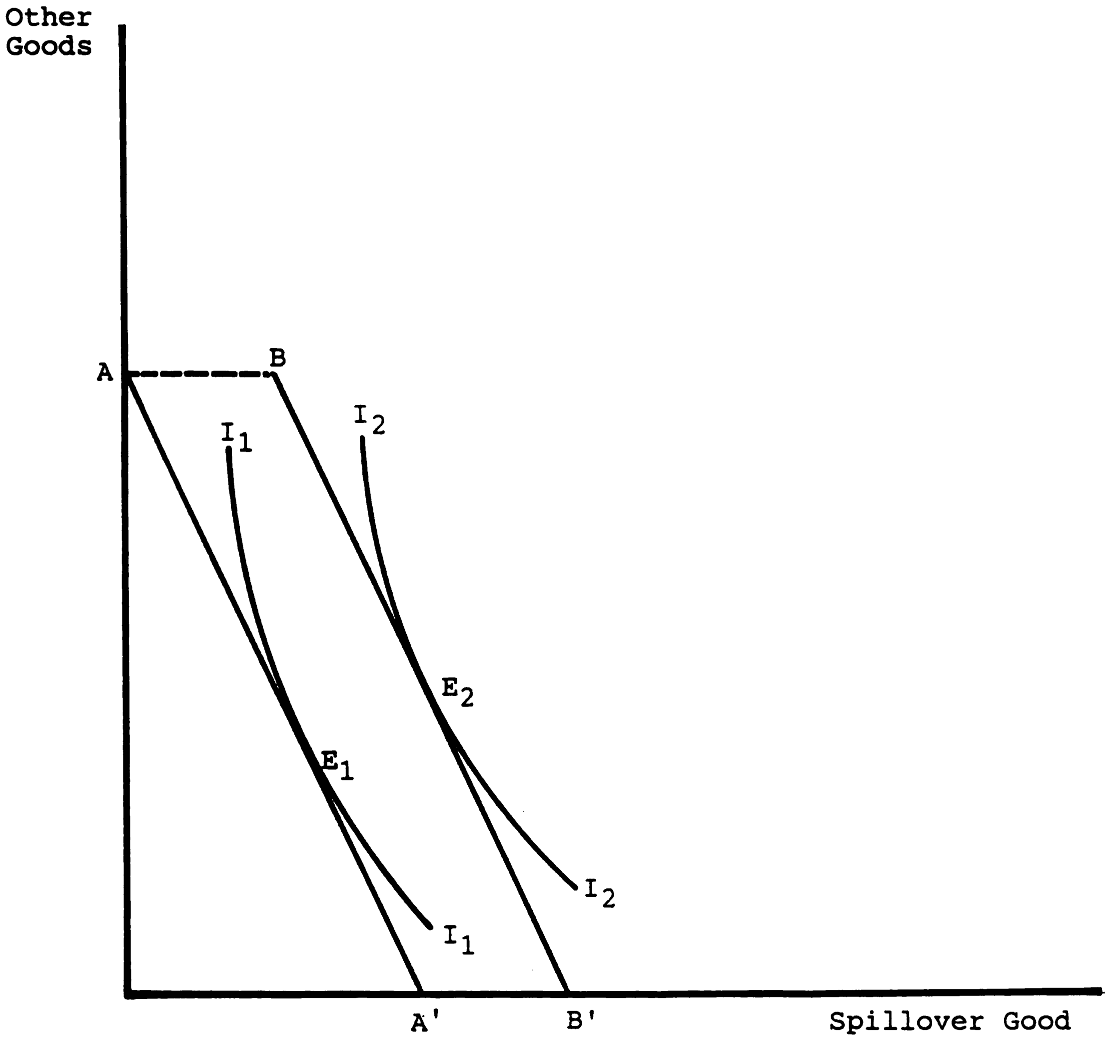

Figure 4: Income Effect of Benefit Spillins

Source: Oates, p. 98.

If a conditional matching grant is to be used to finance a spillover-generating good, the problem of financing such a good now becomes the determination of the appropriate subsidy to be paid by the higher level government to the recipient government (i.e., the determination of the s in the h*[1 - s] budget line slope in Figure 2). A model of intergovernmental grants developed by Harford (pp. 99-103) provides a subsidy from each of two higher levels of government (state and national) to a local government that optimizes the quantity of the spillover-generating public good provided by the local government. Although this model introduces the additional complication of two higher levels of government rather than one, it permits some conclusions to be drawn about the optimal shares of the cost of the spillover-generating good that should be paid by the higher levels of government. These shares can then be translated into the optimal matching rates that can be used to finance the spillover-generating good through a conditional matching grant. The Harford model consists of three equations:

(2.11) $N_1 = a_1 * B(Y) - (1 - s_3 - s_2) * C(Y)$

(2.12) $N_2 = a_2 * B(Y) - (1 - s_3) * C(Y)$

(2.13) $N_3 = B(Y) - C(Y)$, where:

N_1 = The local net benefit equation;

N_2 = The state net benefit equation;

N_3 = The national net benefit equation;

a_1 = The share of the benefits of public good Y retained by the local jurisdiction;

a_2 = The share of the benefits of public good Y retained by the state jurisdiction;

s_2 = The share of the cost of public good Y paid by the state government;

s_3 = The share of the cost of public good Y paid by the national government;

B(Y) = The benefit function for public good Y;

C(Y) = The cost function for public good Y;

$0 \leq a_1 \leq a_2 \leq 1$; and

$0 \leq s_2, s_3 \leq 1$.

The necessary conditions for achieving a socially optimal level of investment in Y are reached by equalizing the marginal cost and marginal benefit that accrues within each level of government. Differentiating equations (2.11) to (2.13) and setting them equal to zero yields the optimal conditions for each level of government:

$$(2.14) \quad a_1 * \frac{dB}{dY} = (1 - s_3 - s_2) * \frac{dC}{dY}$$

$$(2.15) \quad a_2 * \frac{dB}{dY} = (1 - s_3) * \frac{dC}{dY}$$

$$(2.16) \quad \frac{dB}{dY} = \frac{dC}{dY}, \text{ where:}$$

$\frac{dB}{dY}$ = The marginal benefit of public good Y;

$\frac{dC}{dY}$ = The marginal cost of public good Y.

Solving equations (2.15) and (2.16) simultaneously yields the optimal share of the cost of good Y paid by the national government:

$$(2.17) \quad s_3 = 1 - a_2.$$

Solving equations (2.14) and (2.15) simultaneously and substituting (2.17) into the result yields the optimal share of the cost of the good paid by the state government:

(2.18) $s_2 = a_2 - a_1$.

The results correspond to those discussed in earlier literature (e.g., Oates).[9] Namely, (2.18) shows that the state government will compensate the local government for those benefits that spill across local boundaries but remain within state boundaries. Equation (2.17) shows that the federal government will compensate the local government for those benefits that spill across state boundaries.

These cost shares can now be converted into matching rates that, if used to establish an open-ended conditional matching grant, will yield an optimal investment in the spillover-generating good. These matching rates can be calculated as:

(2.19) $m_2 = s_2/(1 - s_3 - s_2)$ and

(2.20) $m_3 = s_3/(1 - s_3 - s_2)$.

Thus, if the federal government grants m_3 dollars to the local government for each dollar the local government invests in the spillover-generating good, and the state government grants m_2 dollars to the local government for each dollar the local government invests in the spillover-generating good, a socially optimal level of the good will be provided by the local government.

Before turning to a review of the economic literature on the returns to agricultural research, a summary of this section is in order. The provision of public goods is an especially difficult problem when decisions are made within a federal (i.e., multi-level) system of government. When a publicly-provided good yields benefits to residents outside the funding jurisdiction, the jurisdiction providing the good will not have an incentive to provide a socially optimal level of the good. As Pigou suggested should be done with individuals, the producing jurisdiction can be given an incentive to provide the socially optimal quantity of the good by providing it a subsidy equal to the difference between the marginal social benefit obtained from the good (including that portion which accrues to outside residents) and the marginal benefit retained by the funding jurisdiction.

In a federal system of government, such a subsidy is typically provided by a higher level government to compensate lower levels of government for the external benefits generated by these jurisdictions. The lowest cost form of such a subsidy is an open-ended matching grant (i.e., a grant of m dollars from the higher level of government for each dollar spent by the lower level government on the spillover-generating good). The matching rate must be established to equate the share of the marginal cost of the good paid by the higher level of government with the share of the marginal benefits of the good that accrue to persons outside the lower level of government.

If benefit spillovers are pervasive in agricultural research, matching grants are clearly an appropriate means through which to finance agricultural research in the United States. The remainder of this chapter will review the methods of measuring the benefits of agricultural research and the evidence that agricultural research does produce such spillovers. The case for using intergovernmental grants to finance agricultural research will then be considered.

The Measurement of Economic Returns from Public Investments in Agricultural Research

This section of the chapter reviews the literature on the ex-post measurement of agricultural research benefits, with special consideration of the measurement of benefit spillovers. The two primary methods of measuring the benefits of agricultural research will be reviewed, and the evidence supporting the hypothesis that the U.S. has traditionally underinvested in agricultural research will be considered. The literature on the measurement of benefit spillovers in agricultural research will then be reviewed and the possibility that benefit spillovers are the cause of the underinvestment problem will be discussed.

Measuring Research Benefits: The Economic Surplus Method

An extensive number of studies have measured the benefits of agricultural research by using measures of economic surplus. This literature originated with the work of Griliches (1958) and has been refined by a number of authors (Willis Peterson, 1967; Hertford and Schmitz; Lindner and Jarrett, 1978 and 1980; Rose; Wise and Fell; Norton and Davis). The approach of this method is shown in Figure 5. Starting with

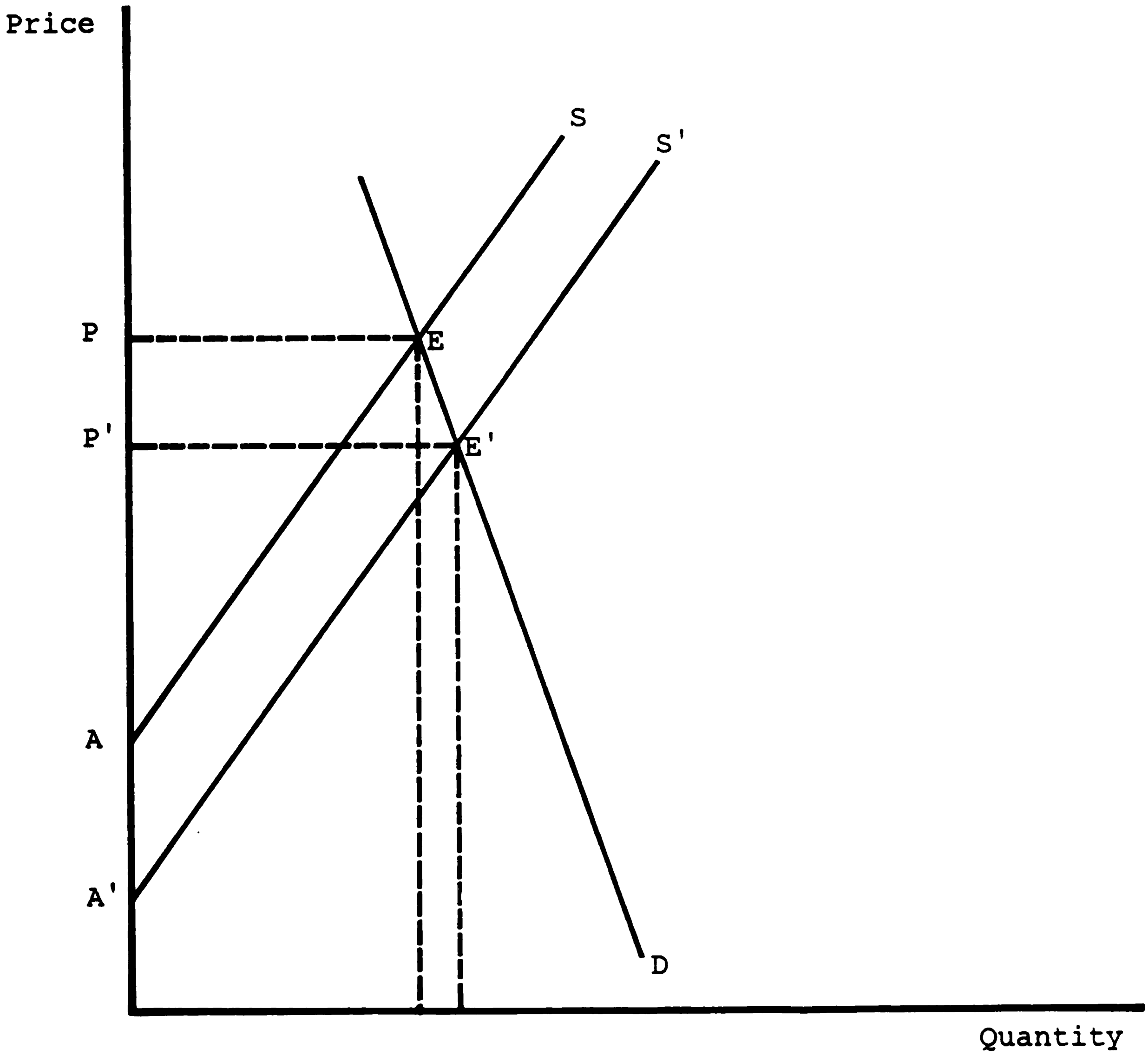

Figure 5: Economic Surplus Generated by a Public Investment in Agricultural Research

Source: Norton and Davis, pp. 686-689.

a commodity supply S and demand D, an investment in public research will shift the supply curve to S', producing a net gain of economic surplus (i.e., the combined net gain of producer and consumer surplus) of the area AEE'A'. Reviewing the literature on a number of economic surplus studies, Norton and Davis (pp. 687-90) derived four formulas for estimating the size of the net economic gain that results from public investments in agricultural research. These formulas are shown in Table 2, along with the authors who developed the formulas and the key assumptions behind their development.

The evolution of this literature has been marked by a number of attempts to improve the accuracy of the estimates and to provide generalized models for estimating the returns to agricultural research. For instance, Griliches' original studies of hybrid corn estimated the limits of the returns to research by assuming the polar cases of (1) a perfectly elastic supply and a downward supply shift due to research (the upper limit), or (2) a perfectly inelastic supply and a rightward supply shift due to research (the lower limit). Later refinements in the theory showed that Griliches' estimates were simply special cases of the Hertford and Schmitz model (with a perfectly elastic supply) and the Lindner and Jarrett and Rose models (with a perfectly inelastic supply). Thus, the more recent models shown in Table 2 provide less restrictive conditions and more accurate estimates than did earlier versions.

Table 2. Formulas for Calculating the Net Economic Surplus Created by Public Research Investments

Author	Formula	Key Assumptions
Hertford and Schmitz	K*P*Q(1 + 1/2(K/n+e))	Demand and supply curves are linear, and the supply shift is parallel. K is a horizontal supply shifter due to research, where K is the horizontal distance from S to S'.
Akino and Hayami	K*P'*Q'(1/(1 + e) + 1/2(K/(e + n)))	Supply elasticity is constant, and the supply shift is pivotal. K is a production function shifter due to research equal to the percentage shift from S to S'.
Lindner and Jarrett; Rose	K*P*Q(1 + 1/2(c*e/(e + n)))	Supply and demand curves are linear, and the supply shift is parallel. K is a vertical supply shifter due to research.
Lindner and Jarrett; Rose	K*P*Q(1/2 + 1/2(c*e*n/(e + n)))	Supply and demand curves are linear, and the supply shift is pivotal. K is a vertical supply shifter due to research.

Where:
P = Equilibrium price before the supply shift;
Q = Equilibrium quantity before the supply shift;
P' = Equilibrium price after the supply shift;
Q' = Equilibrium quantity after the supply shift;
e = Price elasticity of supply;
d = Price elasticity of demand;
c = Absolute cost reduction at Q resulting from research, divided by P

Source: Norton and Davis.

Three factors common to all these models affect the estimated economic benefit generated by agricultural research. First, the elasticities of supply and demand are critical in determining the size and distribution of research benefits. The less elastic are the supply and demand curves, the larger will be the benefits of research, and the larger will be the share of research benefits that accrue to consumers. Second, the total value of the commodity (P*Q in the Hertford and Schmitz, Lindner and Jarrett, and Rose models, or P'*Q' in the Akino and Hayami model) also determines the size of the net economic surplus gain that results from research. Commodities with a larger total value of production will, ceteris paribus, produce larger research benefits. Third, the supply shift factor, K, is a major determinant of net economic benefits and, as shown in Table 2, has been specified in a variety of ways.

Attention must also be paid to the nature of the supply shift that results from research (i.e., the parallel, divergent, or convergent nature of the supply shift). While Figure 5 shows a parallel shift, care must be taken to determine the appropriate form of the supply shift. Recent research has clarified the importance of such shifts and developed the appropriate formulas for estimating returns to research under each type of shift (Lindner and Jarrett; Wise and Fell; Rose).

The choice of the supply shift depends on the nature of the technology resulting from research. If the technology developed is most applicable for those producers with the highest marginal cost and reduces their marginal cost proportionately more than low cost producers, a pivotal or proportional divergent supply shift is most appropriate. On the other hand, if the technology is most applicable to low marginal cost producers, a convergent supply shift should be used. Lindner and Jarrett also recognize that adoption of the technology may be related to farm size, farm specialization, and managerial ability. For these reasons, they argue that biological and chemical innovations will likely produce a divergent shift in supply and that mechanical and organizational innovations will likely produce a convergent shift in supply (Lindner and Jarrett, 1978, pp. 55-57). Thus, it should be noted that the nature of the supply shift is crucial not only to the estimated net economic surplus generated by research, but also to the assumed distribution of that surplus among farmers.

A final comment is required on the normative underpinnings of all economic surplus studies of the returns to agricultural research. The simple addition of consumer and producer surplus represents a normative assumption that places equal weight on the welfare changes experienced by consumers and producers (Boadway and Bruce, p. 281; Sugden and Williams, p.201; Schmid, 1987, pp. 207-208). Such a weighting scheme is defended by some analysts (Harberger, p. 785), and the purpose here is not question the legitimacy of such an assumption, but simply to identify a crucial normative assumption that underlies all such studies and determines, in part, the empirical results obtained in such studies.

Once the net economic surplus arising from research has been calculated, it must be translated into a form that allows it to be compared with other investment opportunities. The most common form for such comparisons is the internal rate of return, defined as the interest rate that equates the present value of the benefits and costs of the research investment (Weston and Brigham, p. 225). In its simplest form, the internal rate of return is the interest rate that solves the equation:

$$(2.21) \quad \sum_{i=1}^{t} \frac{1}{(1 + r)^t} * B = 0, \text{ where,}$$

t =The number of years over which the research investment must be discounted;

B =The net flow of research benefits over years in which the research investment must be discounted;

r = The internal rate of return.

The internal rates of return for a number of economic surplus studies will be examined later in this chapter.

Measuring Research Benefits: The Production Function Method

A second method of measuring the returns from public investments in research uses a production function to measure the contribution of research to agricultural output. Most such models have taken the form:

$$(2.22) \quad Q = f(X, R, e), \text{ where:}$$

Q = The value of agricultural output;

X = A set of conventional inputs;

R = The public investment in agricultural research;

e = A random error term.

Like the economic surplus method, the production function method originated with the work of Griliches (1964) and was refined by later authors (Latimer and Paarlberg; Evenson, 1967; Willis Peterson, 1967; Bredahl and Peterson; Norton, 1981). As with the economic surplus method, these refinements have attempted to achieve increased sophistication and precision in the estimates of research benefits.

Griliches' early work with this method used state-level cross-section data that measured agricultural output and conventional inputs on a per-farm basis and measured research investment as the state's one year lagged expenditure or two year average expenditure. Latimer and Paarlberg used simple 4, 8, and 12 year sums of state research expenditures. Evenson (1967) and Fishelson added more sophisticated lag structures to the research variable.

The lag structure of the research variable is a critical component of the production function approach, since four factors can be expected to cause the impact of research on output to vary over time. First, there may be a lag from the time funds are invested in research until the time scientists produce results. Second, there may be a lag from the time scientists produce results until the results can be adapted to the needs of farmers in a given location. Third, there may be a lag from the time usable results are available until the time farmers adopt the results and output is affected. Fourth, there may be a depreciation of the knowledge as ecological factors (such as pests, weeds, or diseases) erode the effectiveness of the knowledge. Given such factors, the effect of research on output (i.e., the benefits of research) would likely be small in the years immediately following the initial investment, would increase as the results are produced by scientists and adopted by farmers, and would begin to decline as the knowledge becomes obsolete.

Evenson (1967) developed an "inverted-V" lag structure that estimated a mean time lag of 6 to 7 years between an increase in research expenditures and the maximum effect of research on agricultural output. His results indicated that an agricultural research investment in year t had a positive and increasing effect on agricultural output until the year t+6 or t+7, then decreased until reaching zero in the year t+12 or t+14. Fishelson used an "inverted-U" lag structure that increased the impact of research on output from the year of investment until ten years after the investment, then returned to zero sixteen years after the investment.

It should be noted that some studies have used national or regional time-series data rather than state cross-section data to estimate equation (2.22) for aggregate output (Bauer and Hancock; Havlicek and White, 1983a; White and Havlicek, 1979). Except for Bauer and Hancock (who found that a constant 9-year lag was more appropriate than an "inverted-V" or "inverted-U" lag structure) these studies used some form of an "inverted-V" lag structure (often an Almon lag structure) to measure the effect of past research expenditures on current agricultural output.

A second production function approach uses time series data to estimate the equation:

(2.23) $P = f(W, E, R, e)$, where:

P = A productivity index;

W = A weather index;

E = A measure of the education level of farmers;

R = A measure of the level of research investment;

e = A random error term.

Two of the most comprehensive studies of agricultural research benefits have used this "productivity decomposition" method. Lu, et al. used a productivity index model to estimate national and regional rates of return. They also used the Almon lag method to estimate an "inverted-U" lag structure for the research variable. Their results showed that a 13 year-lag was most appropriate at the national level and that regional lags ranged from 9 to 14 years. Evenson, et al. (1979) estimated a number of productivity index models with alternative formulations that measured the effect of research on productivity as well as the interaction between research and extension activities.

Once the production function has been estimated, it is again necessary to translate the results into terms that compare the return to agricultural research investments with

other investment opportunities. This is done in two steps (Davis, 1981a). First, the marginal product of research is calculated using the research production coefficient(s) from the estimated production function. Second, this marginal product is converted into a marginal internal rate of return (i.e., the interest rate is found that equates the discounted benefits and costs of research that accrue over time, as shown in equation 2.21). The results of several returns to research studies will be examined in the following section.

Estimates of the Rate of Return on Public Agricultural Research Investments in the United States

As discussed in the previous section, a wide variety of methods have been used to estimate the benefits of agricultural research spending in the United States. The results of several such studies are summarized in Table 3.

When viewing these results, the immediate observation is that, despite a series of refinements in the measurement techniques, the rates of return on agricultural research investments have remained high when they are measured over a wide variety of time periods and commodities. A number of criticisms have been leveled at this literature, however, and, to the extent that the critics are correct, the estimated rates of return must be interpreted with caution.

First, it has been argued that the returns to research literature has ignored the complementarity between research and other inputs, thereby exaggerating the returns to research (Pasour and Johnson, p. 305). Glenn Johnson has argued that

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Table 3. Results of Studies Measuring the Benefits of Agricultural Research Investments in the United States

Author	Level	Commodity	Years	Internal Rate of Return (Percent)
__Economic Surplus Studies__				
Griliches (1958)	National	Corn	1940-1955	35-40
Griliches (1958)	National	Sorghum	1940-1957	20
Peterson (1967)	National	Poultry	1915-1960	21-25
Schmitz and Seckler	National	Tomato, with no compensation for displaced workers	1958-1969	37-46
	National	Tomato, with 50% compensation for displaced workers	1958-1969	16-28
Peterson and Fitzharris	National	Aggregate	1937-1942	50
	National	Aggregate	1947-1952	51
	National	Aggregate	1957-1962	49
	National	Aggregate	1957-1972	34
Cooke	National	Cucumber	1965-1980	55-75
__Production Function Studies__				
Griliches (1964)	National	Aggregate	1949-1959	35-40
Peterson (1967)	National	Poultry	1915-1960	21
Evenson (1967)	National	Aggregate	1949-1959	47
Fishelson	National, Non-South	Aggregate	1949-1964	39

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Table 3 (cont'd.).

Author	Level	Commodity	Years	Internal Rate of Return (Percent)
Bredahl and Peterson	National	Cash Grains	1969	36
	National	Poultry	1969	37
	National	Dairy	1969	43
	National	Livestock	1969	47
White and Havliceck (1979)	Southern Region	Aggregate, not accounting for spillins from other regions	1949-1972	51
		Aggregate, accounting for spillins from other regions	1949-1972	39
Lu, Cline and Quance	National	Aggregate	1939-1972	26
	Ten Regions	Aggregate	1939-1972	14-44
Evenson, Waggoner, and Ruttan	National	Aggregate	1868-1926	65
	National	Aggregate, technology-oriented	1927-1950	95
	National	Aggregate, science-oriented	1927-1950	110
	National	Aggregate, science-oriented	1948-1971	45
	Southern Region	Aggregate, technology-oriented	1948-1971	130
	Western Region	Aggregate, technology-oriented	1948-1971	95
	Northern Region	Aggregate, technology-oriented	1948-1971	93
	National	Farm management and extension	1948-1971	110

(Continued)

Table 3 (cont'd.).

Author	Level	Commodity	Years	Internal Rate of Return (Percent)
Sim and Araji	Western Region	Wheat	1939-1974	11-29
	National	Wheat	1939-1974	38-45
Sundquist, Cheng, and Norton	23 states	Corn	1977	115
	34 states	Wheat	1977	97
	26 states	Soybeans	1977	118
Davis and Peterson	National	Aggregate	1949	100
	National	Aggregate	1954	79
	National	Aggregate	1959	66
	National	Aggregate	1964	37
	National	Aggregate	1969	37
	National	Aggregate	1974	37
Norton (1981)	National	Cash Grains	1969	31-57
	National	Cash Grains	1974	44-85
	National	Dairy	1969	27-50
	National	Dairy	1974	33-62
	National	Livestock	1969	56-111
	National	Livestock	1974	66-132
	National	Poultry	1969	30-56
White and Havlicek (1981)	Ten regions	Aggregate	1949-1972	31-61
Havlicek and White (1983a)	Ten regions	Aggregate	1977-1981	23-74

(Continued)

Table 3 (cont'd.).

Author	Level	Commodity	Years	Internal Rate of Return (Percent)
Smith, Norton and Havlicek	National	Poultry	1978	25-60
	National	Livestock	1978	22-43
	Northeast Region	Dairy	1978	24-38
Braha and Tweeten	National	Aggregate	1959-1982	41-58

Source: Ruttan, 1982a, pp. 242-43, updated by author.

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productivity growth results from not only from technological innovations, but also from institutional innovations and improvements in human and bio-physical capital, and that investments in all four are required to achieve improvements in productivity (Glenn Johnson, 1986a, pp. 21-27). The complementarity of institutional and technological change was demonstrated by Ulrich, et al. (1987), whose results show that the returns to agricultural research investments are reduced when institutional barriers prevent the adoption of new technologies.

Glenn Johnson's view is also confirmed by the studies of investments in human capital in agriculture, which estimate equally impressive rates of return for public education and extension investments (Welch; Huffman, 1976a; 1978; Evenson, et al., 1979) and for publicly-provided price information on farm commodities (Hayami and Peterson). However, a number of research investment studies (particularly production function studies) have attempted to address this problem by including education and agricultural extension as separate variables or by using the sum of research and extension expenditures as the "research" variable. Evenson, et al. (1979, p. 1105), for example, included an interaction variable for research and extension investments and did find the two had a positive and significant interaction. While care must be taken to consider the complementarity of such investments, the greater problem seems to be in communicating the true results of these studies. While the results of these studies do indicate a strong complementarity between such investments, the results have too often been used to imply that all productivity growth is the result of technological change. The authors of this literature have not reached such conclusions and have often emphasized that other sources of productivity growth are deserving of investigation (Ruttan, 1982a, p. 298-330; Norton and Schuh; Bonnen, 1987, pp. 268-270).

A second criticism is that the economic surplus studies are sensitive to the nature of the supply shift that results from investment in research and that both types of studies must account for the lags in the accumulation, dissemination, and obsolescence of knowledge (Pasour and Johnson, pp. 303-307). Again, researchers have sought to address these criticisms. For instance, while the size of the net economic surplus measured is affected by the type of supply shift employed, it must be noted that most studies have used a divergent supply shift which, if inaccurate, would err in the direction of underestimating the rate of return (Ruttan, 1982b, p. 321). Furthermore, Davis (1981b) demonstrated that the use of a Cobb-Douglas production function is the equivalent of estimating a pivotal divergent supply shift. Since most production function studies have used a Cobb-Douglas specification, any bias introduced by this method of estimation would be in the direction of an underestimation of the rate of return on agricultural research. Finally, Davis (1981a) also found that most errors that have been made by improper deflation of the research and output variables have resulted in a slight underestimation of the rate of return. While the problem of estimating an appropriate lag between research investment and the affect of research on output is important, the previous section has already shown that numerous methods have been used to estimate the types of lags described by Pasour and Johnson.

A third criticism is that past studies have ignored the contributions of private research investments, thereby biasing the rates of return on public research upward (Pasour and Johnson, p. 305). While this is a problem, it has not been ignored by investigators. Two methods have been used to adjust rate of return estimates and account for private research investments. The first method has been to reduce the estimated research benefits by 1/2 (or 2/3 if public extension investments are not included in the model), based on the assumption that private research investments are approximately 1/3 of total public and private research and extension efforts (Bredahl and Peterson). A second method, developed by Evenson, uses a smaller adjustment to reflect the inclusion of the cost of private research in the prices of inputs purchased by farmers. Evenson (1967) estimated that the omission of a private research variable would bias public investment rate of return estimates upward by a factor of 1.22 and that such estimates should therefore be adjusted downward by this factor. While such adjustments are somewhat crude, it should be stressed that larger adjustments would make the assumption that private sector research is significantly more productive than public sector research. Even if such an assumption were justified, it should be noted from Table 3 that very large adjustments would be required to reduce the estimated rates of return to the point where the underinvestment hypothesis would no longer be valid.

A fourth criticism is that the returns to research literature has focused on a select number of success stories that cannot be used to predict the rate of return on future investments (Pasour and Johnson, p. 307). If one only considers the original work of Griliches on hybrid seed corn, such criticism might be justified. Considering the large number of commodities that have been studied, however, this criticism loses some of its validity. In addition, if one considers the rate of return estimates for aggregate output (which, by definition, include both research successes and failures) the evidence continues to show a high rate of return on public agricultural research investments (Ruttan, 1982b, p. 320).

A fifth criticism of such studies is that they have ignored the social cost of taxation to support public agricultural research, thereby biasing the returns to research upward (Fox, 1985b, 1985c). Analysis which included such tax costs, however, still reached the conclusion that the U.S. was underinvesting in agricultural research (Fox, 1985a, pp. 46-50).

A sixth criticism of the returns to research literature is that it has failed to account for the social costs created when agricultural research contributes to the excess capacity of the agricultural sector and increases the cost of government commodity programs (Madden, p. 35). A study by Braha and Tweeten (pp. 24-27) found that public agricultural research was underfunded even after deducting the full social cost of commodity programs. Furthermore, it must be noted that some of the excess capacity in U.S. agriculture must be traced to unstable commodity policies, macroeconomic events, or resource adjustment problems in agriculture (i.e., asset fixity) rather than public research investments. Thus, assigning the full cost of commodity programs to public agricultural research could result in a downward bias in the estimated rate of return on research.

A final criticism is that the literature has been based almost exclusively on partial equilibrium analysis and has ignored substantial redistributive effects that result from research investments. This criticism is more serious than many others. Clearly, some of the effects of technological change on farm workers, the environment and the structure of agriculture are factors that must be considered in a full accounting of the returns to research (Pasour and Johnson, p. 305). The study of tomato mechanization research by Schmitz and Seckler, for instance, found that the net social rate of return on such research would have been negative if displaced workers had been compensated for all lost wages (assuming the lowest possible cost reduction due to research). A study of cu

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cucumber mechanization reached a similar conclusion (Cooke, p. 331).

Caution must be exercised, however, in placing the entire burden of labor displacement on mechanization research. Martin and Olmstead (pp. 602-606) maintain that tomato production would have shifted to Mexico without the development of mechanized harvesters and that the harvester preserved jobs in the tomato input and processing sectors. They also concluded that other research, which lengthened the harvest season for some crops, increased the demand for farm labor. Similarly, a study of cotton mechanization revealed that 79% of the labor that left cotton harvesting operations between 1930 and 1964 could be traced to higher wages in the non-farm sector; only 21% could be traced to a reduced demand for labor arising from cotton mechanization (Willis Peterson and Kislev, p. 214). As these studies demonstrate, any accounting of the effects of agricultural research on farm labor markets must take care to reflect its labor-displacing effects rather than its labor-replacing effects.

Benefit Spillovers in Agricultural Research

Ruttan (1982a, pp. 254-58) has given two reasons for the continued high rates of return on public agricultural research investments. First, he argues that the decentralized system of state agricultural experiment stations has created fifty "firms" whose supporters, primarily the farmers of the state, demand that the station provide research results that keep them competitive with farmers in other states. The station director, facing this competitive pressure, must allocate the state's research funds efficiently or face the displeasure of farmers and legislators. While this may be true, it cannot explain the apparent continuing underinvestment in research since, if legislators were aware of the high rate of return, they would presumably reward the efficiency of the station director with increased funding.

A more likely explanation for this continuing underinvestment is the spillover of research benefits across state boundaries. Ruttan identifies two ways in which spillovers may occur. First, benefits may spill across state lines in the form of lower food prices for consumers. Second, benefits may spill across state lines as farmers in other states adopt the technology developed in the funding state.

As the formulas in Table 2 have shown, the net gain in economic surplus that results from research investments will be larger when the supply and demand for the commodity are inelastic. Most agricultural commodities have such elasticities. When this is true, however, most of the gain in economic surplus will accrue to consumers in the form of lower food prices. The gains that accrue to farmers will often be short-lived and will usually accrue to those astute farmers who adopt the new technology soon after its introduction (Ruttan, 1982a, pp. 257-58). Since many of the gains in consumer welfare will accrue to persons outside the funding state, there will be, to use Breton's phrase, an "imperfect mapping" of the benefits of research. The public finance literature reviewed earlier in this chapter indicates that this condition is a potential source of underinvestment in public goods.

The second source of spillovers, the adoption of the new technology by farmers outside the funding state, could also contribute to the underfunding of research. While the results of research may be applicable to the environmental conditions of the funding state, it is unlikely that they could not be used or adapted for use in other states. The early work of Griliches (1957, 1960) found that the percentage of corn acreage planted with hybrid seed corn took an "S-shape" over time in nearly every state, with some states lagging behind the early-adopting states. The date of introduction of hybrid corn to a state was explained by the profitability of entry into the state (where profitability was measured by the density of production in the state and the cost of research and marketing in the state) (Griliches, 1957, pp. 506-15). The rate of adoption of hybrid corn by farmers in a state (i.e., the slope of the S-curve) was determined by the profitability of switching from open-pollinated corn to hybrid corn (Griliches, 1957, pp. 515-19). Thus, the technology of hybrid corn tended to spill from high density, high profitability states (e.g., Iowa) into lower density, lower profitability states (e.g., Alabama). A similar pattern of adoption was observed for such mechanical technologies as grain combines, cornpickers, balers, and field forage harvesters (Griliches, 1960, p. 276).

More recent studies have also examined the production spillovers created by agricultural research. Araji's survey of scientists and extension specialists indicated that the results of integrated pest management research could be adopted in many states outside the state in which the research was conducted, thereby suggesting the potential for benefit spillovers to arise. On the low end of the estimates, researchers indicated that 16% of the soybean acres in Kansas, Nebraska, and South Dakota could adopt the results of research conducted in Indiana. At the high end of the estimates, scientists indicated that research results could be adopted on 100% of other states' acreage for a number of commodities. The results of alfalfa pest management research conducted in Indiana, for example, could be adopted on 100% of the alfalfa acres in Ohio, Michigan, Illinois, Wisconsin, Minnesota, and Nebraska. Research conducted in California on grapes, apples, and pears could be applied to 100% of these crops produced in a large number of western, midwestern, and northeastern states. Peppermint research conducted in Michigan could be applied to 100% of the acreage planted in Indiana, Idaho, Oregon, and Washington (Araji, pp. 124-31).

Similarly, a study of wheat research (Dalrymple, p. 63) found that 38% of the 1974 U.S. wheat acreage planted in publicly-developed dwarf varieties was planted with varieties developed in other states. The share is even higher for major varieties. For instance, 90% of the acres planted to the Blueboy variety were in twenty states other than the state that developed the variety (North Carolina). Similar spillovers occurred with other wheat varieties: 74% of Caprock acreage (developed in Texas), 71% of TAM W-101 acreage (developed in Texas), and 65% of Twin acreage (developed in Idaho) was planted outside the state that developed the variety.

Schultz (1982, p. 182) has also argued that there are likely to be significant spillovers between commodities, such as the benefits that accrue to livestock producers and consumers from research investments that reduce the price of feed grains. Lyu and White confirmed this by using an economic surplus model to estimate the spillovers from corn research to livestock and poultry markets. Their results indicated that corn research benefits were underestimated by 26% when inter-commodity spillovers results are ignored.

The returns to research literature has used various methods to estimate the spillovers of agricultural research benefits. White and Havlicek (1979) estimated a time series production function model that included separate research variables for research conducted inside and outside the southern region of the United States. Their results indicated that the marginal internal rate of return on research conducted in the southern region declined from 50% to 39% when the outside research variable was included.

Otto and Havlicek estimated production function models for corn, wheat, and sorghum and included an outside research variable (defined as the total research expenditure of the top five national producers of the commodity) to capture the effect of research spillovers. The spillover variable was significant in only the wheat equation. Sundquist, et al., on the other hand, ran production function models for wheat, corn, and soybeans that did produce significant results for the research spillover variable. In their models, the research spillover variable was defined for soybeans as the research investments in all states at the same latitude, and for corn and wheat as the research investments of all neighboring states. Norton (1981) updated Bredahl's research and also ran production function models for dairy, livestock, poultry, and cash grains that included a research spillover variable based on the research investments in similar geoclimatic regions. The spillover variable was insignificant in each case. Davis (1979, p. 95) used a similar geoclimatic specification in a production function model of aggregate output. Again, the results for the spillover variable were insignificant.

Three studies have attempted to examine spillovers on an national aggregate basis. The first, a productivity model estimated by Evenson, et al. (1979; also see Evenson, 1980), used a research spillover variable based on investments in similar geoclimatic regions and subregions. Their research variable for each state was defined as:

(2.24) $R = A(a,b,c) + s*S(a,b,c) + f*F(a,b,c)$, where

R = Total research investment applicable to agricultural production in state i;

A = Research investment made by state i;

S = Research investment made in other states in the same geoclimatic subregion as i;

F = Research investments made in other states in the same geoclimatic region as i;

s and f = "Contiguity parameters" estimated to indicate the share of the research conducted in other states that was applicable to state i;

a, b, and c = "Time shape parameters" estimated to indicate the rising (a), constant (b), and declining (c) impact of research on state i's productivity.

Evenson (1980, pp. 200-206) then ran partial correlations between the research variable R and a state productivity index for various values of s, f, a, b, and c to find the highest correlation. The specification of the research variable was then based on the combination of contiguity and time shape parameters that provided the highest correlation between productivity and research. Using these parameters, Evenson ran a time-series productivity index model similar to that shown in equation (2.23). His results indicated that 67% of the marginal benefit of research accrued inside the funding state in the southern and western regions, and 44% of the marginal benefit accrued inside the funding state in the northern region (Evenson, et al., 1979, p. 1105; Evenson, 1980, p. 211).

The second national study (Ziemer, et al.) used an economic surplus model to estimate the total national net gain from a 10% increase in research spending. Ten regional supply and demand equations were derived using each region's share of total agricultural production and population, respectively. These regional equations were then used to determine the economic surplus that accrued inside and outside each region from research conducted in that region. As expected, their results showed that substantial portion of research benefits spill across regions. At one extreme, the Northeastern region retained 68% of the average benefit of its research; at the other, the Northern Plains region retained only 2% of the average benefit of research conducted in the region. Comparing these estimates to the share of research funded by the federal government in each region, they conclude that insufficient compensation for spillovers is an important cause of underinvestment in agricultural research.

The final national study estimated a production function using pooled time-series/cross-section regional data that included variables for research inside and outside each of the ten USDA production regions (Havlicek and White, 1983a). After calculating the total benefit spillovers that resulted from research, these spillovers were allocated among the regions based on each region's share of the total national research investment. Their results indicated that, at one extreme, the Northeastern region retained 23% of the total benefits produced by its research investment. At the other extreme, the Corn Belt region retained 58% of the total benefits generated by its research. Comparing each region's share of spillovers with the share of its research funded by the federal government, Havlicek and White concluded that only the Corn Belt was compensated adequately for the benefit spillovers it created. Comparing these results to those of their earlier research (White and Havlicek, 1980), they concluded that the undercompensation problem had worsened since 1972.

While the results of the latter two studies do suggest that the federal government is not providing adequate compensation for research benefit spillovers, their results were not appropriate for use in a public finance framework. As emphasized by the public finance literature, the appropriate criterion for judging the adequacy of the existing research funding system must be the share of the marginal benefit of research that spills across state lines and the share of the marginal cost of research paid by the federal government. Neither of these studies provided the results necessary to make such a comparison. Evenson's study (1980) does provide such results on a regional basis, but does not incorporate the results in a public finance framework to determine an optimal system for financing research.

The Role of Intergovernmental Grants in Financing Agricultural Research

Should agricultural research be financed through a system of intergovernmental grants from the federal government to the states? This section will address this question in two parts.

First, the general case for public support of scientific research will be examined. Second, the unique character of agricultural research will be examined and the case for intergovernmental support of agricultural research will be considered.

Arrow (pp. 609-15) cited three reasons why a perfectly competitive market may not lead to a socially optimal allocation of resources. First, uncertainty may exist in production relationships of some goods. Second, the consumption of some goods may be indivisible. Finally, the producers of some goods may not be able to appropriate the market price of their products because they cannot prevent non-paying users from consuming the goods.

Arrow argued that all three of these conditions apply to scientific research. Uncertainty poses two deterrents to obtaining a socially optimal level of research investment in a competitive market. First, since the outcome of research is unknown, inventors may underinvest in research if they cannot shift some of the risk associated with research to those persons willing to assume such risk. Arrow discusses an idealized system of "commodity options" in which inventors wishing to shift risk and investors wishing to assume risk can reach an optimal allocation of risk-bearing, but contends that such arrangements rarely exist in a real economy. While institutions such as insurance policies and stock markets exist to promote risk sharing, they may be inadequate in the case of research, which, according to Arrow, involves a unique moral hazard. Since the success of research is related to "an inextricable tangle of objective uncertainties and decisions of the entrepreneurs," it is almost "certainly uninsurable" (Arrow, p. 613).[10]

The second deterrent posed by uncertainty is that the demand for research may be reduced by the uncertainty of buyers as to the usefulness of the knowledge. Buyers cannot know the value of the research until they have the information, but then the users will have acquired the knowledge and will have little incentive to provide adequate compensation to the inventor. As a result, the demand for research may, according to Arrow (p. 617), be less than socially optimal. Thus, Arrow concludes that uncertainty on both the demand side and the supply side may prevent research investments from reaching a socially optimal level.

A second problem is that the results of research may be indivisible. That is, once the research is conducted and results produced, the cost of transmitting the knowledge to an additional user is very low. Thus, from a social perspective, the knowledge should be made as widely available as possible, since the marginal social benefit will nearly always exceed the marginal social cost of its distribution. To make knowledge this widely available, however, gives rise to the problem of inappropriability and raises the problem of equitable cost-sharing among users.

If an inventor has a monopoly on his knowledge, he may indeed seek to extract a price for sharing that knowledge with buyers. In doing do, however, he must reveal the knowledge to buyers who may then refuse to compensate the seller or may who pass the information on to other buyers (either intentionally or simply by having other buyers observe the initial buyer's use of the knowledge). The spread of information may break the monopoly and prevent the inventor from appropriating a return from many users of his results. Legally imposed property rights, such as patents, can only partially solve this problem, since there may be difficulties in determining the exact source of a piece of knowledge (Arrow, p. 614-15). Thus, Arrow concludes that a perfectly competitive market will underinvest in research because of the product's risky nature, because of the increasing returns to its use, and because producers may not be able to protect their monopoly over the knowledge produced. Because of these conditions, he concludes that public provision of scientific research may be justified.

Some economists do not share Arrow's view that research has the characteristics of a public good. Hirshleifer, for instance, argues that Arrow's analysis omits the possibility of speculative gain by inventors and, as a result, Arrow underestimates the returns available to private inventors and overstates the case for publicly-funded research. As an example, Hirshleifer (p. 571) argues that Eli Whitney, who fought to protect his patent on the cotton gin, would have been better served by speculating in the pecuniary effects of his invention on the prices of cotton, slaves, land, and warehousing and transportation facilities. Had he done so, Hirshleifer contends, Whitney would have been compensated adequately for his invention. Hirshleifer then concedes, however, that such speculation may be difficult since: (1) the limited wealth of the inventor may prevent him from engaging in such speculation; (2) the cost of establishing markets for such speculation may be large when large numbers of parties are involved; (3) by engaging in speculation, the inventor may reveal his knowledge to other speculators, thereby reducing his speculative profits; and (4) the inventor may not be able to insure himself against other risks that may negate the pecuniary effects of his invention. Given these constraints on the inventor's speculative gains, Hirshleifer concludes, public support of research may be justified.

Demsetz is critical of all three of Arrow's arguments in favor of public support of research. First, Demsetz (pp. 2-14) argues that we cannot conclude that the absence of risk-bearing institutions in the economy implies that inefficiency exists, because their absence may result from the cost of insurance exceeding its benefits. Second, the problem of indivisibility arises "only when the costs of contracting are relatively large" (but he concedes that indivisibility will lead to underinvestment when contracting costs are large). Third, he argues that the inappropriability of research is a problem of poorly designed and enforced legal arrangements.[11]

Similarly, Pasour and Johnson argue that agricultural research does not qualify as a public good. While they concede that research is indivisible, they contend that research is not inappropriable, since patents and copyrights can be used to protect the inventor's interest (Pasour and Johnson, p. 310). This view of industrial research is shared by Scitovsky (1954, pp. 144-45). It must be noted, however, that Scitovsky believed agricultural research was a special case that did require public funding (presumably because of the atomistic nature of farming). This solution to the underinvestment problem is best expressed by von Mises (p. 658), who viewed the problem of inappropriability as a "consequence of loopholes left in the system" of public property that can be corrected "by rescinding the institutional barriers preventing the full operation of private ownership."

This view ignores the fact that the establishment of a patent system involves a trade-off of benefits and costs (Hirshleifer and Riley, p. 1404). Namely, a patent system provides the benefit of greater research investment (by providing a means of appropriating the benefits of research) at the cost of worsening the underutilization problem (by pricing information at a level above its marginal cost of zero, a patent system imposes a loss of welfare on society).

Machlup (1968, pp. 470-71) examines a broad set of benefits and costs arising from a patent system. The benefits of a patent system include the development or early introduction of inventions that would not have been introduced or would have been delayed if the patent system had not existed. The costs include: (1) the increased research and development costs incurred by the inventor; (2) the loss of output due to limited use of the patented invention; (3) the loss of output that may result if the patent owner uses the power granted by the patent monopoly to strengthen its market power in other areas; (4) the loss of output that may result if the patent owner uses patents of associated inventions to extend the power granted by the original patent, thereby delaying entry by other firms beyond the life of the original patent; (5) the cost of resource reallocation that may result when new inventions cause accelerated obsolescence of existing physical and human capital; and (6) the administrative and legal costs that result from granting and defending patents.

Nordhaus (1969, pp. 76-89 and 1972; Scherer, 1972) considers a narrower set of costs and benefits associated with a patent system and develops a model of optimal patent life length which equates the marginal cost of the patent system (measured as the consumer surplus loss that occurs due to the restriction of output during the life of the patent plus the cost of research) with the marginal benefit of the patent system (measured as the producer and consumer surplus created by the cost reductions resulting from the additional research stimulated by lengthening the patent life). His results indicate that a fixed-life patent system may impose welfare losses on society by providing excessively long patent protection for most inventions. To avoid such losses, he prescribes a variable-life patent system that would base each invention's patent life on its research costs, riskiness, cost-reducing effect, imitation costs, and market structure (Nordhaus, 1972, pp. 430-31). It should be noted, however, that such a patent system would increase the cost of administering the system.

More relevant for this research, however, is the question of whether a patent system is capable of providing a socially optimal level of agricultural research investment. Villard (p. 488) argues that, even with a patent system, predicting the private benefits of some research, including some applied research, is so difficult that private firms will be unwilling to accept the risk of investing in research. Even abstracting from the risk of research, however, underinvestment in research may still persist under a patent system.

Usher used production-possibility curves and indifference curves to demonstrate that underinvestment will persist when the benefits of research are shared by consumers. Arrow (pp. 619-22) used a model of private profit maximization to arrive at a similar result, or, at the very least, to conclude that a patent system will bias private research efforts toward those activities that are easily appropriable. This implies that a patent system may be effective at stimulating investment in minor innovations that provide small cost savings to producers without affecting total output, but may be ineffective at promoting optimal investment in research for those major innovations that provide substantial cost savings and increased total output (i.e., a patent system may not provide optimal investment when a large share of the benefits of research accrue to consumers rather than the inventor).[12]

This view of the patent system has been confirmed by estimates of the divergence between the private and social rates of return for several industrial innovations (Mansfield, et al., 1977a, pp. 221-40; Mansfield, et al., 1977b, pp. 144-89; Willis Peterson, 1976; Bresnahan; Jaffe; Ulrich, et al., 1986; Martinez and Norton).[13] The work of Mansfield, et al., for example, shows not only that the median social rate of return exceeded the median private rate of return for the seventeen innovations studied (56% to 25%, respectively), but that this divergence was positively and significantly related to the "importance" of the innovation (measured as the annual net social benefit of the innovation three years after its introduction). This result suggests that the divergence between social and private rates of return will be the greatest and, therefore, the problem of underinvestment most severe, for those inventions that provide a large share of their benefits to consumers rather than to inventors.[14]

While Demsetz and Pasour and Johnson do force a clarification of the issues at hand, the conclusion can still reached that there is a role for public support of research. They may be correct that the problem of inappropriability can be overcome by a fully enforced set of patents, but they fail to recognize that the correct comparison is between the costs and benefits of such a patent system and the costs and benefits of a publicly-funded research system.

As Machlup (1984, pp. 133-34) has observed, the proper role for public and private sector research can only be determined by comparing the relative inefficiencies of the tax burden of public research with those of the monopoly burden of private research (i.e., the inefficiency created by pricing knowledge above its marginal user cost of zero). When one considers the transaction costs of enforcing a patent system that identifies the source of each piece of knowledge, the beneficiaries (including consumers) of that knowledge, and the correct compensation due to its owner, the case for publicly-funded research is strengthened. This is particularly true as the number of users and producers of knowledge increases and the transaction costs of patent enforcement increase.

A final word on the justification of publicly-funded research is offered by Nelson (1959). He raises the question: Is it possible that the total public and private research investment exceeds the socially optimal level? Assuming that (1) research results are homogeneous, hence users of research are indifferent between the results of public and private laboratories; (2) the marginal cost of research is equal in public and private laboratories; and (3) private laboratories operate where their marginal cost equals their marginal benefit, then the fact that industry laboratories perform any research is evidence that there is underinvestment in research. If this were not true, there would be no incentive for the private sector to conduct research; it would merely use the results of public research (Nelson, 1959, p. 304).

If there is a case for public funding in some areas of research, what evidence is there that agricultural research should be funded jointly by the federal government and the states? The answer to this question relies mainly on the unique nature of agricultural research.

Unlike some types of research, agricultural research, particularly at the applied end of the research spectrum, is often "soil specific, crop and plant specific, animal production specific, market specific, and location specific" (Schultz, 1985, p. 15). For instance, the climatic conditions conducive to cherry production are significantly different from those conducive to corn or cotton production. Thus, there is often a need to do commodity-specific research in the same climate where the commodity is grown. This is particularly true when researchers are dealing with such factors as weeds, pests, and diseases or are adapting plants to the growing seasons of specific regions. While it is conceivable that such conditions could be approximated at locations far removed from the production region (say, in greenhouses) such efforts would only come at a high cost of facilities and a high risk of error.[15]

There may also be other advantages to a decentralized system of research that places researchers in contact with farmers and keeps researchers informed of the problems faced by producers of particular commodities. Gershinowitz (pp. 149-50) contends that such a decentralized system will speed the adoption of innovations, while Harry Johnson (1965, p. 138) contends that such a research system will respond more rapidly to the changing needs of research users. As Stigler (1957, p. 213) has noted, a federal system of government provides a greater capacity to adapt public goods to local needs and to "allow legitimate variations of types and scales of governmental activity to correspond with variations in the preferences of different groups of citizens".[16]

There is some empirical evidence that the decentralized U.S. system of agricultural research does indeed operate as suggested by Gershinowitz, Stigler, and Harry Johnson. First, the available evidence indicates that the demand for agricultural research comes primarily from farmers and, in particular, from those farmers most likely to be early adopters of the research results (Willis Peterson, 1969; Guttman, 1978; Huffman and Miranowski, 1981; Rose-Ackerman and Evenson, 1985; Merrill, pp. 429-33; Hadwiger, p. 148). Despite the evidence that a large share of the benefits of research accrue to consumers, the general public may be indifferent to the need for public investments in agricultural research. This is not surprising, however, when one considers that such benefits are diffuse and difficult for consumers to identify, and that benefits are often spillovers resulting from research conducted in other states (Olson, 1965, p. 48). Finally, while research may be location specific, the ecosystems to which a technology is applicable may not conform to state lines. As noted earlier, spillovers are often generated across state lines as farmers outside the funding state adopt the technology. As a result, consumers may not recognize the source of benefits created by such technology transfers.[17]

Second, the results of the study by Evenson, et al. (1979) show that there is a significant positive relationship between agricultural productivity and the decentralization of research from the station to the substation level in each state. Commenting on these results, Bonnen observed, "The logic of diminishing returns suggests that national-to-state decentralization, if one could measure it, would have an even stronger impact on productivity" (Bonnen, 1987, p. 295). These results indicate that the location specificity of research can best be addressed by a decentralized system of research.

Third, the location specificity of research should also be evident in the estimated returns from agricultural research. If it is true that research is location specific, then the problem of underinvestment should be greater for those commodities that are produced most widely (i.e., for those commodities that are likely to produce the largest share of marginal benefit spillovers relative to the marginal benefit retained by the funding state). The results of Bredahl and Peterson's and Norton's (1981) research support this hypothesis. In both studies, the rate of return on livestock research (which is less location specific and should, therefore, produce a greater share of spillovers) was higher than the rate of return on cash grains research, thereby indicating a greater degree of underinvestment in those commodities that produce the greatest share of spillovers (Ruttan, 1982a, p. 256).

These two reasons--the location specificity of agricultural research and the spillover of research benefits to farmers and consumers outside the funding state--provide the justification for the use of intergovernmental grants in financing public agricultural research. As suggested by public finance theory, the existence of benefit spillovers may discourage states from providing a socially optimal level of investment in a spillover-generating good. This appears to be true for agricultural research. If so, a system of matching grants would be the least-cost method for inducing a nationally optimal level of state investment in agricultural research.[18]

Summary

How should agricultural research be financed in the United States? This chapter has reviewed two branches of economic literature that are relevant to this question. First, the theory of public goods was reviewed, with special concern for the problems of financing public goods in a federal (i.e., multi-level) system of government. Second, the economic literature on the returns to agricultural research was reviewed, with special emphasis on the measurement of research benefit spillovers among states.

The problem of financing public goods is especially difficult in a federal system of government. When a public good provided by one jurisdiction of government yields benefits to citizens in other jurisdictions, the funding government will not have sufficient incentive to provide a socially optimal level of the spillover-generating good. This jurisdiction can be provided a Pigouvian subsidy that will compensate it for the benefit spillovers it has created. Such subsidies are typically provided by a higher level of government to a lower level of government.

The least-cost method of providing such subsidies is through the use of a conditional matching grant. Under such a system, the grantor provides the recipient with a given number of dollars for each dollar that the recipient spends on the spillover-generating good. Such a grant decreases the recipient's price of the spillover-generating good and biases the recipient's budget allocation toward a socially optimal level of investment in that good.

Such a system of matching grants appears to be especially appropriate for financing U.S. agricultural research. Agricultural research is a location-specific enterprise. That is, it must be conducted in a given ecosystem if it is to be applicable to the conditions within that ecosystem. Since such ecosystems do not coincide with state boundaries, research benefit spillovers will be created as farmers outside the funding state adopt the new technology generated by research. In addition, the inelastic nature of the supply and demand for many farm commodities, along with the atomistic nature of farming, suggests that a preponderance of the benefits of agricultural research will accrue to consumers in the form of lower prices. Since the majority of these consumers will reside outside the funding state, spillovers will again be created. As a result, federal matching grants may be required if a nationally optimal level of investment in agricultural research is to be achieved.

To determine the matching rates needed to finance agricultural research, the marginal product of research that accrues inside and outside the funding state must be estimated. These estimates must then be incorporated into a public finance model to determine the optimal matching rate for financing agricultural research. Chapter III will use the literature reviewed here to provide (1) a model of optimal matching grants that can be used to finance public goods that generate benefit spillovers and (2) a production function model that provides estimates of the marginal product of research that accrues inside and outside each state from research funded by that state. The empirical results of the second model, when combined with the theoretical results of the first model, will yield the optimal matching rates necessary to finance agricultural research.

Notes to Chapter II

1. Adam Smith, for example, cited as a legitimate function of government the support of

> those public institutions and those public works, which, though they may be in the highest degree advantageous to a great society, are, however, of such a nature, that the profit could never repay the expence [sic] to any individual or small number of individuals, and which it therefore cannot be expected that any individual or small number of individuals should erect or maintain (Smith, p. 681).

Alfred Marshall (pp. 208-16), Sidgwick (pp. 464-67), Bastable (pp. 86-100), Say (pp. 283-84, 373-400), and Adams (pp. 26-36) also discussed the public nature of some goods. Several early essays on public goods and public finance are also published in Musgrave and Peacock.

2. Sidgwick had earlier used similar terms to justify the public support of research:

> A modern university, however, is not merely an institution for imparting special kinds of knowledge for professional purposes; it has also the function of advancing knowledge generally and facilitating its acquisition by students whose aims are purely scientific. This speculative pursuit of knowledge is to a large extent--and to an extent incapable at any given time of being definitely determined--indirectly useful to industry; and since, as was before noticed, its results cannot usually be appropriated and sold, there is an obvious reason for remunerating the labor required to produce these results, and defraying the expenses incidental to the work, out of public funds--at any rate if a provision adequate for the purpose is not available from private sources (Sidgwick, pp. 466-67).

3. While Pigouvian taxes and subsidies can internalize external costs and benefits, such claims of social optimality must also be considered "narrow and selective" (Samuels, 1976b, p. 413). For while a subsidy may solve the "free rider" problem (i.e., it compensates the producer for the benefits provided to those persons who use the service but who did not contribute to its cost) the use of subsidies also raises the problem of the "unwilling rider" who must pay taxes to provide a subsidy for a good he does not want. To

prescribe the use of subsidies to correct the free rider problem, while ignoring the unwilling rider, requires a normative assumption that places high value on the welfare of free riders and low value on the welfare of unwilling riders (Schmid, 1978, pp. 44-48, 52, 56, 86).

4. Bastable (p. 99) had earlier cited "model institutions, such as agricultural schools" as an appropriate function of government.

5. Earlier authors identified the indivisible nature of public goods, but were divided on whether it was possible to assess taxes in such a manner that each person would contribute to the supply of such goods based on his share of the total marginal utility derived from such goods. Mazzola (pp. 42-44) and Sax (pp. 180-83) argued such taxes could be levied, while Wicksell (p. 81) and Barrone (pp. 165-67) argued, like Samuelson, that self-interested individuals would not make such contributions and that underinvestment in such goods would result.

6. Any argument in favor of the use of intergovernmental grants must recognize the interpersonal welfare comparisons that are required in determining the "optimal" level of investment in a public good. Some economists reject the possibility of such comparisons on the grounds that (a) all costs are subjective and known only to individual decision makers at the time decisions are made; (b) market prices do not reflect subjective costs accurately since nonmonetary factors may affect the individual's true costs; and (c) central decision makers cannot ascertain the true costs (including all relevant production relationships and utility functions) of all individuals as accurately or quickly as such costs can be expressed in the market. Thus, collective decision-making cannot hope to make the economic calculations necessary to allocate resources efficiently (von Mises, 1935; 1963, pp. 698-715; Hayek, 1935a; 1935b; 1937; 1945; Vaughn). Adopting the subjective theory of cost, Buchanan argues that only a collective system that uses a unanimous decision rule can produce Pareto optimal decisions that approximate the decentralized decisions of the market (an argument made originally by Wicksell). Under certain conditions, however, Buchanan concedes that collective action under a less-than-unanimous voting rule may be preferable to individual transactions or unanimous voting. First, he recognizes that individual negotiations may break down when (a) the number of persons involved is sufficiently large that transaction costs prevent the negotiation and enforcement of private exchanges or (b) the number of persons involved is sufficiently large that individuals will not recognize or will ignore the effects of their

decisions on others and will choose to "free ride" on the collective activities of other parties. Second, when collective action is required, Buchanan concedes that less-than-unanimous voting rules may be necessary, since unanimous rules will become prohibitively expensive in the legislative process and will provide an opportunity for strategic behavior by some parties. Thus, Buchanan provides conditions under which less-than-unanimous collective action is preferable to individual exchange or unanimous voting (Buchanan, 1965, pp. 1-13; 1969, pp. 12-13, 27-41; 1968, 87-95; 1972, pp. 439-52; Wicksell, pp. 87-97). These are the conditions (i.e., large numbers of participants and widely dispersed benefits) under which agricultural research policy is made.

7. A variety of views have developed on what the community indifference curves used in this grant analysis represent. One view is that the indifference curves are those of a "representative citizen." This view may not hold true, however, if the grants will produce a redistribution of income through the provision of selected goods, thereby changing the identity of the representative citizen. A second view is that the indifference curves represent those of the median voter (since this is the voter who will cast the decisive vote in allocating resources between private and public goods under a majority-vote decision rule). As with the "representative citizen" case, this view can only be true if the same person is the median voter before and after the grant is given (Goetz and McKnew). The third and perhaps most acceptable view is that the indifference curves are those of the recipient legislature. This view can only hold true, however, if it is assumed that the preferences of the citizenry are reflected accurately in the legislature or that the legislature is authorized to make judgments on the social welfare of its citizens (Scott, pp. 381-94). This view is supported by Bradford and Oates' demonstration that under certain conditions (fixed tax shares in the jurisdiction, majority rule in the legislature, and standard assumptions about the shape of individuals' indifference curves) a grant to the legislature is equivalent to a grant to each individual in the jurisdiction (Bradford and Oates, 1971a, pp. 416-39 and 1971b, pp. 440-48). Such indifference curves are also consistent with the view of social indifference curves developed by Samuelson (1956).

8. A noteworthy example of the price effect of matching grants may have occurred after the passage of the Smith-Lever Act of 1914, which provided matching federal grants in support of state agricultural extension activities. As the theory of intergovernmental grants

would predict, when the Smith-Lever Act made the cost of extension activities less expensive relative to the cost of research activities (which did not have matching grant support), growth in state appropriations for research declined and growth in state appropriations for extension increased. This represented a substantial shift from prior funding patterns:

> The record shows that with 1914 the States ceased adding to [experiment] station appropriations, in marked contrast to the practice up to that time. In each of the three five-year periods immediately preceding 1914 the total State appropriation practically doubled, or increased in an even greater ratio (Allen, p. 2).

This decline in research funding soon led to calls by experiment station directors for new legislation that provided matching grants for research:

> The Smith-Lever and the Smith-Hughes Acts, in which the Federal government offers to match dollars with the State government to promote agricultural extension and vocational education, place the experiment station under a handicap in securing appropriations from the State legislature, unless the same system is used for all. Members of the legislature unfamiliar with the purposes of different agricultural activities and interested mainly in other questions are not likely to discriminate between various lines of agricultural work. If they match dollars with the Federal government in one and not in the other they are likely to give most support to activities in which one dollar will do the work of two. It is necessary, therefore, to secure new Federal legislation placing the experiment stations upon the same basis as the extension service before we can expect adequate support from the States (Burnett, p. 99).

It was also recognized that matching grants were required to address the problem of benefit spillovers:

> First, there is the fundamental reason that the results of agricultural research are of nation-wide application and benefit and lead to increased wealth and happiness for all the people. Agricultural products are grown for interstate or international use. The people of many of our States are largely dependent upon the products of the farms of other States for

> their food, clothing, etc. Hence, it is right that Federal funds should be available for the support of this work. In the second place, agricultural research is peculiarly long-time and continuous in character and provision for its support ought to be such as will secure it from frequent temporary fluctuations in popular whims or legislative emergencies. The Federal Congress has established the principle of continuing long-time appropriations which (while they may, of course, be modified by Congress at any time, by repeal or amendment of the original act) have all the moral force and effect of permanent endowments for agricultural research and permit constructive planning of such research....Next, I think the principle of making the increased appropriation available only to those States which provide out of State funds an equivalent sum to be expended for the same purpose, is sound in principle and feasible in practice. It insures that those States which need, and recognize the need for, additional support for agricultural research may get it. While there can be no doubt of the nation-wide, or international, benefits from appropriation of Federal funds for its support, the success in getting these results promptly into practice in actual farm operations depends largely upon local understanding of and interest in the work of the State experiment station. Hence, the local State agencies ought to participate in the support and understanding of the administration of the experiment station research work....The suggestion that the individual States be permitted to determine whether they will accept the whole or only part of the funds to be made available under the proposed plan, seems to be a wise one. This would involve no serious difficulty of administration, either nationally or locally, and would provide a plan which would adequately adapt the principle of joint Federal and State support to the varying needs and possibilities of the several States (Thatcher, pp. 103-04).

9. It should be noted that the Harford model is a model of one-way spillovers, while the Oates model is a model of reciprocal spillovers. In a world of one-way spillovers (i.e., if a_1 equals 0 in equation 2.9 or a_2 equals 0 in equation 2.10) the Oates model yields the same results as the Harford model.

10. While most of the early authors cited in endnote 1 emphasized the inappropriability of research, Adams,

like Arrow, stressed that the state could better support research because its ability to bear risk gave it a lower discount rate:

> It is certain that every true discovery and every talent developed will sooner or later find their place in the economy of industry and react upon the life and aims of the people. Such a view is, from the nature of the case, foreign to the individual who, conscious that life is fleeting, is constrained to judge every investment on the basis of proximate rather than ultimate results (Adams, p. 30).

11. This view was expressed by Frank Knight (1924) in his response to Pigou. In Knight's view, any divergence in private and social costs or benefits is due to the failure of government to fulfill its role in defining property rights.

12. Harry Johnson (1976) used a graphical model of firm behavior under a patent system to arrive at the following propositions:

    (a) Any innovation that is profitable to the innovator will be socially beneficial, regardless of whether the welfare of the innovator is included in the welfare of society.
    (b) The reverse is not true. An innovation might be socially profitable to invest in, but not privately profitable to develop; consequently the patent and license system will not make all of the socially desirable investments in research. This proposition is supported by studies that indicate private sector researchers will prefer to participate in joint public-private research projects that maximize the private benefits of the firm rather than social benefits (Ulrich, et al., 1986).
    (c) Where an innovation is profitable to introduce, it will be under-utilized from a social point of view.
    (d) Where there is a choice between a cheaper but less productive and a more expensive but more productive innovation, the patent system biases innovative investment towards the less productive but cheaper alternative.
    (e) Research investment will be biased towards "applied" research and away from "basic" research whose benefits are likely to be more dispersed.
    (f) Innovative investment will tend to be wasteful in two respects. First, excessive resources will be devoted to certain kinds of innovation, in the form of duplication of effort. Second, some innovations will be introduced too rapidly from a societal perspective (Harry Johnson, 1976, pp. 31-36). Other

economists have developed this proposition in more detail (see endnote 14 below).

13. This view is also consistent with the early history of research at the land-grant colleges. Consider, for example, the difference in the development of agricultural research and engineering research. While agricultural research was supported by the public sector, historian Edward Eddy notes that engineering research was poorly supported at the land-grant colleges. While each state had an agricultural experiment station in 1888 (or as soon thereafter as the state became eligible) the first engineering experiment station did not come into existence until 1903. By 1940 there were 46 engineering stations, but, despite occasional efforts to secure federal funds, engineering research did not gain substantial funding until general research appropriations began to increase after World War II. Eddy explains this lack of engineering support as the result of (a) the lack of an effective political organization, such as the Association of American Agricultural Colleges and Experiment Stations, to present the political case for public support of engineering research, and (b) the presence of an effective patent system that allowed private firms to capture sufficient returns to support industrial research, thereby lessening the demand for public support of engineering research. Whether the unequal development of engineering and agricultural research at the land-grant colleges was due to political or economic factors remains a question for historians and economists to address, but it must be noted that much of the early engineering research was in areas that private firms could not support--e.g., the development of industrial tests, grades, and standards or the lessening of industrial pollution (Eddy, pp. 100, 127-129, 172-174, 233-35). Thus, it must be concluded that early research at the land-grant colleges developed along the lines suggested by economic theory (i.e., in areas of atomistic competition, such as agriculture, or in areas where industrial firms could not justify research investments given the limitations of the patent system).

14. It should also be noted that there are some theoretical reasons why a patent system may lead to overinvestment in research. Eads (pp. 5-6) concludes that overinvestment in research (i.e., the private rate of return on research will exceed the social rate of return) will result when firms compete on the basis of product differentiation rather than price. Similarly, Schmid (1985, p. 132) has argued that a patent system may lead to excessive investment in "cosmetic" innovations in some areas of plant breeding. Plant (p. 51) has argued that research overinvestment may arise

when the social costs of obsolete physical and human capital caused by new inventions are considered. Usher (p. 287) has argued that a patent system may cause overinvestment in research, since inventors must race to be the first to apply for a patent, thereby resulting in a wasteful duplication of research efforts. Usher's argument has been formalized by other economists (Barzel; Kitti; Brian Wright, pp. 49-51). These models reach the common conclusion that the race to attain a patent may cause firms to overinvest in research and introduce the invention at the privately optimal date (the date when the private return from the research equals zero, since all inventors introducing the invention after that date will be denied a patent and will suffer a loss due to the wasted research investment) rather than the later socially optimal date (defined as the date upon which the private return to the research investment is maximized). However, such models assume that the entire benefit of research is captured by the inventor. If a share of the research benefits accrue to consumers, underinvestment may still persist under a patent system (Barzel, p. 354).

15. The problem of location specificity was well understood at the time of the writing of the Hatch Act of 1887. The regionalization of production that was occurring at the time led historian Margaret Rossiter (p. 157) to observe:

> Connecticut with its relatively poor land for grain and corn was rapidly losing its remaining markets to western competition. Economic pressures forced Connecticut agriculture back on its comparative geographical advantage in supplying eastern cities. After 1860 those farms that were not abandoned turned increasingly to such perishable food products as fruits, eggs, and dairy products and to other crops, such as hay, which would not pay the long cost of transportation. The rise of such a specialized commercial agriculture required a more precise knowledge of crops, costs, and methods of cultivation and was a great spur to agricultural reform in Connecticut in the late 1860's [including the establishment of the first agricultural experiment station in the United States].

Congress also understood the need for a geographically decentralized research system, as shown by the report of the House Committee on Agriculture on the Hatch bill:

> Experiments in the Agricultural Department at Washington are reliable only for such portions

> of the country as present the same conditions of temperature, moisture, soil, etc.... Agriculture is so variable in the different States that it is impracticable for one station to cover the field of needed investigation. The cotton and rice States have their climate, their peculiar crops, their insect enemies, and their special problems. The great prairie States have their peculiar wants and difficulties, and so of the several sections. Experiments that are at all reliable can only be performed in the several localities and under their varying conditions.... When we consider the vast area of our country it will not be seriously contended that one station in each state would be too many (U. S. Congress, 1887, Appendix, p. 121).

W. B. Kemp, Director of the Maryland Agricultural Experiment Station, would later describe the varying conditions in his state:

> The problems on which information is asked are doubly complicated because of varying conditions even within a single State. In one as small as Maryland with less than 10,000 square miles of land area there are 4 different geological zones with more than 300 distinct soil types and classes named to date, with mean precipitation varying from 20 to 30 inches during the growing season and with the period between killing frost varying from 120 days in one section to 210 days in another. No one fertilizer practice; no one seeding mixture; no one set of variety recommendations can apply over such a range of conditions (U. S. Congress, 1946b, p. 55).

16. Three additional benefits that accrue from a decentralized research system should also be noted. First, Nelson (1961) developed a cost minimization model that showed a decentralized research system may be the most efficient system possible when several promising opportunities exist for solving a scientific problem. The long run cost of research may be reduced as the information produced by parallel research efforts improves the ability of research managers to select the most promising solution. Second, Hardin (pp. 27-29) surveyed the history of federal-state relations in funding agricultural research and concluded that the joint responsibility of funding research has helped protect the experiment stations from political manipulation. By seeking to protect its investment in the stations, each level of government acts as a countervailing balance to prevent the political interference of the other in experiment station affairs.

Third, a federal system of government can provide a laboratory in which local jurisdictions experiment with public services before they are funded by the federal government. Such experimentation often provides a test of the desirability of public services and the administrative tools necessary for successful execution of new programs (Maxwell, p. 117). Indeed, many services (including agricultural research) now provided jointly by the federal government and the states were originally provided solely by the states (Maxwell, p. 117; Key, pp. 1-7; True).

17. Tiebout developed a model of local government finance that indicates that consumers of public services register their preferences by "voting with their feet" (i.e., by moving to the jurisdiction that provides them with the combination of services and taxes that maximizes their utility). However, agricultural research violates two key assumptions of the Tiebout model, namely, the free mobility of citizens and the absence of spillover benefits. Clearly, farmers are limited in their ability to register their demand for more agricultural research by the high cost of disinvesting at their present location and moving to another state, and individual food consumers cannot capture a greater share of research benefits simply by moving to another state. When such spillovers and high relocation costs exist, Tiebout concludes, a system of intergovernmental grants may be justified. Indeed, Stiglitz (1983, p. 48) cited scientific research as a classic example of a public good whose provision cannot be assured by the Tiebout model and that must be provided exclusively or jointly by the national government. Further development of the Tiebout model has also revealed that it may be of limited use in providing an optimal quantity of public goods (Pestieau; Bewley; Stahl and Varaiya; Zodrow; Stiglitz, 1977, 1983; Rose-Ackerman).

18. Any discussion of investment in publicly-provided goods must consider the political structure in which public resource allocation decisions are made, since this structure may contribute to either an underinvestment or overinvestment in public goods. The diffuse and uncertain nature of public good benefits, combined with the high cost of gathering information on such benefits and the low cost of assessing the tax costs of such goods, may worsen the underinvestment problem by distorting the perceived costs and benefits of publicly-provided goods (Downs, pp. 546-54; Harry Johnson, 1968, p. 12; Margolis, 1964, pp. 237-38; Olson, 1965, pp. 43-52). Margolis (1961, p. 270) hypothesizes that the local control of intergovernmental grants may overcome the resistance of local taxpayers more easily

than would shifting the function to a higher level of government. If so, intergovernmental grants may be especially useful in correcting the information bias of taxpayers. Similarly, Douglas (1920a, p. 257) observed that the organizational costs of collective action may be reduced by passing legislation in the national legislature rather than each of the state legislatures. If so, intergovernmental grants may the most appropriate tool for both maintaining local control of a program and overcoming the political transaction costs of establishing the program. The underinvestment problem may also persist because advertising creates a bias in favor of private goods (Galbraith, pp. 221-38; Olson, 1964, p. 250).

Overinvestment in publicly-provided goods may result when decisions are based on bureaucratic self-interest rather than social welfare. That is, bureaucrats may have an incentive to maximize their own welfare, and therefore their budgets, rather than any democratically-determined notion of public welfare (McKean, pp. 247-48; Niskanen, 1968, 1971; Harry Johnson, 1968, p. 12; DeAlessi; Shapiro; Orzechowski; Staaf). The possibility of overinvestment in public goods also arises when voters suffer from "fiscal illusion" (i.e., when voters underestimate the true cost of public goods because part of the cost of such goods is imposed indirectly). Fiscal illusion may arise when public goods are financed by indirect taxation, public ownership of income-generating property, inflation, public debt, gift or luxury taxes, and taxes on specific classes of individuals (Buchanan, 1960, pp. 59-64; Goetz, pp. 176-85). Fiscal illusion may also occur when the benefits or costs of a publicly-provided good are unevenly distributed among voters (Downs, pp. 556-59; Buchanan and Tullock, p. 169; Buchanan, 1961, 1967, pp. 126-43). This version of the overinvestment hypothesis views intergovernmental grants as a means of shifting the cost of local public goods to outside taxpayers, thereby creating an illusion of inexpensive local public goods and leading to overinvestment in such goods (Brennan and Buchanan, pp. 179-186). Overinvestment may also result when the political structure permits the use of logrolling to reach decisions that provide mutual benefits to the logrollers at the expense of third parties (Davis and Meyer; Tullock, 1959). Overinvestment may also be encouraged by the use of a representative legislature for allocation decisions. Such a structure may permit a minority of voters to pass legislation which a majority of voters oppose when the minority is a majority of voters in a majority of represented jurisdictions (Tullock, 1970, p. 423).

CHAPTER III

A MODEL OF OPTIMAL COST-SHARING FOR STATE AND FEDERAL INVESTMENTS IN AGRICULTURAL RESEARCH

This chapter presents a model for determining the optimal cost-sharing arrangements for investments in public agricultural research in the United States. First, the critical assumptions of the model are identified. Second, a public finance model for financing an optimal level of investment in agricultural research in the presence of benefit spillovers is specified. The model employed here is a simplified version of the Harford model presented in Chapter II. This model yields the optimal federal matching rate for financing agricultural research (i.e., the rate at which the federal government should match state spending for agricultural research in order to achieve a nationally optimal level of research investment). To make this public finance model operational, the share of the marginal product of research that accrues outside the funding state must be estimated. Thus, the third section of this chapter presents a production function model capable of estimating agricultural research benefit spillovers. Finally, the data used to estimate the production function model will be presented.

Critical Assumptions of the Model

Any analysis of economic policy is conditioned by the positive and normative assumptions implicit in the analysis. Only by identifying such assumptions can the limitations of policy analysis be known. This section presents the critical assumptions underlying this study. These assumptions are drawn from both the public finance literature on intergovernmental grants and the literature on the returns to agricultural research. The assumptions of this analysis include:

1. The objective of publicly-funded agricultural research is the maximization of the net monetary benefit of research;
2. The resources displaced by technology resulting from public investments in agricultural research have no value and receive no compensation;
3. The results produced by public investments in agricultural research have value in use but no value in consumption (i.e., the value arising from research results from its application, not from the mastery of knowledge for its own sake);
4. Legislators at each level of government act with perfect, costless knowledge in a rational, maximizing manner within their jurisdiction, or (a) state legislators ignore benefits that accrue to other states when making state-level research investment decisions, and (b) national legislators ignore

benefits that accrue to other nations when making national-level research investment decisions;

5. The marginal cost of an additional dollar of public research investment is constant and equal to one dollar (i.e., the marginal burden of taxation is zero and the supply of research inputs purchased with public funds is perfectly elastic);
6. The full incidence of all taxes falls on the jurisdiction imposing the tax (i.e., the full incidence of each state's taxes falls within the state and the full incidence of national taxes falls within the United States);
7. The taxes imposed by state and national governments in support of agricultural research do not have a significant effect in reducing income in the taxing jurisdiction and do not distort the prices of private and public goods in the economy (i.e., the total size of the public agricultural research budget is insignificant when compared to the total income of each state and the nation);
8. Except for the changes in the federal matching rate for state agricultural research investments, the institutional structure of the economy remains fixed;
9. The same spillover pattern (i.e., the share of research benefits retained by each state) will exist in the future as existed during the period for which such spillovers are estimated in the model;

10. The market prices of inputs used in agricultural production reflect the social value of those inputs (i.e., there are no externalities associated with any input).[1]

Chapter VI will review these assumptions and examine the limitations they impose on the results of this research and on the prescriptive validity of this research.

An Optimal Cost-Sharing Model for Agricultural Research with Benefit Spillovers

Chapter II reviewed the public finance literature on the economics of intergovernmental grants and concluded (1) that the least-cost method of financing public goods that generate benefit spillovers across governmental jurisdictions is through the use of a matching grant from a higher level of government to the lower level unit of government, and (2) that the matching rate of such a grant should reflect the share of the total marginal benefit that accrues to persons outside the jurisdictional boundaries of the lower level of government. In the case of agricultural research, the federal government would provide a matching grant to each state that is based on the share of the marginal benefit of research that accrues outside the funding state.

The model of optimal public investment used in this research is a modified version of the Harford model. More specifically, it is a simplified version of the Harford model, since the Harford model deals with three levels of government, while the model used here deals with only two levels of government (the national government and the states).

This model maximizes total national research benefits by providing federal subsidies to the states based on the share of research benefits that spill across state lines. For each state, the model has two equations:

(3.1) $B(X) - C(X)$ (The National Net Benefit Equation)

(3.2) $\alpha_i * B(X) - (1 - s_i) * C(X)$ (The State Net Benefit Equation).

Where:

$B(X)$ = The benefit function of agricultural research;

$C(X)$ = The cost function of agricultural research;

α_i = The share of research benefits that accrue to state i as a result of research conducted in state i;

s_i = The share of the cost of research conducted in state i paid by the federal government;

X = Funds spent on agricultural research in state i.

The optimal share of the cost of research in state i that would be paid by the federal government can be determined by maximizing the state and national net benefit equations. Differentiating equations (3.1) and (3.2) provides:

(3.3) $$\frac{dB(X)}{dX} - \frac{dC(X)}{dX} = 0$$

(3.4) $$\alpha_i * \frac{dB(X)}{dX} - (1 - s_i) * \frac{dC(X)}{dX} = 0.$$

Solving (3.3) and (3.4) simultaneously and rearranging provides the optimal share of the cost of research in state i that would be paid by the federal government:

$$(3.5) \quad s_i = 1 - \alpha_i.$$

Thus, the share of the cost of research paid by the federal government varies directly with the proportion of marginal research benefits that spill out of state i. This result is consistent with the literature on intergovernmental grants reviewed in Chapter II.

Since the intergovernmental grant used here is a matching grant, equation (3.5) should be expressed as a matching rate. The optimal federal matching rate implied by equation (3.5) is:

$$(3.6) \quad m_i = (1 - \alpha_i)/\alpha_i.$$

Thus, to achieve the nationally optimal level of investment in agricultural research, the federal government should provide m_i dollars to state i for every dollar of agricultural research funding provided by state i.

A Model of Agricultural Research Benefit Spillovers

The major task of this investigation now becomes the measurement of the share of the marginal product of agricultural research that is retained by the funding state (i.e., the estimation of the α_i in equation 3.2). To accomplish this task, the marginal product of research inside and outside each funding state must be measured. To estimate these marginal products, a production function of the following form will be estimated from state-level cross-section data:

(3.7) $Q_{it} = f(X_{jit}, R_{it}, E_{it}, W_{it}, e_{it})$,

where:

Q_{it} = The value of aggregate agricultural output per farm in state i during year t;

X_{jit} = A set of n conventional inputs (j = 1...n) used per farm in agricultural production in state i during year t;

R_{it} = Total research investment "relevant" to agricultural production in state i during year t, including research conducted in other states;

E_{it} = Extension investment per farm in state i during year t;

W_{it} = A measure of weather conditions in state i during year t;

e_{it} = An error term.

The estimated coefficients for the research variable will be used in Chapter V to calculate the marginal products of research inside and outside each state which, in turn, can be used in equations (3.5) and (3.6) to calculate the optimal federal matching rate necessary to finance research in each state. As will be seen in the next chapter, the research benefit spillovers estimated by this model will depend critically on the definition of the "relevant" research available in each state (i.e., on the states which are assumed to receive spillovers from state i and on the states from which state i is assumed to receive spillovers).

Variable Specification

This section provides a detailed description of the data used to estimate the production functions in this research. It describes the data used to construct each variable and provides a comparison of this data base to those used in previous studies. Two comments should preface this discussion. First, the descriptions that follow explain the calculation of the aggregate variables for each state. All aggregate variables except research and weather were then divided by the number of farms in the state to provide per farm estimates of output, inputs, and extension. Second, all price indexes used to deflate the data are national price indexes. Although state-level indexes would have been preferable, such data are not available. The sources of all data used in this research are presented in Appendix A.

Aggregate Output

The aggregate output of each state was calculated as the sum of the annual real value of four forms of farm output: cash receipts from marketed products, farm products consumed at home, government payments, and the net change in product inventories held on farms. Receipts from marketed products are reported in twelve commodity categories: food grains, feed grains, oil crops, cotton, tobacco, vegetables, fruits and nuts, other crops, meat animals, poultry and eggs, dairy products, and other livestock products. To eliminate any bias caused by the inclusion of forest product sales in this variable, the value of annual sales of forest products was deducted from the other crop category. As discussed later in this chapter, this adjustment was judged necessary in order to achieve consistency with the specification of the research variable, which excluded forestry research. Government payments, home consumption, and the change in inventories for each state are reported as aggregate figures inclusive of all twelve output categories.

Each of the twelve output sales categories was deflated by its associated index of prices received by farmers for commodities included in the category (1977 = 100 base year). The value of government payments, home consumption, and change in inventories was deflated by a composite price index constructed to reflect the sales of farm products in each state. This index was constructed as:

$$(3.8) \quad P_i = \sum_{j=1}^{12} W_{ji} * I_j,$$

where P_i is the price index for state i, W_{ji} is the weight placed on commodity category j in state i's price index (based in the commodity category's proportion of the total value of farm products marketed in state i) and I_j is the index of prices received by farmers for commodity group j. This method of construction implicitly assumes that the composition of state i's government payments, home consumption, and changes in farm product inventories is identical to the composition of the farm products marketed by farmers in the state i.

Except for the exclusion of forest product sales from the other crops category, this variable is constructed in a similar manner to that used by Davis (1979) and Griliches (1963 and 1964).

Land

The land variable, defined as the number of quality-adjusted acres of land used in farm production in each state, is designed to measure the area of land used in agricultural production adjusted to reflect differences in the quality of land both across states and across time. This variable is constructed by multiplying the total land used in agricultural production in each state by its land quality index. The total land used in production is defined as the sum of the following categories of cropland: harvested cropland, cropland on which all crops failed, cropland used only for pasture or grazing, woodland pasture, and pastureland and rangeland other than cropland and woodland pasture.

The index of land quality is designed to measure the differences in land characteristics occurring across states and across time that contribute to the agricultural value of land (Willis Peterson, 1986, p. 815). The Peterson index was constructed in a two-step process. First, the price of farmland in each state was regressed on the factors affecting the agricultural value of land (topography, fertility, expected prices of farm products, and non-farm factors).

Second, the predicted state values for the 1949 to 1978 period were divided by the 1949 national average value to yield a quality index with a base year of 1949. Thus, adjusting the total land used in production in each state by this index yields a measure of the quality-adjusted land for each state.

This specification represents a significant departure from previous studies. Griliches (1964, p. 966), and Davis (1979, pp. 129-34) adjusted the land variable by using market prices as a proxy for land quality. Since the price of farmland is also determined by non-farm uses, however, the use of a price adjustment method could yield a biased measurement of the land input (i.e., the land input will tend to be overestimated in those states that have high farmland prices generated primarily by the non-farm demand for farmland) (Willis Peterson, 1986, p. 812). Thus, the use of the Peterson index, which isolates the farm-related factors that determine the quality of land, provides a potentially important improvement in the data used in research such as this.

Two adjustments in the data used to specify the land variable should be noted. First, since Peterson did not use all census cross-sections in estimating his quality index (1949, 1959, 1969, and 1978 were used) the 1964 index used here was calculated by interpolating the 1959-1969 index numbers, the 1974 index was calculated by interpolating the 1969-1978 index numbers, and the 1982 index was calculated by extrapolating from the 1969-1978 period.

Second, since some of the land categories needed to construct this variable were not reported in the 1974 and 1969 censuses, this data had to be calculated from the available data. For example, neither census reported the land on which crops failed, woodland pasture, or the pastureland and rangeland other than cropland and woodland pasture. To estimate these data for 1974, the following calculations were made for each state: (1) the land on which all crops had failed was calculated using the proportion of total planted cropland (i.e., harvested cropland plus land on which crops failed) on which crops failed during 1978 and the harvested cropland for 1974; (2) woodland pasture was calculated using the proportion of total woodland that was pastured in 1978 and the total woodland in 1974; and (3) other pastureland and rangeland was calculated using the proportion of total "other land" in pastureland and rangeland during 1978 and the total "other land" in 1974. Similar calculations were made for 1969 employing the relevant proportions from 1964.

<u>Labor</u>

The labor input variable is specified as the sum of the hours of labor provided by (1) hired labor and (2) farm operators and unpaid family members. The total number of hours of hired labor used in each state was calculated as the expenditures on farm wages divided by the average state farm wage rate. Since the USDA includes contributions to Social Security in its category of hired labor expenditures, the total wage expenditure was calculated by reducing the total hired labor expenditure by the amount of the Social Security tax rate (i.e., the total hired labor expenditure was multiplied by [1-SSTR], where SSTR is the Social Security tax rate). The total wage expenditure was then divided by the annual average state farm wage rate per hour to yield the total number of hours of hired labor in the state.

The second category of farm labor, family-provided labor, is defined as the total number of hours of farm labor provided by farm operators and their family members in the state. This was calculated as the annual sum of the average number of hours of farm labor provided per week per family member in each state (including the farm operator) multiplied by the number of family members working on farms in each state during the week. Although this general specification was used for all five cross-sections, some differences in the cross-sections should be noted.

First, prior to 1975, the USDA reported the number of family workers and their average hours worked per week on a monthly basis (i.e., farmers were surveyed for one week each month to report their labor use for the previous week). To find the annual total labor use for the 1964, 1969, and 1974 cross-sections, each month's data were multiplied by 4.3 (i.e., each survey week was assumed to represent the 4.3 weeks surrounding the survey week). Since the USDA reported labor data on a quarterly basis from 1976 to 1980 (i.e., farmers were surveyed for one week each quarter to report their labor use for the previous week) the total annual labor used for the

1978 cross-section was calculated by multiplying each quarter's data by 13 (i.e., each quarter's reported data were assumed to represent the 13 weeks of the quarter).

Second, since the USDA did not report the number of hours worked by family members prior to 1965, the average of the number of hours worked by family members for each month of 1965 and 1966 was used to estimate the average number of hours worked by family members for 1964. This average was used to remove any bias that could arise from the effect of unusual weather conditions on the number of hours worked if only the 1965 figures were used.

Third, since the USDA reported data for only one week in July of 1982, it was deemed necessary to construct a data set that would better reflect the variations in labor use that occur throughout the year. To construct these data, the average of the number of family workers and the average number of hours worked per week by family workers were calculated for each quarter using 1979 and 1980 data. "Quarterly" data for 1982 (for both the number of family workers and the number of hours per worker) were then calculated by multiplying the July 1982 data by the ratio of the 1979-1980 average data for each quarter to the average data for the July 1979-1980 survey (i.e., the variation in labor use in each quarter of 1982 is assumed to be the same as the quarterly variation in labor use during the 1979-1980 period). Total family labor use for 1982 was then calculated as the sum of each quarter's estimated number of family farm workers times the average number of hours per worker times 13 (i.e., as with the 1978 cross-section, each quarter's data were assumed to represent the 13 weeks of the quarter).

This specification of the hired labor variable is identical to that used by Evenson, et al. (1987, pp. 20-21). A similar specification was used by Griliches (1964, p. 967), Davis (1979, pp. 125-27), Bredahl (pp. 24-26) and Norton (1981, pp. 11-12), but only Evenson et al. adjusted the total hired labor expenditures for the employers' Social Security tax. By failing to adjust for Social Security taxes, other studies may have created an upward bias in the hired labor component of the farm labor variable.

The family labor variable was similar to that used by Evenson, et al. (1987, pp.21); however, Evenson, et al. used a regression method to estimate the 1982 data rather than the method used in this research.[2]

Education

The education variable, designed to measure differences in the quality of labor both across states and over time, is defined as the weighted school years completed per person among the rural farm population of males age 25 years and older. The weights employed are the mean incomes of all rural farm males age 25 or older in the United States for each education category. To calculate this variable, the proportion of farm males age 25 or older in each education category in each state is multiplied by the U.S. mean income for all farm males 25 or older in that education category.

Since the education categories reported by the U. S. Department of Commerce had changed over time, the combining of some categories was deemed necessary to provide consistency. For example, since the 1960 census provided four separate categories for persons with zero to eight years of schooling, while the 1970 census provided three categories and the 1980 census provided one category for persons with zero to eight years of schooling, the categories of the 1960 and 1970 censuses were combined to match the 1980 category. Similar combinations were made for the four or greater years of college category. Corresponding adjustments were made for the average U.S. income associated with each education category (i.e., average incomes for each category were calculated based on the average incomes of the original categories). The average income figures were then expressed in constant dollars by deflating them by the Consumer Price Index (1977 = 100 base year). Since the data on the education level of the farm population are provided in the decennial census of the U.S. population rather than the Census of Agriculture, the data for the 1964 and 1969 cross-sections were obtained by interpolating the data from the 1960 and 1970 censuses, the 1974 and 1978 cross-sections were obtained by interpolating the data from the 1970 and 1980 censuses, and the data for the 1982 cross-section were obtained by extrapolating from the 1970 and 1980 censuses.[3]

Most previous studies have attempted to assess the differences in labor quality as reflected by the income earned by the farm labor force. The specification used here is identical (except for the changes in categories explained above) to that employed by Griliches (1963, pp. 336-41; 1964, p. 967) and Davis (1979, pp. 127-29). Bredahl (pp. 24-26) attempted a similar adjustment by multiplying the labor variable (days of labor per farm) by the ratio of the state average farm wage rate to the national average farm wage rate.

Fertilizer

The fertilizer input variable, specified as the real expenditures for fertilizer in each state during the cross-section years, was defined as the total state expenditures on fertilizer deflated by the index of prices paid by farmers for fertilizer products (1977 = 100 base year). Thus, this specification implicitly assumes that 1977 prices reflect the appropriate price weights for the fertilizer inputs.

This specification is identical to that used by Davis (1979). While earlier studies (Griliches, 1963; Bredahl) used the quantities of specific fertilizer inputs (i.e., nitrogen, potash, and phosphoric acid) weighted according to their prices, Davis (1979, pp. 61-62) found that the use of deflated fertilizer expenditures in estimating a cross-section production function did not introduce bias into the estimated coefficients in either individual cross-sections or cross-sections that were pooled over time. Thus, the fertilizer expenditure specification was chosen for this model.

Machinery

The machinery variable is designed to measure the total flow of services derived from the stock of farm machinery. This flow was measured as the deflated sum of (1) expenditures on fuel and oil, (2) expenditures on custom-hired machinery, (3) expenditures on farm machinery repairs, and (4) the amortized flow of services obtained from the stock of farm machinery.

The first component, deflated expenditures on fuels and oils, was calculated as the nominal state expenditure on fuels and oils deflated by the index of prices paid by farmers for fuels and energy (1977 = 100 base year). The second component, the real value of custom-hired services, was calculated as the nominal annual state expenditures on custom-hired services deflated by the index of prices paid by farmers for farm and motor supplies.

The third component of the machinery variable, the machinery repair component, required the calculation of farm machinery repair expenditures at the state level. Since the USDA farm income data report farm repair expenditures on the state level as an aggregate of machinery repairs and building repairs and the data on national repair expenditures in these categories are reported separately, the national proportion of total farm repair expenditures directed at farm machinery was multiplied by total state repair expenditures to calculate the state level farm machinery repair expenditures. This measure of nominal state machinery repair expenditures was then deflated by the index of prices paid by farmers for farm and motor supplies (1977 = 100 base year) to yield the real farm machinery repair expenditures for each state.

The final component of the machinery variable calculated the flow of services from the stock of machines on farms. This was calculated by multiplying the value of the stock of machinery on farms in each state by an amortization factor of .15 (representing an interest rate of 8% and an assumed machine life of 10 years). This amortization assumption is supported by economic and engineering studies (Reid and Bradford, p. 330; Wendell Bowers, p. 110) and was employed by earlier researchers in this area (Griliches, 1963, p. 336 and 1964, p. 966; Bredahl, p. 44; Norton, 1981, p. 11). This nominal flow of machinery services in each state was then deflated by the index of prices paid by farmers for tractors and other self-propelled machines (1977 = 100 base year).

It should be noted that state-level data on the value of machinery were reported for the first time by the USDA in 1970. Prior to that time, the USDA reported only national machinery data in its national balance sheet statistics. Thus, the 1969 data for this variable came from the 1969 Census of Agriculture. Since the USDA data in recent years included some machinery not included in the 1969 census data (primarily the farm-use portion of trucks and autos) the 1969 state census data were adjusted to include these machines by multiplying the state value of machinery reported in the 1969 census by the ratio of the 1969 national value of machinery reported by the USDA to the national value of machinery reported in the 1969 census. Since the 1964 census did not report the value of machinery, it was necessary to calculate the value of farm machinery in each state from available national data. To accomplish this, the USDA's national value of farm machinery in 1964 was multiplied by each state's share of the national stock of machinery reported in the 1969 census.

Livestock

The livestock inventory variable represents the real flow of livestock capital services used in agricultural production each year in each state. The livestock inventory variable is defined as the sum of the real value of livestock purchases in each state and the real flow of services derived from the stock of livestock capital in the state.

The real value of livestock purchases is defined as the nominal value of livestock purchase expenditures deflated by the index of prices paid by farmers for feeder livestock (1977 = 100 base year). The flow of livestock services derived from livestock capital was calculated by amortizing the value of each category of livestock capital in the state. It should be noted that each type of livestock was amortized at a different rate to reflect the different life span of each species. First, the value of all breeding cattle on farms (dairy cows, beef cows, and bulls) was amortized using an 8% interest rate and a 10-year breeding life for breeding cattle. Second, the flow of services from breeding swine was calculated by amortizing the value of breeding swine using an 8% interest rate and a 6-year breeding life. Third, the value of all breeding sheep was amortized using an 8% interest rate and a 6-year breeding life. Finally, since the breeding life of turkeys and chickens is assumed to be one year, no amortization was required to calculate the flow of services from these animals (i.e., the entire value of turkey breeding hens and chickens is included in the livestock inventory variable). The sum of these amortized values was then deflated by the index of prices received by farmers for meat animals to provide the real flow of services provided by the breeding stock on farms.

There are some minor differences between this specification of the livestock variable and those used in previous studies. Griliches (1964, p. 967), Bredahl (p. 68), Norton, (1981, p. 12) and Davis (1979, p. 135) all used a 10-year breeding life for all types of livestock rather than separate breeding lives for each species. Given the diversity of the animals included in this variable, however, it was deemed necessary to use the specific breeding lives suggested by animal scientists for each species (Blakely and Bade, p. 675; Ensminger, p. 882).

<u>Other Inputs</u>

Several inputs are included in the "other inputs" category. This variable includes seed, feed, buildings, and other miscellaneous inputs. The specification of each of these categories will be discussed.

The seed variable represents the total seed inputs used in farm production. This represents the sum of two classes of seed inputs--purchased seed and seed produced on the farm on which it is planted.

Purchased seed is the real expenditures on seed in each state, measured as the nominal expenditures on seed in each state deflated by the index of prices paid by farmers for seed inputs (1977 = 100 base year). Farm-produced seed represents the real value of the seed produced on the farm on which it is planted. Given that wheat and soybeans represent the preponderance of farm-produced seed (some potatoes, peanuts and rice are also retained for farm use as seed) these two commodities are the only two commodities included in the farm-produced seed category.

Since the USDA reported the quantities of wheat and soybeans used as seed on the farm where produced until 1975, these data were used to measure the quantities of farm-produced seed for the 1964, 1969, and 1974 cross-sections. It should be noted that the seed used in each of these years is the seed use reported in the disposition of the previous year's crop. That is, the soybean seed used to plant the 1964 crop is reported in the disposition of the 1963 crop.

Since the seed used on farms where it was produced was not reported after 1975, it was necessary to calculate these data from other available information. For the 1978 and 1982 cross-sections, the USDA reported the seeding rates (in bushels per acre) for wheat and soybeans in each state and the acreage planted in wheat and soybeans in each state. These were used to estimate the total quantity of wheat and soybean seed used in each state for 1978 and 1982. The quantity of farm-produced seed was then calculated by multiplying the total seed use in each state for each commodity by the fraction of total seed that was farm-produced in the last year for which such data are available (1975). For example, the quantity of farm-produced wheat or soybean seed used in state i in 1978 was calculated as:

(3.9) $FPSU_i = A_i * SR_i(FPSU_{1975i}/TSU_{1975i})$,

where $FPSU_i$ equals the quantity of farm-produced wheat or soybean seed used in state i in 1978, A_i equals the wheat or soybean acreage planted in i, SR is the seeding rate in i, $FPSU_{1975i}$ is the quantity of farm-produced seed used in 1975 in i, and TSU_{1975i} equals the total seed used in i in 1975. It should be noted that this method implicitly assumes the proportion of farm-produced seed is the same in 1978 and 1982 as in 1975. Given the short time frame of this extrapolation, this assumption appears reasonable.

Each seed input (wheat and soybeans) was then multiplied by the average annual state price for the commodity in the year in which the seed was produced to provide the nominal value of home-produced seed for the state. In effect, this value represents the nominal opportunity cost of the seed produced on farms. The nominal value of farm-produced wheat seed was then deflated by the index of prices received by farmers for food grains (1977 = 100 base year) to yield the real value of farm-produced wheat seed, and the nominal value of farm-produced soybean seed was deflated by the index of prices received by farmers for oil-bearing crops (1977 = 100 base year) to yield the real value of farm-produced soybean seed.

The inclusion of the farm-produced seed provides a broader definition of the seed variable than some previous studies. Davis (1979, p. 135), Bredahl (p. 43), and Griliches (1963, p.336 and 1964, p. 967) included only purchased seed in their specification of the seed variable, while Evenson, et al. (1987, p. 23) also included farm-produced peanuts, beans, potatoes, and rice in the seed variable.

The feed variable, like the seed variable, is specified as the sum of each state's real expenditures on purchased feed inputs plus the real value of farm-produced feed inputs. The real value of purchased feed inputs was defined as the nominal value of feed expenditures by state deflated by the index of prices paid by farmers for feed.

The real value of farm-produced feed was defined as the real value of all corn, barley, oats, sorghum, hay, and wheat used as feed on the farms on which the commodities were produced. Since the USDA reported the quantities of corn, barley, oats, sorghum, and hay used for feed on the farms on which they were produced for all years prior to 1981, the USDA data were used for these commodities for all of the cross-sections except 1982. As with the seed variable, the data employed for the feed variable were the quantities of output produced in the prior crop year disposed of through on-farm use (e.g., the feed used on farms in 1964 came from the 1963 crop).

For the 1982 cross-section, the quantity of farm-produced feed was calculated as the share of the 1981 crop that would have been used as feed on farms based on the feeding patterns of the most recent year for which data were available (1980). Thus, the quantities of farm-produced corn, barley, oats, sorghum, and hay for state i were calculated as:

$$(3.10) \quad FPFU_{1981i} = PROD_{1981i} * (FPFU_{1980i} / PROD_{1980i}),$$

where $FPFU_{1981i}$ is the quantity of each feed used on the farm on which it was produced for the 1981 crop (i.e, the farm-produced feed for 1982), $PROD_{1981i}$ is the total quantity of the commodity produced in state i in 1981, $FPFU_{1980i}$ equals the quantity of the commodity used as feed on the producing farm during the 1980 crop year, and $PROD_{1980i}$ is the total production of the commodity in state i during 1980. Thus, this variable assumes the feed disposition patterns for the 1981 crop would be the same as those that prevailed for the 1980 crop year.

The wheat used on farms as feed was reported by the USDA prior to 1975. These data were used for the 1964, 1969, and 1974 cross-sections. For the 1978 cross-section, the USDA reported total wheat used on farms producing the wheat (including both seed and feed use). Thus, farm-produced wheat feed for 1978 was calculated as the total on-farm wheat use in the state minus the farm-produced wheat seed use in the state (where farm-produced wheat seed was estimated as explained earlier in this section). For the 1982 cross-section, total state wheat use on farms was calculated in a similar manner to the other feed commodities (explained in the preceding paragraph). Again, each state's farm-produced wheat seed was calculated as explained earlier, and the farm-produced wheat feed was calculated as the residual of total farm-produced wheat use minus farm-produced wheat seed.

For all cross-sections, the farm-produced feeds were valued at their market value to estimate the opportunity cost of using such commodities as feed rather than selling them at their market value. The nominal state value of farm-produced feed was then deflated by the corresponding index of prices received by farmers (i.e., the index of prices received by farmers for food grains was used to deflate the nominal value of farm-produced wheat, and the index of prices received by farmers for feed grains and hay was used to deflate the nominal value of farm-produced corn, barley, oats, sorghum, and hay).

Again, this specification is broader than those used by Davis (1979, p. 135) or Griliches (1963 p. 336 and 1964 p. 967), who include only purchased feeds in their specification of the variable. Bredahl (pp. 53-56 and 67) and Norton (1981, p. 12) included farm-produced feed in the feed variable, and a specification similar to the one used here was used by Evenson, et al. (1987, pp. 26-28).

The buildings portion of the "other inputs" variable represents the flow of services from farm building assets. This variable consists of the sum of the annual state repair expenditures on farm buildings (excluding farm dwellings) plus the amortized flow of services derived during the cross section year from existing farm buildings in the state.

Since repairs are reported only on an aggregate basis on the state level (i.e., including farm buildings, farm dwellings, and farm machinery) but repairs are disaggregated into the above three categories at the national level, the national proportion of total repairs expenditures that were directed toward farm service buildings (i.e, excluding farm dwellings) was used to calculate the expenditures on farm building repairs at the state level for each cross-section.

Since state level data report only the aggregate value of all farm buildings (including both farm service buildings and farm dwellings) while national level data report the disaggregated data for both dwelling and service buildings, the national proportion of the total value of farm buildings that is credited to farm service buildings was used to calculate the value of farm service buildings in each state. The annual flow of services obtained from farm buildings was amortized at an 5% interest rate and an assumed useful life of 20 years obtained from engineering estimates of building life (Phillips, p. 5). Thus, the nominal flow of services for state i was calculated as:

$$(3.11) \quad BLD_i = REP_i*NRPRO + BVAL_i*NVPRO*.08,$$

where BLD_i is the total nominal value of building services used in agricultural production in state i, REP_i is the total repair expenditures reported for state i, NRPRO is the national proportion of total repair expenditures directed toward farm service buildings during the cross-section year, $BVAL_i$ is the value of all farm buildings (including dwellings) in state i, NVPRO is the national proportion of total farm building assets classified as farm service buildings during the cross-section year, and .08 is an amortization factor (based on an assumed 20-year life for buildings and an 5% interest rate). This nominal state value was then deflated by the index of prices paid by farmers for building and fencing materials (1977 = 100 base year) to yield the real flow of services obtained from farm buildings in each state.

This specification of the building variable was similar to that of Davis (1979, p. 136) and Evenson, et al. (1987, pp. 25-26), although the amortization of building services may differ. Since they did not report their assumed building life, a direct comparison to their specifications was not possible. Bredahl (pp. 26-30) and Griliches (1964, p. 966) used the total value of land and buildings as a single variable. In an earlier study, Griliches (1963, p. 336) used the sum of building depreciation and interest to represent the flow of building services.

The final component of the "other inputs" variable is the category of other miscellaneous inputs. This component is the sum of real pesticide expenditures (defined as the state expenditures for pesticides deflated by the index of prices paid by farmers for agricultural chemicals) and real miscellaneous expenditures (defined as state expenditures for miscellaneous farm inputs deflated by the index of prices paid by farmers for all items used in production).

Research

The research variable is designed to measure the real investment in research applicable to each state during each cross-section year. Two specifications of the research variable were used in this investigation. The first included only the total agricultural research spending in state i during year t. This specification is intended to provide a check of the results of this study against those of earlier investigators who did not include a spillover component in the research variable. The second research specification, designed to measure research benefit spillovers, included total agricultural research spending in state i plus total research spending in other "relevant" states during year t.

The first specification, which excludes research benefit spillovers, was defined as total gross funds for research at the state agricultural experiment station minus three categories of research designated as "non-agricultural" research. This net agricultural research spending figure was then deflated by an index of professors' salaries (discussed below) to yield the real net agricultural research spending in the state.

The categories designated as "non-agricultural" research--timber forest production, recreation resources, and fish and wildlife research--were excluded from the research variable because they were deemed to be directed at problem areas other than agricultural production. Furthermore, it is important to note that these three research categories are funded primarily by a different funding mechanism than the agricultural research conducted at the state agricultural experiment stations. While agricultural research is funded through the Hatch Act (reviewed in Chapter I), these three research categories are funded through the McIntire-Stennis Act of 1962. This act provides matching funds to support research in the areas of commercial forest production and management, the preservation and improvement of habitat for fish and wildlife, and the management of forest lands for recreation uses (U.S. Office of the Federal Register, p. 807).[4] Since much of this research was non-agricultural in nature, and most of the available McIntire-Stennis funds were directed at these three problem areas (for example, 88% of the McIntire-Stennis funds spent at state agricultural experiment stations in Fiscal Year 1983 were spent in these three categories) it was deemed appropriate to exclude these three categories from the research variable.

It should again be noted that the output variable was constructed to exclude the sale of forest products on farms.

Two factors dictated the decision to exclude forestry output and forestry research from the model. First, most McIntire-Stennis research is aimed primarily at commercial forestry production rather than the relatively minor sort of forest production typical in most farm operations. Second, spending in these three categories is a major portion of total experiment station spending (in Fiscal Year 1983, for example, these three categories accounted for nearly 8% of total national experiment station spending and, if combined into one spending category, would have been the second largest spending category at experiment stations behind only the beef cattle category). Given these factors, it was judged that, in order to maintain consistency and minimize the possibility of introducing bias into the research coefficient in the estimated production functions, forest-related farm output and the research in these three forestry-related categories should be excluded from the data.

In order to measure the spillovers created by agricultural research, the second specification of the research variable was redefined to include research spending in other states. Two elements must be considered when specifying this form of the research variable. First, the variable must identify the outside states whose research is applicable in a given state. Second, the variable must identify the share of the research in these outside states that is applicable to the given state. Since little is known about the pattern of spillovers that exists in the U.S. (i.e., about which states' research is applicable to other states and how much of their research is applicable to these other states) the most appropriate method of addressing these two considerations was deemed to be an ad hoc approach that estimated research benefit spillovers under a variety of assumed scenarios. Thus, the specification of the research variable used to measure research spillovers was defined as:

$$(3.12) \quad Totres_i = Res_i + \sum_{j=1}^{n} \Phi * Res_j,$$

where,

- $Totres_i$ = Total research spending applicable to agricultural production in state i;
- Res_i = Agricultural research spending in state i;
- Res_j = Agricultural research spending in the j = 1...n states whose research is "relevant" to production in state i ($j \neq i$);
- Φ = A "pervasiveness weight" that indicates the proportion of research spending in the relevant states that is applicable to agricultural production in state i (by definition, $0 \leq \Phi \leq 1$).

Two considerations determine the definition of the spillover component of the research variable. The first of these considerations is a question of the relevance of agricultural research. Namely, farm output in state i is affected by research conducted in what other states? Or, stated conversely, research in one state affects agricultural production (and generates benefit spillovers) in what other states? Presumably, the answer to this question depends on a number of ecological, institutional, and human factors. Since no prior knowledge of spillover patterns exists, however, this question is answered here by estimating research spillovers under two assumed relevance scenarios. First, a "neighboring states" specification will be estimated (i.e., the research conducted in all states that share a border with state i will be assumed to be relevant to agricultural production in state i). Second, a "production region" specification will be estimated (i.e., the research conducted in all other states in the same USDA production region as state i will be assumed to be relevant to agricultural production in state i).

The second of these considerations is a question of the pervasiveness of agricultural research. Namely, how much of the research conducted in the relevant states is applicable to agricultural production in state i? Since agricultural research is devoted primarily to the problems of the funding state, not all of the research conducted in one state will be relevant to the states that neighbor the funding state or that are in the same production region as the funding state.
The concept of pervasiveness was originally introduced by

Evenson (1980, pp. 200-201) as a "contiguity index" that measured the contribution of research in one state to increased agricultural production in another state (shown in equation 2.24). Since there is again no prior knowledge of the correct pervasiveness weights, three assumed pervasiveness weights (Φ = .10, .20, or .30) will be used under each of the two relevance scenarios. The decision to use these weights was based on pragmatic considerations. First, it was decided that the pervasiveness weight would be increased in increments of .10 in order to provide a broad range of spillover scenarios. Second, as will be seen in Chapter IV, the performance of the econometric models declined rapidly as the pervasiveness weight increased beyond .30. Thus, .10 was chosen as the minimum pervasiveness weight and .30 was chosen as the maximum pervasiveness weight.

To reiterate, this study will estimate the state research benefit spillovers and their corresponding optimal matching rates for six spillover scenarios (three pervasiveness scenarios under each of the two relevance scenarios). To provide clarity to these assumptions, the construction of the research variable for one state--the state of Alabama--will be considered in detail.

Alabama shares a border with four state--Georgia, Florida, Mississippi, and Tennessee. Under the "neighboring states" relevance assumption, the research in these four states is assumed to be relevant to agricultural production in Alabama. Under the .10 pervasiveness assumption, 10% of the research conducted in these four states is assumed to be applicable to Alabama (at the same time, 10% of Alabama's research is assumed to be relevant in each of these four states). Therefore, the research variable in Alabama would equal Alabama's research spending plus 10% of the sum of the research spending in these other four state (as shown in equation 3.12). Under a .20 pervasiveness assumption, the Alabama research variable is defined as Alabama's research spending plus 20% of the sum of the research spending in these other four states. Under a .30 pervasiveness assumption, the Alabama research variable is defined as Alabama's research spending plus 30% of the research spending in these other four states.

Under the second relevance scenario, (the "production region" scenario) the research conducted in all other states in the same USDA production region is assumed to be relevant to a given state. As shown in Figure 6, this scenario assumes that research in Florida, Georgia, and South Carolina is relevant to agricultural production in Alabama. Spillovers will again be estimated under each of the three pervasiveness scenarios (i.e., the .10 scenario assumes that 10% of the research conducted in these other three states is applicable to agricultural production in Alabama, the .20 scenario assumes that 20% of the research in these states is applicable to Alabama, and the .30 scenario assumes that 30% of the research in these states is applicable to Alabama). At the

Figure 6: USDA Production Regions

Source: U.S. Department of Agriculture, 1987, p. iv.

same time, of course, the research variable for any one of these other states would be the sum of its own research plus the pervasiveness-weighted total of research in the other states in the production region, including Alabama.[5]

Once the production functions are estimated for each of these scenarios, the marginal products of research can be calculated for each state. These marginal products will then be used in Chapter V to estimate the share of the total marginal product of research that accrues inside and outside each state (for example, under the neighboring states specification example discussed above, an additional dollar of research conducted in Alabama would also produce research benefits in Florida, Georgia, Mississippi, and Tennessee). These shares will then be used to calculate the optimal federal matching rate for financing agricultural research under each spillover scenario. In this manner, the empirical results of the production function model and the theoretical results of the public finance model are combined to yield the optimal matching rates for financing agricultural research.

A number of institutional factors had to be accounted for in constructing the data for the research variable. First, both New York and Connecticut have two separately financed experiment stations within the state. In each case the total net research spending for the state was used for the research variable. Second, in a number of states, McIntire-Stennis funds are used to support forestry research at both the state agricultural experiment station and other state institutions.

Since the USDA reports separate data for each institution receiving McIntire-Stennis funds, only the non-agricultural research reported as having been conducted by the agricultural experiment station was deducted from the total research spending at the agricultural experiment station.

Third, since research spending is reported on a fiscal year basis while all output and input data are reported on a calendar year basis, the research spending data were "centered" on the calendar year to assure consistency. Prior to 1975, the fiscal year t ran from July 1 of calendar year t-1 to June 30 of calendar year t. Thus, for the 1964, 1969, and 1974 cross sections, an equally-weighted average of research in fiscal year t and fiscal year t+1 was used to center the research variable on a calendar year basis (e.g., research spending for calendar year 1964 was equal to .50 times research spending for Fiscal Year 1964 plus .50 times research spending for Fiscal Year 1965). Since the beginning of fiscal year t was shifted to October 1 of calendar year t-1 in 1975, a corresponding adjustment was made to center the research variable for the 1978 and 1982 cross-sections (e.g., for the 1978 cross-section the research variable was defined to equal .75 times research spending during Fiscal Year 1978 plus .25 times research spending for Fiscal Year 1979).

A fourth necessary adjustment was the conversion of the index of professors' salaries from an academic year basis to a calendar year basis. Since the data are reported by Pardey (p. 149) as the national average academic-year salary of college and university teachers (weighted by the number of persons holding each rank) for the academic year (Pardey, p. 149), these data were converted to a calendar year basis for cross-section t by equally weighting the national average salary for academic year t-1 and academic year t. The index of salaries for cross-section year t was then calculated by dividing the national average salary for calendar year t by the national average salary for calendar year 1977. This provides an index of professors' salaries with a base year of calendar year 1977 = 100.[6]

A fifth adjustment in the data was required since research spending data were not available on a commodity basis until the establishment of the Current Research Information System in 1966. Thus, spending on non-agricultural research had to be estimated for the 1964 and 1965 Fiscal Years. Two methods were used to estimate non-agricultural research spending during this period. The first method multiplied total experiment station spending in each state during Fiscal Years 1964 and 1965 by the ratio of non-agricultural research spending (i.e., forestry, fish and wildlife, and recreation resources research) to total experiment station spending in the state for Fiscal Year 1969. The second method estimated the funds for non-agricultural research in Fiscal Years 1964 and 1965 by multiplying the amount of federal McIntire-Stennis funds appropriated to each state for Fiscal Years 1964 and 1965 by 2 (since the McIntire-Stennis Act required states to match federal funding on a one-to-one basis). Since these two methods produced similar estimates of non-agricultural research spending (for example, the total national non-agricultural research estimated by method one was about 2% larger than the total non-agricultural research estimated by method two) and since Fiscal Year 1964 was the first year that McIntire-Stennis funds were made available to the states, thereby suggesting that states probably did not significantly exceed the one-to-one matching rate for forestry-related research, the second method was used to estimate total non-agricultural research funding for each state for Fiscal Years 1964 and 1965.

The two specifications of the research variable used in this study are similar to those employed in other studies. The first, which includes only in-state research spending during year t, is similar to that employed by Bredahl (pp. 74-78) and Norton (1981, pp. 11-12) on a commodity level and by Davis (1979, pp. 69-74) on an aggregate level. Such a specification is as acceptable as more sophisticated specifications of lagged research spending on both theoretical and empirical grounds. Bredahl (pp. 5-10) demonstrated that such a specification does not bias the estimated research coefficient (and thereby the estimated marginal product of research) if research spending is assumed to grow at a constant annual rate, while Davis (1979, pp. 69-74; 1981b) found that the research coefficients estimated by production functions using current research spending did not differ significantly from those estimated by equations using lagged measures of research spending. Given these results, a specification using current research spending was chosen for this study.

The second specification of the research variable, which includes in-state research spending and research spending in other relevant states, is somewhat similar to that used by Evenson (1980, pp. 200-203) in his productivity decomposition studies (as shown in equation 2.24). While Evenson used geoclimatic regions to define the relevance of outside research, this study will consider other specifications of relevance.

It should be noted that no other studies have reported some of the adjustments made in the research data for this study. For instance, none reported having adjusted the research spending data or index of professors' salaries to place these components on a calendar year basis. More important, however, is that previous studies by Griliches (1964) and Davis (1979) did not report having adjusted the data to reflect the growth of forestry research after the passage of the McIntire-Stennis Act. This adjustment was not necessary for Griliches, since his analysis was conducted before the passage of the McIntire-Stennis Act. Davis did not make such an adjustment, however, and estimated that while research had a positive and significant effect on output during the 1949 to 1959 period, it had a positive but insignificant effect during the 1964 to 1974 period (Davis, pp. 64, 72). In addition, it must be noted that in the

Cobb-Douglas specification of the production function used by Davis, the inclusion of non-agricultural research in the research variable would affect the marginal product of research even if the research coefficient was unaffected by its inclusion. Since the marginal product of research in the Cobb-Douglas specification equals the research coefficient times the average product of research, the inclusion of forestry research in Davis' model would have reduced the average product of research and, in turn, would have reduced the estimated marginal product of research. Thus, one of the questions addressed in Chapter IV is whether the exclusion of non-agricultural research from the research variable is a more appropriate specification of the research variable.

Extension

The extension variable is defined as the real per farm expenditures in each state on production-oriented extension activities during each cross-section year. This variable was constructed by multiplying total state extension spending by the estimated proportion of extension work devoted to agricultural production activities. Total extension spending was calculated by "centering" extension spending for the appropriate fiscal years on the cross-section calendar years in the same manner as was done for research spending. These calendar year data were then multiplied by the national share of extension agents' time devoted to agricultural production activities to yield total state spending on production-oriented extension activities.

Cline estimated that the national share of extension agents' time devoted to agricultural production activities averaged 36% for the 1951 to 1973 period, with a high share of 39% in 1951 and a low share of 34% in 1961 (reported in Davis, 1979, p. 139, and Lu, et al., p. 19). Given the stability of his estimate, the 36% average share was used for all five cross-sections in this research. Total state spending on production-oriented extension activities was then deflated by the same index of professors' salaries that was used to deflate the research variable. This yielded the real state expenditure on agricultural extension activities.

The specification used here is similar to that used by Davis (1979, p. 43-48), but differs from those studies that used a total research and extension spending variable rather than separate variables for research and extension spending (Griliches, 1964, p. 966; Lu, et al. p. 19; Havlicek and White, 1983a, p. 23). As Davis stressed, the combined specification is valid only if research and extension are either perfect substitutes or perfect complements. Thus, the use of separate variables is a more flexible specification which permits the estimation of separate marginal products for research and extension spending.

A final note of explanation is required concerning the specification of the research variable on a total state spending basis and the extension variable on a state spending per farm basis. These specifications were chosen since they best represent (1) the public good nature of agricultural research (i.e., one farmer's consumption of the knowledge produced by research does not reduce the availability of such knowledge to other farmers) and (2) the "semi-private" nature of extension work that usually precludes the use of an extension agent's time by more than one farmer at a time. Such a difference in the nature of these publicly-provided services suggests that the former is more appropriately specified on a total spending basis, while the latter is best measured as the dollars spent per farm to provide extension assistance to farmers.

Weather

Given the effect of weather on farm output, it was deemed necessary to include a weather variable in this research; however, given the large number of weather-related factors that can combine to affect farm output (e.g., rainfall, wind speed, temperature, and duration and intensity of sunlight) it was deemed to be inadequate to use one weather factor as a reliable measure of weather conditions (Hobbs, pp. 112-19; Critchfield, pp. 293-325). In addition, while it is possible to construct an index of weather conditions from several weather factors, such an extensive undertaking is beyond the scope of this research. Thus, it was deemed best to use the USDA's index of pasture conditions as a measure of weather conditions. This index is designed to reflect the general affect of weather conditions on pastureland across states and over time within the same state.

The July pasture conditions index was chosen to measure weather conditions in each state. This specification is similar to Davis (1979, p. 38). Other studies (Griliches, 1963 and 1964; Bredahl; Norton, 1981) did not include a weather variable.

Summary

This chapter has used two branches of economic literature to provide a model capable of estimating the optimal matching rates for financing agricultural research. First, the literature on the economics of intergovernmental grants was used to develop a public finance model that establishes the optimal federal matching rates for financing agricultural research. These matching rates are based on the share of the marginal product of research that spills across state lines. Second, to find the share of the marginal product of research that spills across state lines, a production function model is developed that specifies state output per farm as a function of (1) state use of conventional inputs per farm, (2) state research expenditures plus research expenditures in other relevant states, (3) state extension expenditures per farm, and (4) weather.

Since no prior information is available on the direction or extent of research benefit spillovers, six ad hoc assumptions will be used to estimate the research benefit spillovers under a variety of scenarios. One set of scenarios assumes the research conducted in neighboring states is relevant to the agricultural production in a given state.

Under a second set of scenarios, the research conducted in all other states in the same USDA production region as a given state will be assumed to be relevant to that state.

Under each of these "relevance" scenarios, three specifications of the "pervasiveness" of research (i.e., the share of the research conducted in the "relevant" states that is assumed to be applicable to the given state) will be estimated. These three scenarios will assume that 10%, 20% or 30% of the research conducted in the other relevant states is applicable to the given state.

Using these two assumptions of "relevance" and three assumptions of "pervasiveness," a production function will be estimated for each of the six spillover scenarios. The results of these estimates will be reported in Chapter IV. These results will then be used in Chapter V to calculate the marginal products of research that accrue inside and outside each state. These marginal products will then be incorporated into the public finance model, thereby yielding the optimal matching rates needed to finance agricultural research under each of the spillover scenarios.

Notes to Chapter III

1. Madden has also identified several other implicit normative assumptions that undergird all economic analysis of agricultural research: (a) The analysis of agricultural research has a higher value than other possible uses of the economist's resources, and the political system, which must allocate its scarce resources among several competing political issues, places a higher value on addressing agricultural research policy than on other political issues; (b) The values embedded in the existing structure of legal institutions are the correct social values within which to conduct economic policy research; (c) The prevailing set of market values, which are the product of the prevailing system of property institutions and distribution of income, are an accurate reflection of the social value of goods and the social cost of inputs; (d) Any increase in the real money value of goods available in the economy is an increase in the welfare of the persons participating in that economy; and (e) The results of agricultural research that have no market value have no social value. These normative assumptions delimit any such economic research, since they "determine the scope of findings, the array of policy options that can be addressed by the findings, and the way the findings are interpreted" (Madden, pp. 6-9, 15-20).

2. The specification of the labor variable employed here is substantially different from that employed by Griliches (1964) and Davis (1979). Their studies estimated the number of days worked on farms from the following formula (Davis, 1979, p. 125-26):

   $$L = (300 - OF/N)*[N*(1 - .4* A) + .65*(F - N)] + HE/W,$$

   where:

   L = the total number of days worked on farms in state i during the year;
   OF = the total number of days worked at off-farm jobs in state i during the year;
   N = the number of farms in state i (assumed to equal the number of farmers in state i);
   A = the fraction of farmers over age 65 in state i;
   F = the number of family members working on farms in state i, including the farmers in state i;
   HE = farm expenditures on hired labor in state i;
   W = the farm wage rate in state i.

   An attempt to reconstruct Davis' data indicated that this formula could not be used since, beginning in 1969, some states reported fewer total family members working on farms than there were farmers in the state (i.e., the (F - N) term in the above equation, which represents the number of unpaid family workers, was negative). Using the data sources cited by Davis (1979, p. 127), this was found to be true for 3 states in 1969, 3 states in 1974, and 7 states in 1978. This negative result is probably due in part to the different data sources used to collect these two variables (the number of family workers comes from the USDA Farm Labor publication, while the number of farmers comes from the Census of Agriculture). Given these results, the Griliches-Davis specification was not employed in this study.

3. The national average income of farm males over 25 in each education category was calculated using U.S. Census data for the farm male population by income and education category. For each education category, the proportion of U.S. farm males in each income category was multiplied by the average income in that category to yield a national average income for that education category. That is, the national average income in each education category was calculated as:

$Y_i = P_{ij} * I_j$, where:
Y_i = The national average income of farm males in education category i;
P_{ij} = The proportion of U.S. farm males in education category i and income category j; and
I_j = The average income of U.S. farm males in income category j.

Using this method, the average income of all males over 25 years of age in the U.S. (in current dollars) for each level of education for each decennial census was as follows:

Years of Education	1960	1970	1980
Elementary:			
0 to 7	$3207	$4495	$ 8763
8	4394	5995	11113
High School:			
1 to 3	5419	7541	13578
4	6374	9012	16929
College:			
1 to 3	7828	10585	18978
4 or more	10693	15202	26983

It should be noted that although the calculated figures for 1970 are identical to those calculated by Davis (1979, p. 130) there are some minor differences between the averages used here and those used by Davis for the

1960 cross-section. These differences range from $37 for the 8 years of elementary school category to $10 for the 4 or more years of college category. These differences apparently result from the use of different average income estimates for some lower income categories. The averages used in this study were $800 for the $1-$999 income range, $1700 for the $1000-$1999 income range, and $2600 for the $2000-$2999 income range. Houthakker's (p. 24) estimates of average income were used for all higher income categories. These adjustments in the lower categories were necessary, since the income categories reported in the 1960 census were different than those reported by Houthakker in some lower income categories. The averages used here in the lower income categories were chosen to approximate the ratio of the difference between the minimum of the category and the average of the category to the difference between the minimum and the maximum of the category. For example, the $1-999 income category reported in the Census was reported by Houthakker as two categories of $1-499 (with an average of $400) and $500-999 (with an average of $900). In both cases, the ratio of the difference between the average and the minimum to the difference between the minimum and the maximum was approximately 0.80. That is (400-1)/(499-1) equals 0.80 and (900-500)/(999-500) equals 0.80. This ratio was then used to estimate the average income in the combined category of $1-999 as $800 (i.e., (999-1)*.80 equals $800). Similar adjustments were used to combine Houthakker's $1000-1499 and $1500-1999 categories into a $1000-1999 category and his $2000-2499 and $2500-2999 categories into a $2000-2999 category, thereby matching his income categories to those reported in the Census. Since Davis did not report how this aspect of the data was handled in his estimates of income, direct comparisons of the reported differences are not possible.

4. The McIntire-Stennis Act had a one-to-one matching requirement. Each state received $10,000, and the remainder of the funds were allocated among the states according to the following formula (U.S. Congress, 1964a, p. 294):

   (a) Forty percent on the basis of total non-federal commercial forest land in the state;
   (b) Forty percent on the basis of timber cut annually from growing stock in the state;
   (c) Twenty percent on the basis of non-federal funds invested in forestry research by the state.

5. One other difference between "in-state" research and "outside" research should also be noted. Two specifications of the research variable were tried in this study. The first specification was that described in the text of this chapter (i.e., the total state

research expenditures minus "forestry-related" research expenditures). A second specification, similar to that used by Evenson (1980), specified each state's total research expenditures as the sum of the state's expenditures in several "production-oriented" research categories. These categories (listed in the Current Research Information System) were used by Evenson to prevent "non-production" research (particularly economic research) from biasing the estimated research production coefficient. Evenson then combined farm management research with extension expenditures to form his "extension and applied economics" variable. Thus, a second specification of the research variable was constructed in this study using Evenson's specification for research spending (i.e., the sum of his "production-oriented" research categories). However, farm management research was not combined with the extension spending.

In this study, "in-state" research and "outside" research were each specified using each of these two research specifications (i.e., the text specification and the Evenson specification). The combination that performed the best in the econometric models (as measured by the adjusted R^2 and the signs and significance of the coefficients) was the text definition for "in-state" research and Evenson's specification for "outside" research. Thus, this specification is used in this study and reported in Chapter IV. This specification of "in-state" and "outside" research is roughly similar to Evenson's. The major difference is that Evenson's specification (1980, p. 204) included farm management research in the extension variable and excluded all other types of agricultural economics research from the model. This study includes all "in-state" agricultural economics research in the "in-state" research expenditure component of equation (3.12) and excludes all "outside" agricultural economics research.

The research categories included in the "outside" research component were (CRIS classification numbers appear in parentheses): Range (700), Citrus and subtropical fruit (900), Deciduous and small fruits and edible tree nuts (1000), Potatoes (1100), Vegetables (1200), Corn (1400), Grain sorghum (1500), Rice (1600), Wheat (1700), Other small grains (1800), Pasture (1900), Forage crops (2000), Cotton (2100), Cottonseed (2200), Soybeans (2300), Peanuts (2400), Other oilseeds and oil crops (2500), Tobacco (2600), Sugar crops (2700), Miscellaneous and new crops (2800), Poultry (2900), Beef cattle (3000), Dairy cattle (3100), Swine (3200), Sheep and wool (3300), Other animals (3400), General purpose supplies--machinery, equipment, fertilizers, feedstuffs, and pesticides (3600), Structures and facilities (3900), Weeds (6100), Seeds (6200), Biological cell systems

(6300), Invertebrates (6500), Microorganisms (6600), Plants (6700), and Animals (6800). Since the CRIS system did not come into existence until 1966, total research expenditures in each state in Fiscal Years 1964 and 1965 were multiplied by the ratio of the total spending in the above categories to total research spending in the state during the 1969 Fiscal Year. This yielded an estimate of the total research expenditures in these categories for Fiscal Years 1964 and 1965. This estimate was then used as the "Evenson" specification for research spending in the 1964 cross-section.

6. The average salary of university professors on a calendar year basis (in current dollars) and the values of the index of professors' salaries for the cross-section years were (calendar year 1977 = 100):

Year	Salary	Index
1964	$8,709	49.2
1969	11,396	64.4
1974	15,005	84.8
1978	18,413	104.1
1982	24,700	139.6.

As Pardey (pp. 62-70) has discussed, a research price index constructed to include only one input (in this case, labor) will be biased when other types of inputs are also used to produce research. He then constructed a research price index using the expenditure shares of experiment station spending for labor, land and buildings, and other expenses as input weights that were multiplied by separate price indexes for each input to yield an aggregate price index for research inputs. His results indicated that a labor-based index such as that employed by this study would overestimate the rate of increase in research input prices by 0.3 percent annually during the 1960-1969 period and underestimate the rate of increase by 0.6 percent annually during the 1970-1975 period. Since Pardey's index had not been published at the time this research was conducted and the USDA did not report experiment station expenditures by expenditure category after 1974, the index of professors' salaries was deemed the best available index of research input prices.

An additional difference from some previous studies should also be noted. Some previous studies have attempted to establish a measure of the flow of research spending by only including the amortized value of research expenditures on buildings (Evenson, 1967) or by subtracting all building expenditures from total research expenditures (Davis, 1979, p. 137). Other studies have not made this adjustment (Griliches, 1964; Bredahl; Norton, 1981). As noted above, data on experiment station spending by expenditure category were not reported after 1974. Given this limitation in the available data, this adjustment was not made in the research variable used in this study. It should be noted, however, that any bias introduced by the specification employed here would be in the direction of underestimating the marginal product of research (since the inclusion of all building expenditures would reduce the average product of research which, given the Cobb-Douglas specification used here, would in turn reduce the estimated marginal product).

FINANCING AGRICULTURAL RESEARCH IN A FEDERAL SYSTEM OF GOVERNMENT: OPTIMAL COST-SHARING FOR STATE AND NATIONAL INVESTMENTS

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CHAPTER IV

EMPIRICAL RESULTS

This chapter presents the estimates of the production function models described in Chapter III. These results will be used in Chapter V to calculate the marginal products of research inside and outside each state. These estimated marginal products will then be used to calculate the optimal federal matching rates necessary to finance agricultural research in each state.

This chapter focuses on: (1) the selection of the observation set used to estimate the production functions; (2) the presentation of the production functions estimated without a research spillover component in the research variable; (3) the calculation of the marginal products of conventional inputs, research spending, and extension spending; (4) the calculation of the marginal internal rate of return for agricultural research spending under this specification; (5) the comparison of these results to previous studies; and (6) the presentation of the production functions specified to include a spillover component in the research variable and the calculation of the marginal product and internal rate of return on research for this specification.

Since little prior knowledge exists about the direction or extent of the spillover pattern that exists in the U.S., the production functions that do include a spillover component are specified for six assumed research spillover patterns. These estimates will provide a broad set of spillover scenarios that will then be used in Chapter V to estimate the marginal product of research that accrues inside and outside each state from research conducted in that state. These marginal products will then be incorporated into the public finance model specified in Chapter III, thereby providing the optimal federal matching rates for financing agricultural research in each state under each spillover scenario.

Selection of the Observation Set

Past studies have used a variety of observation sets to estimate the production functions employed in calculating the marginal product of research. Because some states' data were reported on a combined basis rather than according to individual states, Griliches (1964) used a 39 "state" data set that was a combination of 35 actual states and 4 "states" that were combinations of individual states.[1] Bredahl (pp. 46-72) used observation sets ranging from 41 to 48 states in his commodity-level study, omitting those states with fewer than 50 farms reported in a given commodity category.

Davis (1979, pp. 56-60) compared the Griliches observation set with a 48-state set and a 40-state set, omitting seven New England states from the last observation set because (1) the size of the farm sector relative to the non-farm sector, as measured by the ratio of farm income to non-farm income, was much smaller in the 8 omitted states than the remaining 40 states, and (2) the research in these states was oriented toward consumer and environmental issues rather than farm production.[2] In addition, Maryland was excluded from the latter data set, according to Davis, because its "experiment station expenditure on research is boosted considerably by USDA funds intended for more basic research less directed toward the problems of that state" (Davis, 1979, p. 57).

Several factors were considered in selecting the observation set for this study. In addition to Davis' observations about the relative size of the farm sector and the non-production orientation of the research conducted in his excluded states, additional information should be considered. An examination of the composition of the research conducted in seven of Davis' excluded states (all except Maryland) revealed that the average ratio of total state research spending to total state agricultural output for these states was significantly greater than the national average ratio of total state research spending to total farm output. This tends to confirm Davis' contention that the research conducted in these states is more oriented toward non-production activities than is research conducted in most other states. In addition, it should be noted that the composition of agricultural output in these states differs widely from that of the national average. In 1982, for example, New Hampshire, Massachusetts, and Rhode Island derived 10%, 26%, and 40% of their respective farm output from greenhouse and nursery products. Only 2.8% of national farm output was derived from these sources.

In considering the case of Maryland, however, an examination of USDA documents did not confirm Davis' claim that Maryland had received an inordinate amount of USDA contract money for basic research. While a large portion of USDA basic research money is spent at Beltsville, Maryland, such funds do not come under the control of the Maryland Agricultural Experiment Station and are accounted for and reported separately. In addition, Maryland's ratio of total experiment station spending to total farm output was below the national average ratio for each of the five cross-sections, thereby suggesting that Maryland does not conduct an inordinate amount of basic research.

Given this background, a 48-state data set was compared with a 41-state data set to determine the most appropriate set for estimating the marginal product of research. Among the states excluded by Davis, only Maryland was returned to the observation set, since no evidence could be found that Maryland's research spending is inflated by USDA research spending. The effect of using these alternative observation sets on the estimated production coefficients of research will be discussed in the following section.

Estimates of the Production Function Model Excluding Research Spillovers

The first production functions to be estimated were those that excluded the research spillover component of the research variable. That is, the research variable included only the research spending by the state agricultural experiment station in the state and does not include research spending in other states. This specification is similar to that used by Griliches (1964) and Davis (1979) and does not permit the measurement of spillovers.

These estimates serve two purposes. First, they will be used to select an appropriate observation set for estimating the production functions that do include a research spillover component in their specifications. Second, they provide a basis for comparison with previous studies of the rate of return on agricultural research investments. This comparison is useful for two reasons. First, it represents a continuation of the research originated by Griliches (1964) and updated by Davis (1979). Second, it provides a basis for examining the effect of the growth in forestry-related spending on the estimated marginal product of agricultural research. As discussed in Chapter III, Davis (1979) did not correct for the growth in forestry-related research after the passage of the McIntire-Stennis Act of 1962. By correcting for the growth in forestry-related spending, this research can examine whether his study may have underestimated the rate of return on agricultural research after 1962.

The production functions estimated in this stage of the research are cross-section estimates of Cobb-Douglas functions of the following specification. Data for 1964, 1969, 1974, 1978, and 1982 were used. Complete descriptions of these variables were provided in Chapter III (all values are expressed in 1977 dollars):

(4.1) $Output_i = f(Land_i, Labor_i * Education_i, Fertilizer_i, Machinery_i, Livestock_i, Other\ Inputs_i, Research_i, Extension_i, Weather_i, e_i)$,

where:

$Output_i$ = Total value of farm output per farm in state i;

$Land_i$ = Total quality-adjusted acres of land per farm used in farm production in state i;

$Labor_i$ = Total days of labor used per farm in state i;

$Education_i$ = Average annual per capita income of rural farm males over 25 years of age in state i;

$Fertilizer_i$ = Total expenditures per farm for fertilizer inputs in state i;

$Machinery_i$ = Total expenditures per farm for machinery inputs in state i;

$Livestock_i$ = Total expenditures per farm for livestock inputs in state i;

$Other_i$ = Total expenditures per farm for other production inputs in state i;

$Research_i$ = Total expenditures for agricultural research in state i;

$Extension_i$ = Total state expenditures per farm for agricultural extension in state i;

$Weather_i$ = Weather index for state i;

e_i = An error term.

Comparison of Observation Sets

As discussed above, the first task in estimating these production functions was the choice between a 48-state and a 41-state observation set. Table 4 shows the estimated production functions for the five cross-sections using the 41-state observation set. This observation set was chosen since (1) the discussion in the previous section concluded that the size and composition of the farm sector and the focus of the research programs in the seven excluded states were substantially different than those in the 41-state observation set, and (2) as expected, the research production coefficients estimated using the 41-state set were larger and more significant than those estimated with the 48-state set.[3] These results are similar to those estimated by Davis (1979, p. 56) in his comparison of a 48-state and a 40-state observation set. Given these results, the 41-state observation set was chosen to conduct the remainder of this research.

Assessment of Estimated Equations

The equations reported in Table 4, which do not include the spillover component of the research variable, are of interest for two reasons. First, these equations represent an update of the research that originated with Griliches' study (1964) of the 1949 to 1959 period and which has not been

Table 4. Estimates of Production Functions Excluding Research Spillovers

Variable[a]	1982	1978	1974	1969	1964
Research	0.17 (3.41)[b]	0.050 (0.74)	0.11 (2.03)[c]	0.064 (1.65)[d]	0.093 (2.18)[c]
Extension	0.14 (2.25)[c]	0.0071 (0.11)	0.10 (1.89)[c]	0.035 (0.76)	0.051 (1.04)
Land	0.085 (1.37)[d]	0.082 (1.34)[d]	0.010 (0.19)	0.023 (0.19)	0.0069 (0.16)
Labor * Education	-0.066 (-0.68)	0.25 (1.69)[c]	0.052 (0.41)	0.15 (1.46)[d]	0.14 (1.24)
Fertilizer	0.31 (3.71)[b]	0.43 (4.14)[b]	0.33 (4.57)[b]	0.29 (5.82)[b]	0.22 (4.93)[b]
Machinery	0.39 (1.68)[d]	0.068 (0.25)	0.37 (2.09)[c]	0.54 (4.46)[b]	0.45 (3.94)[b]
Livestock	0.12 (1.79)[c]	0.11 (1.85)[c]	0.31 (3.86)[b]	0.14 (2.69)[b]	0.24 (3.57)[b]
Other	0.17 (1.09)	0.21 (1.27)	0.077 (0.49)	0.15 (1.29)	0.051 (0.45)
Weather	-0.45 (-1.20)	-0.19 (-0.96)	0.38 (2.17)[c]	-0.32 (-1.80)[c]	-0.036 (-0.39)
Constant	1.19 (0.58)	-0.73 (-0.53)	-3.39 (-2.35)	-1.17 (-1.08)	-1.29 (-1.07)
Adjusted R^2	0.90262	0.90203	0.91812	0.96631	0.96470
S.S.R.	0.78600	0.83498	0.63161	0.35754	0.34721
F-statistic	42.19	41.92	50.84	128.46	122.46
Sum of Coefficients	1.009	1.15	1.149	1.293	1.107

[a]Values in parentheses are t-statistics.
[b]Coefficient significant at the .01 level.
[c]Coefficient significant at the .05 level.
[d]Coefficient significant at the .10 level.

Source: Author.

updated since Davis' study (1979) of the 1949 to 1974 period. Second, given the changes that were made in some variables, particularly the removal of non-agricultural research from total research expenditures to eliminate effect of the passage of the McIntire-Stennis Act, these equations provide an important comparison to the results estimated by Davis. This comparison is of interest since Davis found that both the research production coefficient and the marginal product of research declined during the 1964 to 1974 period.

Several observations should be noted to place these results in their proper perspective. First, the labor variable in the 1982 cross-section is the only input coefficient with an unexpected (negative and insignificant) sign. It should be recalled that labor data were collected on a monthly or quarterly basis prior to 1982, but were only collected in July during 1982. These data were then adjusted to estimate the quarterly labor data for 1982.[4] Whether this change in the quality of these data explains the negative sign on this coefficient is unclear. Given the lack of an effective alternative specification, however, the existing labor data had to be employed.

A second observation is that the sum of the estimated conventional input coefficients is similar to those estimated in other studies. The sum of the estimated coefficients reported in Table 4 ranges from a minimum of 1.009 in 1982 to a maximum of 1.29 in 1969. Griliches (1964, p. 966) estimated the sum of conventional coefficients to range from 1.197 to

1.282 for the 1949 to 1959 period, while Davis (1979, p. 64) estimated the sum of the conventional input coefficients to range from 1.149 to 1.289 for the 1949 to 1974 period. Bredahl (pp. 46-70) used 1969 data to estimate that the sum of conventional input coefficients ranged from 1.078 for dairy to 1.176 for cash grains.

Third, it is important to compare the results of the research and extension variables estimated here with those reported by Davis for the 1964 to 1974 period. As explained in Chapter III, the passage the McIntire-Stennis Act in 1962 established a system of forestry research funding that was administered by the state agricultural experiment stations. Since much of the research conducted with McIntire-Stennis funds is not related to agricultural production, however, the categories of research funded by this legislation were excluded from total experiment station funding to yield the net spending on agricultural production research. Davis (1979, pp. 58-64) did not make such an adjustment in his data and reported that both the significance of the research production coefficient and the marginal product of research declined during the 1964 to 1974 period. The results reported in Table 4, however, indicate that the significance of a research variable constructed to remove the effect of McIntire-Stennis funding has, in general, a degree of significance as great as that reported by Griliches (1964, p. 966) and Davis (1979, p. 64) for the era prior to the passage of the McIntire-Stennis Act. Such results suggest that future efforts to estimate returns to agricultural research must exercise care in developing a definition of research spending that reflects accurately the expenditures related to agricultural production problems.

The results reported here indicate that extension spending had a positive effect on output per farm, but that the effect was insignificant in three of the cross-sections. These results are in contrast to the consistently negative but insignificant effect estimated by Davis (1979, p. 64). Thus, the results estimated in this study are more consistent with prior expectations than Davis' estimates.

The weather coefficient was negative for all years except 1974. The cause of these results is unclear. Indeed, given the multitude of production factors affected by weather (e.g., crop yields, livestock weight gain rates, etc.) and the effects of all these factors on the value of farm output, the expected sign of this variable is somewhat uncertain. It should be noted, however, that the estimated results are generally consistent with those estimated by Davis for the 1964 to 1974 cross-sections. Davis (1979, p. 64) estimated a positive but insignificant coefficient for weather in 1964, while the estimated coefficient was negative but insignificant in this study. Both studies estimated a negative coefficient for 1969 and a significant, positive coefficient for 1974. A final factor that must be considered is that the specification employed here may simply be an inappropriate proxy for measuring state weather conditions.[5]

A final issue of some interest is the stability of the research production coefficient over time. To examine this question, the data from the cross-sections were pooled in a sequential fashion over time to test for the stability of the regression coefficients (i.e., 1964 and 1969 were pooled and tested, then 1964, 1969, and 1974 were pooled and tested, etc.). The results indicated that there was no significant difference in the equations for the 1964 to 1969 period or for the 1974 to 1982 period (i.e., the production functions were stable across the 1964 to 1969 period and the 1974 to 1982 period, but not across the 1964 to 1982 period).[6] The stability of the research coefficient was tested further by the use of a slope dummy on the research variable. These results also indicated that there was a significant difference between the research coefficient estimated for the 1964 to 1969 period and the research coefficient estimated for the 1974 to 1982 period.

Estimated Marginal Products and Internal Rates of Return to Research

The next step in assessing the effectiveness of agricultural research is the calculation of the marginal product of research and, since the benefits of research are expected to accrue over time, the internal rate of return for agricultural research spending. Since the equations reported in Table 4 were estimated using a Cobb-Douglas specification, the marginal products of each conventional input can be calculated by multiplying each production coefficient by its average product. It should be noted that the estimated average products were calculated using the geometric means of output and each input for each cross-section. Since the research variable is specified using total research spending rather that research spending per farm (to reflect the public good nature of research) the marginal product of research is equal to the research production coefficient times the average product of research (calculated at the geometric means) times the average number of farms per state (calculated at the arithmetic mean) (Bredahl, p. 86).

The estimated marginal products for each of the cross-sections are shown in Table 5. An examination of these results suggests the marginal products estimated here are comparable to those estimated in previous studies. While the marginal product of fertilizer appears high, it is comparable to previous estimates. With the exception of 1974, for which Davis (1979, p. 75) estimated the marginal product of fertilizer to be $18.36, the estimates reported here are consistent with prior studies.[7]

The estimated marginal products of extension are more difficult to assess. Griliches (1964) estimated the marginal product of research and extension spending (combined into one variable) to equal $13, while Davis (1979, p. 75) estimated the marginal product of extension to be $32 dollars for 1949 and negative for all cross-sections from 1954 to 1974. Huffman (1976a) estimated the marginal product of extension to equal $1000 to $3000 per day. Converting the 1982 estimate to a per

Table 5. Estimates of Marginal Products for Production Functions Excluding Research Spillovers (1977 dollars)

Variable[a]	1982	1978	1974	1969	1964
Research	$36.14	$10.75	$24.74	$16.77	$23.41
Extension	63.59	3.33	45.91	19.38	27.05
Land	11.12	9.95	1.09	2.56	0.65
Labor	-7.36	26.14	3.94	10.47	6.52
Fertilizer	6.82	7.19	4.95	5.91	5.89
Machinery	2.26	0.32	1.76	2.71	2.25
Livestock	1.86	1.69	3.45	1.79	2.60
Other	0.47	0.51	0.19	0.36	0.12

[a]The units for these marginal products are: Research--marginal dollars per an addition dollar of research spending; Extension--marginal dollars per an additional dollar of extension spending per farm; Land--marginal dollars per an additional acre of quality-adjusted land; Labor--marginal dollars per additional day of labor; All other inputs--marginal dollars per an additional dollar of the input.

Source: Author.

day basis suggests the marginal product of extension equaled $5596 per day in 1982.[8] Although this figure is higher than Huffman's estimates, it must be noted that the estimated marginal product of extension was much higher in 1982 than in the other cross-sections. In general, the estimated marginal products of extension appear comparable to previous estimates.

The marginal products of research estimated here are comparable to those estimated by Griliches (1964) and Davis (1979, p. 75) for the 1949 to 1959 period. However, Davis estimated the marginal product of research fell from the $10 to $25 range during the 1949 to 1959 period to the $4 to $15 range for the 1964 to 1974 period. This study, which corrected the research variable for the passage of the McIntire-Stennis Act of 1962, does not find a similar decline during the post-1964 period. It is important to note again that even if the increase in forestry research following the passage of the McIntire-Stennis Act did not affect the estimated research production coefficient in Davis' study, it would introduce a downward bias into his calculation of the marginal product of research by decreasing the average product of research (which, given his use of the Cobb-Douglas specification, must be multiplied by the production coefficient to calculate the marginal product of research).

Bredahl (pp. 2-14) demonstrated that the use of current research spending to specify the research variable (as was done in this study) implies that the marginal product of research estimated from each cross-section represents the long run total increase in output that results over time from an additional dollar invested in agricultural research during the cross-section year. Thus, since the benefits of research accrue over time, it is necessary to convert the benefits to a current year basis to provide a comparison of agricultural research with other investment opportunities. The internal rate of return permits such a comparison by estimating the interest rate required to equate the cost of research with its benefits.

The two most critical factors in the calculation of the internal rate of return are (1) the assumed lag structure, and (2) the assumed length of the lag (i.e., the length of time over which research is assumed to have an affect on agricultural output). Prior studies (Evenson, 1967, p. 1422) have concluded that the distribution of research benefits is best approximated by the "inverted-V" structure shown in Figure 7. This lag structure suggests the impact of research on farm output will increase from the time of investment (0) until reaching a maximum at the mean lag (S), then will decrease due to the obsolescence or depreciation of the knowledge produced by the research. In selecting this method of calculating the internal rate of return, it should be noted that Davis (1979, p. 108) found that this method yielded a low to moderate estimate of the internal rate of return when compared to methods used by some other investigators. Given this lag structure, the marginal internal rate of return can

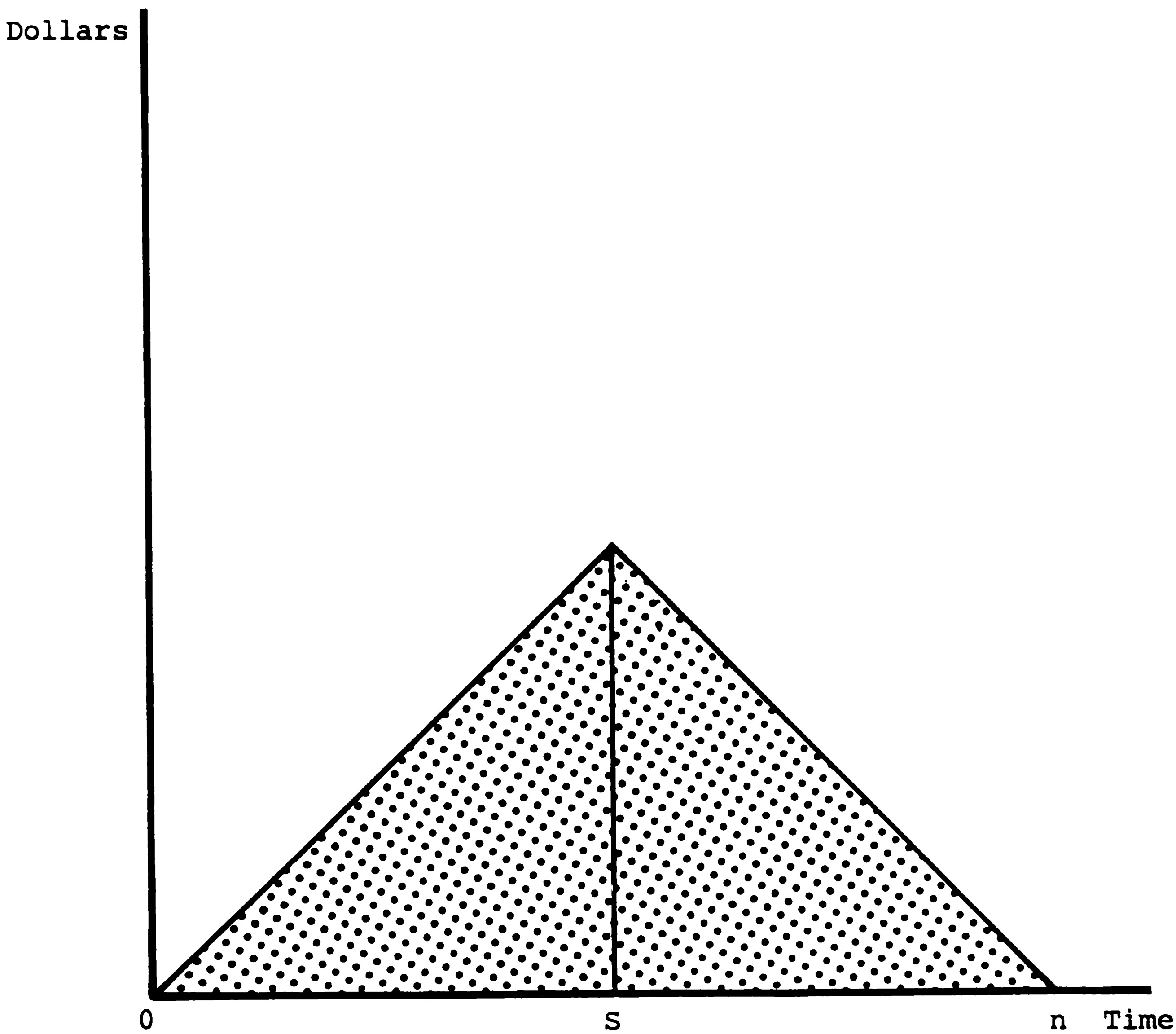

Figure 7: Assumed Distribution of Research Benefits over Time

Source: Norton (1981), p. 8.

be estimated from the equation (Bredahl, pp. 10-14; Davis, 1979, pp. 102-105; Norton, 1981, p. 8):

$$(4.2) \quad MPR * [\sum_{i=1}^{n} w_i/(1 + r)^i] - 1 = 0,$$

where:

MPR = The estimated marginal product of research;

n = The number of years over which research is assumed to have an effect on output;

r = The marginal internal rate of return to research investment;

w_i = $(2*i - 1)/2*S^2$ for i = 1 to S;

w_i = $(2*n - (2i - 1))/2*S^2$ for i = S + 1 to n;

S = n/2 = The assumed mean lag.

Table 6 shows the estimated marginal internal rates of return under a variety of assumed mean lags and adjustments for the omission of private sector research from the model. As discussed in Chapter II, two methods of adjustment have been used in previous studies to correct the marginal internal rate of return for the omission of private sector research. The first is to divide the marginal product of research by two, thereby assuming that public and private sector research spending are of equal size (Evenson, 1967, p. 1424; Bredahl and Peterson, p. 688; Norton, 1981, p. 8). A second method of adjustment is to divide the marginal product of research by 1.22, thereby following Evenson's estimate that, since private sector research is partially accounted for in the prices of purchased inputs, the coefficient on public sector

Table 6. Estimates of Marginal Internal Rates of Return on Research for Production Functions Excluding Research Spillovers

Year	Mean Lag[a]	Unadjusted	Adjustment Method 1[b]	Adjustment Method 2[c]
1982	5	159%	101	140
	6	127	81	112
	7	105	68	93
	8	89	58	79
	9	78	51	69
1978	5	71	42	61
	6	58	34	50
	7	49	29	42
	8	42	25	37
	9	37	22	32
1964	5	124	78	109
	6	99	63	88
	7	83	53	73
	8	71	46	63
	9	62	40	55
1969	5	96	59	84
	6	77	48	68
	7	65	41	57
	8	56	35	49
	9	49	31	43
1964	5	120	75	105
	6	96	61	84
	7	80	51	71
	8	69	44	61
	9	60	39	53

[a]The mean lag equals .5 times the number of years over which research is assumed to affect agricultural output, e.g., a mean lag of 5 years indicates that research is assumed to affect farm output for a period of ten years after the initial investment.
[b]Adjustment method 1 adjusts for the omission of private sector research from the model by dividing the marginal product of research by 2.
[c]Adjustment method 2 adjusts for the omission of private sector research from the model by dividing the marginal product of research by 1.22.

Source: Author.

research is biased by a factor of 1.22 (Lu, et al., pp. 29-30; Davis, 1979, p. 101). Given that both methods of adjustment have been used in past studies, the marginal internal rates of return calculated under both methods are reported in Table 6. Since most previous studies that have included past research spending in the research variable have concluded that the mean lag is approximately six to seven years (Evenson, 1967, p. 1422; Havlicek and White, 1983a, p. 25; Davis, 1979, p. 107), these mean lags will be used for comparison purposes.

The results estimated using the 6 and 7 year mean lags are comparable to the results of previous studies reported in Table 3. Comparing these results to studies of the same time period, the estimated internal rates of return reported here for aggregate research spending are bracketed by the previous commodity-level estimates (calculated using the first adjustment method) for the 1969 and 1974 cross-sections (Bredahl and Peterson, p. 688; Norton, 1981, p. 9).[9] Comparing these estimates to previous studies conducted on aggregate output, the results reported here also appear comparable to the regional estimates of 23% to 74% reported by Havlicek and White (1983a, p. 26) for the 1977 to 1981 period. It should also be noted that the results reported in Table 6 are closer to the 66% to 100% range reported by Davis for the 1949 to 1959 period than the 37% he estimated for the 1964 to 1974 period (Davis, 1979, p. 110). Given that the data employed here were corrected for the growth of forestry research spending after 1962, while the data employed by Davis were not, these results suggest that future investigations in this area should consider adjusting the research spending data for the growth of forestry-related research spending that occurred after the passage of the McIntire-Stennis Act of 1962.

To summarize, the production functions estimated in this section did not include research conducted outside the state in the specification of the research variable (i.e., no spillover effects were included). The results reported above indicate that: (1) a 41-state observation set appears to be the most appropriate for measuring the marginal product of agricultural research; (2) in several respects (the sum of estimated production coefficients, estimated marginal products of conventional inputs, estimated marginal products of research and extension spending, and the estimated internal rate of return on research) the results reported here are similar to those reported in other studies; and (3) the exclusion of "non-agricultural" research (i.e., forestry-related research) from the research variable appears to be an important change from the research specification used in some previous studies. The results indicate that the internal rate of return on research is similar to that reported by other studies conducted for the period prior to the passage of the McIntire-Stennis Act of 1962. This result differs from Davis' (1979) conclusion that the internal rate of return for research declined during the 1964-1974 period.

Estimates of the Production Function Model Including Research Spillovers

This investigation now turns to the estimation of production functions that are specified to include a research spillover component in the research variable. To repeat the discussion in Chapter III, production functions will estimated for six spillover scenarios. These estimates will then be used to calculate the marginal products of research that accrue inside and outside any given state. These estimates of the marginal products will then be incorporated into the public finance model developed in Chapter III. The public finance model will then yield the optimal matching rates for financing agricultural research in each state.

In this stage of the research, the production function model is specified to include the spillover effects of agricultural research. Except for the research variable, all variables are specified as before. As discussed in Chapter III, the research variable is now specified as:

$$(4.3)\quad Totres_i = Res_i + \sum_{j=1}^{n} \Phi * Res_j,$$

where

$Totres_i$ = Total research spending applicable to agricultural production in state i;

Res_i = Agricultural research spending in state i;

Res_j = Agricultural research spending in the j = 1...n states whose research is relevant to production in state i ($j \neq i$);

Φ = A "pervasiveness weight" that indicates the proportion of research spending in the relevant states that is applicable to agricultural production in state i (by definition, $0 \leq \Phi \leq 1$).

Since the appropriate definitions of relevant states and the appropriate pervasiveness weights are unknown, two specifications of relevance and three specifications of pervasiveness will be used to provide estimates of the optimal matching rates required to finance agricultural research under six spillover scenarios.

To review the specification of this variable discussed in Chapter III, the two definitions of relevance that are employed here are (1) a "neighboring states" specification that assumes all states that share a border with state i are relevant to state i, and (2) a "production region" specification that assumes all states within the same USDA production region (shown earlier in Figure 6) as state i are relevant to state i.[10] Under each of these relevance assumptions, pervasiveness weights of 0.10, 0.20, and 0.30 are used to specify the share of the research conducted in the relevant states that is assumed to be applicable in state i. These weights assume that for each dollar spent for agricultural research in the states relevant to state i, 10 cents, 20 cents, or 30 cents, respectively, will be applicable to agricultural output in state i.

Assessment of Estimated Equations

Tables 7 through 11 show the production functions estimated for each cross-section under each of the six spillover scenarios. An examination of these results suggests that (1) judged by the adjusted R^2, the neighboring states specification is generally superior to the production region specification, (2) the significance of the research coefficient generally declines as the pervasiveness weight increases until, beyond a weight of .30, the research coefficient becomes insignificant, (3) although the adjusted R^2 of the functions estimated with the research spillover specification was similar to those estimated for functions excluding the spillover specification (reported in Table 4), the adjusted R^2 was higher only for the spillover equations estimated for 1982 and 1978 under the neighboring states specification, and (4) the introduction of the spillover specification reduced the size and significance of the land coefficient (yielding negative but insignificant land coefficients for 1974 and 1964).

Estimated Marginal Products and Internal Rates of Return to Research

To provide a comparison of these equations to those estimated without a spillover component in the research variable, the marginal products and internal rates of return

Table 7. Estimates of Production Functions Including Research Spillovers: 1982 Cross-section[a]

Variable	Neighboring States Φ: .10	.20	.30	Production Regions .10	.20	.30
Research	0.23 (3.47)[b]	0.26 (3.46)[b]	0.27 (3.37)[b]	0.23 (3.11)[b]	0.29 (2.98)[b]	0.34 (2.85)[b]
Extension	0.12 (2.07)[c]	0.12 (1.99)[c]	0.12 (1.94)[c]	0.12 (2.00)[c]	0.12 (1.89)[c]	0.11 (1.82)[c]
Land	0.047 (0.79)	0.023 (0.39)	0.0051 (0.088)	0.064 (1.03)	0.048 (0.78)	0.033 (0.54)
Labor * Education	-0.031 (-0.32)	-0.0045 (-0.046)	0.016 (0.17)	-0.083 (-0.82)	-0.096 (-0.93)	-0.11 (-1.03)
Fertilizer	0.32 (3.85)[b]	0.32 (3.91)[b]	0.33 (3.94)[b]	0.31 (3.63)[b]	0.31 (3.47)[b]	0.30 (3.29)[b]
Machinery	0.49 (2.09)[c]	0.55 (2.34)[c]	0.59 (2.49)[b]	0.48 (1.99)[c]	0.55 '2.24)[c]	0.61 (2.44)[c]
Livestock	0.14 (2.05)[c]	0.15 (2.19)[c]	0.16 (2.31)[c]	0.14 (1.96)[c]	0.15 (2.13)[c]	0.16 (2.29)[c]
Other	0.12 (0.77)	0.090 (0.58)	0.069 (0.44)	0.14 (0.85)	0.11 (0.68)	0.085 (0.52)
Weather	-0.53 (-1.42)[d]	-0.57 (-1.52)[d]	-0.59 (-1.58)[d]	-0.56 (-1.47)[d]	-0.65 (-1.66)[d]	-0.72 (-1.83)[c]
Constant	-0.20 (-0.091)	-1.21 (-0.51)	-1.89 (-0.75)	0.55 (-0.25)	-0.18 (-0.078)	-0.89 (-0.35)
Adjusted R^2	.90353	.90335	.90203	.89798	.89597	.89391
S.S.R.	0.77864	0.78009	0.79075	0.82348	0.83965	0.85630
F-statistic	42.63	42.54	41.92	40.12	39.28	38.45

[a]Values in parentheses are t-statistics. Φ equals the "pervasiveness weight" on outside research under each relevance scenario.
[b]Coefficient significant at the .01 level.
[c]Coefficient significant at the .05 level.
[d]Coefficient significant at the .10 level.

Source: Author

Table 8. Estimates of Production Functions Including Research Spillovers: 1978 Cross-section[a]

	Neighboring States			Production Regions		
Φ:	.10	.20	.30	.10	.20	.30
Variable						
Research	0.080	0.10	0.12	0.048	0.048	0.046
	(0.99)	(1.19)	(1.33)[d]	(0.52)	(0.41)	(0.34)
Extension	0.0093	0.011	0.10	-0.0023	-0.0066	-0.0095
	(0.15)	(0.18)	(0.18)	(-0.037)	(-0.11)	(-0.16)
Land	0.075	0.069	0.064	0.076	0.074	0.072
	(1.29)	(1.21)	(1.13)	(1.25)	(1.22)	(1.19)
Labor * Education	0.25	0.25	0.26	0.26	0.27	0.27
	(1.76)[c]	(1.84)[c]	(1.94)[c]	(1.74)[c]	(1.75)[c]	(1.76)[c]
Fertilizer	0.43	0.42	0.42	0.45	0.45	0.45
	(4.25)[b]	(4.33)[b]	(4.42)[b]	(4.21)[b]	(4.19)[b]	(4.15)[b]
Machinery	0.11	0.14	0.16	0.071	0.072	0.071
	(0.39)	(0.50)	(0.57)	(0.25)	(0.25)	(0.24)
Livestock	0.11	0.12	0.12	0.11	0.11	0.11
	(1.89)[c]	(1.93)[c]	(1.96)[c]	(1.83)[c]	(1.82)[c]	(1.82)[c]
Other	0.19	0.18	0.17	0.21	0.21	0.21
	(1.17)	(1.09)	(1.03)	(1.25)	(1.24)	(1.24)
Weather	-0.19	-0.19	-0.20	-0.22	-0.24	-0.25
	(-1.02)	(-1.08)	(-1.15)	(-1.17)	(-1.29)	(-1.39)[d]
Constant	-1.34	-1.89	-2.33	-0.77	-0.79	-0.79
	(-0.82)	(-1.04)	(-1.18)	(-0.48)	(-0.42)	(-0.37)
Adjusted R^2	.90335	.90467	.90563	.90115	.90083	.90064
S.S.R.	0.82360	0.81249	0.80424	0.84248	0.84521	0.84679
F-statistic	42.54	43.17	43.65	41.52	41.37	41.29

[a]Values in parentheses are t-statistics. Φ equals the "pervasiveness weight" on outside research under each relevance scenario.
[b]Coefficient significant at the .01 level.
[c]Coefficient significant at the .05 level.
[d]Coefficient significant at the .10 level.

Source: Author.

Table 9. Estimates of Production Functions Including Research Spillovers: 1974 Cross-section[a]

Variable	Φ: Neighboring States .10	.20	.30	Production Regions .10	.20	.30
Research	0.12	0.12	0.11	0.13	0.14	0.14
	(1.79)[c]	(1.62)[d]	(1.45)[d]	(1.75)[c]	(1.50)[d]	(1.22)
Extension	0.092	0.087	0.083	0.096	0.092	0.087
	(1.73)[c]	(1.64)[d]	(1.57)[d]	(1.78)[c]	(1.69)[c]	(1.59)[d]
Land	-0.0027	-0.0093	-0.014	0.0035	-0.0018	-0.0071
	(-0.053)	(-0.18)	(-0.27)	(0.068)	(-0.034)	(-0.13)
Labor * Education	0.067	0.080	0.092	0.048	0.048	0.056
	(0.53)	(0.63)	(0.72)	(0.36)	(0.36)	(0.41)
Fertilizer	0.35	0.36	0.36	0.34	0.34	0.35
	(4.78)[b]	(4.93)[b]	(5.05)[b]	(4.50)[b]	(4.42)[b]	(4.38)[b]
Machinery	0.41	0.42	0.42	0.39	0.41	0.41
	(2.19)[c]	(2.19)[c]	(2.16)[c]	(2.13)[c]	(2.12)[c]	(2.05)[c]
Livestock	0.31	0.30	0.30	0.32	0.32	0.32
	(3.79)[b]	(3.72)[b]	(3.67)[b]	(3.89)[b]	(3.88)[b]	(3.83)[b]
Other	0.067	0.064	0.065	0.063	0.054	0.052
	(0.42)	(0.39)	(0.39)	(0.39)	(0.33)	(0.31)
Weather	0.37	0.36	0.36	0.37	0.35	0.34
	(2.09)[c]	(2.01)[c]	(1.97)[c]	(2.06)[c]	(1.97)[c]	(1.89)[c]
Constant	-3.95	-4.24	-4.33	-3.73	-3.97	-4.04
	(-2.42)	(-2.34)	(-2.21)	(-2.36)	(-2.25)	(-2.04)
Adjusted R^2	.91599	.91488	.91309	.91559	.91352	.91150
S.S.R.	0.64806	0.65972	0.67041	0.65114	0.66710	0.68267
F-statistic	49.46	48.52	47.69	49.21	47.95	46.78

[a]Values in parentheses are t-statistics. Φ equals the "pervasiveness weight" on outside research under each relevance scenario.
[b]Coefficient significant at the .01 level.
[c]Coefficient significant at the .05 level.
[d]Coefficient significant at the .10 level.

Source: Author.

Table 10. Estimates of Production Functions Including Research Spillovers: 1969 Cross-section[a]

	Neighboring States			Production Regions		
Φ:	.10	.20	.30	.10	.20	.30
Variable						
Research	0.077	0.080	0.078	0.072	0.074	0.072
	(1.68)[d]	(1.60)[d]	(1.48)[d]	(1.42)[d]	(1.23)	(1.04)
Extension	0.028	0.024	0.021	0.028	0.023	0.019
	(0.62)	(0.53)	(0.46)	(0.61)	(0.49)	(0.41)
Land	0.013	0.0069	0.0028	0.018	0.014	0.010
	(0.32)	(0.17)	(0.068)	(0.41)	(0.32)	(0.24)
Labor * Education	0.16	0.17	0.18	0.15	0.16	0.16
	(1.36)[d]	(1.72)[c]	(1.78)[c]	(1.51)[d]	(1.56)[d]	(1.61)[d]
Fertilizer	0.29	0.29	0.29	0.29	0.29	0.29
	(5.97)[b]	(6.05)[b]	(6.11)[b]	(5.75)[b]	(5.70)[b]	(5.68)[b]
Machinery	0.58	0.57	0.58	0.54	0.55	0.55
	(4.63)[b]	(4.67)[b]	(4.64)[b]	(4.49)[b]	(4.48)[b]	(4.45)[b]
Livestock	0.14	0.14	0.15	0.15	0.15	0.15
	(2.74)[b]	(2.74)[b]	(2.73)[b]	(2.75)[b]	(2.78)[b]	(2.79)[b]
Other	0.14	0.13	0.13	0.14	0.14	0.14
	(1.18)	(1.11)	(1.07)	(1.21)	(1.16)	(1.12)
Weather	-0.34	-0.35	-0.35	-0.34	-0.36	-0.37
	(-1.91)[c]	(-1.94)[c]	(-1.95)[c]	(-1.91)[c]	(-1.98)[c]	(-2.01)[c]
Constant	-1.57	-1.79	-1.88	-1.32	-1.39	-1.39
	(-1.33)	(-1.39)	(-1.38)	(-1.13)	(-1.12)	(-1.06)
Adjusted R^2	.96643	.96615	.96577	.96560	.96505	.96459
S.S.R.	0.35626	0.35923	0.36330	0.36506	0.37085	0.37573
F-statistic	128.94	127.85	126.37	125.75	123.73	122.08

[a]Values in parentheses are t-statistics. Φ equals the "pervasiveness weight" on outside research under each relevance scenario.
[b]Coefficient significant at the .01 level.
[c]Coefficient significant at the .05 level.
[d]Coefficient significant at the .10 level.

Source: Author.

Table 11. Estimates of Production Functions Including Research Spillovers: 1964 Cross-section[a]

	Neighboring States			Production Regions		
Φ:	.10	.20	.30	.10	.20	.30
Variable						
Research	0.096	0.091	0.082	0.11	0.10	0.091
	(1.87)[c]	(1.61)[d]	(1.37)[d]	(1.82)[c]	(1.49)[d]	(1.19)
Extension	0.038	0.031	0.027	0.041	0.033	0.027
	(0.77)	(0.64)	(0.55)	(0.82)	(0.66)	(0.53)
Land	-0.010	-0.019	-0.023	-0.0022	-0.0014	-0.0049
	(-0.25)	(-0.44)	(-0.53)	(0.050)	(-0.032)	(-0.11)
Labor * Education	0.16	0.17	0.18	0.14	0.14	0.14
	(1.42)[d]	(1.49)[d]	(1.53)[d]	(1.20)	(1.19)	(1.21)
Fertilizer	0.22	0.23	0.23	0.23	0.23	0.24
	(5.06)[b]	(5.14)[b]	(5.22)[b]	(5.06)[b]	(5.19)[b]	(5.33)[b]
Machinery	0.48	0.50	0.51	0.47	0.48	0.49
	(4.18)[b]	(4.22)[b]	(4.17)[b]	(4.06)[b]	(4.08)[b]	(4.06)[b]
Livestock	0.26	0.26	0.26	0.25	0.25	0.25
	(3.69)[b]	(3.67)[b]	(3.63)[b]	(3.60)[b]	(3.59)[b]	(3.55)[b]
Other	0.019	0.0085	0.0062	0.031	0.022	0.019
	(0.16)	(0.071)	(0.051)	(0.27)	(0.19)	(0.16)
Weather	-0.039	-0.044	-0.049	-0.052	-0.067	-0.079
	(-0.42)	(-0.46)	(-0.51)	(-0.56)	(-0.72)	(-0.83)
Constant	-1.64	-1.75	-1.73	-1.37	-1.36	-1.27
	(-1.19)	(-1.17)	(-1.08)	(-1.04)	(-0.98)	(-0.87)
Adjusted R^2	.96343	.96242	.96161	.96323	.96204	.96106
S.S.R.	0.35976	0.36961	0.37762	0.36166	0.37431	0.38301
F-statistic	118.07	114.83	112.32	117.43	113.62	110.69

[a]Values in parentheses are t-statistics. Φ equals the "pervasiveness weight" on outside research under each relevance scenario.
[b]Coefficient significant at the .01 level.
[c]Coefficient significant at the .05 level.
[d]Coefficient significant at the .10 level.

Source: Author.

were again calculated using the "inverted-V" lag structure shown in Figure 7 and equation (4.2). Table 12 shows the marginal products of research and the marginal internal rates of return for the spillover equations. For reasons of brevity, the marginal internal rates of return were calculated using a seven-year mean lag and the first adjustment method of dividing the marginal product of research by two. As expected, the results reported in Table 12, when compared to the internal rates of return reported in Table 6, indicate that the marginal products and internal rates of return to research decline when the cost of relevant research performed outside each state is included in the research variable.[11]

Summary

This chapter has presented the production function estimates that will be used to calculate the optimal matching rates for financing U.S. agricultural research. The first set of equations did not include a spillover component as a part of the research variable. These equations served two purposes. First, they were used to select an appropriate observation set. Second, they were used to provide a comparison to past studies of the internal rate of return on agricultural research.

The second set of equations (reported in Tables 7 through 11) were estimated to include a spillover component as a part of the research variable. Since no prior knowledge exists to indicate the correct spillover specification, six spillover scenarios were estimated. The research coefficients estimated

Table 12. **Estimates of Marginal Products of Research and Marginal Internal Rates of Return on Research Under Alternative Spillover Specifications**[a]

Neighboring States Specification

Marginal Products (1977 Dollars)

Φ:	.10	.20	.30
1982	$33.47	$29.49	$25.29
1978	11.99	11.77	11.71
1974	19.22	15.22	11.62
1969	14.51	11.98	9.74
1964	17.45	13.17	9.91

Internal Rates of Return (Seven year mean lag)

1982	65%	60%	54%
1978	32	31	31
1974	45	38	31
1969	37	32	27
1964	42	34	27

Production Region Specification

Marginal Products (1977 Dollars)

Φ:	.10	.20	.30
1982	$35.07	$35.25	$34.63
1978	7.57	6.09	4.92
1974	21.96	19.20	16.28
1969	14.32	12.00	9.92
1964	21.12	15.70	12.15

Internal Rates of Return (Seven year mean lag)

1982	67%	67%	66%
1978	21	17	13
1974	49	45	40
1969	37	32	27
1964	48	39	32

[a]All internal rates of return were calculated using the first adjustment method described in Table 6 (i.e., the marginal product research was divided by two before the internal rate of return was calculated). Φ equals the "pervasiveness weight" on outside research under each relevance scenario.

Source: Author.

in these equations will be used in Chapter V to calculate the marginal products of research that accrue inside and outside each state from an additional dollar of research conducted in that state. These marginal products of research will then be used to calculate the share of the total marginal product of research that accrues inside a given state from research conducted in that state. These shares will then be incorporated into the public finance model developed in Chapter III, thereby yielding the optimal matching rates for financing agricultural research.

Notes to Chapter IV

1. The combined states were: (a) Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont, (b) Delaware and Maryland, (c) Arizona and New Mexico, and (d) Nevada, Utah, and Wyoming.

2. The states omitted by Davis were Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, Rhode Island, and Vermont.

3. The 48-state data sets yielded the following estimated equations (t-statistics in parentheses):

	1982	1978	1974	1969	1964
Research	0.051	0.0098	0.031	0.041	0.025
	(1.16)	(0.24)	(0.79)	(1.42)	(0.89)
Extension	0.21	0.028	0.079	0.072	0.037
	(3.13)	(0.53)	(1.56)	(1.66)	(0.87)
Land	-0.048	0.046	-0.031	-0.0084	-0.048
	(-0.87)	(0.97)	(-0.69)	(0.26)	(-1.48)
Labor * Education	0.029	0.27	0.19	0.12	0.23
	(0.28)	(2.29)	(1.94)	(1.38)	(2.71)
Fertilizer	0.30	0.44	0.36	0.29	0.20
	(3.42)	(4.73)	(5.10)	(6.44)	(5.61)
Machinery	0.46	-0.021	0.32	0.55	0.45
	(1.94)	(0.088)	(1.78)	(4.79)	(4.18)
Livestock	0.21	0.12	0.24	0.18	0.27
	(2.74)	(2.26)	(3.25)	(3.82)	(4.71)
Other Inputs	0.16	0.29	0.17	0.11	0.049
	(0.94)	(2.21)	(1.13)	(1.09)	(0.49)
Constant	-1.00	-1.17	-2.59	-1.89	-1.61
	(-0.73)	(-1.04)	(-2.05)	(-2.11)	(-1.74)

4. See Chapter III for a complete description of the adjustments made to construct the 1982 labor data.

5. The equations in Table 4 were also estimated without the weather variable, yielding the following regression coefficients and t-statistics for the research and extension variables:

	Research	Extension
1982:	.18	.16
	(3.61)	(2.76)
1978:	.079	.032
	(1.31)	(0.54)
1974:	.099	.12
	(1.76)	(2.11)
1969:	.069	.056
	(1.69)	(1.21)
1964:	.097	.053
	(2.37)	(1.11)

These results suggest that if any bias has resulted from the inclusion of the weather variable, it has resulted in an underestimation of the research production coefficient and, in turn, the marginal product of research.

6. The formula used to test the pooling of these cross-section data sets was:

$$F = [(SSR_p - \sum_{i=1}^{t} SSR_i)/(t*k-k)] / [\sum_{i=1}^{t} SSR_i/(t*n-t*k)]$$

where:

SSR_p = the sum of squared residuals for the equation estimated using the pooled data set;
SSR_i = the sum of squared residuals for the equations estimated using the individual cross-section data sets;
n = the number of observations in each of the pooled cross-sections (41);
k = the number of variables in the estimated equation (9), and
t = the number of cross-sections pooled (Kmenta, p. 373; Davis, 1979, p. 86).

This statistic has an F-distribution with (t*k-k) and (t*n-t*k) degrees of freedom. The sum of squared residuals for the individual cross-sections are listed in Table 4. The pooled data sets yielded the following estimated equations (t-statistics in parentheses):

	1964-1969	1964-1974	1964-1978	1964-1982	1974-1978	1974-1982
Research	0.075	0.10	0.10	0.15	0.11	0.17
	(2.65)	(3.42)	(3.94)	(6.44)	(2.94)	(5.67)
Extension	0.036	0.0087	0.015	0.072	0.091	0.15
	(1.18)	(0.29)	(0.63)	(3.31)	(2.45)	(4.64)
Land	0.020	0.048	0.061	0.82	0.066	0.10
	(0.69)	(1.61)	(2.33)	(3.23)	(1.74)	(3.02)
Labor * Education	0.18	0.20	0.19	0.051	0.600	-0.075
	(3.23)	(3.31)	(4.11)	(1.41)	(0.89)	(-1.49)
Fertilizer	0.25	0.20	0.22	0.22	0.34	0.31
	(8.32)	(6.46)	(7.52)	(7.33)	(6.19)	(6.59)
Machinery	0.48	0.27	0.24	0.23	0.24	0.19
	(6.18)	(3.58)	(3.42)	(3.19)	(1.74)	(1.57)
Livestock	0.19	0.18	0.15	0.15	0.15	0.15
	(4.70)	(4.16)	(4.51)	(4.82)	(3.49)	(4.15)
Other Inputs	0.088	0.23	0.25	0.28	0.25	0.28
	(1.14)	(2.99)	(3.81)	(4.48)	(2.48)	(3.45)
Constant	-1.49	-2.81	-2.33	-1.78	-2.12	-1.72
	(-1.99)	(-3.63)	(-3.56)	(-2.81)	(-2.29)	(-2.09)
S.S.R.	0.79383	2.24354	3.32462	4.95123	1.69803	3.02917
F-Statistic	276.36	212.87	265.32	278.81	93.07	121.84

The calculated F-values (used to test the hypothesis that all coefficients of the pooled equations are equal) and critical 1% F-values for each of the pooled equations are listed below (degrees of freedom are shown in parentheses):

Pooled Equations	Calculated F-value	Critical F-value
1964 to 1969	0.89	2.56 (9,64)
1964 to 1974	3.62	2.03 (18,96)
1964 to 1978	2.52	1.70 (27,128)
1964 to 1982	2.99	1.59 (36,160)
1974 to 1978	1.12	2.56 (9,64)
1974 to 1982	1.83	2.03 (18,96)

If the calculated F-value is less than the critical F-value, the hypothesis that the coefficients are equal in the pooled cross-sections cannot be rejected (Kmenta, pp. 373-74). Thus, these results indicate that the 1964 and 1969 equations can be pooled and that the 1974, 1978, and 1982 equations can be pooled.

7. The ranges of estimated marginal products reported by Griliches (1964, p. 969) and Davis (1979, p. 75) were:

Input	Davis	Griliches
Land	.049-.15[a]	0.10-0.12[a]
Labor	4.20-18.51[b]	5.76-10.43[b]
Fertilizer	2.63-18.36[c]	6.97-12.67[d]
Machinery	Not Reported	1.18-1.26[c]
Other	0.69-2.07[c]	1.22-1.25[c]

The units associated with these variables are: (a) dollars per year per marginal dollar; (b) dollars per marginal day; (c) dollars per marginal dollar; and (d) dollars per marginal ton. Griliches estimated the ratio of the marginal product to factor price for fertilizer was between 3 and 5 for the period of his study.

8. Congressional documents indicated that the national average salary for extension agents was approximately $22,000 for 1982. Dividing this salary by an assumed 250 work days per year yields a salary of $88 per day. Multiplying the estimated marginal product of extension ($63.59 per marginal dollar) by the daily salary of $88 yields an estimated marginal product of extension of $5596 per day for 1982. Again, it should be noted that the marginal product of extension was higher in 1982 than in other years. This year was chosen for comparison purposes because USDA data on extension agent's salaries could not be found for the other years in the study.

9. The assumed mean lags and estimated marginal internal rates of return reported by Bredahl and Peterson (p. 688) and Norton (1981, p. 9) were:

Author	Year	Commodity	Mean Lag	IRR
Bredahl-	1969	Cash Grains	5	36%
Peterson	1969	Poultry	6	37
	1969	Dairy	6	43
	1969	Livestock	7	46

Author	Year	Commodity	Mean Lag	IRR
Norton	1969	Cash Grains	5	57%
	1969	Poultry	6	46
	1969	Dairy	6	42
	1969	Livestock	7	75
Norton	1974	Cash Grains	5	85
	1974	Poultry	6	51
	1974	Dairy	6	N.R.
	1974	Livestock	7	88

It should be noted that both studies used the first adjustment method to estimate the internal rate of return.

Since the benefits of extension also accrue over time, they should also be converted into an internal rate of return. Assuming an inverted-V distribution of extension benefits and a 7-year mean lag, equation (4.2) was used to calculate the unadjusted internal rate of return on extension spending. These calculations indicated that the internal rate of return on extension spending was 150% for 1982, 19% for 1978, 122% for 1974, 71% for 1969, and 88% for 1964. These figures appear comparable to the 110% internal rate of return reported by Huffman (1978) and by Evenson (1980, p. 213; also see Evenson, et al., 1979). Since the lag structures used by these authors were not reported, direct comparisons to their estimates could be made.

10. A "geoclimatic region" specification was also used as a third specification of relevance. This specification assumed all research conducted in states in the same geoclimatic region as state i was relevant to state i. Since the boundaries of these regions did not follow state boundaries and most states were part of more than one region (see USDA, 1957, pp. 451-627), the research spending in each state was allocated among its geoclimatic regions according to the share of the state's agricultural production produced in each region. Thus, the research relevant to state i was defined as the research conducted in state i plus a pervasiveness weight times the weighted sum of the research in all other states that share a geoclimatic region with state i (where the weights on each of the outside states' research were the shares of their production produced in the geoclimatic region shared with state i). While this specification is conceptually appealing, it yielded poor results. The research coefficient was insignificant for all pervasiveness weights and was often negative. While Evenson (1980; also see Evenson, et al., 1987) did use a geoclimatic specification successfully, it should be noted that the data employed in his studies were further

disaggregated to a subregional level. Evenson's research used a smaller pervasiveness weight on regional research than subregional research (i.e., the relevance of outside research was greater for those subregions that state i shared with other states than for the entire region that i shared with other states). Since the regions used here were often much larger than the subregions used by Evenson, in all likelihood the use of regional data rather than subregional data introduced excessive "noise" into the research spillover variable and prevented the estimation of satisfactory results. Given the large number of subregions (36) identified by the USDA, however, the development of the data needed to replicate Evenson's specification was beyond the limits of this study.

11. These estimated internal rates of return include the cost of "outside" research for each state, but they do not include the outside benefits generated by each state. Thus, they represent lower bound estimates of the marginal product of research and the internal rate of return on research.

CHAPTER V

CALCULATION OF OPTIMAL MATCHING RATES FOR FINANCING AGRICULTURAL RESEARCH

The final stage of this research is the calculation of the matching rates necessary to yield an optimal level of state spending on agricultural research. As discussed in Chapter III, these matching rates are determined by the share of the marginal benefit of research that is retained by the funding state. To calculate these shares, the research coefficients from the production functions reported in Tables 7 through 11 will be used to calculate the marginal products of research inside and outside each state under each spillover specification. These shares will then be incorporated into the public finance model developed in Chapter III. The public finance model will then yield the optimal matching rate for financing agricultural research in each state under each spillover scenario.

This chapter will also examine the sensitivity of the optimal matching rates to the assumed spillover specification by examining the optimal matching rate for each of the six spillover scenarios. To review the earlier discussion of these assumed scenarios, the estimates reported in Chapter IV were based on two specifications of "relevance" (a "neighboring states" assumption and a "production region" assumption). Under each of these assumptions, three specifications of "pervasiveness" were estimated (where pervasiveness is defined as the share of the research conducted in the relevant states that is applicable to the recipient state and is specified here at .10, .20, or .30).

Calculation of Optimal Matching Rates

Assuming the research production elasticities reported in Tables 7 through 11 are constant across states, the marginal product of research can be calculated for each state and under each spillover scenario as:

(5.1) $MPR_i = \delta * n_i * Output_i / Totres_i$,

where:

MPR_i = The marginal product of research in state i;

δ = The research production coefficient estimated for cross section year t for a given specification of relevance (i.e., "neighboring states" or "production region") and pervasiveness weight (i.e., .10, .20, or .30);

n_i = The number of farms in state i;

$Output_i$ = Output per farm in state i;

$Totres_i$ = Total research spending applicable to state i (including spending in other relevant states as defined in equation 4.3).

Given the marginal product of research in each state, the total marginal product of research in state i is calculated as the sum of the marginal product of research in state i plus the weighted marginal products of research in all other states in which state i's research was assumed to be relevant:

$$(5.2) \quad TMPR_i = MPR_i + \sum_{j=1}^{n} \Phi * MPR_j,$$

where:

$TMPR_i$ = The total marginal product resulting from research spending in state i;

MPR_i = The marginal product of research accruing to state i from an additional dollar of research spending in state i;

MPR_j = The marginal product of research accruing to other states in which state i's research is relevant from an additional dollar of research spending in state i ($j = 1...n$, $j \neq i$);

Φ = The assumed pervasiveness weight (Φ = .10, .20, or .30).

From these calculations, the share of the marginal product of research retained by each state can be calculated as:

$$(5.3) \quad \alpha_i = MPR_i/TMPR_i.$$

This share provides the linkage between the production function models and the public finance model. As discussed in Chapter III, the optimal federal matching rate for funding agricultural research in each state is calculated as (shown originally as equation 3.6):

(5.4) $m_i = (1 - \alpha_i)/\alpha_i$.

Tables 13 through 17 show the optimal matching rates for each state under each of the six assumed spillover scenarios for the five cross-sections. The full set of calculations used to produce these matching rates are shown in Appendix B. To provide clarity, one sample calculation will be presented here. Using the 1982 cross-section data, the optimal matching rate for the state of Alabama will be calculated using the assumptions that (1) the pervasiveness weight is .10, and (2) the states neighboring Alabama (Florida, Georgia, Mississippi, and Tennessee) are the states in which Alabama's research is relevant.

Equation (5.1) yielded a marginal product of research of \$24.82 for Alabama. This indicates that an additional dollar of research spending in Alabama would have yielded a marginal product of \$24.82 within Alabama. The pervasiveness weight of .10, it should be recalled, assumed that the additional dollar of research spending in Alabama also provided 10 cents worth of research spending that was relevant in Florida, Georgia, Mississippi, and Tennessee, whose marginal products were calculated (using equation 5.1) to be \$20.36, \$23.13, \$27.22, and \$20.24, respectively. Thus, the additional dollar of research spending in Alabama also yielded marginal products of \$2.03 in Florida, \$2.31 in Georgia, \$2.72 in Mississippi,

Table 13: Optimal Federal Matching Rates for Financing Agricultural Research Under Alternative Spillover Specifications, 1982 Cross-section

State	Neighboring States			Production Region		
Φ:	0.10	0.20	0.30	0.10	0.20	0.30
	--------(Federal	dollars	per state	dollar)--------		
Alabama	0.37	0.80	1.29	0.23	0.51	0.82
Arizona	0.41	0.89	1.47	0.64	1.16	1.66
Arkansas	0.59	1.27	2.02	0.12	0.24	0.37
California	0.09	0.14	0.17	0.10	0.16	0.21
Colorado	0.81	1.49	2.15	0.55	0.92	1.22
Florida	0.24	0.39	0.50	0.34	0.59	0.80
Georgia	0.36	0.69	1.03	0.24	0.45	0.65
Idaho	0.30	0.63	1.00	0.35	0.69	1.04
Illinois	0.29	0.61	0.96	0.25	0.50	0.77
Indiana	0.47	0.84	1.18	0.67	1.26	1.82
Iowa	0.33	0.62	0.89	0.24	0.47	0.69
Kansas	0.30	0.55	0.79	0.28	0.52	0.73
Kentucky	0.71	1.55	2.46	0.19	0.42	0.67
Louisiana	0.71	1.41	2.12	0.40	0.76	1.09
Maryland	0.21	0.43	0.65	0.28	0.66	1.10
Michigan	0.42	0.85	1.29	0.34	0.70	1.08
Minnesota	0.38	0.72	1.05	0.12	0.24	0.36
Mississippi	0.34	0.62	0.89	0.19	0.39	0.59
Missouri	0.79	1.73	2.73	0.55	1.15	1.79
Montana	0.44	0.80	1.15	0.50	1.01	1.53
Nebraska	0.32	0.57	0.81	0.25	0.44	0.62
Nevada	2.98	8.57	15.91	2.54	6.19	10.37
New Jersey	0.57	1.20	1.89	0.91	1.94	3.08
New Mexico	0.72	1.84	3.19	0.64	1.47	2.39
New York	0.29	0.49	0.64	0.44	0.72	0.93
North Carolina	0.29	0.49	0.64	0.34	0.57	0.76
North Dakota	0.34	0.62	0.88	0.46	0.92	1.41
Ohio	0.36	0.70	1.04	0.66	1.33	2.02
Oklahoma	0.64	1.48	2.44	0.13	0.31	0.52
Oregon	0.73	1.68	2.82	0.42	0.98	1.65
Pennsylvania	0.26	0.54	0.83	0.12	0.24	0.36
South Carolina	0.28	0.64	1.06	0.46	1.07	1.77
South Dakota	0.42	1.06	1.81	0.27	0.67	1.15
Tennessee	1.07	2.47	4.05	0.29	0.62	0.97
Texas	0.18	0.28	0.36	0.08	0.13	0.17
Utah	0.87	1.74	2.64	1.50	3.15	4.90
Virginia	0.72	1.36	1.99	0.62	1.19	1.77
Washington	0.15	0.26	0.34	0.22	0.51	0.87
West Virginia	2.83	6.92	11.61	2.28	5.97	10.47
Wisconsin	0.68	1.32	1.94	0.22	0.42	0.62
Wyoming	1.19	2.86	4.77	1.08	2.57	4.27
Average	0.59	1.32	2.13	0.50	1.08	1.71
Average (Excluding Nev. and W. Va.)	0.47	0.99	1.54	0.40	0.82	1.26

Source: Author.

Table 14: Optimal Federal Matching Rates for Financing Agricultural Research Under Alternative Spillover Specifications, 1978 Cross-section

State	Neighboring States			Production Region		
Φ:	0.10	0.20	0.30	0.10	0.20	0.30
	-------(Federal dollars per state dollar)-------					
Alabama	0.37	0.81	1.28	0.25	0.54	0.85
Arizona	0.37	0.79	1.29	0.64	1.15	1.65
Arkansas	0.46	0.99	1.59	0.09	0.19	0.29
California	0.09	0.15	0.19	0.09	0.16	0.21
Colorado	0.62	1.17	1.69	0.48	0.81	1.11
Florida	0.23	0.38	0.49	0.34	0.59	0.81
Georgia	0.32	0.65	1.01	0.22	0.42	0.63
Idaho	0.27	0.58	0.93	0.36	0.72	1.09
Illinois	0.31	0.63	0.97	0.25	0.52	0.80
Indiana	0.44	0.81	1.16	0.66	1.28	1.89
Iowa	0.30	0.56	0.81	0.22	0.42	0.62
Kansas	0.28	0.53	0.76	0.25	0.47	0.68
Kentucky	0.63	1.39	2.23	0.15	0.33	0.52
Louisiana	0.79	1.57	2.35	0.48	0.90	1.30
Maryland	0.22	0.44	0.65	0.27	0.64	1.06
Michigan	0.48	0.95	1.41	0.38	0.78	1.19
Minnesota	0.44	0.81	1.16	0.12	0.24	0.35
Mississippi	0.36	0.67	0.96	0.23	0.46	0.69
Missouri	0.75	1.63	2.57	0.51	1.07	1.65
Montana	0.47	0.83	1.16	0.62	1.21	1.81
Nebraska	0.39	0.69	0.96	0.29	0.51	0.71
Nevada	3.17	8.85	16.22	3.03	7.13	11.76
New Jersey	0.64	1.29	1.99	1.01	2.08	3.22
New Mexico	0.59	1.51	2.63	0.58	1.36	2.24
New York	0.28	0.47	0.61	0.44	0.72	0.95
North Carolina	0.42	0.70	0.93	0.49	0.82	1.09
North Dakota	0.28	0.54	0.79	0.39	0.82	1.27
Ohio	0.42	0.78	1.12	0.82	1.59	2.34
Oklahoma	0.82	1.82	2.93	0.16	0.37	0.63
Oregon	0.80	1.81	2.99	0.44	1.02	1.70
Pennsylvania	0.26	0.56	0.87	0.12	0.24	0.36
South Carolina	0.26	0.54	0.85	0.49	1.07	1.73
South Dakota	0.45	1.13	1.93	0.29	0.69	1.17
Tennessee	1.35	2.94	4.65	0.37	0.73	1.09
Texas	0.18	0.29	0.39	0.06	0.11	0.14
Utah	0.96	1.86	2.77	1.64	3.36	5.17
Virginia	0.59	1.14	1.68	0.49	0.98	1.47
Washington	0.17	0.28	0.37	0.22	0.51	0.85
West Virginia	2.45	5.92	9.92	1.90	4.87	8.41
Wisconsin	0.71	1.41	2.11	0.19	0.39	0.58
Wyoming	0.91	2.23	3.75	0.90	2.17	3.62
Average	0.59	1.30	2.08	0.51	1.08	1.70
Average (Excluding Nev. and W.Va.)	0.48	0.98	1.51	0.41	0.83	1.27

Source: Author.

Table 15: Optimal Federal Matching Rates for Financing Agricultural Research Under Alternative Spillover Specifications, 1974 Cross-section

State	Neighboring States			Production Region		
Φ:	0.10	0.20	0.30	0.10	0.20	0.30
	--------(Federal dollars per state dollar)-------					
Alabama	0.44	0.93	1.47	0.31	0.65	0.79
Arizona	0.35	0.79	1.33	0.69	1.24	1.46
Arkansas	0.56	1.19	1.88	0.12	0.24	0.27
California	0.10	0.15	0.19	0.09	0.16	0.16
Colorado	0.33	0.72	1.15	0.27	0.52	0.65
Florida	0.23	0.39	0.51	0.35	0.62	0.67
Georgia	0.30	0.60	0.92	0.21	0.39	0.45
Idaho	0.22	0.49	0.80	0.35	0.70	0.88
Illinois	0.32	0.67	1.04	0.28	0.56	0.67
Indiana	0.45	0.84	1.21	0.67	1.31	1.53
Iowa	0.31	0.57	0.81	0.22	0.43	0.51
Kansas	0.33	0.60	0.86	0.26	0.49	0.55
Kentucky	0.72	1.55	2.46	0.22	0.47	0.57
Louisiana	0.59	1.19	1.79	0.35	0.67	0.74
Maryland	0.24	0.47	0.71	0.31	0.73	0.95
Michigan	0.47	0.92	1.36	0.39	0.78	0.86
Minnesota	0.37	0.71	1.04	0.10	0.21	0.23
Mississippi	0.34	0.64	0.92	0.21	0.43	0.49
Missouri	0.79	1.69	2.65	0.56	1.14	1.36
Montana	0.54	0.96	1.34	0.80	1.53	1.85
Nebraska	0.49	0.84	1.16	0.33	0.58	0.63
Nevada	3.77	10.38	18.91	3.71	8.55	11.47
New Jersey	0.67	1.34	2.04	0.99	2.01	2.42
New Mexico	0.68	1.58	2.61	0.75	1.63	2.12
New York	0.21	0.36	0.48	0.31	0.52	0.58
North Carolina	0.28	0.47	0.62	0.29	0.49	0.53
North Dakota	0.29	0.56	0.80	0.38	0.79	0.97
Ohio	0.32	0.62	0.92	0.61	1.23	1.46
Oklahoma	0.76	1.59	2.51	0.14	0.31	0.35
Oregon	0.79	1.79	2.99	0.42	0.98	1.19
Pennsylvania	0.32	0.67	1.03	0.14	0.28	0.34
South Carolina	0.27	0.59	0.94	0.38	0.87	1.09
South Dakota	0.41	0.99	1.69	0.26	0.59	0.74
Tennessee	1.21	2.79	4.58	0.35	0.74	0.89
Texas	0.20	0.33	0.44	0.07	0.13	0.13
Utah	1.07	1.94	2.74	1.81	3.69	4.63
Virginia	0.62	1.19	1.77	0.55	1.08	1.27
Washington	0.21	0.33	0.42	0.24	0.55	0.66
West Virginia	2.07	4.90	8.13	1.70	4.31	5.79
Wisconsin	0.71	1.39	2.08	0.23	0.45	0.49
Wyoming	1.32	2.93	4.67	1.33	2.92	3.82
Average	0.60	1.31	2.09	0.53	1.12	1.39
Average (Excluding Nev. and W. Va.)	0.48	0.98	1.51	0.42	0.85	1.02

Source: Author.

Table 16: Optimal Federal Matching Rates for Financing Agricultural Research Under Alternative Spillover Specifications, 1969 Cross-section

State	Neighboring States			Production Region		
Φ:	0.10	0.20	0.30	0.10	0.20	0.30
	--------(Federal	dollars	per state	dollar)-------		
Alabama	0.44	0.92	1.41	0.29	0.59	0.92
Arizona	0.35	0.76	1.25	0.66	1.17	1.64
Arkansas	0.56	1.24	1.99	0.13	0.26	0.39
California	0.12	0.18	0.22	0.09	0.16	0.21
Colorado	0.39	0.84	1.33	0.31	0.61	0.89
Florida	0.22	0.37	0.48	0.35	0.61	0.83
Georgia	0.37	0.74	1.13	0.26	0.48	0.70
Idaho	0.27	0.59	0.97	0.44	0.88	1.34
Illinois	0.32	0.66	1.02	0.27	0.55	0.83
Indiana	0.39	0.75	1.09	0.61	1.21	1.80
Iowa	0.33	0.60	0.84	0.23	0.44	0.66
Kansas	0.36	0.65	0.91	0.31	0.56	0.79
Kentucky	0.90	1.95	3.08	0.29	0.59	0.90
Louisiana	0.78	1.48	2.16	0.47	0.88	1.25
Maryland	0.29	0.55	0.79	0.34	0.79	1.32
Michigan	0.56	1.06	1.53	0.53	1.01	1.45
Minnesota	0.32	0.64	0.98	0.09	0.19	0.29
Mississippi	0.25	0.49	0.73	0.16	0.33	0.51
Missouri	0.80	1.67	2.58	0.58	1.16	1.74
Montana	0.46	0.83	1.17	0.64	1.22	1.79
Nebraska	0.40	0.73	1.02	0.28	0.51	0.70
Nevada	3.13	8.65	15.73	3.22	7.39	12.03
New Jersey	0.60	1.22	1.85	0.88	1.79	2.75
New Mexico	0.64	1.48	2.44	0.63	1.37	2.17
New York	0.17	0.31	0.42	0.26	0.45	0.61
North Carolina	0.32	0.53	0.69	0.29	0.50	0.69
North Dakota	0.27	0.51	0.74	0.30	0.68	1.10
Ohio	0.32	0.63	0.94	0.64	1.31	2.01
Oklahoma	0.79	1.69	2.67	0.18	0.39	0.64
Oregon	0.76	1.70	2.82	0.40	0.92	1.56
Pennsylvania	0.34	0.69	1.07	0.16	0.31	0.47
South Carolina	0.19	0.45	0.74	0.31	0.75	1.28
South Dakota	0.53	1.22	1.99	0.31	0.69	1.12
Tennessee	1.28	2.76	4.35	0.38	0.75	1.13
Texas	0.17	0.28	0.37	0.06	0.10	0.14
Utah	0.87	1.61	2.32	1.56	3.23	4.96
Virginia	0.41	0.87	1.38	0.35	0.76	1.21
Washington	0.20	0.32	0.41	0.23	0.54	0.92
West Virginia	2.17	5.07	8.33	1.80	4.44	7.57
Wisconsin	0.65	1.33	2.03	0.22	0.43	0.64
Wyoming	1.17	2.61	4.18	1.23	2.69	4.27
Average	0.58	1.26	2.00	0.51	1.07	1.66
Average (Excluding Nev. and W. Va.)	0.48	0.97	1.49	0.40	0.82	1.25

Source: Author.

Table 17: Optimal Federal Matching Rates for Financing Agricultural Research Under Alternative Spillover Specifications, 1964 Cross-section

State	Neighboring States			Production Region		
Φ:	0.10	0.20	0.30	0.10	0.20	0.30
	--------(Federal dollars per state dollar)-------					
Alabama	0.45	0.89	1.37	0.29	0.59	0.92
Arizona	0.37	0.82	1.36	0.64	1.17	1.64
Arkansas	0.66	1.38	2.16	0.13	0.27	0.40
California	0.10	0.16	0.19	0.09	0.14	0.18
Colorado	0.49	1.00	1.53	0.36	0.67	0.98
Florida	0.24	0.41	0.54	0.37	0.67	0.92
Georgia	0.36	0.72	1.10	0.23	0.46	0.67
Idaho	0.32	0.68	1.09	0.47	0.94	1.41
Illinois	0.36	0.71	1.07	0.32	0.62	0.92
Indiana	0.38	0.73	1.09	0.59	1.19	1.82
Iowa	0.31	0.58	0.83	0.23	0.44	0.64
Kansas	0.31	0.58	0.82	0.27	0.51	0.74
Kentucky	0.98	2.07	3.24	0.35	0.71	1.09
Louisiana	0.84	1.60	2.34	0.45	0.86	1.23
Maryland	0.31	0.61	0.92	0.37	0.87	1.44
Michigan	0.41	0.82	1.21	0.29	0.59	0.93
Minnesota	0.45	0.86	1.24	0.14	0.28	0.42
Mississippi	0.28	0.54	0.79	0.15	0.32	0.49
Missouri	0.68	1.47	2.33	0.49	1.04	1.61
Montana	0.40	0.74	1.06	0.55	1.08	1.61
Nebraska	0.36	0.68	0.98	0.25	0.47	0.67
Nevada	3.50	9.94	18.35	3.32	7.84	12.95
New Jersey	0.49	1.01	1.56	0.72	1.48	2.29
New Mexico	0.69	1.63	2.71	0.67	1.48	2.37
New York	0.23	0.39	0.53	0.32	0.53	0.70
North Carolina	0.24	0.42	0.58	0.22	0.41	0.58
North Dakota	0.27	0.54	0.80	0.39	0.82	1.30
Ohio	0.33	0.63	0.92	0.61	1.24	1.89
Oklahoma	0.85	1.79	2.78	0.20	0.44	0.70
Oregon	0.77	1.70	2.79	0.43	0.97	1.63
Pennsylvania	0.31	0.65	1.02	0.13	0.28	0.43
South Carolina	0.26	0.54	0.84	0.32	0.74	1.20
South Dakota	0.48	1.09	1.79	0.32	0.69	1.09
Tennessee	1.06	2.42	3.94	0.33	0.69	1.08
Texas	0.15	0.25	0.35	0.05	0.09	0.13
Utah	0.71	1.38	2.02	1.27	2.67	4.14
Virginia	0.51	0.99	1.47	0.46	0.90	1.34
Washington	0.19	0.32	0.42	0.26	0.61	1.04
West Virginia	1.86	4.40	7.29	1.58	3.85	6.53
Wisconsin	0.65	1.30	1.95	0.20	0.39	0.58
Wyoming	1.05	2.27	3.59	1.09	2.34	3.67
Average	0.58	1.26	2.02	0.49	1.03	1.62
Average (Excluding Nev. and W. Va.)	0.47	0.96	1.47	0.39	0.79	1.20

Source: Author.

and \$2.02 in Tennessee, for a total marginal product of research spending in Alabama of \$33.90 (calculated as \$24.82+ 2.03 + 2.31 + 2.72 + 2.02 from equation 5.2). The share of marginal research benefits retained by Alabama, a_1, equals .73 (calculated as \$24.82/\$33.90 from equation 5.3). This indicates that the optimal matching rate for Alabama under this scenario is .37 as shown in column 1 of Table 13 (calculated as [1-.73]/.73 from equation 5.4). Thus, under this set of spillover assumptions, this result suggests the federal government should pay the state of Alabama, on an open-ended basis, 37 cents for each dollar that Alabama spends on agricultural research. Similar calculations were made for each state in each of the five cross-sections and under each of the six spillover scenarios.

Discussion of Results

Since the precise pattern of research benefit spillovers that prevails in the United States is unknown, Tables 13 through 17 each present six spillover scenarios that permit some broad conclusions to be drawn about spillover patterns and the matching rates needed to finance agricultural research. First, higher assumed pervasiveness weights yielded higher matching rates. This result was expected, since a higher pervasiveness weight suggests that a greater share of agricultural research is applicable beyond state boundaries, thereby yielding greater benefit spillovers and a higher optimal matching rate. Second, the matching rates calculated under each of the six spillover scenarios demonstrate a surprising degree of stability over time. An examination of either individual states or the national average matching rates over time suggests the underlying spillover pattern assumed by each scenario appears to be stable over time. In reaching such a conclusion, however, it should be noted that these results suggest that the share of research benefits retained by the funding states is stable, but not necessarily that the marginal product of research is stable.

Finally, some caution should be exercised in interpreting the optimal matching rates of individual states, since the matching rates estimated here are tied inextricably to the assumed definitions of "relevance" and "pervasiveness." These assumptions sometimes yield results that are at odds with prior expectations. For example, Nevada and West Virginia consistently have the highest matching rates while California and Texas frequently have some of the lowest matching rates.

These results are clearly an artifact of the assumption that only neighboring states or states in the same production region are relevant to the funding state. California, for instance, is penalized by the neighboring states assumption in two ways. First, since much of California's research is in fruits, vegetables, and livestock products that may produce spillovers in states beyond its neighbors (Araji), California's spillovers may be underestimated. Second, California has no neighbor to the west and, as shown in Appendix B, California's neighbors (Arizona, Nevada, and Oregon) often had lower marginal products of research than most other states, thereby reducing the spillovers credited to California.[1]

On the other hand, Missouri and Tennessee benefit greatly under the neighboring states specification. Each shares a border with more states (8) than any other state in the nation. As a result, both are credited with generating large spillover benefits relative to the internal benefits they create, thereby yielding high matching rates for both. As expected, both have lower matching rates under the production region specification than under the neighboring states specification.

A final comment should be made regarding the high matching rates reported for Nevada and West Virginia for all six spillover scenarios. As shown in Appendix B, both states generated marginal products outside the state that were consistently near or below the national average. Both states, however, had very low marginal products inside the state compared to the national average, thereby yielding the highest matching rates among the states included in the sample.[2] Given the unusual nature of these results, Tables 13 through 17 report the national average matching rates for the entire sample and for the entire sample excluding Nevada and West Virginia.

Comparison to Previous Studies

Among previous studies, only Evenson (1980, p. 211) reported the marginal product of research generated both inside and outside the funding state. The results of his productivity decomposition model, which estimated separate marginal products for "science-oriented" agricultural research and "technology-oriented" agricultural research, implied that the optimal matching rates for agricultural research ranged from $2.10 for "science-oriented" research to $0.48 for "technology-oriented" research.[3] Since the research variable employed in this study included both types of research, the matching rates estimated here would be expected to fall between the extremes estimated by Evenson. An examination of both the national average and individual state matching rates suggests this is true for most states under most spillover scenarios.

Two other studies can also be used to evaluate the estimated results. Ziemer, et al. (p. 175) used an economic surplus model to estimate the welfare effects of a 10% increase in research and extension expenditures. Their results indicated that, on average, each dollar of research and extension funding yielded $8.62 of economic surplus inside the production region in which the funds were spent and $34.84 of economic surplus outside the funding region, or that, on average, the funding regions retained 19% of the average benefits they created.[4] Havlicek and White (1981a, p. 26) used a production function model to estimate the total annual benefits retained by the funding regions. Their results indicate that the regions funding agricultural research retained 49% of the total benefits generated by their research.[5]

While the results of the latter two studies are not directly comparable to the results reported here (since the first reports the average product of research and the second reports the total product of research rather than the marginal products of research necessary to calculate the optimal matching rates) they do provide some indication of the validity of the results reported here. These studies suggest that the share of research benefits retained by the funding state could be quite low and, as a consequence, the matching rates necessary to finance an optimal level of agricultural research spending could be higher than those estimated by this study.

Comparison to the Existing Hatch Funding System

The purpose of this study was to determine the system of intergovernmental grants that would yield an optimal level of state investments in agricultural research. The results of this study, combined with those of previous studies, suggest that, if the United States is to alleviate the problem of underinvestment, changes are required in the present system of financing public agricultural research. The present system, which uses a matching rate of 1.00, matches each state dollar with one federal dollar up to the limit established by the Hatch Act. The optimal matching rates reported earlier in this chapter bracket the present Hatch matching rate for all spillover scenarios and all cross-sections.

These results suggest that the problem of underinvestment in agricultural research arises from the closed-ended nature of the Hatch system rather than from its matching rate. While it is true that the optimal matching rate for some states may vary widely from the present 1.00 rate, it is unlikely that the establishment of individual rates tailored to each state is politically feasible. Thus, while further research is required to estimate more reliable state-by-state spillover patterns and their associated matching rates, the present results suggest that the problem of underinvestment could best be alleviated by the establishment of an open-ended matching grant rather than the existing closed-ended system of grants. While a continuation of the present matching rate may still result in underinvestment (since it implicitly assumes that 50% of the benefits of research are retained by the funding state or, in the parlance of the public finance model, the α_i in equation 5.3 equals .50) the degree of underinvestment would probably be reduced by an open-ended system of grants.

Summary

This chapter presents the final results of this research. The estimated research coefficient for each production function model was used to estimate the marginal product of research in each state under each spillover scenario. These marginal products were then used to calculate the marginal product of research that would accrue inside each state and in other states in which the given state's research is relevant. These calculations provided the total marginal product of research for each state and the share of the total marginal product of research that was retained by each state. These shares were then incorporated into the public finance model of matching grants developed in Chapter III. Since no prior knowledge exists on the spillover patterns that prevail in the U.S., these calculations were made for each state under six spillover scenarios.

The results indicate that the average optimal federal matching rates (i.e., the rate at which the federal government should match state spending on agricultural research) ranged from 0.40 to 1.54, depending on the assumed spillover pattern. These results suggest that the 1.00 matching rate used by the existing Hatch Act formula may be adequate, but that policymakers should consider making the Hatch program an open-ended system of grants (rather than the existing closed-ended system) in order to provide states the incentive to invest in a more optimal level of agricultural research.

Notes to Chapter V

1. In examining these results, it should be noted that the estimated marginal products of research reported in Appendix B for aggregate production in these states are generally within the range of the estimated marginal products of research for individual commodities in these states reported by Bredahl and Peterson (p. 690) and Norton (1981, p. 10).

2. Again, it should be noted that Bredahl and Peterson (p. 690) and Norton (1981, p. 10) estimated the marginal products of research for individual commodities to be rather low in Nevada and West Virginia compared to other states. Thus, the results estimated in Appendix B are consistent with prior estimates.

3. Evenson defined "science-oriented" research as research in which the primary objective was the answering of questions related to the production of new technology. He defined "technology-oriented" research as research in which the primary objective was the production of new technology (Evenson, et al., 1979). The marginal products estimated by Evenson (1980, p. 211) for the 1948 to 1971 period and the optimal matching rates implied by his results were as follows (reported by Evenson as the marginal product from an additional $1,000 of agricultural research):

	Inside Funding State	Outside Funding State	Optimal Matching Rate
Science-oriented Research	$1,450	$3,050	$2.10
Technology-oriented Research			
--South	$14,100	$7,100	0.50
--North	5,070	6,530	1.29
--West	8,270	3,930	0.48

4. Their results indicated that the Northeast region retained the largest share of the average benefits it generated (68%) and the Northern Plains retained the smallest share of the average benefits it generated (2%).

5. Their results indicated that the Northeast region retained the smallest share of the total annual benefits it generated (23%) and the Corn Belt retained the largest share of the total annual benefits it generated (58%).

CHAPTER VI

CONCLUSION

This research represents the first attempt to apply public finance principles to the problem of financing agricultural research in the United States. This chapter summarizes the theoretical model used in this research and the empirical results of the model. It then examines the limitations and policy implications of the empirical results and suggests promising areas of future research.

Summary

Research Objectives

This research has addressed the problem of achieving an optimal level of public investment in agricultural research in the United States. This problem was addressed in three stages. First, the theory of public finance (particularly the theory of intergovernmental grants) was reviewed, and a model for financing a nationally optimal level of investment in agricultural research was developed. Second, an econometric model that measures interstate spillovers of agricultural research benefits was developed and estimated. Finally, the results of the econometric model were incorporated into the public finance model to estimate the optimal matching rates for federal matching grants in support of agricultural research.

Research Method

Agricultural research constitutes a classic problem in public finance. Due to its nature (high exclusion costs and zero marginal cost for an additional user once the results are produced) the production of research is often funded by the public sector. Because agricultural research is frequently a location-specific venture, it is often funded by state governments in the United States. Due to the existence of benefit spillovers that accrue to consumers and producers in other states, however, state governments, operating in isolation, will have no incentive to provide a nationally optimal level of agricultural research.

An individual state will achieve its optimal level of research investment at that point where its marginal cost of research funds equals the marginal benefit of research received by its residents. If any research benefits accrue to residents outside the state, the individual state will, without some sort of cost-sharing arrangement with those outside residents, provide a level of research investment that is suboptimal from a national perspective.

This problem is recognized in the public finance literature as a problem of "imperfect mapping." When such a problem arises, it can be corrected by the use of intergovernmental grants from the federal government to the states. To achieve a nationally optimal level of investment at minimum cost to the federal government, an open-ended matching grant, which matches a given number of federal dollars for each dollar of state spending on agricultural research, should be used. The matching rate for such grants must be established at a level that compensates each state for the marginal benefit spillover produced by that state. When this condition is met, each state will equate the share of the total marginal benefit it retains from its research with its share of the total marginal cost of that research, while the federal government will equate its share of the total marginal cost of conducting agricultural research in that state with the share of the total marginal benefit of research that accrues outside the state.

This research estimated the optimal matching rates for each state under six scenarios of research spillovers. A Cobb-Douglas production function was estimated for the years 1964, 1969, 1974, 1978, and 1982 using conventional inputs, extension spending, weather, and research spending as the independent variables. The research variable was specified to include research in other "relevant" states (defined by two specifications of relevance, a "neighboring states" specification and a "production region" specification). Under each relevance scenario, the research variable was specified for three levels of assumed "pervasiveness" (defined as the share of research spending in the relevant states that affects agricultural production in the state receiving the research spillovers). These specifications then permitted the calculation of the marginal product of research that accrued inside the funding state and the marginal products of research that accrued to all relevant states outside the funding state. These marginal products were then used to calculate the matching rates required to finance a nationally optimal level of agricultural research investment in each state.

Research Results

The estimated national average optimal matching rates (expressed as the number of federal dollars that should be appropriated to match each state dollar of research spending) ranged from 0.40 to 1.54 for the different spillover scenarios and cross-sections employed in this study. The optimal matching rates for individual states varied widely around these means and were sensitive to the assumed definitions of relevance and pervasiveness. As expected, a higher degree of assumed pervasiveness yielded higher matching rates. The optimal matching rate of any individual state was determined by the assumed pervasiveness of its research, the number of other states in which its research was assumed to be relevant, and the marginal product of research in the states in which its research was assumed to be relevant.

Limitations of the Research Method

As Shackle (p. 4) has observed, a theoretical model is "in one sense complete and self-sufficient, able, on its own terms, to answer all questions which those terms allowed." Stated conversely, a theory can only answer those questions which its assumptions permit to be asked. This problem is particularly burdensome for the policy analyst since, as Samuels (1976a, p. 394) observes, a failure to recognize the constraining nature of a model's assumptions "smacks of contrivance: a way of assuming away critical problems or limits." An accurate interpretation of economic policy analysis is only possible if the assumptions that define the research method are identified explicitly and their limitations defined. This section reviews the assumptions identified in Chapter III and discusses the limitations they impose on the results of this analysis.

Assumptions of the Public Finance Model

The first assumption of the public finance model was that the objective of publicly-funded agricultural research is the maximization of the net monetary benefits of research. This is a standard assumption of Pigouvian analysis, namely, that money prices reflect accurately the satisfaction or dissatisfaction associated with the marginal product of an investment (Myint, p. 185). This assumption implies that all public research investment is dedicated to increasing the output of agricultural commodities. Many forms of agricultural research investment are dedicated to objectives other than the enhancement of production, such as soil and water conservation, environmental problems, or consumer issues. This assumption should not be taken to imply that these areas do not produce results of value to society or that such areas are not deserving of intergovernmental support. Instead, it should simply be recognized that the analysis of these areas or research is beyond the scope of this analysis.

More important, perhaps, is the question of which measure of monetary benefits of research will be maximized in the process of allocating agricultural research resources. For example, Heady (1949, 1961) observed that the allocation of research resources is inseparable from the objective function of the decision maker. If the objective of agricultural research is the maximization of farmers' welfare, then research resources should be allocated toward those commodities whose demand is the most price elastic (often those commodities with large export markets). If, on the other hand, the objective of agricultural research is the maximization of consumer welfare, research resources should be allocated toward those commodities whose demand is the least price elastic. Because the international spillovers that accrue to residents outside the United States (or, stated conversely, the benefits retained by the United States) are different under each of these approaches, the optimal allocation of total U.S. research resources will differ under each approach. In addition, the distribution of domestic benefits between farmers and consumers will differ under each approach. As discussed in Chapter I, it must be reiterated that any notion of social optimality is inseparable from the objective function defined at the outset of the analysis process.

The second assumption of the public finance model was that any resources displaced by the technological change produced by agricultural research have no value and receive no compensation. This is a standard assumption of most studies of agricultural research and imposes an important limitation on the results of all such studies. Two studies that have attempted to account for some of these costs (Schmitz and Seckler; Cooke) have shown that the rate of return on research investments is overestimated when such costs are ignored. This is a particularly important and difficult question to address when agricultural research funding is considered in a federal system of government, since these displacement costs may be imposed on parties outside the funding state. To the extent that these costs are ignored, the optimal matching rates estimated here may overcompensate states for their research.

The fourth assumption of the public finance model is that legislators act with perfect knowledge in a rational, maximizing manner within their jurisdictions. Oehmke has demonstrated, however, that if this assumption is violated (i.e., if legislators' expectations of the returns to research lag behind the actual returns to research) then research funding will be persistently suboptimal. If such lags in expectations do exist, underfunding may persist even in the presence of an appropriately-designed system of intergovernmental grants. Furthermore, the diffuse nature of agricultural research benefits suggests that voters and legislators may still underestimate the impact of agricultural research, resulting in continued underinvestment in research even in the presence of an open-ended system of grants (Olson, 1965, p. 48).

More important, this assumption implies that the problems of preference articulation and interpersonal weighting have been solved at both the state and national level (i.e., no free or unwilling riders exist). This is clearly not true, and the provision of agricultural research, as with any public good, will involve overruling some unwilling riders whose preferences are ignored in the maximizing calculus of the public finance model.

As noted in Chapter II, a system of intergovernmental grants can solve the free rider problem (i.e., it compensates those who provide a service that is used but not financed by others), but it also introduces the unwilling rider into the policy equation (i.e., some people are taxed to provide a service they do not want). This conflict is unavoidable (Schmid, 1978, pp. 46-56; 86). The solution to this conflict ultimately depends on the value placed on the welfare of the free rider, the unwilling rider, and the subsidized party. The policy solutions proposed in this research are based on a normative assumption that places a positive value on the welfare of the providers and beneficiaries of agricultural research, and a zero value on the welfare of those taxpayers unwilling to support such a program. The resolution of such policy issues depends ultimately on values, decision rules, and the distribution of power in society. As Rose-Ackerman has observed, these factors are unavoidable when dealing with issues that involve collective choice about the provision of public goods. Consequently, she insists, "The economist's dream of doing away with politics cannot be realized" (Rose-Ackerman, p. 56).

A fifth assumption of the public finance model is that the marginal cost of an additional dollar of public research investment is constant and equal to one dollar. A number of studies have examined the marginal excess burden of public taxation (Browning; Stuart; Ballard, Shoven, and Whalley) and have estimated that the marginal cost of an additional dollar of public revenue has an opportunity cost of $1.09 to $1.56. If the marginal cost of public funds is indeed greater than one dollar, then the matching rates estimated in this study could overcompensate the states for the research benefit spillovers they create. The second part of this assumption is that the supply of research inputs is perfectly elastic. If the supply of research inputs is less than perfectly elastic, the marginal cost of research will be underestimated in the model, and the optimal matching rates estimated here would tend to overcompensate the states for their research investments. Given the specialized nature of many research inputs, this may be true.

The sixth assumption of the public finance model is that the full burden of all taxes levied to pay for agricultural research are borne by the taxing jurisdiction. This assumption may be violated if taxing jurisdictions (in this case, the states) can "export" a share of their tax burden to residents in other jurisdictions. McLure (1967) found that, on average, 20% of the burden of state taxes in the U.S. falls on persons outside the taxing state. The ability of states to export their tax burden depends on (1) what is taxed (labor, capital, inputs, property, or products), (2) the elasticities of supply and demand for the taxed item (which are determined by the mobility of factors, the geographic extent of product markets, and the taxing state's share of those markets), and (3) the deductibility of state taxes from federal tax obligations (McLure, 1967, 1983; Phares; King, pp. 224-27; Feldstein and Metcalf). To the extent that state taxes are exported, the taxing state is compensated for the spillovers of agricultural research benefits that it has created and, since the cost of research has declined, the state should be induced to invest more in research. Since the public finance model used here has ignored the exportation of state tax burdens, the federal matching rates calculated in Chapter V would tend to be too high and the states would tend to be overcompensated for their research benefit spillovers.

The seventh assumption of the public finance model is that the income of each state is not significantly reduced by the taxes paid to support public agricultural research. If this is not true, those states that pay a high level of taxes to the national government could suffer a loss of income that would reduce their level of investment in agricultural research (James, pp. 262-64).

The ninth assumption of the public finance model is that the benefit spillover pattern (i.e., the share of marginal research benefits that accrue outside each state) will remain the same in the future as in the period estimated by the model. It remains a critical question whether the technologies to be developed in the future are of such a nature that the spillover pattern will be substantially different from past estimates. If so, the matching rates for financing future research must be adjusted to reflect such changes.

Assumptions of the Production Function Model

Beyond the typical limitations imposed on all analysis of this sort by the chosen functional form and data set, this study is also limited by its assumptions regarding the relevance and pervasiveness of agricultural research. As shown in Chapter V, the matching rates required to finance agricultural research are determined by the relevance and pervasiveness assumptions used to specify the production functions. While it is generally accepted that research spillovers do exist, the pattern of research spillovers that prevails in the U.S. is unknown. Consequently, six spillover scenarios, composed of two relevance assumptions and three pervasiveness assumptions, were estimated in order to provide a range of potential estimates of the optimal matching rates required to finance agricultural research.

The direction of any bias introduced into the estimated optimal matching rates by these assumptions is ambiguous. On one hand, the assumed pervasiveness weights were .10, .20, and .30 (i.e., 10%, 20%, or 30% of the research conducted in the relevant states was assumed to be applicable to agricultural production in the recipient state). These weights may be somewhat high when compared to the weight of .25 that Evenson (1980, p. 202) used on smaller geoclimatic areas. If the assumed pervasiveness weights are too large, the estimated matching rates would also be too high, thereby causing states to be overcompensated for their agricultural research spending. On the other hand, Araji (pp. 124-31) and Dalrymple (p. 63) found that the results of some types of commodity research may be applicable to areas far beyond the neighboring states or production regions assumed to be relevant in this study. If the assumed areas of relevance are too small, the estimated matching rates would be too low and states would be undercompensated for their agricultural research spending. Thus, the estimated matching rates should be understood to apply only for the assumptions used in this study.

Implications for Agricultural Research Policy in the United States

This analysis has examined the problem of financing agricultural research in a federal system of government. The need for such an examination of the prevailing system is evident in Hildreth's (p. 240) observation that the increasing reliance of agriculture on basic research and the development of improved communications systems have likely led to changes in the spillover patterns that existed when the system was designed. The regionalization of production in the United States, development of national and international markets, and migration of the domestic population have also likely led to changes in spillover patterns, thereby leading to a need to reexamine the agricultural research funding system. In addition, the agricultural research system is also faced with increased political tension over the underinvestment problem, the use of competitive or formula funds in financing agricultural research, the declining federal share of agricultural research funding, and the appropriateness of the existing Hatch allocation formula.

This analysis helps clarify the roles that the federal government and the states should play in financing agricultural research. The optimal matching rates calculated in Chapter V bracket the 1.00 matching rate used in the existing Hatch Act system of grants. If correct, these results imply that the problem of underinvestment in agricultural research is caused primarily by the closed-ended nature of the Hatch system. An open-ended grant system would provide a more adequate level of compensation to the states, thereby providing a stronger incentive for the states to supply a nationally optimal level of agricultural research.

This analysis also helps clarify a number of other issues in agricultural research policy. First, this analysis sheds light on the debate over the role of competitive grants and formula funds in financing agricultural research (Eliot Marshall, 1979a, 1979b; Strobel). Typically, proponents have posed these two options as mutually exclusive choices and have debated each option's ability to (1) guarantee scientific quality, (2) stimulate innovative research, (3) provide funding stability, (4) prevent the politicization of the research process by legislators, administrators, or peer reviewers, (5) prevent an excessive allocation of research resources to "grantsmanship" and administrative detail, and (6) serve the utilitarian demands of society that must be met in order to justify public funding of research (Ruttan, 1982a, pp. 215-36; Stein; Roy; Piel; Sanders; Raymond Bowers; Gustafson; Link; Link and Morrell; Cole, et al.; Leopold; Chubin; Foster; Bredahl, et al., 1980 and 1982; Becker; Eliot Marshall, 1979a and 1979b; Johnson and Wittwer, pp. 8-9; U.S. General Accounting Office, 1983, 1986a, 1986b).

While these factors are important in assessing the performance of the agricultural research system, the analysis presented here suggests a different view of this debate. The public finance model used here demonstrates that, in isolation, states will not provide a nationally optimal level of agricultural research investment in the presence of interstate benefit spillovers. Thus, matching grants must play a central role in providing a socially optimal level of agricultural research. Such grants are likely to be administered through a formula funding system. Furthermore, the model also suggests that, in those cases where the spillovers of research benefits are ubiquitous (i.e., where the share of the research benefits retained by the state approaches zero or, in the parlance of the public finance model represented in equations 3.2 and 3.6, α_i equals zero) the full burden of funding must fall to the federal government if an optimal level of spending is to be achieved. Such spending is likely to take the form of a competitive grants program.

Two implications can be drawn from this analysis. First, it must be noted that, in isolation, neither formula funding nor competitive grants will provide a socially optimal level of agricultural research funding. Both are necessary to address the problem of benefit spillovers. Second, it must be noted that the emphasis here is on compensating for benefit spillovers, not distinctions between basic or applied research. While it is true that basic research will likely create such ubiquitous benefits that the full burden of its funding would fall to the federal government, it may also be true that an individual state will retain a very small share of the total benefits of some forms of applied research. In either case, the federal government must pay a large share of the cost of such research if an optimal level of investment is to be achieved. The criterion for achieving an economically efficient level of research spending must be the benefit spillover pattern of the research, not its basic or applied nature. Casting the debate in terms of "basic" versus "applied" research ignores the spillover aspects of the agricultural research funding problem and fails to define the proper roles for the federal government and the states in funding agricultural research.

A second important policy issue is the effect of general intergovernmental relations on agricultural research policy, since any discussion of the intergovernmental support of agricultural research must also recognize the general policy climate in which all intergovernmental policy is made. The system of intergovernmental grants (for all programs, not only for agricultural research) has recently undergone a period of contraction. The share of the federal budget devoted to intergovernmental grants grew from 5.3% in 1950 to 17% in 1978, then declined to 11.5% in 1984. This represented a growth from 0.8% of GNP in 1950 to 3.7% in 1978, and then a decline to 2.7% in 1984. The share of state budgets funded by federal aid grew from 10.4% in 1950 to 26.8% in 1978, then declined to 21.2% in 1984. (Aronson and Hilley, p. 49). By 1981, 534 federal programs dispensed aid to lower levels of government to achieve a number of objectives ranging from spillover compensation to income redistribution to macroeconomic stabilization (George Peterson, 1984, p. 219).

This growth in grant programs has also led to an increase in the number and complexity of decisions that must be made at the national level to determine the eligibility of grant recipients. The information required to make such decisions has led some policy participants to complain that the national government is suffering from "political overload" and is incapable of making thoughtful, detailed decisions about local needs (George Peterson, 1984, p. 221; Beer; Walker, pp. 3-16 and 192-221; Deil Wright, pp. 91-94). The overload problem is particularly severe for those programs that provide competitive project grants based on the quality of recipient proposals (Break, 1980b, p. 254). This overload, combined with concerns about the pro-spending bias in matching grant programs and the imposition of detailed eligibility requirements on state-level policymakers, has led economic, political, and legal scholars to call for reform of intergovernmental grant programs (Northwestern University Law Review; Yale Law Journal; Stubblebine, p. 144; George Peterson, 1984, pp. 229-31 and 1982, pp. 163-68; Break, 1980b, p. 277; Reichley, p. 247; Penner, pp. 111-121; Craig and Inman; Brown; Haughwont and Richardson).

These reform proposals often involve (1) the consolidation of several grant programs into a few lump-sum block grants with minimum federal direction regarding the specific spending objectives, (2) the elimination of matching requirements to eliminate the spending bias inherent in such grants, and (3) the elimination of competitive project grants. However, even some critics of existing grant programs concede the need to use matching grants to correct spillover problems (Penner, p. 119). Given the general direction in which intergovernmental grant policy is moving, any changes in the agricultural research system should be undertaken with caution. If agricultural research is consolidated with other programs into a lump-sum block grant program, the underinvestment problem will likely worsen in the future.

It should also be noted that the problem of political overload reflects a general dissatisfaction with the growing tendency to force more political issues to be resolved at the national level. Again, this tendency is particularly burdensome for programs that are administered as competitive project grants (Walker, pp. 11-12; Deil Wright, pp. 91-94, 231-36, and 243-48). Any proposal to change the structure of the agricultural research funding system, including an increased reliance on centrally-administered competitive research grants, could face two major challenges. First, such a proposal could be viewed as contributing to the general problem of political overload. Second, it could also be viewed moving against the existing political trends in intergovernmental grant policy. The decentralized decision-making structure of the agricultural research system has been shown to be responsible for much of its success (Evenson, et al., 1979) and could remain, in a period of political overload, a potential asset of the system.

A third important policy problem involves the responsiveness of state governments to changes in the matching rates offered by the federal government. The spending response of the states ultimately depends on the elasticity of demand for agricultural research. As Break (1980a, p. 102) observed, matching grants will be more successful for those goods with higher price elasticities of demand, since a reduction in price will elicit a larger increase in state spending for such goods. While no price elasticity estimates have been made for agricultural research, studies of a number of other public services have found the demand for such services to be inelastic (Inman, pp. 286-88; Ohls and Wales). If this proves true for agricultural research, it may suggest that the federal matching rate will have to be set quite high to induce substantial increases in state spending on agricultural research.

A fourth policy issue concerns the establishment of uniform matching rates across all states and all forms of research spending in each state. As Rafuse (p. 1056) has noted, a uniform matching rate across all states will provide a socially optimal level of spending only if all states have similar spillover patterns (i.e., the share of the marginal benefit of research that spills out of each state is identical) and the price elasticity of demand for the subsidized good is the same in each state. If this is not true for agricultural research, and it is unlikely to be true given the specialization of agricultural production that prevails in the United States, a uniform matching rate across all states would leave some states undercompensated, while others would be overcompensated.

Similarly, Stutzer has demonstrated that if the spillovers generated by a state vary as the level of state spending on the spillover-generating good varies, then a variable matching rate based on each state's level of spending would be more efficient than a constant matching rate for all spending by that state. This may be particularly relevant for agricultural research, since the composition of research may change as the spending level changes, thereby producing changes in the spillover pattern. Designing variable rates across states and for various levels of agricultural research in each state will be a demanding empirical task and would likely encounter substantial political difficulty. As some observers of fiscal federalism in the U.S. have concluded, any effort "to develop a federal formula that varied from one place to another (with some communities expected to cough up 75 percent of the total cost while others got by with as little as 20 percent) would create endless political controversy that could easily undermine the whole program" (Paul Peterson, et al., pp. 24-25). Thus, any such program might collapse under the weight of its political transaction costs.

A fifth policy issue involves the problem of international compensation for research benefit spillovers. Just as research benefits spill across state boundaries within the U.S., studies have also presented evidence that benefits spill across national boundaries (Edwards and Freebairn; Evenson and Kislev; Carter; Davis, et al., 1987). Just as with interstate spillovers, the existence of international spillovers suggests that national research investment will be suboptimal from an international perspective. The correction of such a spillover problem will require the development of an international institutional structure that can provide compensation among nations, just as the federal government provides compensation among states (Musgrave, 1986, pp. 43-63).

A final policy issue concerns the establishment of a cap on federal obligations to match state funding efforts. As explained in Chapter II, an open-ended matching grant is the most efficient means of achieving an optimal level of agricultural research spending. A closed-ended grant will still leave some states (those that fund research beyond the limit imposed by the cap) in a sub-optimal position. It should be noted, however, that closed-ended grants do provide a safeguard against potential abuses of an open-ended grant program. In a case study of open-ended federal matching grants for state social services, Derthick (pp. 1-6 and 106-15) found that states defined the eligible social services as broadly as possible in order to maximize the services provided to their residents while shifting more of the cost to the federal level. As a result, the federal government was funding programs that were not intended to be subsidized. As that case demonstrated, any provision of an open-ended matching grant must include clear definitions of what forms of spending are permissible for federal compensation. Lacking such definitions, the establishment of a closed-ended grant may be the only means of preventing unwarranted spending. As noted in Chapter II, closed-ended grants are often used because they also provide the grantor a greater opportunity to formulate long-term budget plans. Thus, the relative merits of closed-ended and open-ended grants will continue to be an issue in agricultural research policy.

Retaining a closed-ended system of grants, however, again raises the issue of what formula should be used to allocate federal agricultural research funds among the states. If the objective of an intergovernmental grant program is to compensate the states for the research benefit spillovers they create, then the formula used to allocate federal agricultural research funds should presumably reflect the benefit spillovers generated by each state's research. A formula based on value of production or land in farms might be a more appropriate measure of benefit spillovers than the existing population-based formula. As discussed in Chapter I, however, such a change in the Hatch formula has important distributional consequences for different regions of the country. Further research is needed before definitive policy prescriptions can be provided.

A Postscript to Economic Policy Analysis

The final section of Chapter I, "A Preface to Economic Policy Analysis," presented a general discussion of the fundamental nature of all economic policy analysis. This section returns to that discussion, with special reference to the economic policy analysis and prescriptions reported in this research. This research has been concerned with the institutional structure that governs the financing of U.S. agricultural research. As such, it has sought to address what

Brinkmann (p. 331) called questions "as to how economic incentives underlie social behavior," and, more importantly, questions as to how economic incentives (i.e., the methods of sharing the cost of agricultural research) could be changed in order to encourage a desired social behavior (i.e., the provision of a more optimal level of research).

It bears repeating, however, that the prescriptive validity of all such economic analysis is predetermined by the premises established at the outset of the analysis (Samuels, 1988, p. 866). It is obvious that both the normative and the positive assumptions used in this analysis acted to predetermine the results of the analysis. For example, the assumption that resources displaced by research had no value and received no compensation helped to predetermine the estimated net benefit of research by assuming away the costs (and thus the need to measure the costs) imposed on the owners of displaced resources. On the empirical side, it bears repeating that the research benefit spillovers were estimated under assumed spillover patterns. Thus, the prescriptions drawn from these estimates remain only as artifacts determined in part by the spillover patterns assumed at the outset.

As with all economic policy analysis, the claims of social optimality in this study rest on a set of premises established at the outset of the analysis. As Samuels has observed, however, one must be cognizant that such premises (particularly normative premises) are selective, thereby obscuring the underlying forces at work in the policy process:

> One characteristic [of such analysis] is its presumptive optimality reasoning...[which] with the use of additional selective assumptions, interprets certain arrangements and/or results as optimal. This presumptive optimality reasoning is narrow and selective. [The analyst is] able to reach such conclusions only because of the introduction of antecedent normative premises with which the optimality conclusion is tautological. For perspective, consider the usual production possibility curve. Let the axes represent any two values (commodities or social values or criteria, such as inflation and unemployment, and so on), and add the actual social welfare function formed by the aggregation of the weighted preferences of the population. Four things are transpiring concurrently in society with regard to what the diagram summarizes: first, the working out of the values to be placed on the axes; second, the formation of the production possibility curve (for example, the forces producing the Phillips curve or, in other cases, enforcement costs); third, the determination of preferences; and fourth, the formation of the power structure governing, among other things, the weighting of preferences. The momentary equilibrium which results is an episodic resting place in the evolution of the underlying forces. [Such] optimality analysis relates to a very narrow slice of the activity represented on the diagram and in a highly presumptive and selective manner.... Such optimality exists only within the model of...valuation and adjustment and is tautological with the limits of the model. Specific optimal solutions are a function of the range and specification of variables introduced; [such a model] produces optimal (or efficient) results because the latter are defined in terms of the former. Such conclusions are, as Mishan states, a function of faith and facts; moreover, they abstract from the provision of specificity arising from methodological collectivist forces.... Such optimality is only presumptive: Each efficient solution gives effect only to the interests implicitly or explicitly recognized in the analysis (Samuels, 1976b, p. 413).

The "socially optimal" results reported here (and as embodied in the model presented in Figure 3) can now be seen in a broader perspective. Placing agricultural research on one of the axes, thereby giving it preferential status relative to other possible choices of public or private spending, is a presumption that assumes away the political nature of the problem by ignoring the issues of power and preference that must first be settled in the policy process (i.e., the "working out of the values" and the determination and "weighting of preferences" described above by Samuels).

This is intended neither to decry nor apologize for the results of economic policy analysis such as that conducted here. It is intended simply to reiterate the necessarily partial nature of such analysis, the limitations imposed by its presumptive nature, and the larger issues that must be resolved for a fuller analysis to take place.

Suggestions for Future Research

Several areas of future research should be pursued if greater light is to be shed on the problems of financing agricultural research. First, much more must be known about research benefit spillover patterns before more definitive prescriptions about the optimal federal matching rate can be reached. Given the difficulties associated with specifying the spillover patterns for aggregate output, perhaps a more promising and more sophisticated method of estimating benefit spillover patterns can be specified for individual commodities. If an appropriate range of commodities is chosen for investigation, perhaps a series of commodity case studies would indicate the proper range for establishing federal matching rates. Similarly, the different spillover patterns associated with different types of research (applied, basic, adaptive, maintenance, etc.) should be investigated.

Second, economists should explore the process by which research conducted in one state is adapted for use in another. Work in this area must open the "black box" of research and investigate similarities in states (or sub-state areas) that promote spillovers, along with the differences in regions that must be accounted for by adaptive research. In this same line of work, more must be known about the lags between research spending in one state and increased output in another. This study has implicitly assumed the lag structure for research spilling into a state is the same as the lag structure for research conducted within the recipient state. The relaxation of this assumption could be vital to achieving more accurate measures of research spillovers. Such work should go beyond empirical analysis to examine the process of the invention, adaptation, and dissemination of new knowledge. As Glenn Johnson (1964, p. 122) has observed, such studies must go beyond empirical analysis to also include historical analysis, sociological analysis, biographical analysis of scientists and industrialists, and case studies of research and educational institutions.

A third area that deserves attention is the reaction of state governments to changes in federal matching rates for agricultural research. The responsiveness of states to changes in the federal matching rate will ultimately depend on the price elasticity of research, about which little is known. Future studies which draw on existing public finance theory could open new lines of work that could provide a better theoretical and empirical basis for formulating research policy.

A fourth set of questions revolve around the possible complementarity of agricultural research and other public programs. For example, are greater research spillovers made possible by public programs in soil conservation, public education, or agricultural extension? If so, such programs must be viewed as complements to research, and public funding decisions must consider the need for balanced public investments across many programs rather than focusing exclusively on agricultural research.

A fifth issue involves the formula used to allocate federal agricultural research grants to the states under a closed-ended system of funding. If agricultural research continues to be funded under a closed-ended system of grants rather than an open-ended system, what formula should be used to allocate federal funds? As discussed in Chapter I, the existing Hatch Act formula allocates research funds according to each state's share of the national farm and rural non-farm population. Is this the appropriate formula for allocating agricultural research funds? If the objective of such a program is to compensate the states for the benefit spillovers they create, are there criteria other than population (e.g., land in farms or value of production) that would provide a more logical basis for allocating Hatch Act funds? Future analysis should focus on finding a theoretically defensible and empirically feasible funding mechanism.

A final promising area of future research could be cross-country comparisons of national research funding systems. The Canadian system of provincial federalism, for example, funds a greater share of its agricultural research spending at the federal level than does the American system (Brooks and Furtan, p. 357). If national research policy is to be made in an informed manner, policymakers must understand the relative success of different national research systems at providing an optimal level of agricultural research. In addition, the problems of designing appropriate research systems for small versus large nations (e.g., African versus North American nations) need to be explored, especially within the context of international benefit spillovers.

APPENDICES

APPENDIX A

DATA SOURCES AND REGRESSION DATA

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This appendix provides a detailed description of the data sources used in this research. The components used to construct each variable described in Chapter III are listed in the order in which they appear in the chapter.

Aggregate Output

Data for this variable were collected from the following sources for the five cross sections:

Value of commodities marketed, government payments, and change in inventories held on farms (USDA, 1986b, pp. 56-304);

1. Value of home consumption of farm products (USDA, 1985a, pp. 10-34; 1981c, pp. 33-57; 1975b, p. 8; and 1970b, pp. 12-36);
2. Value of forest product sales (USDA, 1975d, pp. 44-83; 1970b, pp. 93-122; and 1965b, pp. 90);
3. Commodity group indexes of prices received by farmers for farm products (USDA, 1984a, pp. 9-16; 1981a, pp. 11-24).

It should be noted that forest product sales were not included in the other crops marketed category after 1977 (USDA, 1986b, pp. 56-304); thus, it was not necessary to deduct forest product sales from the other crops category for the 1978 and 1982 cross-sections.

Land

The land variable was constructed using data from the following sources:

1. All categories of farm land for all cross-sections (U.S. Department of Commerce, 1984, Table 1);
2. Index of land quality (Willis Peterson, 1986, p. 817).

Labor

The data used to construct the labor variable came from the following sources:

1. Expenditures on hired labor (USDA, 1986a, pp.56-304);
2. Social Security tax rate (U. S. Department of Health and Human Services, p. 23);
3. Annual average wage rate, number of family workers on farms, and average number of hours worked per week (USDA, 1982-1964, various issues).

Education

The following sources were used to construct the education variable:

1. Education level of rural farm males 25 years of age or older in each state (U. S. Department of Commerce, 1981, Table 66; 1973a, Table 51; 1961b, Table 47);
2. Average income of U.S. rural males 25 years of age or older by level of education (U. S. Department of Commerce, 1984, pp. 447-48; 1973b, p. 860; 1961a, p. 590; Houthakker, p.24).

Fertilizer

The data for the construction of the fertilizer variable were obtained from the following sources:

1. Expenditures for fertilizer products (USDA, 1986b, pp. 56-304);
2. Index of prices paid by farmers for fertilizer products (USDA, 1984a, p. 20; 1981a, p. 32).

Machinery

The machinery variable was constructed from the following data sources:

1. Fuel and oil expenditures, custom-hired machinery expenditures and total expenditures on farm repairs (USDA, 1986b, pp. 56-304);
2. National level farm repair expenditures (USDA, 1986a, p. 39);
3. Value of farm machinery (USDA, 1985a, pp. 148-97; 1981c, pp. 8-32; 1979b, pp. 15-45; U. S. Department of Commerce, 1972, Table 6).
4. Indexes of prices paid by farmers for fuels and energy, farm and motor supplies, and tractors and other self-propelled machinery (USDA, 1984a, pp. 21-22; 1981a, pp. 34-37).

Livestock

The data used to construct the livestock variable were obtained from the following sources:

1. Total hog and pig inventory, breeding hog inventory, and value of hog and pig inventory (USDA, 1984c, pp. 8 and

12; 1980b, pp. 8, 13; 1977a, pp. 10, 15; 1972a, pp. 14. 20; 1966b, pp. 5-6; 1965a, p. 322);

2. Total cattle inventory, dairy cows, beef cows, bulls, and value of cattle inventory (USDA, 1983a, pp. 266-68; 1979a, 301-303; 1975a, pp. 298-300; 1971, pp. 306-308; 1965a, 308-309);

3. Total sheep and lamb inventory, breeding sheep inventory, and value of sheep and lamb inventory (USDA, 1983b, pp. 3-5; 1981e, pp. 8-9; 1977b, pp. 7- 8; 1972c, pp. 7-8; 1967, pp. 17-18);

4. Total value of chicken inventory and turkey breeding hen inventory (USDA, 1984b, pp. 356, 365; 1979a, pp. 396, 407; 1975a, pp. 396, 407; 1972d, pp. 5, 8; 1970a, p. 402; 1967, pp. 29-30; 1965a, p. 408,).

<u>Other Inputs</u>

The data used to construct the "other input" variables came from the following sources:

1. Purchased seed and feed expenditures (USDA, 1986b, pp. 56-304);

2. Farm-produced seed and feed (USDA, 1964a, pp. 14-20, 31; 1964b, pp. 7, 34, 41, 47, 55, 136, 274; 1969a, pp. 14-19, 30; 1969b, pp. 7, 33, 39, 45, 54, 135, 271; 1974a, pp. 13-18, 29; 1974b, pp. 7, 32, 40, 46, 53, 136, 270; 1976a, pp. 9, 131, 284-85; 1978a, pp. 25-31, 43; 1978b, pp. 8, 34, 41, 46, 53, 270; 1979a, pp. 285-85, 1980a p. 5; 1981b, pp. 8, 34, 46, 53, 271 8; 1982a, pp. 29-34; 1983a, p. 256-57; 1984b, pp. 5, 32, 40, 45, 52, 128, 247);

4. State farm repair expenditures (USDA, 1986b, pp. 56-304);
2. National farm repair expenditures (USDA, 1986a, p. 39);
3. State farm building value (USDA, 1985b, pp. 4-51);
4. National farm building value (USDA, 1986a, p.61);
5. Expenditures on pesticides and other miscellaneous inputs (USDA, 1986b, pp. 56-304);
6. Indexes of prices paid by farmers for feed, seed, feeder livestock, building and fencing materials, agricultural chemicals, and items used for production (USDA, 1984a, pp. 18-23; 1981a, pp. 27-39);
7. Index of prices received by farmers for meat animals (USDA, 1984a, p. 15; 1981a, p. 24).

Research

The data used to construct the research variable were obtained from the following sources:

1. Total state expenditures on agricultural research and on non-agricultural research (USDA, 1985c, pp. 25-58; 1984d, pp. 25-57; 1982c, pp. 35-65; 1981d, pp. 35-67; 1976b, pp. 36-63; 1975c, pp. 37-64; 1972b, pp. 35-67; 1970c, pp. 53-79; 1966a, pp. 10-18; 1965c, pp.10-14);
2. Index of professors' salaries (Pardey, p. 150).

Extension

The data used to construct the extension variable were obtained from the following sources:

1. Total state extension expenditures (U. S. Congress, 1983, p. 607; 1982, p. 740; 1979, p. 1275; 1978, p. 696; 1975,

pp. 436-37; 1974, 192-93; 1970, pp. 603- 604; 1969, pp. 98-99; 1965, pp. 463-64; 1964b, pp. 339-340)

2. Proportion of extension agents' time devoted to agricultural production activities (Davis, 1979, p. 139);
3. Index of professors' salaries, (Pardey, p. 150).

Weather

The following data sources were used to construct the weather variable:

1. July pasture conditions index (USDA, 1982b, p. B-20; 1978c, p. B-20; 1974c, p. B-11; 1969c, p. 38; 1964c, p. 49).

Regression Data

The data used to estimate the production functions are shown in Tables A.1 to A.5. In each case, the data shown are the state aggregates of the variables described in Chapter III. All monetary variables were deflated into real 1977 dollars as described in Chapter III. The data shown in these tables are:

Output = State farm output (1000's of dollars);

Extension = State expenditures on extension (1000's of dollars);

Education = Average per capita income of rural farm males in the state (dollars);

Fertilizer = State expenditures on fertilizer (1000's of dollars);

Labor = Hours of labor used in farm production in the state (1000's of hours);

Land = Quality-adjusted acres of land used in farm production in the state (acres);

Livestock = State expenditures on livestock services (1000's of dollars);

Machinery = State expenditures on farm machinery services (1000's of dollars);

Other = State expenditures on other farm inputs (1000's of dollars);

Research = State expenditures on agricultural research (1000's of dollars);

$Resout_1$ = Research expenditures in other relevant states under the "neighboring states" relevance assumption, not weighted by the pervasiveness weight (1000's of dollars);

$Resout_2$ = Research expenditures in other relevant states under the "production region" relevance assumption, not weighted by the pervasiveness weight (1000's of dollars);

Weather = July index of pasture conditions on the state;

Nfarms = Number of farms in the state.

Table A.1: Regression Data, 1982 Cross-section

State	Output	Education	Extension	Fertilizer	Labor
Alabama	1,849,600	10,996	14,445	85,924	101,984
Arizona	1,315,995	12,074	4,896	41,884	72,508
Arkansas	2,738,620	10,629	11,897	94,576	103,089
California	10,569,083	11,939	32,153	298,570	604,125
Colorado	2,114,961	12,236	10,102	53,922	94,011
Florida	3,195,413	11,586	18,784	161,492	225,679
Georgia	2,838,071	10,615	25,094	151,669	113,733
Idaho	1,661,217	12,160	5,018	111,540	121,870
Illinois	6,618,910	11,308	18,467	525,218	247,843
Indiana	3,833,305	11,517	16,724	323,782	150,413
Iowa	7,731,658	11,344	16,569	402,613	395,937
Kansas	4,379,913	11,716	16,306	180,144	241,779
Kentucky	2,244,305	10,062	16,941	108,633	183,108
Louisiana	1,615,800	11,133	16,863	68,856	74,902
Maryland	848,092	11,408	8,087	54,628	57,095
Michigan	2,274,032	11,285	17,407	171,288	193,123
Minnesota	5,308,992	10,804	16,725	262,881	412,427
Mississippi	2,161,034	11,862	16,130	86,904	99,486
Missouri	3,206,737	11,037	16,374	191,508	253,660
Montana	1,179,789	11,975	4,829	55,430	86,837
Nebraska	5,226,905	11,458	11,143	229,025	237,237
Nevada	165,263	12,222	2,221	3,880	11,876
New Jersey	396,570	12,617	7,258	20,435	31,190
New Mexico	693,636	12,397	4,801	12,671	48,969
New York	1,953,098	11,672	25,202	86,670	194,685
N. Carolina	3,142,803	10,247	26,479	176,435	210,689
North Dakota	2,246,849	10,881	6,249	110,499	168,528
Ohio	3,060,160	11,433	18,384	257,733	223,630
Oklahoma	2,261,980	11,623	13,742	82,505	109,931
Oregon	1,255,317	12,568	9,056	73,706	119,964
Pennsylvania	2,242,231	11,055	14,006	110,335	218,577
S. Carolina	951,592	11,032	13,058	71,840	63,626
South Dakota	2,087,456	11,134	5,137	55,410	101,009
Tennessee	1,728,765	10,473	15,249	95,399	135,409
Texas	7,876,752	11,261	31,676	258,411	382,996
Utah	399,228	12,684	4,534	7,172	52,433
Virginia	1,225,519	10,604	21,429	91,328	132,597
Washington	2,118,112	12,399	10,605	121,874	140,096
W. Virginia	157,333	11,110	6,270	8,600	54,643
Wisconsin	3,853,131	10,944	19,532	191,122	406,438
Wyoming	392,693	12,388	3,433	12,328	31,328

(Continued)

Table A.1 (cont'd.).

State	Land	Livestock	Machinery	Other	Research
Alabama	7,828,753	127,892	256,822	659,224	10,818
Arizona	30,874,359	116,775	120,511	381,848	12,068
Arkansas	15,302,072	176,845	395,206	804,678	12,334
California	38,160,900	578,928	941,895	2,849,944	59,303
Colorado	22,589,880	538,695	265,406	716,741	19,050
Florida	14,945,331	106,352	284,716	624,837	33,338
Georgia	9,506,781	153,604	345,232	921,932	21,091
Idaho	13,244,462	119,100	274,878	596,748	8,010
Illinois	40,962,671	211,270	1,120,730	2,226,083	13,678
Indiana	20,340,140	124,000	687,782	1,426,973	19,485
Iowa	44,196,930	577,721	1,224,664	3,795,808	16,449
Kansas	45,156,093	757,589	754,582	1,626,371	17,783
Kentucky	13,248,066	72,225	423,014	572,973	9,406
Louisiana	9,533,369	49,398	275,443	381,039	18,498
Maryland	2,656,197	58,329	122,895	422,727	5,047
Michigan	10,416,698	78,734	454,901	892,063	15,526
Minnesota	30,099,618	306,974	1,019,368	2,377,942	18,941
Mississippi	11,262,874	86,261	326,562	556,003	13,967
Missouri	34,383,187	135,665	660,265	1,392,934	11,833
Montana	33,965,756	98,514	290,946	423,294	7,629
Nebraska	49,745,680	994,213	776,616	2,087,153	19,451
Nevada	10,138,567	22,309	31,898	82,101	2,696
New Jersey	968,051	11,250	65,038	114,237	7,268
New Mexico	29,090,120	161,550	95,838	245,334	4,081
New York	7,728,152	94,995	370,391	945,805	27,458
N. Carolina	8,605,638	132,673	475,439	1,041,978	25,544
North Dakota	31,835,541	66,510	531,593	650,581	11,886
Ohio	16,079,592	102,164	637,259	1,166,852	13,992
Oklahoma	31,017,691	326,123	416,639	637,345	8,821
Oregon	18,476,940	73,584	239,703	440,896	13,460
Pennsylvania	7,484,110	158,019	402,661	1,174,207	10,322
S. Carolina	4,162,817	32,803	171,438	268,932	8,751
South Dakota	33,991,039	177,365	419,763	924,731	5,581
Tennessee	11,159,154	87,513	360,893	549,071	9,741
Texas	123,388,436	1,137,636	1,174,264	2,587,881	28,818
Utah	8,511,433	43,962	87,228	243,395	6,235
Virginia	6,452,032	72,847	278,550	549,059	14,112
Washington	11,970,317	112,877	318,201	652,405	14,302
W. Virginia	2,380,817	20,991	64,047	113,477	2,866
Wisconsin	16,210,643	189,134	771,669	2,000,614	19,975
Wyoming	36,926,972	100,052	95,956	192,947	3,171

(Continued)

Table A.1 (cont'd.).

State	$Resout_1$	$Resout_2$	Weather	NFarms
Alabama	63,169	49,991	88	48,448
Arizona	53,768	37,604	67	7,334
Arkansas	74,097	28,135	82	50,525
California	21,319	22,234	92	82,463
Colorado	49,708	33,877	81	27,111
Florida	27,510	34,707	86	36,352
Georgia	71,197	41,263	89	49,630
Idaho	38,110	40,783	92	24,714
Illinois	57,866	45,770	93	98,483
Indiana	38,328	40,171	91	77,180
Iowa	38,115	43,917	93	115,413
Kansas	44,258	30,277	91	73,315
Kentucky	64,972	43,135	88	101,642
Louisiana	44,849	22,535	84	31,628
Maryland	22,403	42,088	80	16,183
Michigan	40,792	28,393	87	58,661
Minnesota	40,939	25,648	87	94,382
Mississippi	42,872	25,627	89	42,415
Missouri	85,657	47,069	84	112,447
Montana	22,687	39,837	99	23,570
Nebraska	53,068	30,006	91	60,243
Nevada	72,869	44,272	87	2,719
New Jersey	27,562	41,814	81	8,277
New Mexico	51,020	42,836	70	13,484
New York	17,418	27,649	78	42,207
N. Carolina	25,930	28,581	88	72,792
North Dakota	24,820	36,473	92	36,431
Ohio	42,952	45,041	84	86,934
Oklahoma	72,516	22,314	87	72,523
Oregon	63,224	55,463	88	34,087
Pennsylvania	39,246	38,855	83	55,535
S. Carolina	40,199	52,184	89	24,929
South Dakota	59,636	41,062	95	37,148
Tennessee	98,954	42,808	82	90,565
Texas	36,570	7,371	72	185,020
Utah	31,814	41,956	88	13,984
Virginia	43,703	39,783	91	51,859
Washington	16,005	53,989	79	36,080
W. Virginia	39,930	48,340	84	18,742
Wisconsin	45,298	24,001	88	82,199
Wyoming	49,987	43,689	93	8,861

Source: Author.

Table A.2: Regression Data, 1978 Cross-section.

State	Output	Education	Extension	Fertilizer	Labor
Alabama	1,691,176	12,217	15,821	118,888	105,104
Arizona	1,368,527	13,389	4,868	44,995	79,568
Arkansas	3,248,338	11,974	12,305	116,331	145,962
California	9,198,662	14,058	28,430	340,521	586,924
Colorado	2,211,746	14,135	8,372	68,903	108,380
Florida	2,810,637	13,281	18,513	186,637	215,041
Georgia	2,445,829	12,102	21,015	222,613	120,252
Idaho	1,634,191	14,188	5,380	107,032	102,186
Illinois	6,035,444	13,182	17,602	550,995	305,659
Indiana	3,426,804	13,490	14,489	362,770	175,684
Iowa	8,036,949	13,320	15,524	496,036	457,098
Kansas	4,000,630	13,682	14,894	254,776	215,236
Kentucky	2,262,904	11,434	14,289	135,412	205,088
Louisiana	1,392,654	12,151	14,157	88,124	87,856
Maryland	773,281	13,044	8,273	57,944	50,400
Michigan	1,897,312	13,061	18,508	181,828	176,381
Minnesota	4,773,368	12,414	10,638	319,617	417,896
Mississippi	1,966,894	12,490	15,459	111,682	112,238
Missouri	3,253,321	12,807	9,229	231,884	253,854
Montana	1,100,433	13,824	4,241	64,954	88,044
Nebraska	4,421,899	13,353	10,567	267,810	258,569
Nevada	153,398	14,261	2,664	4,914	12,320
New Jersey	361,506	14,242	7,403	22,802	43,205
New Mexico	739,895	13,569	4,103	17,092	52,388
New York	1,762,350	13,529	13,432	96,185	211,317
N. Carolina	2,070,733	11,375	25,104	225,841	218,860
North Dakota	2,021,711	12,542	5,356	150,296	144,672
Ohio	2,888,624	13,396	17,538	274,979	252,090
Oklahoma	1,903,479	13,342	11,581	115,587	159,867
Oregon	1,100,619	14,536	9,867	77,383	107,048
Pennsylvania	1,975,414	12,887	13,646	114,880	249,237
S. Carolina	917,296	12,112	12,518	105,241	82,575
South Dakota	1,833,226	12,859	5,248	76,311	145,533
Tennessee	1,456,418	11,670	14,124	115,732	158,286
Texas	7,121,262	12,863	32,844	335,575	466,626
Utah	397,163	14,738	4,135	11,933	46,787
Virginia	1,199,557	11,770	20,284	103,836	135,931
Washington	1,916,746	14,427	8,537	125,817	134,740
W. Virginia	171,236	12,254	6,118	11,356	39,986
Wisconsin	3,339,464	12,563	17,185	190,957	414,849
Wyoming	462,166	14,266	2,714	16,364	31,567

(Continued)

Table A.2 (cont'd.).

State	Land	Livestock	Machinery	Other	Research
Alabama	8,370,689	100,961	296,003	787,172	10,606
Arizona	30,675,559	256,743	150,582	424,039	10,320
Arkansas	15,413,604	181,070	460,077	999,610	11,406
California	37,589,173	757,090	1,036,500	2,653,127	53,421
Colorado	23,113,133	763,653	336,196	802,650	14,082
Florida	14,406,192	83,168	326,884	686,609	28,696
Georgia	9,668,627	154,592	389,695	1,061,021	16,036
Idaho	13,128,874	107,933	318,224	582,556	6,780
Illinois	41,164,310	223,319	1,240,983	2,105,652	12,549
Indiana	20,230,226	129,800	746,669	1,375,888	16,457
Iowa	44,233,422	972,582	1,367,472	3,252,784	15,946
Kansas	44,878,435	922,013	812,585	1,717,041	14,584
Kentucky	13,276,175	66,257	463,214	679,869	8,374
Louisiana	9,873,456	39,420	301,520	421,991	15,946
Maryland	2,632,291	42,902	145,906	413,132	5,287
Michigan	10,001,161	55,329	518,829	782,987	16,328
Minnesota	29,917,565	276,632	1,090,113	2,099,705	19,637
Mississippi	11,521,283	82,371	368,804	692,546	12,278
Missouri	34,948,109	112,062	777,304	1,515,729	11,216
Montana	34,577,875	108,910	300,419	505,878	7,327
Nebraska	48,640,111	845,590	815,577	1,732,370	18,677
Nevada	10,559,512	21,713	35,156	90,828	2,809
New Jersey	1,012,673	10,180	79,518	127,048	9,033
New Mexico	28,963,782	234,704	115,681	262,027	3,154
New York	7,856,924	69,876	443,625	1,060,283	27,791
N. Carolina	8,447,936	109,535	572,484	1,081,911	23,999
North Dakota	31,442,348	51,252	579,448	588,318	9,149
Ohio	16,029,145	106,397	744,439	1,219,641	16,851
Oklahoma	32,377,696	295,396	489,095	878,874	8,927
Oregon	18,305,443	63,853	271,969	448,406	13,176
Pennsylvania	7,569,309	114,612	494,975	1,195,257	10,379
S. Carolina	4,372,924	36,875	216,845	320,819	9,301
South Dakota	34,177,028	211,698	468,263	891,750	5,470
Tennessee	11,148,323	57,105	414,293	608,589	11,142
Texas	127,780,636	1,010,074	1,319,227	2,947,507	24,206
Utah	8,830,291	37,143	104,721	248,719	5,788
Virginia	6,269,640	56,523	320,788	566,940	11,948
Washington	11,548,823	126,505	352,369	576,761	13,651
W. Virginia	2,363,999	14,775	79,287	132,847	3,024
Wisconsin	16,207,538	133,818	848,439	1,950,256	17,789
Wyoming	35,751,256	140,819	96,858	189,401	2,583

(Continued)

Table A.2 (cont'd.).

State	$Resout_1$	$Resout_2$	Weather	NFarms
Alabama	55,257	42,908	74	50,780
Arizona	47,558	30,646	77	6,298
Arkansas	66,716	24,750	65	51,751
California	18,847	20,171	92	73,194
Colorado	40,912	29,127	69	26,907
Florida	22,058	29,710	84	36,109
Georgia	67,448	37,645	67	51,405
Idaho	34,364	32,817	88	24,249
Illinois	49,130	40,927	83	104,690
Indiana	37,429	38,523	86	82,483
Iowa	35,820	39,151	93	121,339
Kansas	37,507	25,295	71	74,171
Kentucky	59,407	40,865	83	102,263
Louisiana	39,154	20,372	71	31,370
Maryland	19,638	39,021	78	15,540
Michigan	35,090	27,085	80	60,426
Minnesota	33,883	23,783	95	98,671
Mississippi	41,103	23,509	78	44,104
Missouri	76,506	41,538	82	114,963
Montana	17,944	32,264	100	23,565
Nebraska	42,484	21,928	82	63,768
Nevada	64,741	35,814	86	2,399
New Jersey	25,980	38,397	80	7,984
New Mexico	40,722	35,374	73	12,311
New York	16,342	25,667	68	43,075
N. Carolina	25,624	26,814	82	81,706
North Dakota	23,643	29,773	99	40,357
Ohio	38,125	38,509	84	89,131
Oklahoma	59,175	18,782	64	72,237
Oregon	56,670	49,453	96	28,503
Pennsylvania	39,564	35,910	85	56,202
S. Carolina	34,268	43,654	64	26,706
South Dakota	54,321	32,954	95	38,741
Tennessee	86,496	38,227	79	86,910
Texas	31,923	5,864	38	175,395
Utah	25,557	33,767	71	12,764
Virginia	42,695	38,645	91	49,936
Washington	14,565	48,199	90	30,987
W. Virginia	37,697	45,137	91	17,475
Wisconsin	44,517	25,270	92	86,505
Wyoming	42,139	35,660	92	8,040

Source: Author.

Table A.3: Regression Data, 1974 Cross-section

State	Output	Education	Extension	Fertilizer	Labor
Alabama	1,301,941	12,116	13,861	120,990	125,699
Arizona	1,261,714	13,196	3,897	50,099	61,457
Arkansas	2,297,593	11,953	11,048	110,634	175,013
California	9,295,472	14,355	23,623	366,964	644,182
Colorado	2,029,969	14,336	6,597	65,250	120,533
Florida	2,470,392	13,249	12,433	198,700	225,123
Georgia	2,358,091	12,086	19,585	240,012	207,000
Idaho	1,497,842	14,480	4,031	114,163	104,320
Illinois	4,885,167	13,436	16,383	522,033	320,573
Indiana	2,621,318	13,820	11,777	358,562	291,972
Iowa	6,375,198	13,647	13,158	506,850	454,362
Kansas	3,025,242	13,979	13,272	258,407	246,187
Kentucky	1,759,071	11,466	13,324	127,351	249,836
Louisiana	1,342,785	11,975	12,580	90,760	105,125
Maryland	639,210	13,098	7,144	61,345	73,590
Michigan	1,772,407	13,303	16,495	167,149	258,750
Minnesota	3,966,641	12,524	12,156	323,172	431,151
Mississippi	1,664,096	12,221	13,090	111,773	182,195
Missouri	2,608,973	12,987	15,544	235,945	378,067
Montana	887,969	13,992	3,786	48,730	89,539
Nebraska	3,226,343	13,597	8,554	260,732	271,704
Nevada	126,398	14,599	2,208	4,100	12,208
New Jersey	374,302	14,332	7,286	25,467	38,537
New Mexico	645,518	13,272	3,705	20,172	49,166
New York	1,785,950	13,822	23,316	91,576	247,855
N. Carolina	2,788,564	11,334	23,949	227,275	309,871
North Dakota	1,614,012	12,677	4,340	112,367	140,537
Ohio	2,519,965	13,732	15,300	270,783	338,297
Oklahoma	1,846,203	13,410	10,287	110,087	239,544
Oregon	1,027,704	14,687	8,290	88,165	105,036
Pennsylvania	1,683,747	13,188	12,842	103,840	314,464
S. Carolina	943,681	11,969	10,317	110,287	112,321
South Dakota	1,734,789	13,028	4,757	76,071	156,677
Tennessee	1,254,066	11,613	13,080	104,915	248,178
Texas	5,530,525	12,909	27,866	359,736	517,143
Utah	343,589	15,037	2,978	11,782	37,706
Virginia	1,073,033	11,620	18,205	105,646	194,219
Washington	1,684,646	14,680	7,295	126,204	154,624
W. Virginia	181,161	12,210	5,644	8,862	68,052
Wisconsin	2,787,457	12,678	13,711	168,443	428,680
Wyoming	375,601	14,522	2,226	14,665	40,722

(Continued)

Table A.3 (cont'd.).

State	Land	Livestock	Machinery	Other	Research
Alabama	8,466,171	138,331	290,473	668,082	9,370
Arizona	29,512,830	199,735	109,994	372,092	8,114
Arkansas	14,215,546	174,137	417,733	840,176	10,212
California	36,682,586	815,932	748,862	2,409,464	48,189
Colorado	23,285,257	574,799	284,081	656,790	5,300
Florida	13,821,866	124,188	269,534	568,829	24,620
Georgia	9,409,615	189,243	382,286	950,483	14,360
Idaho	12,963,879	101,050	274,671	466,249	4,616
Illinois	39,902,558	286,094	1,118,714	1,765,335	11,912
Indiana	19,776,607	135,087	656,024	1,156,017	13,557
Iowa	44,239,433	862,614	1,179,779	2,905,100	13,853
Kansas	46,714,795	538,128	723,832	1,232,378	11,354
Kentucky	12,899,676	125,322	393,389	533,301	8,047
Louisiana	8,980,614	65,327	305,786	369,037	12,629
Maryland	2,618,351	48,433	121,415	314,981	4,866
Michigan	9,591,541	85,143	452,086	639,229	14,569
Minnesota	28,749,214	337,232	937,085	1,555,962	13,013
Mississippi	11,348,759	124,048	396,221	592,080	10,665
Missouri	34,069,794	214,919	678,093	1,338,781	10,897
Montana	35,128,069	128,093	265,031	402,454	6,048
Nebraska	45,133,070	634,588	674,796	1,542,944	15,333
Nevada	10,965,686	33,350	24,522	71,324	2,389
New Jersey	960,443	17,886	61,880	127,212	10,133
New Mexico	28,361,272	206,106	88,029	219,854	3,223
New York	7,715,596	105,333	406,053	859,275	21,840
N. Carolina	8,136,939	113,362	551,731	814,568	19,236
North Dakota	32,395,537	85,722	494,081	479,610	6,910
Ohio	15,603,239	158,251	658,278	999,711	11,495
Oklahoma	32,463,345	476,499	435,695	707,720	8,227
Oregon	17,953,195	68,231	222,764	342,544	10,360
Pennsylvania	7,149,413	138,082	413,173	853,149	9,932
S. Carolina	4,219,912	44,654	209,367	270,566	7,249
South Dakota	36,278,828	244,509	405,233	778,814	4,937
Tennessee	11,188,186	91,476	382,487	456,533	8,280
Texas	127,066,905	884,879	1,173,056	2,326,157	20,363
Utah	8,694,503	46,801	87,275	170,423	4,399
Virginia	6,322,829	67,916	276,167	439,312	10,976
Washington	11,383,905	93,848	304,011	499,390	11,538
W. Virginia	2,265,241	20,167	72,031	116,782	3,068
Wisconsin	15,657,672	179,025	663,393	1,368,120	15,559
Wyoming	35,176,745	108,066	80,703	163,682	3,067

(Continued)

Table A.3 (cont'd.).

State	$Resout_1$	$Resout_2$	Weather	Nfarms
Alabama	44,163	33,820	72	56,678
Arizona	40,383	21,179	62	11,282
Arkansas	54,738	18,963	62	50,959
California	12,984	14,936	86	67,674
Colorado	36,669	23,334	58	25,501
Florida	19,811	24,348	80	32,466
Georgia	51,925	30,139	79	54,911
Idaho	26,344	22,860	74	23,680
Illinois	42,124	36,120	68	111,049
Indiana	29,603	33,879	72	87,915
Iowa	24,779	34,393	64	126,104
Kansas	30,800	19,925	49	79,188
Kentucky	49,433	30,665	86	102,053
Louisiana	32,328	17,652	77	33,240
Maryland	17,110	38,165	70	15,163
Michigan	28,736	17,279	78	64,094
Minnesota	26,867	19,213	65	98,537
Mississippi	33,405	19,179	80	53,620
Missouri	64,711	35,188	51	115,711
Montana	13,356	21,796	77	23,324
Nebraska	33,533	16,738	45	67,597
Nevada	52,369	25,597	65	2,076
New Jersey	23,225	36,278	67	7,409
New Mexico	29,937	23,938	49	11,282
New York	18,120	26,861	81	43,682
N. Carolina	18,082	19,487	80	91,280
North Dakota	15,040	25,134	71	42,710
Ohio	31,365	34,902	68	92,158
Oklahoma	47,413	14,676	55	69,719
Oregon	46,591	41,779	86	26,753
Pennsylvania	34,472	35,110	80	53,171
S. Carolina	27,371	37,348	76	29,275
South Dakota	40,014	26,101	61	42,825
Tennessee	73,351	28,950	75	93,659
Texas	28,380	6,505	45	174,068
Utah	15,786	23,321	60	12,184
Virginia	31,417	27,728	69	52,699
Washington	10,265	39,826	91	29,410
W. Virginia	30,983	33,617	86	16,909
Wisconsin	32,668	15,940	78	89,479
Wyoming	30,986	24,416	71	8,018

Source: Author.

Table A.4: Regression Data, 1969 Cross-section

State	Output	Education	Extension	Fertilizer	Labor
Alabama	1,440,433	10,718	11,576	114,692	170,718
Arizona	1,283,461	11,674	2,981	37,742	75,953
Arkansas	2,303,553	10,710	8,714	81,992	214,818
California	7,674,236	12,997	19,873	259,110	598,620
Colorado	1,789,622	13,045	5,198	42,188	124,878
Florida	2,306,780	11,783	10,263	210,077	245,551
Georgia	2,102,247	10,686	15,153	194,402	203,576
Idaho	1,179,522	13,275	3,598	68,333	115,984
Illinois	5,453,961	12,279	13,089	378,860	346,647
Indiana	3,006,378	12,699	11,023	227,929	248,636
Iowa	6,717,841	12,515	11,668	319,281	503,364
Kansas	3,283,138	12,808	11,554	154,319	245,329
Kentucky	1,585,373	10,339	10,609	104,323	272,841
Louisiana	1,252,109	10,583	10,605	71,996	136,915
Maryland	660,734	11,761	5,995	44,740	71,302
Michigan	1,669,462	12,150	13,464	114,575	307,141
Minnesota	3,655,067	11,352	9,434	180,342	437,395
Mississippi	1,933,574	10,804	10,163	101,856	237,403
Missouri	2,945,185	11,760	13,637	207,598	362,085
Montana	1,031,605	12,723	3,241	29,442	97,297
Nebraska	3,537,385	12,416	7,261	157,933	258,452
Nevada	134,945	13,381	1,704	1,996	11,923
New Jersey	433,351	12,979	6,240	24,819	45,072
New Mexico	716,909	11,788	3,482	15,527	58,316
New York	1,871,280	12,647	19,859	77,096	252,377
N. Carolina	2,536,230	10,195	19,621	193,967	423,326
North Dakota	1,694,415	11,510	3,865	63,598	148,645
Ohio	2,473,159	12,625	12,509	176,827	325,389
Oklahoma	1,815,126	12,052	8,592	78,577	239,225
Oregon	977,601	13,281	7,680	56,790	138,378
Pennsylvania	1,728,902	12,112	10,384	89,240	287,922
S. Carolina	859,314	10,585	6,988	97,065	148,730
South Dakota	1,636,850	11,877	4,196	44,946	166,644
Tennessee	1,347,103	10,411	10,507	97,519	237,184
Texas	6,263,501	11,586	20,482	287,902	601,961
Utah	358,009	13,823	2,480	8,358	46,440
Virginia	1,021,588	10,331	13,577	89,263	222,804
Washington	1,483,323	13,350	6,778	80,046	162,979
W. Virginia	179,605	11,010	4,690	9,808	67,858
Wisconsin	2,679,843	11,479	11,577	110,160	467,764
Wyoming	376,199	13,306	2,087	10,954	41,928

(Continued)

Table A.4 (cont'd.).

State	Land	Livestock	Machinery	Other	Research
Alabama	9,108,578	111,758	248,928	703,348	8,721
Arizona	28,215,227	233,265	110,261	378,413	7,683
Arkansas	14,827,988	136,599	391,445	866,369	7,539
California	35,797,099	668,987	809,672	2,407,869	44,620
Colorado	23,113,999	516,392	262,401	672,600	5,158
Florida	13,222,033	106,674	250,760	539,255	19,137
Georgia	9,176,553	168,274	344,985	990,723	12,530
Idaho	11,736,322	78,708	260,168	430,386	4,212
Illinois	37,710,325	339,879	1,063,115	1,973,814	12,101
Indiana	18,404,011	127,977	610,656	1,211,121	13,153
Iowa	40,192,793	951,956	1,115,621	3,243,585	13,437
Kansas	43,581,111	589,659	716,443	1,217,630	13,074
Kentucky	13,252,818	104,272	362,890	625,104	8,023
Louisiana	9,614,802	50,716	279,891	383,423	11,085
Maryland	2,564,069	51,075	110,736	351,990	5,243
Michigan	9,184,043	81,301	427,879	740,908	14,307
Minnesota	26,770,074	308,476	840,026	1,719,942	8,491
Mississippi	11,897,639	106,640	353,831	671,723	6,922
Missouri	34,540,053	191,320	655,602	1,471,702	11,987
Montana	34,804,728	94,787	275,797	404,369	5,472
Nebraska	40,832,301	593,854	643,607	1,516,748	13,463
Nevada	11,248,112	21,969	28,311	65,703	2,221
New Jersey	934,266	24,479	67,904	168,643	9,215
New Mexico	27,199,515	206,490	96,837	236,980	3,030
New York	8,070,479	115,063	379,773	1,014,261	17,286
N. Carolina	7,693,190	104,939	479,875	958,847	15,102
North Dakota	30,901,429	61,004	499,717	468,226	5,352
Ohio	15,297,717	160,552	581,259	1,167,385	10,532
Oklahoma	34,158,216	310,135	433,598	670,420	7,548
Oregon	16,862,628	61,816	208,498	372,888	10,688
Pennsylvania	7,441,646	144,086	369,460	998,755	9,913
S. Carolina	4,040,662	31,675	182,624	285,534	4,209
South Dakota	33,956,845	186,973	405,481	853,333	5,186
Tennessee	11,830,184	72,768	349,406	575,406	8,847
Texas	131,921,788	731,285	1,239,613	2,253,582	15,967
Utah	8,922,030	44,163	81,845	190,525	3,769
Virginia	6,386,904	56,116	240,651	503,653	5,459
Washington	11,112,159	54,283	284,674	473,449	11,124
W. Virginia	2,921,506	16,862	58,103	142,299	3,008
Wisconsin	15,519,293	150,671	609,319	1,579,707	11,461
Wyoming	34,361,689	97,858	83,857	171,020	2,825

(Continued)

Table A.4 (cont'd.).

State	$Resout_1$	$Resout_2$	Weather	Nfarms
Alabama	33,724	25,822	77	72,491
Arizona	38,047	16,992	83	5,890
Arkansas	46,263	13,803	71	60,433
California	11,815	13,000	89	77,875
Colorado	31,137	19,533	88	27,950
Florida	13,770	17,179	91	35,586
Georgia	42,269	23,783	75	67,431
Idaho	22,219	19,145	90	25,475
Illinois	38,575	33,418	94	123,565
Indiana	28,187	32,000	96	101,479
Iowa	20,848	32,412	95	140,354
Kansas	27,285	17,497	90	86,057
Kentucky	46,876	26,168	92	125,069
Louisiana	22,288	10,908	71	42,269
Maryland	15,590	35,679	75	17,181
Michigan	24,206	13,421	93	77,946
Minnesota	23,637	16,874	91	110,747
Mississippi	28,300	15,653	70	72,577
Missouri	57,991	32,068	83	137,067
Montana	12,469	18,821	87	24,951
Nebraska	32,311	15,843	89	72,527
Nevada	48,710	21,108	93	2,112
New Jersey	20,932	34,882	85	8,493
New Mexico	24,833	20,233	78	11,641
New York	17,636	27,027	90	51,909
N. Carolina	16,322	18,984	86	119,386
North Dakota	12,599	22,696	89	46,381
Ohio	30,419	33,483	95	111,332
Oklahoma	39,864	11,380	75	83,037
Oregon	44,165	39,962	90	29,063
Pennsylvania	31,481	33,425	89	62,824
S. Carolina	19,609	28,280	75	39,559
South Dakota	33,173	22,366	86	45,726
Tennessee	55,813	23,908	72	121,406
Texas	23,170	5,522	58	213,550
Utah	14,314	19,717	88	13,045
Virginia	28,929	24,556	94	64,572
Washington	8,542	37,880	89	34,033
W. Virginia	29,016	29,139	86	23,142
Wisconsin	30,160	14,300	92	98,973
Wyoming	25,755	20,048	79	8,838

Source: Author.

Table A.5: Regression Data, 1964 Cross-section.

State	Output	Education	Extension	Fertilizer	Labor
Alabama	1,260,875	9,981	10,590	85,653	214,375
Arizona	971,867	11,086	2,757	32,191	75,470
Arkansas	1,868,251	10,184	8,622	62,528	246,282
California	6,765,043	12,440	18,784	195,442	695,019
Colorado	1,383,993	12,471	4,622	20,923	128,404
Florida	1,741,255	11,318	7,658	154,693	252,620
Georgia	1,766,381	9,990	12,871	136,314	304,397
Idaho	908,684	12,869	3,545	37,900	156,958
Illinois	4,739,124	11,860	11,455	264,589	469,350
Indiana	2,461,357	12,265	9,727	180,930	382,745
Iowa	6,214,387	12,072	11,420	165,037	632,481
Kansas	2,616,068	12,342	10,770	80,689	321,490
Kentucky	1,453,481	9,947	9,728	76,095	392,645
Louisiana	990,273	9,796	10,133	44,470	210,391
Maryland	600,646	11,193	5,972	38,305	104,622
Michigan	1,674,909	11,627	11,630	98,781	440,333
Minnesota	3,206,739	10,944	7,636	98,856	580,410
Mississippi	1,659,800	10,061	9,806	78,511	373,769
Missouri	2,569,874	11,221	10,821	138,016	504,071
Montana	843,487	12,271	3,043	13,467	108,367
Nebraska	2,727,658	12,024	6,516	82,830	322,750
Nevada	94,712	12,650	1,424	1,361	13,732
New Jersey	486,766	12,249	5,248	23,818	81,398
New Mexico	504,666	11,451	3,278	11,465	73,625
New York	1,891,260	12,032	17,649	72,230	321,715
N. Carolina	2,567,596	9,785	18,128	162,811	604,613
North Dakota	1,286,248	11,127	3,514	29,430	180,295
Ohio	2,315,553	12,197	10,068	144,584	463,405
Oklahoma	1,436,147	11,471	8,470	44,733	244,842
Oregon	838,491	12,740	7,102	36,668	188,799
Pennsylvania	1,730,810	11,698	9,968	73,346	375,212
S. Carolina	837,787	9,962	6,528	78,107	256,244
South Dakota	1,421,519	11,532	3,968	15,651	195,917
Tennessee	1,297,038	9,933	10,089	71,261	360,774
Texas	4,928,995	11,022	17,263	171,146	739,229
Utah	324,444	13,451	2,599	4,972	57,019
Virginia	1,103,123	9,964	11,210	68,909	301,991
Washington	1,126,399	12,727	6,157	50,226	211,264
W. Virginia	214,884	10,557	4,509	8,211	91,759
Wisconsin	2,687,248	10,996	10,543	74,582	607,183
Wyoming	346,118	12,699	2,145	5,344	50,456

(Continued)

Table A.5 (cont'd.).

State	Land	Livestock	Machinery	Other	Research
Alabama	9,527,014	111,014	222,768	592,245	8,247
Arizona	30,337,535	154,439	97,072	309,418	6,460
Arkansas	14,271,746	122,242	342,527	661,134	7,915
California	36,250,636	680,677	716,803	2,218,728	39,877
Colorado	23,229,271	328,216	230,429	521,493	5,277
Florida	12,499,872	83,948	219,090	395,093	15,948
Georgia	9,416,985	166,859	300,297	809,387	10,379
Idaho	12,312,876	77,402	231,324	379,500	4,059
Illinois	38,347,098	442,211	903,397	1,845,145	11,462
Indiana	19,069,802	191,265	524,323	1,198,015	9,294
Iowa	39,810,111	987,074	935,609	2,863,712	11,766
Kansas	43,465,848	432,831	614,208	1,020,699	8,582
Kentucky	13,503,175	108,495	310,169	601,407	7,836
Louisiana	9,634,673	58,387	237,374	338,169	10,386
Maryland	2,752,672	52,408	100,735	321,252	4,449
Michigan	10,874,768	101,831	398,235	767,548	9,613
Minnesota	29,041,181	318,421	745,368	1,740,325	11,994
Mississippi	11,808,804	103,774	308,523	618,443	7,410
Missouri	33,908,940	210,282	567,294	1,279,247	8,197
Montana	36,688,243	105,131	244,509	331,954	4,365
Nebraska	41,866,637	449,969	553,820	1,335,810	8,598
Nevada	9,264,677	16,215	23,451	53,636	1,703
New Jersey	1,041,536	49,462	64,358	214,139	7,796
New Mexico	27,084,811	95,149	87,660	185,961	2,481
New York	9,333,022	132,517	348,701	1,064,921	20,178
N. Carolina	8,027,055	107,676	428,234	762,216	10,953
North Dakota	31,803,765	85,096	436,642	459,002	4,824
Ohio	15,919,875	201,697	511,737	1,190,519	8,910
Oklahoma	32,843,372	220,571	360,464	510,359	6,726
Oregon	18,586,925	76,054	188,298	343,551	10,816
Pennsylvania	8,546,298	179,690	339,615	1,007,487	8,051
S. Carolina	4,424,304	33,996	164,811	269,143	5,133
South Dakota	34,668,567	204,625	346,807	758,008	4,557
Tennessee	11,595,900	84,806	296,568	570,265	6,292
Texas	129,655,681	553,254	1,072,627	1,705,453	12,245
Utah	10,020,225	46,497	76,038	180,582	3,154
Virginia	6,611,866	69,864	215,828	443,384	7,607
Washington	13,680,331	65,352	255,674	439,384	9,695
W. Virginia	3,247,448	23,395	55,296	163,414	2,938
Wisconsin	16,805,258	176,162	551,485	1,452,609	12,714
Wyoming	35,826,545	82,148	73,354	141,937	2,799

(Continued)

Table A.5 (cont'd.).

State	$Resout_1$	$Resout_2$	Weather	Nfarms
Alabama	28,309	22,796	86	92,530
Arizona	33,568	15,201	84	6,477
Arkansas	38,009	13,537	45	79,898
California	10,786	12,097	76	80,852
Colorado	23,057	16,846	61	29,798
Florida	12,094	16,251	89	40,542
Georgia	35,106	21,795	89	83,366
Idaho	19,935	16,632	92	29,661
Illinois	32,925	25,865	75	132,822
Indiana	23,643	26,650	87	108,082
Iowa	23,567	25,516	85	154,162
Kansas	20,252	12,982	64	92,440
Kentucky	40,398	23,371	73	133,038
Louisiana	20,272	11,544	73	62,466
Maryland	16,683	35,176	65	20,760
Michigan	21,351	16,532	75	93,504
Minnesota	22,667	14,836	61	131,163
Mississippi	25,756	15,387	82	109,141
Missouri	47,517	26,898	71	147,315
Montana	11,541	16,885	91	27,020
Nebraska	25,125	12,080	69	80,163
Nevada	43,974	18,744	89	2,156
New Jersey	21,827	34,513	64	10,641
New Mexico	20,807	17,970	51	14,206
New York	15,310	23,683	56	66,510
N. Carolina	17,525	19,298	81	148,202
North Dakota	13,689	15,553	86	48,836
Ohio	23,525	26,672	76	120,381
Oklahoma	31,487	8,727	50	88,726
Oregon	39,377	35,547	88	39,757
Pennsylvania	31,031	33,505	64	83,086
S. Carolina	15,036	24,186	85	56,248
South Dakota	29,594	15,341	64	49,703
Tennessee	51,091	22,964	75	133,446
Texas	21,940	4,920	43	205,110
Utah	13,151	17,502	86	15,759
Virginia	22,952	19,240	65	80,354
Washington	8,495	34,499	92	45,574
W. Virginia	28,283	26,272	68	34,504
Wisconsin	28,044	13,624	52	118,816
Wyoming	20,431	17,443	83	9,038

Source: Author.

APPENDIX B

CALCULATION OF OPTIMAL MATCHING RATES

APPENDIX B

CALCULATION OF OPTIMAL MATCHING RATES

This appendix presents the complete calculations of the optimal matching rates for financing agricultural research. Each table presents the calculations for a different spillover scenario for each cross section.

Column 1 of each table shows the estimated marginal product that accrues inside state i from research conducted in state i (MPR_i) calculated using equation (5.1):

(5.1) $MPR_i = \delta * n_i * Output_i / Totres_i$, where:

MPR_i = The marginal product of research in state i;

δ = The research production coefficient estimated for cross section year t for a given specification of relevance (i.e., "neighboring states" or "production region") and pervasiveness weight (i.e., .10, .20, or .30);

$Totres_i$ = Total research spending applicable to state i (including spending in other relevant states as defined in equation 4.3).

n_i = The number of farms in state i;

$Output_i$ = Output per farm in state i;

Column 2 shows the marginal product of research that accrues to all other states as a result of research conducted in state i (MPR_o) calculated as the second term of the right-hand side of equation (5.2):

$$(5.2) \quad TMPR_i = MPR_i + \sum_{j=1}^{n} \Phi * MPR_j,$$

where:

$TMPR_i$ = The total marginal product resulting from research spending in state i;

MPR_i = The marginal product of research accruing to state i from an additional dollar of research spending in state i;

MPR_j = The marginal product of research accruing to other states in which state i's research is relevant from an additional dollar of research spending in state i (j = 1...n, j ≠ i);

Φ = The assumed pervasiveness weight (Φ = .10, .20, or .30).

Column 3 shows the share of the total marginal product of research that is retained by the state i (α_i). This share was calculated as Column 1/(Column 1 + Column 2) from equation (5.3):

$$(5.3) \quad \alpha_i = MPR_i/TMPR_i.$$

The optimal matching rate (Column 4) is then calculated as (1 - Column 3)/Column 3 as shown in equation (5.4):

$$(5.4)\ m_i = (1 - \alpha_i)/\alpha_i.$$

To provide clarity, the discussion of one sample calculation that was presented in Chapter V will be repeated here. Using the 1982 cross-section data, the optimal matching rate for the state of Alabama will be calculated using the assumptions that (1) the pervasiveness weight is .10, and (2) the states neighboring Alabama (Florida, Georgia, Mississippi, and Tennessee) are the states in which Alabama's research is relevant (shown in Table B.1).

Equation (5.1) yielded a marginal product of research of $24.82 for Alabama. This indicates that an additional dollar of research spending in Alabama would have yielded a marginal product of $24.82 within Alabama. The pervasiveness weight of .10, it should be recalled, assumed that the additional dollar of research spending in Alabama also provided 10 cents worth of research spending that was relevant in Florida, Georgia, Mississippi, and Tennessee, whose marginal products were calculated (using equation 5.1) to be $20.36, $23.13, $27.22, and $20.24, respectively. Thus, the additional dollar of research spending in Alabama also yielded marginal products of $2.03 in Florida, $2.31 in Georgia, $2.72 in Mississippi, and $2.02 in Tennessee (calculated as the .10 pervasiveness weight times the marginal product in these states from the second term on the right hand side of equation 5.2 above), for a total marginal product of research spending in Alabama of $33.90 (calculated as $24.82 + 2.03 + 2.31 + 2.72 + 2.02 from equation 5.2).

The share of marginal research benefits retained by Alabama (α_1) equals .73 (calculated as $24.82/$33.90 from equation 5.3). This indicates that the optimal matching rate for Alabama under this scenario is .37 (calculated as [1-.73]/.73 from equation 5.4).

Table B.1: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.10), 1982 Cross-section

State	MPR_I	MPR_O	α_i	Matching Rate
Alabama	24.83	9.10	0.73	0.37
Arizona	17.35	7.05	0.71	0.41
Arkansas	31.90	18.80	0.63	0.59
California	39.57	3.58	0.92	0.09
Colorado	20.25	16.45	0.55	0.81
Florida	20.36	4.80	0.81	0.24
Georgia	23.14	8.26	0.74	0.36
Idaho	32.32	9.73	0.77	0.30
Illinois	78.21	23.04	0.77	0.29
Indiana	37.81	17.58	0.68	0.47
Iowa	87.77	29.37	0.75	0.33
Kansas	45.36	13.73	0.77	0.30
Kentucky	32.46	23.14	0.58	0.71
Louisiana	16.17	11.49	0.58	0.71
Maryland	26.77	5.67	0.83	0.21
Michigan	26.68	11.25	0.70	0.42
Minnesota	53.01	20.15	0.72	0.38
Mississippi	27.23	9.31	0.75	0.34
Missouri	36.16	28.91	0.56	0.80
Montana	27.42	12.09	0.69	0.44
Nebraska	48.56	15.44	0.76	0.32
Nevada	3.81	11.36	0.25	2.98
New Jersey	9.10	5.16	0.64	0.57
New Mexico	17.37	12.58	0.58	0.72
New York	15.38	4.53	0.77	0.29
North Carolina	25.69	7.58	0.77	0.29
North Dakota	35.97	12.20	0.75	0.34
Ohio	38.49	13.84	0.74	0.36
Oklahoma	32.37	20.68	0.61	0.64
Oregon	14.59	10.63	0.58	0.73
Pennsylvania	36.20	9.50	0.79	0.26
South Carolina	17.14	4.88	0.78	0.28
South Dakota	41.59	17.60	0.70	0.42
Tennessee	20.25	21.67	0.48	1.07
Texas	55.79	9.78	0.85	0.18
Utah	9.75	8.48	0.53	0.87
Virginia	15.25	11.04	0.58	0.72
Washington	30.63	4.69	0.87	0.15
West Virginia	5.28	14.92	0.26	2.83
Wisconsin	36.16	24.57	0.60	0.68
Wyoming	11.06	13.13	0.46	1.19

Source: Author.

Table B.2: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.20), 1982 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	20.51	16.48	0.55	0.80
Arizona	14.99	13.32	0.53	0.89
Arkansas	26.22	33.22	0.44	1.27
California	43.23	6.00	0.88	0.14
Colorado	18.97	28.36	0.40	1.50
Florida	21.39	8.28	0.72	0.39
Georgia	20.89	14.37	0.59	0.69
Idaho	27.63	17.53	0.61	0.63
Illinois	68.15	41.91	0.62	0.61
Indiana	36.71	30.88	0.54	0.84
Iowa	83.51	51.70	0.62	0.62
Kansas	42.76	23.63	0.64	0.55
Kentucky	26.05	40.36	0.39	1.55
Louisiana	15.29	21.57	0.41	1.41
Maryland	23.14	9.96	0.70	0.43
Michigan	24.96	21.29	0.54	0.85
Minnesota	50.88	36.74	0.58	0.72
Mississippi	24.93	15.45	0.62	0.62
Missouri	28.79	49.76	0.37	1.73
Montana	25.21	20.21	0.56	0.80
Nebraska	45.20	25.85	0.64	0.57
Nevada	2.49	21.32	0.10	8.57
New Jersey	8.07	9.70	0.45	1.20
New Mexico	12.62	23.17	0.35	1.84
New York	16.41	8.03	0.67	0.49
North Carolina	26.59	12.96	0.67	0.49
North Dakota	34.67	21.42	0.62	0.62
Ohio	35.23	24.72	0.59	0.70
Oklahoma	25.22	37.21	0.40	1.48
Oregon	12.50	20.96	0.37	1.68
Pennsylvania	32.08	17.33	0.65	0.54
South Carolina	14.73	9.50	0.61	0.64
South Dakota	31.00	32.74	0.49	1.06
Tennessee	15.22	37.58	0.29	2.47
Texas	56.68	15.87	0.78	0.28
Utah	8.24	14.37	0.36	1.74
Virginia	13.94	18.95	0.42	1.36
Washington	31.46	8.03	0.80	0.26
West Virginia	3.77	26.09	0.13	6.92
Wisconsin	34.50	45.50	0.43	1.32
Wyoming	7.75	22.21	0.26	2.86

Source: Author.

Table B.3: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.30), 1982 Cross-section

State	MPR_I	MPR_o	α_I	Matching Rate
Alabama	16.78	21.71	0.44	1.29
Arizona	12.60	18.52	0.40	1.47
Arkansas	21.39	43.12	0.33	2.02
California	43.44	7.46	0.85	0.17
Colorado	16.81	36.08	0.32	2.15
Florida	20.74	10.45	0.67	0.50
Georgia	18.05	18.51	0.49	1.03
Idaho	23.07	23.08	0.50	1.00
Illinois	57.58	54.99	0.51	0.96
Indiana	33.40	39.42	0.46	1.18
Iowa	74.87	66.44	0.53	0.89
Kansas	38.07	29.93	0.56	0.79
Kentucky	20.97	51.49	0.29	2.46
Louisiana	13.65	28.98	0.32	2.12
Maryland	19.46	12.72	0.60	0.65
Michigan	22.11	28.54	0.44	1.29
Minnesota	45.91	48.38	0.49	1.05
Mississippi	21.75	19.10	0.53	0.88
Missouri	23.07	62.92	0.27	2.73
Montana	22.07	25.29	0.47	1.15
Nebraska	39.90	32.34	0.55	0.81
Nevada	1.82	28.92	0.06	15.91
New Jersey	6.89	13.06	0.35	1.90
New Mexico	9.66	30.85	0.24	3.19
New York	16.13	10.29	0.61	0.64
North Carolina	25.46	16.32	0.61	0.64
North Dakota	31.38	27.60	0.53	0.88
Ohio	30.74	32.03	0.49	1.04
Oklahoma	19.97	48.74	0.29	2.44
Oregon	10.45	29.48	0.26	2.82
Pennsylvania	27.40	22.83	0.55	0.83
South Carolina	12.35	13.05	0.49	1.06
South Dakota	24.01	43.53	0.36	1.81
Tennessee	11.84	47.89	0.20	4.05
Texas	53.45	19.40	0.73	0.36
Utah	6.83	18.04	0.27	2.64
Virginia	12.15	24.18	0.33	1.99
Washington	29.94	10.06	0.75	0.34
West Virginia	2.86	33.22	0.08	11.61
Wisconsin	31.00	60.14	0.34	1.94
Wyoming	5.84	27.84	0.17	4.77

Source: Author.

Table B.4: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.10), 1982 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	26.90	6.15	0.81	0.23
Arizona	19.12	12.18	0.61	0.64
Arkansas	41.58	4.80	0.90	0.12
California	39.51	3.99	0.91	0.10
Colorado	21.68	11.93	0.65	0.55
Florida	19.97	6.84	0.74	0.34
Georgia	25.89	6.25	0.81	0.24
Idaho	31.61	10.94	0.74	0.35
Illinois	83.40	20.55	0.80	0.25
Indiana	37.51	25.14	0.60	0.67
Iowa	85.33	20.36	0.81	0.24
Kansas	48.41	13.64	0.78	0.28
Kentucky	37.63	7.41	0.84	0.20
Louisiana	17.91	7.17	0.71	0.40
Maryland	21.08	5.91	0.78	0.28
Michigan	28.48	9.64	0.75	0.34
Minnesota	56.78	6.81	0.89	0.12
Mississippi	30.07	5.95	0.83	0.20
Missouri	44.59	24.43	0.65	0.55
Montana	23.37	11.76	0.67	0.50
Nebraska	53.55	13.12	0.80	0.25
Nevada	5.34	13.56	0.28	2.54
New Jersey	7.97	7.22	0.52	0.91
New Mexico	19.07	12.19	0.61	0.64
New York	14.86	6.53	0.69	0.44
North Carolina	25.45	8.63	0.75	0.34
North Dakota	33.27	15.15	0.69	0.46
Ohio	38.05	25.08	0.60	0.66
Oklahoma	47.07	6.13	0.88	0.13
Oregon	15.19	6.42	0.70	0.42
Pennsylvania	36.30	4.39	0.89	0.12
South Carolina	15.67	7.27	0.68	0.46
South Dakota	49.56	13.52	0.79	0.27
Tennessee	28.36	8.34	0.77	0.29
Texas	61.30	4.71	0.93	0.08
Utah	8.80	13.22	0.40	1.50
Virginia	15.58	9.61	0.62	0.62
Washington	24.73	5.47	0.82	0.22
West Virginia	4.70	10.70	0.31	2.28
Wisconsin	39.61	8.53	0.82	0.22
Wyoming	11.98	12.90	0.48	1.08

Source: Author.

Table B.5: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.20), 1982 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	25.77	13.09	0.66	0.51
Arizona	19.48	22.60	0.46	1.16
Arkansas	44.22	10.64	0.81	0.24
California	48.08	7.86	0.86	0.16
Colorado	23.75	21.75	0.52	0.92
Florida	23.01	13.64	0.63	0.59
Georgia	28.05	12.63	0.69	0.45
Idaho	29.80	20.54	0.59	0.69
Illinois	84.07	42.32	0.67	0.50
Indiana	40.40	51.06	0.44	1.26
Iowa	88.86	41.36	0.68	0.47
Kansas	53.28	27.48	0.66	0.52
Kentucky	36.09	15.26	0.70	0.42
Louisiana	20.37	15.41	0.57	0.76
Maryland	18.27	12.09	0.60	0.66
Michigan	31.10	21.81	0.59	0.70
Minnesota	63.96	15.24	0.81	0.24
Mississippi	32.83	12.92	0.72	0.39
Missouri	43.77	50.38	0.46	1.15
Montana	21.94	22.11	0.50	1.01
Nebraska	59.55	26.23	0.69	0.44
Nevada	4.15	25.67	0.14	6.19
New Jersey	7.36	14.28	0.34	1.94
New Mexico	15.90	23.32	0.41	1.47
New York	17.17	12.31	0.58	0.72
North Carolina	29.16	16.65	0.64	0.57
North Dakota	33.97	31.34	0.52	0.92
Ohio	38.58	51.42	0.43	1.33
Oklahoma	49.38	15.08	0.77	0.31
Oregon	14.83	14.51	0.51	0.98
Pennsylvania	35.94	8.56	0.81	0.24
South Carolina	14.38	15.36	0.48	1.07
South Dakota	43.89	29.36	0.60	0.67
Tennessee	27.39	17.00	0.62	0.62
Texas	75.41	9.88	0.88	0.13
Utah	7.92	24.92	0.24	3.15
Virginia	16.10	19.26	0.46	1.20
Washington	24.47	12.58	0.66	0.51
West Virginia	3.64	21.75	0.14	5.97
Wisconsin	45.10	19.01	0.70	0.42
Wyoming	9.56	24.59	0.28	2.57

Source: Author.

Table B.6: Calculation of Optimal Matching Rates for Production Region Specification ($\Phi = 0.30$), 1982 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	24.36	20.08	0.55	0.82
Arizona	19.16	31.76	0.38	1.66
Arkansas	44.82	16.70	0.73	0.37
California	54.47	11.34	0.83	0.21
Colorado	24.62	30.12	0.45	1.22
Florida	24.83	19.93	0.55	0.80
Georgia	28.83	18.73	0.61	0.65
Idaho	27.90	29.14	0.49	1.04
Illinois	82.11	62.97	0.57	0.77
Indiana	41.33	75.20	0.35	1.82
Iowa	88.74	60.98	0.59	0.69
Kansas	55.43	40.67	0.58	0.73
Kentucky	34.15	22.93	0.60	0.67
Louisiana	21.75	23.63	0.48	1.09
Maryland	16.32	18.02	0.48	1.10
Michigan	32.16	34.79	0.48	1.08
Minnesota	67.77	24.11	0.74	0.36
Mississippi	33.93	19.97	0.63	0.59
Missouri	42.01	75.00	0.36	1.79
Montana	20.49	31.36	0.40	1.53
Nebraska	62.46	38.56	0.62	0.62
Nevada	3.52	36.45	0.09	10.37
New Jersey	6.81	20.87	0.25	3.07
New Mexico	13.93	33.33	0.29	2.39
New York	18.57	17.34	0.52	0.93
North Carolina	31.32	23.78	0.57	0.76
North Dakota	33.46	47.26	0.41	1.41
Ohio	37.83	76.25	0.33	2.02
Oklahoma	49.57	25.89	0.66	0.52
Oregon	14.18	23.42	0.38	1.65
Pennsylvania	34.69	12.51	0.73	0.36
South Carolina	13.26	23.41	0.36	1.77
South Dakota	39.65	45.41	0.47	1.15
Tennessee	26.03	25.36	0.51	0.97
Texas	86.31	14.87	0.85	0.17
Utah	7.21	35.34	0.17	4.90
Virginia	16.00	28.37	0.36	1.77
Washington	23.61	20.59	0.53	0.87
West Virginia	3.08	32.25	0.09	10.47
Wisconsin	48.21	29.98	0.62	0.62
Wyoming	8.20	35.05	0.19	4.27

Source: Author.

Table B.7: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.10), 1978 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	8.39	3.14	0.73	0.37
Arizona	7.26	2.66	0.73	0.37
Arkansas	14.38	6.59	0.69	0.46
California	13.31	1.33	0.91	0.10
Colorado	9.74	6.06	0.62	0.62
Florida	7.28	1.70	0.81	0.23
Georgia	8.59	2.73	0.76	0.32
Idaho	12.80	3.50	0.79	0.27
Illinois	27.65	8.50	0.76	0.31
Indiana	13.57	5.91	0.70	0.44
Iowa	32.92	9.89	0.77	0.30
Kansas	17.46	4.92	0.78	0.28
Kentucky	12.65	8.00	0.61	0.63
Louisiana	5.61	4.48	0.56	0.80
Maryland	8.53	1.90	0.82	0.22
Michigan	7.65	3.68	0.68	0.48
Minnesota	16.59	7.24	0.70	0.44
Mississippi	9.60	3.43	0.74	0.36
Missouri	13.80	10.37	0.57	0.75
Montana	9.65	4.57	0.68	0.47
Nebraska	15.43	5.99	0.72	0.39
Nevada	1.32	4.18	0.24	3.17
New Jersey	2.49	1.58	0.61	0.64
New Mexico	8.19	4.80	0.63	0.59
New York	4.79	1.35	0.78	0.28
North Carolina	6.24	2.62	0.70	0.42
North Dakota	14.05	3.97	0.78	0.28
Ohio	11.18	4.69	0.70	0.42
Oklahoma	10.26	8.43	0.55	0.82
Oregon	4.67	3.76	0.55	0.80
Pennsylvania	11.02	2.90	0.79	0.26
South Carolina	5.77	1.48	0.80	0.26
South Dakota	13.45	6.12	0.69	0.45
Tennessee	5.89	7.95	0.43	1.35
Texas	20.79	3.84	0.84	0.18
Utah	3.81	3.66	0.51	0.96
Virginia	5.92	3.53	0.63	0.60
Washington	10.15	1.75	0.85	0.17
West Virginia	2.02	4.93	0.29	2.45
Wisconsin	12.01	8.48	0.59	0.71
Wyoming	5.44	4.94	0.52	0.91

Source: Author.

Table B.8: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.20), 1978 Cross-section

State	MPR_I	MPR_o	α_I	Matching Rate
Alabama	7.81	6.30	0.55	0.81
Arizona	6.90	5.45	0.56	0.79
Arkansas	13.13	13.06	0.50	0.99
California	16.08	2.47	0.87	0.15
Colorado	9.93	11.59	0.46	1.17
Florida	8.49	3.22	0.73	0.38
Georgia	8.28	5.42	0.60	0.65
Idaho	11.97	6.99	0.63	0.58
Illinois	26.97	17.01	0.61	0.63
Indiana	14.31	11.61	0.55	0.81
Iowa	34.78	19.46	0.64	0.56
Kansas	18.11	9.53	0.66	0.53
Kentucky	11.17	15.59	0.42	1.40
Louisiana	5.86	9.20	0.39	1.57
Maryland	8.39	3.66	0.70	0.44
Michigan	8.13	7.73	0.51	0.95
Minnesota	18.07	14.62	0.55	0.81
Mississippi	9.60	6.38	0.60	0.67
Missouri	12.27	19.99	0.38	1.63
Montana	10.08	8.39	0.55	0.83
Nebraska	16.27	11.15	0.59	0.69
Nevada	0.97	8.62	0.10	8.85
New Jersey	2.54	3.29	0.44	1.30
New Mexico	6.55	9.86	0.40	1.51
New York	5.67	2.67	0.68	0.47
North Carolina	7.11	4.99	0.59	0.70
North Dakota	14.57	7.88	0.65	0.54
Ohio	11.80	9.21	0.56	0.78
Oklahoma	9.17	16.65	0.36	1.82
Oregon	4.49	8.12	0.36	1.81
Pennsylvania	10.80	6.01	0.64	0.56
South Carolina	5.68	3.08	0.65	0.54
South Dakota	11.22	12.64	0.47	1.13
Tennessee	5.12	15.04	0.25	2.94
Texas	23.28	6.94	0.77	0.30
Utah	3.64	6.80	0.35	1.86
Virginia	5.86	6.68	0.47	1.14
Washington	11.57	3.29	0.78	0.28
West Virginia	1.62	9.60	0.14	5.92
Wisconsin	12.51	17.59	0.42	1.41
Wyoming	4.20	9.37	0.31	2.23

Source: Author.

Table B.9: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.30), 1978 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	7.47	9.58	0.44	1.28
Arizona	6.68	8.65	0.44	1.30
Arkansas	12.41	19.69	0.39	1.59
California	18.69	3.57	0.84	0.19
Colorado	10.07	17.10	0.37	1.70
Florida	9.55	4.67	0.67	0.49
Georgia	8.09	8.21	0.50	1.01
Idaho	11.48	10.66	0.52	0.93
Illinois	26.54	25.69	0.51	0.97
Indiana	14.85	17.29	0.46	1.16
Iowa	36.13	29.11	0.55	0.81
Kansas	18.58	14.08	0.57	0.76
Kentucky	10.37	23.11	0.31	2.23
Louisiana	6.03	14.19	0.30	2.35
Maryland	8.30	5.37	0.61	0.65
Michigan	8.48	11.99	0.41	1.41
Minnesota	19.22	22.21	0.46	1.16
Mississippi	9.59	9.19	0.51	0.96
Missouri	11.43	29.42	0.28	2.57
Montana	10.39	12.05	0.46	1.16
Nebraska	16.89	16.15	0.51	0.96
Nevada	0.83	13.43	0.06	16.22
New Jersey	2.58	5.14	0.33	1.99
New Mexico	5.78	15.18	0.28	2.63
New York	6.47	3.97	0.62	0.61
North Carolina	7.84	7.27	0.52	0.93
North Dakota	14.94	11.92	0.56	0.80
Ohio	12.25	13.74	0.47	1.12
Oklahoma	8.56	25.07	0.25	2.93
Oregon	4.38	13.13	0.25	3.00
Pennsylvania	10.65	9.31	0.53	0.87
South Carolina	5.62	4.78	0.54	0.85
South Dakota	10.11	19.52	0.34	1.93
Tennessee	4.71	21.90	0.18	4.65
Texas	25.30	9.83	0.72	0.39
Utah	3.54	9.81	0.27	2.77
Virginia	5.81	9.80	0.37	1.68
Washington	12.76	4.76	0.73	0.37
West Virginia	1.43	14.22	0.09	9.92
Wisconsin	12.87	27.11	0.32	2.11
Wyoming	3.64	13.68	0.21	3.75

Source: Author.

Table B.10: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.10), 1978 Cross-section

State	MPR_I	MPR_o	α_I	Matching Rate
Alabama	5.45	1.34	0.80	0.25
Arizona	4.91	3.12	0.61	0.64
Arkansas	11.23	1.02	0.92	0.09
California	7.96	0.79	0.91	0.10
Colorado	6.25	2.99	0.68	0.48
Florida	4.26	1.46	0.74	0.34
Georgia	5.93	1.29	0.82	0.22
Idaho	7.80	2.83	0.73	0.36
Illinois	17.41	4.44	0.80	0.25
Indiana	8.10	5.37	0.60	0.66
Iowa	19.42	4.24	0.82	0.22
Kansas	11.22	2.82	0.80	0.25
Kentucky	8.72	1.31	0.87	0.15
Louisiana	3.72	1.77	0.68	0.48
Maryland	4.04	1.09	0.79	0.27
Michigan	4.78	1.83	0.72	0.38
Minnesota	10.41	1.27	0.89	0.12
Mississippi	6.45	1.49	0.81	0.23
Missouri	10.16	5.16	0.66	0.51
Montana	5.00	3.11	0.62	0.62
Nebraska	10.17	2.93	0.78	0.29
Nevada	1.15	3.50	0.25	3.03
New Jersey	1.35	1.36	0.50	1.01
New Mexico	5.31	3.08	0.63	0.58
New York	2.79	1.22	0.70	0.44
North Carolina	3.73	1.81	0.67	0.49
North Dakota	8.00	3.14	0.72	0.39
Ohio	6.70	5.51	0.55	0.82
Oklahoma	8.46	1.38	0.86	0.16
Oregon	2.92	1.29	0.69	0.44
Pennsylvania	6.79	0.82	0.89	0.12
South Carolina	3.22	1.56	0.67	0.49
South Dakota	10.04	2.94	0.77	0.29
Tennessee	4.67	1.72	0.73	0.37
Texas	13.79	0.85	0.94	0.06
Utah	2.08	3.40	0.38	1.64
Virginia	3.64	1.82	0.67	0.50
Washington	4.98	1.09	0.82	0.22
West Virginia	1.09	2.08	0.34	1.90
Wisconsin	7.89	1.52	0.84	0.19
Wyoming	3.61	3.25	0.53	0.90

Source: Author.

Table B.11: Calculation of Optimal Matching Rates for Production Region Specification ($\Phi = 0.20$), 1978 Cross-section

State	MPR_I	MPR_o	α_I	Matching Rate
Alabama	4.23	2.26	0.65	0.54
Arizona	3.99	4.61	0.46	1.15
Arkansas	9.53	1.78	0.84	0.19
California	7.68	1.25	0.86	0.16
Colorado	5.33	4.34	0.55	0.81
Florida	3.89	2.33	0.63	0.60
Georgia	4.98	2.11	0.70	0.42
Idaho	5.88	4.23	0.58	0.72
Illinois	13.97	7.34	0.66	0.53
Indiana	6.81	8.77	0.44	1.29
Iowa	16.23	6.89	0.70	0.42
Kansas	9.78	4.58	0.68	0.47
Kentucky	6.56	2.14	0.75	0.33
Louisiana	3.34	3.02	0.53	0.90
Maryland	2.84	1.80	0.61	0.64
Michigan	4.19	3.28	0.56	0.78
Minnesota	9.39	2.24	0.81	0.24
Mississippi	5.56	2.57	0.68	0.46
Missouri	8.00	8.53	0.48	1.07
Montana	3.83	4.64	0.45	1.21
Nebraska	9.20	4.70	0.66	0.51
Nevada	0.74	5.26	0.12	7.13
New Jersey	1.04	2.16	0.32	2.08
New Mexico	3.47	4.72	0.42	1.36
New York	2.57	1.85	0.58	0.72
North Carolina	3.39	2.78	0.55	0.82
North Dakota	6.43	5.26	0.55	0.82
Ohio	5.65	9.00	0.39	1.59
Oklahoma	7.20	2.69	0.73	0.37
Oregon	2.29	2.33	0.50	1.02
Pennsylvania	5.40	1.29	0.81	0.24
South Carolina	2.44	2.62	0.48	1.07
South Dakota	7.30	5.08	0.59	0.70
Tennessee	3.72	2.71	0.58	0.73
Texas	13.47	1.44	0.90	0.11
Utah	1.52	5.11	0.23	3.36
Virginia	2.93	2.87	0.50	0.98
Washington	3.95	2.00	0.66	0.51
West Virginia	0.68	3.32	0.17	4.87
Wisconsin	7.02	2.72	0.72	0.39
Wyoming	2.28	4.95	0.32	2.17

Source: Author.

Table B.12: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.30), 1978 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	3.31	2.83	0.54	0.85
Arizona	3.23	5.31	0.38	1.65
Arkansas	7.94	2.28	0.78	0.29
California	7.11	1.48	0.83	0.21
Colorado	4.46	4.94	0.47	1.11
Florida	3.44	2.79	0.55	0.81
Georgia	4.12	2.59	0.61	0.63
Idaho	4.52	4.92	0.48	1.09
Illinois	11.18	8.99	0.55	0.80
Indiana	5.63	10.66	0.35	1.89
Iowa	13.35	8.34	0.62	0.62
Kansas	8.30	5.61	0.60	0.68
Kentucky	5.04	2.63	0.66	0.52
Louisiana	2.90	3.78	0.43	1.30
Maryland	2.09	2.22	0.49	1.06
Michigan	3.57	4.28	0.45	1.20
Minnesota	8.20	2.89	0.74	0.35
Mississippi	4.68	3.25	0.59	0.69
Missouri	6.32	10.45	0.38	1.65
Montana	2.98	5.38	0.36	1.81
Nebraska	8.05	5.68	0.59	0.71
Nevada	0.52	6.12	0.08	11.76
New Jersey	0.81	2.60	0.24	3.22
New Mexico	2.47	5.54	0.31	2.24
New York	2.28	2.16	0.51	0.95
North Carolina	2.97	3.25	0.48	1.09
North Dakota	5.14	6.55	0.44	1.27
Ohio	4.68	10.94	0.30	2.34
Oklahoma	6.01	3.78	0.61	0.63
Oregon	1.81	3.08	0.37	1.70
Pennsylvania	4.30	1.56	0.73	0.36
South Carolina	1.88	3.26	0.37	1.73
South Dakota	5.49	6.45	0.46	1.17
Tennessee	2.96	3.25	0.48	1.10
Texas	12.62	1.80	0.87	0.14
Utah	1.15	5.93	0.16	5.17
Virginia	2.34	3.44	0.41	1.47
Washington	3.14	2.68	0.54	0.85
West Virginia	0.48	4.00	0.11	8.41
Wisconsin	6.06	3.53	0.63	0.58
Wyoming	1.60	5.80	0.22	3.62

Source: Author.

Table B.13: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.10), 1974 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	11.33	4.95	0.70	0.44
Arizona	12.46	4.39	0.74	0.35
Arkansas	17.58	9.78	0.64	0.56
California	22.54	2.27	0.91	0.10
Colorado	27.17	8.96	0.75	0.33
Florida	11.14	2.58	0.81	0.23
Georgia	14.47	4.35	0.77	0.30
Idaho	24.79	5.49	0.82	0.22
Illinois	36.36	11.79	0.76	0.32
Indiana	19.04	8.55	0.69	0.45
Iowa	46.84	14.65	0.76	0.31
Kansas	25.15	8.30	0.75	0.33
Kentucky	16.25	11.64	0.58	0.72
Louisiana	10.16	6.04	0.63	0.59
Maryland	11.66	2.77	0.81	0.24
Michigan	12.19	5.75	0.68	0.47
Minnesota	30.32	11.09	0.73	0.37
Mississippi	14.26	4.87	0.75	0.34
Missouri	18.03	14.28	0.56	0.79
Montana	14.43	7.84	0.65	0.54
Nebraska	20.72	10.09	0.67	0.49
Nevada	1.99	7.49	0.21	3.77
New Jersey	3.61	2.42	0.60	0.67
New Mexico	12.46	8.53	0.59	0.68
New York	9.06	1.87	0.83	0.21
North Carolina	15.90	4.46	0.78	0.28
North Dakota	23.02	6.80	0.77	0.30
Ohio	20.67	6.61	0.76	0.32
Oklahoma	17.08	12.90	0.57	0.76
Oregon	8.21	6.54	0.56	0.80
Pennsylvania	15.10	4.85	0.76	0.32
South Carolina	11.34	3.04	0.79	0.27
South Dakota	23.29	9.58	0.71	0.41
Tennessee	9.64	11.69	0.45	1.21
Texas	28.61	5.73	0.83	0.20
Utah	6.90	7.37	0.48	1.07
Virginia	9.12	5.70	0.62	0.62
Washington	16.09	3.30	0.83	0.21
West Virginia	3.53	7.28	0.33	2.07
Wisconsin	17.77	12.57	0.59	0.71
Wyoming	7.31	9.66	0.43	1.32

Source: Author.

Table B.14: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.20), 1974 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	8.58	7.98	0.52	0.93
Arizona	9.35	7.40	0.56	0.79
Arkansas	13.03	15.53	0.46	1.19
California	21.96	3.36	0.87	0.15
Colorado	19.28	13.91	0.58	0.72
Florida	10.37	4.00	0.72	0.39
Georgia	11.44	6.88	0.62	0.60
Idaho	18.18	8.97	0.67	0.49
Illinois	28.83	19.37	0.60	0.67
Indiana	16.15	13.62	0.54	0.84
Iowa	40.67	23.33	0.64	0.57
Kansas	20.73	12.50	0.62	0.60
Kentucky	11.77	18.30	0.39	1.55
Louisiana	8.44	10.01	0.46	1.19
Maryland	9.25	4.36	0.68	0.47
Michigan	10.47	9.66	0.52	0.92
Minnesota	25.89	18.29	0.59	0.71
Mississippi	11.51	7.32	0.61	0.64
Missouri	13.13	22.20	0.37	1.69
Montana	12.22	11.73	0.51	0.96
Nebraska	17.57	14.82	0.54	0.84
Nevada	1.18	12.24	0.09	10.38
New Jersey	3.04	4.08	0.43	1.34
New Mexico	8.41	13.33	0.39	1.58
New York	8.42	3.01	0.74	0.36
North Carolina	14.64	6.87	0.68	0.47
North Dakota	19.53	10.84	0.64	0.56
Ohio	17.02	10.55	0.62	0.62
Oklahoma	12.51	20.01	0.38	1.60
Oregon	6.27	11.24	0.36	1.79
Pennsylvania	12.01	8.02	0.60	0.67
South Carolina	8.90	5.22	0.63	0.59
South Dakota	16.09	16.01	0.50	1.00
Tennessee	6.56	18.31	0.26	2.79
Texas	25.49	8.48	0.75	0.33
Utah	5.46	10.57	0.34	1.94
Virginia	7.46	8.91	0.46	1.19
Washington	14.87	4.89	0.75	0.33
West Virginia	2.35	11.50	0.17	4.90
Wisconsin	15.14	21.17	0.42	1.40
Wyoming	4.87	14.25	0.25	2.93

Source: Author.

Table B.15: Calculation of Optimal Matching Rates for Neighboring States Specification ($\Phi = 0.30$), 1974 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	6.33	9.29	0.41	1.47
Arizona	6.86	9.11	0.43	1.33
Arkansas	9.49	17.88	0.35	1.88
California	19.63	3.68	0.84	0.19
Colorado	13.70	15.74	0.47	1.15
Florida	8.89	4.50	0.66	0.51
Georgia	8.66	7.95	0.52	0.92
Idaho	13.16	10.59	0.55	0.80
Illinois	21.89	22.74	0.49	1.04
Indiana	12.85	15.60	0.45	1.21
Iowa	32.94	26.82	0.55	0.81
Kansas	16.16	13.86	0.54	0.86
Kentucky	8.46	20.83	0.29	2.46
Louisiana	6.62	11.82	0.36	1.79
Maryland	7.03	4.96	0.59	0.71
Michigan	8.41	11.46	0.42	1.36
Minnesota	20.71	21.55	0.49	1.04
Mississippi	8.85	8.10	0.52	0.92
Missouri	9.47	25.07	0.27	2.65
Montana	9.71	12.99	0.43	1.34
Nebraska	13.98	16.18	0.46	1.16
Nevada	0.77	14.53	0.05	18.92
New Jersey	2.41	4.90	0.33	2.04
New Mexico	5.82	15.20	0.28	2.61
New York	7.20	3.46	0.68	0.48
North Carolina	12.44	7.72	0.62	0.62
North Dakota	15.54	12.51	0.55	0.80
Ohio	13.26	12.14	0.52	0.92
Oklahoma	9.05	22.71	0.28	2.51
Oregon	4.64	13.87	0.25	2.99
Pennsylvania	9.14	9.45	0.49	1.03
South Carolina	6.71	6.33	0.51	0.94
South Dakota	11.26	18.98	0.37	1.69
Tennessee	4.55	20.85	0.18	4.58
Texas	21.07	9.29	0.69	0.44
Utah	4.14	11.35	0.27	2.74
Virginia	5.79	10.23	0.36	1.77
Washington	12.68	5.34	0.70	0.42
West Virginia	1.61	13.10	0.11	8.13
Wisconsin	12.09	25.18	0.32	2.08
Wyoming	3.34	15.59	0.18	4.67

Source: Author.

Table B.16: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.10), 1974 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	13.27	4.07	0.77	0.31
Arizona	16.03	11.06	0.59	0.69
Arkansas	24.67	2.93	0.89	0.12
California	24.32	2.33	0.91	0.10
Colorado	34.57	9.20	0.79	0.27
Florida	11.87	4.21	0.74	0.35
Georgia	17.64	3.63	0.83	0.21
Idaho	28.21	9.84	0.74	0.35
Illinois	40.91	11.34	0.78	0.28
Indiana	20.11	13.42	0.60	0.67
Iowa	47.93	10.64	0.82	0.22
Kansas	29.47	7.68	0.79	0.26
Kentucky	20.58	4.55	0.82	0.22
Louisiana	12.13	4.19	0.74	0.35
Maryland	9.57	2.93	0.77	0.31
Michigan	14.14	5.57	0.72	0.39
Minnesota	34.53	3.53	0.91	0.10
Mississippi	17.19	3.68	0.82	0.21
Missouri	23.53	13.08	0.64	0.56
Montana	14.03	11.26	0.55	0.80
Nebraska	24.66	8.16	0.75	0.33
Nevada	3.32	12.33	0.21	3.71
New Jersey	3.54	3.53	0.50	1.00
New Mexico	14.94	11.17	0.57	0.75
New York	9.47	2.94	0.76	0.31
North Carolina	17.11	4.90	0.78	0.29
North Dakota	22.27	8.40	0.73	0.38
Ohio	21.86	13.25	0.62	0.61
Oklahoma	24.76	3.42	0.88	0.14
Oregon	9.19	3.84	0.71	0.42
Pennsylvania	16.28	2.26	0.88	0.14
South Carolina	11.17	4.28	0.72	0.38
South Dakota	29.88	7.64	0.80	0.26
Tennessee	14.59	5.15	0.74	0.35
Texas	34.22	2.48	0.93	0.07
Utah	6.64	12.00	0.36	1.81
Virginia	10.15	5.59	0.64	0.55
Washington	14.11	3.35	0.81	0.24
West Virginia	3.66	6.24	0.37	1.70
Wisconsin	21.13	4.87	0.81	0.23
Wyoming	8.86	11.77	0.43	1.33

Source: Author.

Table B.17: Calculation of Optimal Matching Rates for Production Region Specification ($\Phi = 0.20$), 1974 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	11.30	7.38	0.60	0.65
Arizona	14.30	17.77	0.45	1.24
Arkansas	22.97	5.54	0.81	0.24
California	25.43	3.96	0.87	0.16
Colorado	28.52	14.93	0.66	0.52
Florida	11.73	7.29	0.62	0.62
Georgia	16.19	6.40	0.72	0.40
Idaho	22.82	16.06	0.59	0.70
Illinois	35.74	20.11	0.64	0.56
Indiana	18.05	23.65	0.43	1.31
Iowa	43.05	18.65	0.70	0.43
Kansas	27.61	13.40	0.67	0.49
Kentucky	17.37	8.21	0.68	0.47
Louisiana	11.63	7.81	0.60	0.67
Maryland	7.16	5.22	0.58	0.73
Michigan	13.77	10.75	0.56	0.78
Minnesota	32.95	6.92	0.83	0.21
Mississippi	16.07	6.92	0.70	0.43
Missouri	20.37	23.19	0.47	1.14
Montana	11.94	18.24	0.40	1.53
Nebraska	24.18	14.09	0.63	0.58
Nevada	2.36	20.16	0.10	8.55
New Jersey	3.01	6.05	0.33	2.01
New Mexico	11.28	18.37	0.38	1.63
New York	9.19	4.82	0.66	0.52
North Carolina	16.88	8.31	0.67	0.49
North Dakota	18.93	15.14	0.56	0.80
Ohio	19.10	23.44	0.45	1.23
Oklahoma	23.16	7.15	0.76	0.31
Oregon	7.69	7.50	0.51	0.98
Pennsylvania	13.90	3.87	0.78	0.28
South Carolina	8.98	7.84	0.53	0.87
South Dakota	23.91	14.14	0.63	0.59
Tennessee	12.48	9.19	0.58	0.74
Texas	35.74	4.63	0.89	0.13
Utah	5.31	19.57	0.21	3.69
Virginia	9.09	9.86	0.48	1.08
Washington	12.09	6.62	0.65	0.55
West Virginia	2.59	11.16	0.19	4.31
Wisconsin	20.82	9.34	0.69	0.45
Wyoming	6.61	19.31	0.26	2.92

Source: Author.

Table B.18: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.30), 1974 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	9.34	7.38	0.56	0.79
Arizona	12.21	17.77	0.41	1.46
Arkansas	20.23	5.54	0.79	0.27
California	24.71	3.96	0.86	0.16
Colorado	23.11	14.93	0.61	0.65
Florida	10.83	7.29	0.60	0.67
Georgia	14.11	6.40	0.69	0.45
Idaho	18.28	16.06	0.53	0.88
Illinois	30.06	20.11	0.60	0.67
Indiana	15.47	23.65	0.40	1.53
Iowa	36.93	18.65	0.66	0.51
Kansas	24.44	13.40	0.65	0.55
Kentucky	14.28	8.21	0.64	0.57
Louisiana	10.49	7.81	0.57	0.74
Maryland	5.48	5.22	0.51	0.95
Michigan	12.56	10.75	0.54	0.86
Minnesota	29.57	6.92	0.81	0.23
Mississippi	14.19	6.92	0.67	0.49
Missouri	17.03	23.19	0.42	1.36
Montana	9.88	18.24	0.35	1.85
Nebraska	22.19	14.09	0.61	0.63
Nevada	1.76	20.16	0.08	11.47
New Jersey	2.49	6.05	0.29	2.43
New Mexico	8.69	18.37	0.32	2.12
New York	8.36	4.82	0.63	0.58
North Carolina	15.56	8.31	0.65	0.53
North Dakota	15.64	15.14	0.51	0.97
Ohio	16.06	23.44	0.41	1.46
Oklahoma	20.47	7.15	0.74	0.35
Oregon	6.28	7.50	0.46	1.19
Pennsylvania	11.52	3.87	0.75	0.34
South Carolina	7.16	7.84	0.48	1.10
South Dakota	19.02	14.14	0.57	0.74
Tennessee	10.35	9.19	0.53	0.89
Texas	34.70	4.63	0.88	0.13
Utah	4.22	19.57	0.18	4.64
Virginia	7.79	9.86	0.44	1.27
Washington	10.04	6.62	0.60	0.66
West Virginia	1.93	11.16	0.15	5.79
Wisconsin	19.18	9.34	0.67	0.49
Wyoming	5.06	19.31	0.21	3.82

Source: Author.

Table B.19: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.10), 1969 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	9.17	4.08	0.69	0.44
Arizona	8.60	2.97	0.74	0.35
Arkansas	14.58	8.09	0.64	0.56
California	12.90	1.51	0.90	0.12
Colorado	16.66	6.51	0.72	0.39
Florida	8.66	1.88	0.82	0.22
Georgia	9.66	3.57	0.73	0.37
Idaho	14.12	3.85	0.79	0.27
Illinois	26.32	8.44	0.76	0.32
Indiana	14.49	5.76	0.72	0.40
Iowa	33.33	11.04	0.75	0.33
Kansas	16.00	5.78	0.73	0.36
Kentucky	9.60	8.65	0.53	0.90
Louisiana	7.24	5.62	0.56	0.78
Maryland	7.48	2.20	0.77	0.29
Michigan	7.68	4.28	0.64	0.56
Minnesota	25.93	8.21	0.76	0.32
Mississippi	15.27	3.82	0.80	0.25
Missouri	12.75	10.21	0.56	0.80
Montana	11.82	5.40	0.69	0.46
Nebraska	16.32	6.56	0.71	0.40
Nevada	1.47	4.59	0.24	3.13
New Jersey	2.95	1.78	0.62	0.60
New Mexico	10.01	6.38	0.61	0.64
New York	7.56	1.31	0.85	0.17
North Carolina	11.67	3.70	0.76	0.32
North Dakota	19.73	5.26	0.79	0.27
Ohio	14.03	4.43	0.76	0.32
Oklahoma	12.12	9.64	0.56	0.80
Oregon	4.98	3.80	0.57	0.76
Pennsylvania	10.19	3.44	0.75	0.34
South Carolina	10.72	2.13	0.83	0.20
South Dakota	14.82	7.92	0.65	0.53
Tennessee	7.19	9.21	0.44	1.28
Texas	26.38	4.40	0.86	0.17
Utah	5.30	4.62	0.53	0.87
Virginia	9.42	3.83	0.71	0.41
Washington	9.54	1.91	0.83	0.20
West Virginia	2.34	5.07	0.32	2.17
Wisconsin	14.25	9.33	0.60	0.65
Wyoming	5.36	6.27	0.46	1.17

Source: Author.

Table B.20: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.20), 1969 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	7.45	6.82	0.52	0.92
Arizona	6.71	5.09	0.57	0.76
Arkansas	10.97	13.56	0.45	1.24
California	13.07	2.32	0.85	0.18
Colorado	12.58	10.60	0.54	0.84
Florida	8.43	3.09	0.73	0.37
Georgia	8.01	5.94	0.57	0.74
Idaho	10.90	6.52	0.63	0.60
Illinois	22.02	14.57	0.60	0.66
Indiana	12.80	9.64	0.57	0.75
Iowa	30.52	18.33	0.62	0.60
Kansas	14.17	9.22	0.61	0.65
Kentucky	7.29	14.20	0.34	1.95
Louisiana	6.44	9.52	0.40	1.48
Maryland	6.32	3.49	0.64	0.55
Michigan	6.98	7.39	0.49	1.06
Minnesota	22.12	14.22	0.61	0.64
Mississippi	12.29	6.05	0.67	0.49
Missouri	9.99	16.68	0.37	1.67
Montana	10.36	8.59	0.55	0.83
Nebraska	14.20	10.32	0.58	0.73
Nevada	0.90	7.80	0.10	8.65
New Jersey	2.59	3.15	0.45	1.22
New Mexico	7.17	10.59	0.40	1.48
New York	7.19	2.22	0.76	0.31
North Carolina	11.05	5.82	0.65	0.53
North Dakota	17.22	8.71	0.66	0.51
Ohio	11.91	7.45	0.62	0.63
Oklahoma	9.36	15.84	0.37	1.69
Oregon	4.01	6.82	0.37	1.70
Pennsylvania	8.53	5.93	0.59	0.69
South Carolina	8.46	3.81	0.69	0.45
South Dakota	11.08	13.54	0.45	1.22
Tennessee	5.39	14.87	0.27	2.76
Texas	24.32	6.79	0.78	0.28
Utah	4.32	6.97	0.38	1.61
Virginia	7.27	6.34	0.53	0.87
Washington	9.25	2.98	0.76	0.32
West Virginia	1.63	8.26	0.16	5.07
Wisconsin	12.26	16.33	0.43	1.33
Wyoming	3.77	9.85	0.28	2.61

Source: Author.

Table B.21: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.30), 1969 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	5.96	8.44	0.41	1.41
Arizona	5.24	6.56	0.44	1.25
Arkansas	8.39	16.73	0.33	1.99
California	12.43	2.72	0.82	0.22
Colorado	9.63	12.84	0.43	1.33
Florida	7.73	3.74	0.67	0.48
Georgia	6.50	7.33	0.47	1.13
Idaho	8.46	8.17	0.51	0.97
Illinois	17.97	18.32	0.50	1.02
Indiana	10.85	11.83	0.48	1.09
Iowa	26.61	22.39	0.54	0.84
Kansas	12.05	10.99	0.52	0.91
Kentucky	5.60	17.22	0.25	3.08
Louisiana	5.50	11.85	0.32	2.16
Maryland	5.20	4.14	0.56	0.80
Michigan	6.04	9.26	0.39	1.53
Minnesota	18.30	17.91	0.51	0.98
Mississippi	9.79	7.19	0.58	0.73
Missouri	7.82	20.18	0.28	2.58
Montana	8.73	10.24	0.46	1.17
Nebraska	11.92	12.21	0.49	1.02
Nevada	0.63	9.83	0.06	15.73
New Jersey	2.18	4.03	0.35	1.85
New Mexico	5.34	13.03	0.29	2.44
New York	6.47	2.74	0.70	0.42
North Carolina	9.89	6.87	0.59	0.69
North Dakota	14.47	10.64	0.58	0.74
Ohio	9.81	9.20	0.52	0.94
Oklahoma	7.26	19.36	0.27	2.67
Oregon	3.19	8.99	0.26	2.82
Pennsylvania	6.97	7.46	0.48	1.07
South Carolina	6.64	4.92	0.57	0.74
South Dakota	8.43	16.86	0.33	2.00
Tennessee	4.11	17.88	0.19	4.35
Texas	21.32	7.94	0.73	0.37
Utah	3.46	8.02	0.30	2.32
Virginia	5.64	7.80	0.42	1.38
Washington	8.45	3.49	0.71	0.41
West Virginia	1.20	9.96	0.11	8.33
Wisconsin	10.19	20.67	0.33	2.03
Wyoming	2.78	11.62	0.19	4.18

Source: Author.

Table B.22: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.10), 1969 Cross-section

State	MPR_I	MPR_o	α_I	Matching Rate
Alabama	9.18	2.69	0.77	0.29
Arizona	9.85	6.46	0.60	0.66
Arkansas	18.60	2.38	0.89	0.13
California	12.03	1.20	0.91	0.10
Colorado	18.12	5.64	0.76	0.31
Florida	7.96	2.81	0.74	0.35
Georgia	10.15	2.59	0.80	0.26
Idaho	13.86	6.06	0.70	0.44
Illinois	25.43	6.90	0.79	0.27
Indiana	13.24	8.12	0.62	0.61
Iowa	29.00	6.55	0.82	0.23
Kansas	15.95	4.88	0.77	0.31
Kentucky	10.73	3.08	0.78	0.29
Louisiana	7.40	3.50	0.68	0.47
Maryland	5.40	1.86	0.74	0.34
Michigan	7.68	4.08	0.65	0.53
Minnesota	25.85	2.26	0.92	0.09
Mississippi	16.40	2.60	0.86	0.16
Missouri	13.96	8.05	0.63	0.58
Montana	10.10	6.44	0.61	0.64
Nebraska	16.93	4.78	0.78	0.28
Nevada	2.24	7.22	0.24	3.22
New Jersey	2.46	2.15	0.53	0.88
New Mexico	10.21	6.43	0.61	0.63
New York	6.74	1.72	0.80	0.26
North Carolina	10.74	3.08	0.78	0.29
North Dakota	16.01	4.88	0.77	0.30
Ohio	12.83	8.16	0.61	0.64
Oklahoma	15.05	2.73	0.85	0.18
Oregon	4.79	1.92	0.71	0.40
Pennsylvania	9.39	1.46	0.87	0.16
South Carolina	8.79	2.73	0.76	0.31
South Dakota	15.88	4.89	0.76	0.31
Tennessee	8.63	3.29	0.72	0.38
Texas	27.30	1.50	0.95	0.06
Utah	4.49	7.00	0.39	1.56
Virginia	9.29	3.23	0.74	0.35
Washington	7.16	1.68	0.81	0.23
West Virginia	2.18	3.94	0.36	1.80
Wisconsin	14.97	3.35	0.82	0.22
Wyoming	5.61	6.89	0.45	1.23

Source: Author.

Table B.23: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.20), 1969 Cross-section

State	MPR_I	MPR_o	α_I	Matching Rate
Alabama	7.78	4.66	0.63	0.60
Arizona	8.69	10.19	0.46	1.17
Arkansas	16.77	4.30	0.80	0.26
California	12.19	1.97	0.86	0.16
Colorado	14.81	8.97	0.62	0.61
Florida	7.66	4.69	0.62	0.61
Georgia	9.12	4.40	0.67	0.48
Idaho	11.00	9.73	0.53	0.88
Illinois	21.78	11.92	0.65	0.55
Indiana	11.53	13.97	0.45	1.21
Iowa	25.29	11.22	0.69	0.44
Kansas	14.86	8.30	0.64	0.56
Kentucky	8.97	5.28	0.63	0.59
Louisiana	7.08	6.24	0.53	0.88
Maryland	4.00	3.20	0.56	0.80
Michigan	7.37	7.43	0.50	1.01
Minnesota	23.10	4.28	0.84	0.19
Mississippi	14.43	4.77	0.75	0.33
Missouri	12.00	13.87	0.46	1.16
Montana	8.38	10.25	0.45	1.22
Nebraska	15.95	8.08	0.66	0.51
Nevada	1.57	11.62	0.12	7.39
New Jersey	2.01	3.60	0.36	1.79
New Mexico	7.60	10.41	0.42	1.37
New York	6.19	2.76	0.69	0.45
North Carolina	10.06	5.06	0.67	0.50
North Dakota	12.85	8.70	0.60	0.68
Ohio	10.77	14.12	0.43	1.31
Oklahoma	13.86	5.50	0.72	0.40
Oregon	3.92	3.63	0.52	0.92
Pennsylvania	7.81	2.44	0.76	0.31
South Carolina	6.53	4.91	0.57	0.75
South Dakota	12.71	8.73	0.59	0.69
Tennessee	7.41	5.59	0.57	0.75
Texas	27.52	2.77	0.91	0.10
Utah	3.48	11.23	0.24	3.23
Virginia	7.39	5.59	0.57	0.76
Washington	5.95	3.22	0.65	0.54
West Virginia	1.52	6.77	0.18	4.44
Wisconsin	14.03	6.09	0.70	0.43
Wyoming	4.13	11.10	0.27	2.69

Source: Author.

Table B.24: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.30), 1969 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	6.30	5.82	0.52	0.92
Arizona	7.23	11.83	0.38	1.64
Arkansas	14.20	5.48	0.72	0.39
California	11.39	2.36	0.83	0.21
Colorado	11.70	10.49	0.53	0.90
Florida	6.84	5.66	0.55	0.83
Georgia	7.70	5.40	0.59	0.70
Idaho	8.53	11.44	0.43	1.34
Illinois	17.75	14.66	0.55	0.83
Indiana	9.51	17.13	0.36	1.80
Iowa	20.88	13.72	0.60	0.66
Kansas	12.90	10.18	0.56	0.79
Kentucky	7.19	6.50	0.53	0.90
Louisiana	6.28	7.85	0.44	1.25
Maryland	2.98	3.94	0.43	1.32
Michigan	6.56	9.50	0.41	1.45
Minnesota	19.42	5.64	0.77	0.29
Mississippi	11.98	6.14	0.66	0.51
Missouri	9.81	17.04	0.37	1.74
Montana	6.68	12.00	0.36	1.80
Nebraska	13.98	9.85	0.59	0.70
Nevada	1.14	13.66	0.08	12.03
New Jersey	1.59	4.36	0.27	2.75
New Mexico	5.67	12.30	0.32	2.17
New York	5.31	3.24	0.62	0.61
North Carolina	8.78	6.02	0.59	0.69
North Dakota	10.03	11.04	0.48	1.10
Ohio	8.65	17.39	0.33	2.01
Oklahoma	11.92	7.68	0.61	0.64
Oregon	3.10	4.84	0.39	1.56
Pennsylvania	6.24	2.96	0.68	0.47
South Carolina	4.87	6.25	0.44	1.28
South Dakota	9.91	11.07	0.47	1.12
Tennessee	6.05	6.84	0.47	1.13
Texas	25.59	3.58	0.88	0.14
Utah	2.66	13.20	0.17	4.96
Virginia	5.73	6.94	0.45	1.21
Washington	4.75	4.35	0.52	0.92
West Virginia	1.10	8.33	0.12	7.57
Wisconsin	12.25	7.79	0.61	0.64
Wyoming	3.06	13.08	0.19	4.27

Source: Author.

Table B.25: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.10), 1964 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	10.93	4.88	0.69	0.45
Arizona	9.50	3.49	0.73	0.37
Arkansas	15.31	10.03	0.60	0.66
California	15.86	1.64	0.91	0.10
Colorado	17.52	8.57	0.67	0.49
Florida	9.74	2.31	0.81	0.24
Georgia	12.21	4.37	0.74	0.36
Idaho	14.41	4.57	0.76	0.32
Illinois	30.83	10.99	0.74	0.36
Indiana	20.27	7.60	0.73	0.38
Iowa	42.24	12.98	0.76	0.31
Kansas	23.68	7.41	0.76	0.31
Kentucky	11.75	11.51	0.51	0.98
Louisiana	7.66	6.40	0.54	0.84
Maryland	9.43	2.92	0.76	0.31
Michigan	13.69	5.66	0.71	0.41
Minnesota	21.59	9.70	0.69	0.45
Mississippi	15.96	4.48	0.78	0.28
Missouri	19.05	13.00	0.59	0.68
Montana	14.67	5.94	0.71	0.40
Nebraska	23.57	8.53	0.73	0.36
Nevada	1.49	5.22	0.22	3.50
New Jersey	4.68	2.33	0.67	0.50
New Mexico	10.62	7.38	0.59	0.69
New York	8.36	1.96	0.81	0.23
North Carolina	19.40	4.59	0.81	0.24
North Dakota	19.94	5.44	0.79	0.27
Ohio	19.74	6.42	0.75	0.33
Oklahoma	13.96	11.90	0.54	0.85
Oregon	5.46	4.20	0.56	0.77
Pennsylvania	14.90	4.58	0.76	0.31
South Carolina	12.12	3.16	0.79	0.26
South Dakota	18.16	8.66	0.68	0.48
Tennessee	10.92	11.53	0.49	1.06
Texas	32.77	4.76	0.87	0.15
Utah	6.97	4.98	0.58	0.71
Virginia	10.69	5.51	0.66	0.51
Washington	10.25	1.99	0.84	0.19
West Virginia	3.58	6.65	0.35	1.86
Wisconsin	16.62	10.84	0.61	0.65
Wyoming	6.86	7.17	0.49	1.05

Source: Author.

Table B.26: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.20), 1964 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	8.25	7.41	0.53	0.90
Arizona	6.71	5.50	0.55	0.82
Arkansas	10.96	15.13	0.42	1.38
California	14.65	2.32	0.86	0.16
Colorado	12.74	12.74	0.50	1.00
Florida	8.63	3.50	0.71	0.41
Georgia	9.24	6.68	0.58	0.72
Idaho	10.28	7.02	0.59	0.68
Illinois	23.90	17.03	0.58	0.71
Indiana	15.97	11.73	0.58	0.73
Iowa	34.32	19.74	0.63	0.58
Kansas	18.84	10.84	0.63	0.58
Kentucky	8.31	17.24	0.33	2.07
Louisiana	6.24	9.99	0.38	1.60
Maryland	7.02	4.31	0.62	0.61
Michigan	10.98	8.96	0.55	0.82
Minnesota	17.66	15.10	0.54	0.86
Mississippi	12.02	6.52	0.65	0.54
Missouri	13.21	19.48	0.40	1.47
Montana	11.50	8.54	0.57	0.74
Nebraska	18.22	12.34	0.60	0.68
Nevada	0.82	8.16	0.09	9.94
New Jersey	3.64	3.69	0.50	1.01
New Mexico	6.91	11.29	0.38	1.63
New York	7.41	2.94	0.72	0.40
North Carolina	16.16	6.80	0.70	0.42
North Dakota	15.48	8.30	0.65	0.54
Ohio	15.48	9.72	0.61	0.63
Oklahoma	10.04	17.93	0.36	1.79
Oregon	4.08	6.95	0.37	1.70
Pennsylvania	11.05	7.16	0.61	0.65
South Carolina	9.37	5.08	0.65	0.54
South Dakota	12.35	13.49	0.48	1.09
Tennessee	7.15	17.28	0.29	2.42
Texas	26.97	6.83	0.80	0.25
Utah	5.10	7.02	0.42	1.38
Virginia	8.23	8.18	0.50	0.99
Washington	9.00	2.87	0.76	0.32
West Virginia	2.28	10.02	0.19	4.40
Wisconsin	13.35	17.37	0.43	1.30
Wyoming	4.57	10.39	0.31	2.27

Source: Author.

Table B.27: Calculation of Optimal Matching Rates for Neighboring States Specification (Φ = 0.30), 1964 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	6.18	8.44	0.42	1.37
Arizona	4.82	6.56	0.42	1.36
Arkansas	7.93	17.09	0.32	2.16
California	12.87	2.51	0.84	0.20
Colorado	9.31	14.23	0.40	1.53
Florida	7.29	3.93	0.65	0.54
Georgia	6.93	7.65	0.48	1.10
Idaho	7.42	8.06	0.48	1.09
Illinois	18.21	19.55	0.48	1.07
Indiana	12.32	13.39	0.48	1.09
Iowa	27.05	22.37	0.55	0.83
Kansas	14.63	11.95	0.55	0.82
Kentucky	5.97	19.35	0.24	3.24
Louisiana	4.93	11.52	0.30	2.34
Maryland	5.21	4.79	0.52	0.92
Michigan	8.57	10.39	0.45	1.21
Minnesota	13.99	17.39	0.45	1.24
Mississippi	8.99	7.19	0.56	0.80
Missouri	9.39	21.84	0.30	2.33
Montana	8.84	9.33	0.49	1.06
Nebraska	13.86	13.55	0.51	0.98
Nevada	0.52	9.57	0.05	18.35
New Jersey	2.78	4.33	0.39	1.56
New Mexico	4.74	12.86	0.27	2.71
New York	6.26	3.29	0.66	0.53
North Carolina	12.99	7.56	0.63	0.58
North Dakota	11.81	9.45	0.56	0.80
Ohio	11.89	10.97	0.52	0.92
Oklahoma	7.28	20.24	0.26	2.78
Oregon	3.04	8.51	0.26	2.80
Pennsylvania	8.18	8.31	0.50	1.02
South Carolina	7.12	5.97	0.54	0.84
South Dakota	8.68	15.50	0.36	1.79
Tennessee	4.92	19.38	0.20	3.94
Texas	21.47	7.47	0.74	0.35
Utah	3.75	7.57	0.33	2.02
Virginia	6.24	9.19	0.40	1.47
Washington	7.54	3.14	0.71	0.42
West Virginia	1.54	11.25	0.12	7.29
Wisconsin	10.43	20.35	0.34	1.95
Wyoming	3.18	11.40	0.22	3.59

Table B.28: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.10), 1964 Cross-section

State	MPR_I	MPR_O	α_I	Matching Rate
Alabama	11.98	3.51	0.77	0.29
Arizona	12.18	7.84	0.61	0.64
Arkansas	20.16	2.71	0.88	0.13
California	16.47	1.44	0.92	0.09
Colorado	19.88	7.07	0.74	0.36
Florida	9.91	3.71	0.73	0.37
Georgia	14.07	3.30	0.81	0.23
Idaho	15.88	7.47	0.68	0.47
Illinois	33.73	10.76	0.76	0.32
Indiana	20.58	12.07	0.63	0.59
Iowa	43.40	9.79	0.82	0.23
Kansas	26.48	7.13	0.79	0.27
Kentucky	14.29	5.05	0.74	0.35
Louisiana	8.58	3.87	0.69	0.45
Maryland	7.54	2.79	0.73	0.37
Michigan	14.87	4.29	0.78	0.29
Minnesota	23.79	3.40	0.88	0.14
Mississippi	18.55	2.87	0.87	0.15
Missouri	23.61	11.77	0.67	0.50
Montana	13.93	7.66	0.65	0.55
Nebraska	27.82	7.00	0.80	0.25
Nevada	2.65	8.79	0.23	3.32
New Jersey	4.33	3.11	0.58	0.72
New Mexico	11.80	7.88	0.60	0.67
New York	8.39	2.70	0.76	0.32
North Carolina	19.93	4.48	0.82	0.22
North Dakota	20.16	7.76	0.72	0.39
Ohio	20.00	12.13	0.62	0.61
Oklahoma	18.90	3.87	0.83	0.20
Oregon	5.83	2.50	0.70	0.43
Pennsylvania	15.18	2.03	0.88	0.13
South Carolina	11.09	3.60	0.76	0.32
South Dakota	23.34	7.45	0.76	0.32
Tennessee	15.10	4.97	0.75	0.33
Texas	38.70	1.89	0.95	0.05
Utah	6.61	8.39	0.44	1.27
Virginia	11.57	5.32	0.69	0.46
Washington	8.57	2.23	0.79	0.26
West Virginia	3.86	6.09	0.39	1.58
Wisconsin	19.09	3.87	0.83	0.20
Wyoming	7.62	8.29	0.48	1.09

Source: Author.

Table B.29: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.20), 1964 Cross-section

State	MPR_I	MPR_o	α_I	Matching Rate
Alabama	9.85	5.89	0.63	0.60
Arizona	10.23	11.93	0.46	1.17
Arkansas	17.59	4.73	0.79	0.27
California	15.99	2.29	0.87	0.14
Colorado	16.01	10.77	0.60	0.67
Florida	9.07	6.05	0.60	0.67
Georgia	11.99	5.46	0.69	0.46
Idaho	12.30	11.51	0.52	0.94
Illinois	28.49	17.77	0.62	0.62
Indiana	16.83	20.10	0.46	1.19
Iowa	36.84	16.10	0.70	0.44
Kansas	23.40	11.92	0.66	0.51
Kentucky	11.62	8.30	0.58	0.71
Louisiana	7.80	6.68	0.54	0.86
Maryland	5.23	4.53	0.54	0.87
Michigan	12.96	7.77	0.63	0.60
Minnesota	21.43	6.07	0.78	0.28
Mississippi	15.83	5.08	0.76	0.32
Missouri	18.93	19.68	0.49	1.04
Montana	10.90	11.79	0.48	1.08
Nebraska	24.77	11.65	0.68	0.47
Nevada	1.74	13.62	0.11	7.84
New Jersey	3.31	4.91	0.40	1.48
New Mexico	8.31	12.31	0.40	1.48
New York	7.59	4.05	0.65	0.53
North Carolina	17.33	7.16	0.71	0.41
North Dakota	16.21	13.36	0.55	0.82
Ohio	16.26	20.22	0.45	1.24
Oklahoma	16.95	7.45	0.69	0.44
Oregon	4.68	4.56	0.51	0.97
Pennsylvania	11.73	3.23	0.78	0.28
South Carolina	8.40	6.18	0.58	0.74
South Dakota	18.64	12.88	0.59	0.69
Tennessee	11.92	8.24	0.59	0.69
Texas	37.26	3.39	0.92	0.09
Utah	4.88	13.00	0.27	2.67
Virginia	9.63	8.70	0.53	0.90
Washington	6.79	4.13	0.62	0.61
West Virginia	2.62	10.10	0.21	3.85
Wisconsin	17.41	6.88	0.72	0.40
Wyoming	5.50	12.87	0.30	2.34

Source: Author.

Table B.30: Calculation of Optimal Matching Rates for Production Region Specification (Φ = 0.30), 1964 Cross-section

State	MPR_I	MPR_o	α_I	Matching Rate
Alabama	7.61	6.98	0.52	0.92
Arizona	8.02	13.17	0.38	1.64
Arkansas	14.20	5.72	0.71	0.40
California	14.15	2.60	0.84	0.18
Colorado	12.19	11.92	0.51	0.98
Florida	7.61	6.98	0.52	0.92
Georgia	9.50	6.41	0.60	0.67
Idaho	9.14	12.84	0.42	1.41
Illinois	22.44	20.67	0.52	0.92
Indiana	12.96	23.52	0.36	1.82
Iowa	29.12	18.67	0.61	0.64
Kansas	19.08	14.03	0.58	0.74
Kentucky	8.91	9.67	0.48	1.09
Louisiana	6.51	8.03	0.45	1.23
Maryland	3.64	5.23	0.41	1.44
Michigan	10.46	9.69	0.52	0.93
Minnesota	17.74	7.50	0.70	0.42
Mississippi	12.56	6.21	0.67	0.49
Missouri	14.38	23.09	0.38	1.61
Montana	8.14	13.14	0.38	1.61
Nebraska	20.31	13.66	0.60	0.67
Nevada	1.18	15.23	0.07	12.95
New Jersey	2.44	5.60	0.30	2.29
New Mexico	5.83	13.83	0.30	2.37
New York	6.31	4.44	0.59	0.70
North Carolina	13.96	8.15	0.63	0.58
North Dakota	12.33	16.05	0.43	1.30
Ohio	12.46	23.67	0.34	1.90
Oklahoma	13.99	9.81	0.59	0.70
Oregon	3.55	5.78	0.38	1.63
Pennsylvania	8.70	3.72	0.70	0.43
South Carolina	6.15	7.41	0.45	1.20
South Dakota	14.12	15.52	0.48	1.10
Tennessee	8.95	9.65	0.48	1.08
Texas	32.69	4.20	0.89	0.13
Utah	3.51	14.53	0.19	4.14
Virginia	7.50	10.09	0.43	1.34
Washington	5.11	5.31	0.49	1.04
West Virginia	1.81	11.80	0.13	6.53
Wisconsin	14.55	8.46	0.63	0.58
Wyoming	3.92	14.40	0.21	3.67

Source: Author.

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