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Theory and econometric analysis of state government demand for public agricultural research

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Theory and econometric analysis of state government demand for public agricultural research

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I. INTRODUCTION

A. Identifying the Problem

During the closing decade of the 20th century, we are approaching the end of one of the most remarkable transitions in the history of agriculture. Agricultural production has been transformed from a land-dependent production process to a technology-driven production process. All increases in food production, in the U.S. and elsewhere in the world, must come from higher yields (Kuznets, 1977). Expansion of agricultural production, thus, will have to be obtained entirely from intensive cultivation made possible by advances in science and technology. The implication of this transition emphasizes the role of effective research and its management, so as to ensure that agricultural production can meet the growing and diverse needs of the next century.

Over the last several decades economists have conducted studies of the impact of research on the productivity of agriculture (Griliches, 1958; Evenson, 1968; Pray, 1978; Cline, 1975; White and Havlicek, 1982; Braha and Tweeten, 1986). These studies have differed in their focus of inquiry. Some studies focussed on aggregate levels of productivity; others focussed on a specific commodity at national, regional or state level. All the studies, however, reach the same conclusion that economic returns to investment in public agricultural research have been very high in comparison to almost any other public investment. Results of a large number of studies (see Table 1) indicate rates of return to be well over 10 to 15 percent - the level that private firms consider adequate to attract investment.

The contribution of research to increased agricultural productivity has been studied primarily by two methods by studies looking at ex post evaluations (Norton and Davis, 1981). The first method, called the "index method", uses cost-benefit analysis to determine returns to investment in research. Benefits are measured as the residual after all other factors that contribute to increased productivity have been accounted for. The calculated returns represent the average rate of return per dollar invested over the period studied, with benefits from previous research assumed to continue indefinitely. The second method, called the "regression analysis of productivity", estimates the incremental return from increased investment, rather than average returns from all investment. This method estimates the component of change in increased productivity that can be attributed to research. Because regression methods are used, the significance of the estimated returns from research can be tested statistically.

The estimates of rates of return from the index method and the regression method are presented in Table 1. Almost all studies indicate high rates of return to investment in public agricultural research. These rates are considerably higher than those for other public sector investments, ranging between 30 and 60 percent, and have stayed at that high level from 1940s through to 1980s.

Table 1. Summary of agricultural research productivity studies (Ruttan, 1982)

Study	Country	Commodity	Time-Period	Annual Rate of Return (%)
Index Number				
Griliches, 1958	USA	Hybrid corn	1940-1955	35-40
Griliches, 1958	USA	Hybrid sorghum	1940-1957	20
Peterson, 1967	USA	Poultry	1915-1960	21-25
Evenson, 1969	South Africa	Sugarcane	1945-1962	40
Barletza, 1970	Mexico	Wheat	1943-1963	90
Ayer, 1970	Brazil	Cotton	1924-1967	77
Peters and Fitzharris, 1977	USA	Aggregate	1937-1942	50
			1947-1952	51
			1957-1962	49
			1957-1972	34
Pray, 1978	Punjab	Ag. Research	1906-1956	34-44
Pray, 1980	Bangladesh	Wheat	1961-1977	30-35
Regression Analysis				
Griliches, 1964	USA	Aggregate	1880-1938	35
Peterson, 1967	USA	Poultry	1915-1960	21
Evenson, 1968	USA	Aggregate	1949-1959	47
Evenson and Jha, 1973	India	Aggregate	1953-1971	40
Cline, 1975	USA	Aggregate	1939-1948	41-50
Bredahl and Peterson, 1976	USA	Cash grains	1969	36
Evenson and Flores, 1978	Asia	Rice	1950-1965	32-39
			1966-1975	73
Evenson, 1979	USA	Aggregate	1863-1926	65

From an economic perspective, the rule for optimum investment is that, as long as the internal rate of return is higher than the opportunity cost of capital, it is profitable to increase the stock of knowledge by investing in research. The persistently high rates of return to public agricultural research have lead some authors, notably Ruttan (1982), to argue that there has been underinvestment in agricultural research. According to this argument, the wide margin between the average returns and the opportunity cost of capital implies that not enough resources have been invested in research that would bring down the rates to levels comparable to other public sector investments. This study analyzes the issue of underinvestment and provides insight as to why there has been insufficient demand for research in agriculture. Before doing this, however, the accuracy of rate of return estimates is addressed.

Early studies on the role of investment in agricultural productivity presented "external" rather than "internal" rates of return. In the "external" method the annual flow of benefits is divided by the accumulated costs and expressed as a percentage. This rate of return is highly sensitive to the rate of interest used to reflect the opportunity cost of capital. The "internal" rate, on the other hand, is the rate of interest that makes the accumulated present value of the flow of costs equal the discounted flow of benefits at a given point in time. These two accounting methods give very different results. For example, Griliches (1958), using a 5 percent opportunity cost of capital, calculates the "external" rate of return to hybrid corn research to be 743 percent which converts to 37 percent in terms of the "internal" rate. This rather large difference in the two rates lead researchers to be cautious about the rate of return studies.

The estimation procedure of the rate of return to research involves three steps (Scobie, 1979): (1) measuring the shift in the supply curve to estimate the output-increasing effect of technological change, and given the shift, computing the gross annual research benefit; (2) computing the costs of the project; and (3) estimating the social profitability of the investment by a discounted cash-flow analysis. Hertford and Schmitz (1977) point out that, regardless of the methodology used, accurate estimation of the change in production attributable to research is the most crucial step in an effort to measure the productivity of research. The standard approach measures the social surplus resulting from a shift in the supply curve due to the technical change. Linder and Jarret (1978) note that accurate surplus measures depend on the shape and level of supply and demand curves. The results of earlier studies, particularly those of Griliches (1958) derive from assuming a perfectly elastic supply curve. Two types of shifts are commonly considered in the literature: a "pivotal" shift and a "parallel" shift. Linder and Jarret (1978) have analyzed the effect of the type of the curve chosen and have shown that estimates of gross benefits can vary sixfold depending on the nature of the shift.

Several methodological problems concerning the measurement of benefits have been noted by Linder and Jarret (1978), Scobie (1979), and Rose (1980). In particular, estimates of social loss due to absence of the new technology are made by ignoring the other possible scenarios that might have prevailed. These omissions cause a bias in the estimation of the benefits. Further, introducing trade and price policies, and government intervention in general, can change the results. Akino and Hayami (1975), in their study on rice program in Japan, show that in the absence of trade, producers would have been net losers from agricultural research.

On the cost side, the rate of return studies suffer from two problems. First, it is argued that spillover effects originating in the public good character of research are not internalized. Second, the costs of diffusion and assimilation are not counted. That is, these studies fail to take into account the complementary nature of the inputs and the related education and extension and marketing costs incurred to realize the productivity gains from the adoption of new technology.

In conclusion, it is clear that the assumptions employed in the early rate of return studies, particularly those within the index number framework, did lead to exaggerated rates of return estimates. However, most of the recent studies account for the complementary nature of inputs and assume divergent supply function shifts. The production function studies explicitly taken into account the complementary effect of inputs. In fact, with the recent studies incorporating most of the earlier criticisms, it is likely that they underestimate rather than overestimate returns to public agricultural research (de Janvry and Dethier, 1985; Ruttan, 1987). Also, with internal rates ranging between 30 and 60 percent, it is difficult to conceive that the true rates are so low so as not to justify more investment in agricultural research.

B. Motivation and Objective of Study

An explanation for the continued high rates of return is offered by the underinvestment hypothesis. Evenson, Waggoner, and Ruttan (1979, p. 67) assert that high rates of return are indicative of underinvestment and assert that "there is little doubt that a level of expenditure that would push rates of return to below 20 percent would be in public interest." According to the underinvestment hypothesis, at the margin, public investment in agricultural research has a higher rate of return than any other area of public expenditure and that a reshuffling of fiscal priorities is in order, within a fixed total budget.

Studies examining the productivity of research in agriculture make a case for the underinvestment thesis, but do not explain why investment in research activities is so low. These studies say very little about the research-resource allocation and the underlying factors that determine this allocation. Behind the rate of return estimates are price and quantity relationships involving supply and demand curves and their interactions which generate the observed levels of return.

This study analyzes demand for public agricultural research. The objective is to perform theoretical modeling and econometric analysis of the demand for public agricultural research by state governments. The theoretical models are built upon the public choice models of pure and impure public goods. Demand functions are derived from these models and fitted using U.S. annual data from 1951-1982 for the 48 contiguous states, and statistical tests are performed to evaluate their performance.

The motivation for modeling agricultural research as a public good derives from the nature of agricultural research, which is characterized by varying degrees of nonexcludability and nonrivalry. Nonexcludability occurs when potential beneficiaries from the good can only be excluded from using the good at a prohibitive cost or difficulty. Nonrivalry refers to the condition that the use of a unit of the good by one agent does not diminish the consumption amount available from the same unit for the other agents. Agricultural research produced by any state is available for all the other states to use without depleting the amount available. If these properties hold strictly, a good is referred to as a pure public good. When one or both of these properties do not hold perfectly, the good is referred to as an impure public good (Cornes and Sandler, 1986, p. 6). Most public goods are modeled as impure public goods. For these goods the provider of the good can exclude certain beneficiaries, at a reasonable cost, from consumption of the good, or the nature of the good is such that it gets used up, to some extent, in consumption.

When exclusion is impossible and there is nonrivalry in consumption of the good, production through private initiative does not occur. Provision of the good entails a unanimous collective agreement between beneficiaries and the producers. Two things may prevent the spontaneous emergence of such an agreement. First, if exclusion is not possible, a beneficiary is induced not to take part in the collective agreement and still benefit from the good provided by other agents. This is referred to as free-riding in the literature and is used to characterize the situation when one agent relies on public good supplied by others (Cornes and Sandler, 1986, p. 22). Free riding leads to an inefficient solution. If, in the limit, every agent attempts to free ride, the public good will not be produced. Secondly, whatever the situation on exclusion, the transaction and information costs necessary to reach an agreement may prevent its achievement -- all the more so when the number of agents concerned is large. In these cases, there arises the need for a public agent (i.e., government) to achieve as far as possible what these free private arrangements would have done and to provide the public good to the optimum point.

A considerable amount of work in the literature on public goods has been devoted to public sector expenditure modeling. The issue as to why certain goods have to be provided through the budget and the related "good" (in terms of efficiency and equity) tax structure form the basis of this literature. Early reference to government's role in the provision of goods and services that could not be exchanged through the market was made by Hume, Adam Smith, and John Stuart Mill. Wicksell (1967) noted that though the provision of the public goods, like private goods, should be in line with individual preferences, provision of public goods could not be implemented through a voluntary exchange. A political process of budget determination by voting was needed to reveal preferences. Lindahl (1958) introduced the notion of 'pseudo demand curves' and defined an equilibrium for public goods as the point where vertically aggregated demand curves intersect the supply schedule. Lindahl's formulation, with its vertical addition of demand curves, was a significant feature of Samuelson's formulation (1954). In the Samuelson model, efficient allocation called for an equality of the marginal rate of transformation of the public and private good with the sum of marginal rates of substitution in consumption. Lindahl's model was compatible with Samuelson's outcome.

In recent years work on provision of public goods has focussed on comparing the properties of different equilibria that result from different conjectures under which public goods may be supplied (Cornes and Sandler, 1984a, 1984b; McGuire and Groth, 1985; Bergstrom, Blume, and Varian, 1986; Andreoni, 1988; McGuire, 1990). Provision of public goods has been analyzed mainly for the Nash-Cournot and Lindahl allocational equilibria and compared to the Pareto efficient equilibrium. Under the Nash conjecture, agents adjust their provision of public good contribution independently, given the optimizing choice of the other agents. A Nash-Cournot equilibrium is based on self-interested utility maximization and results in a suboptimal solution, as will be seen in the next chapter. The Lindahl equilibrium is achieved as the result of a cooperative game in which agents, given their individualized tax share, determine the utility-maximizing public good quantity. When such an equilibrium is attained, it is Pareto efficient. Besides these two commonly used conjectures, agents can be assumed to make choices under non-Nash conjectures --- that is, when agents anticipate that their own optimizing choice influences decisions of other agents. This implies replacing the assumption of zero conjectures with the assumption of nonzero conjectures.

In this study, agricultural research will be modeled as a public good and its provision level analyzed for the two polar cases of cooperative and noncooperative behavior, viz, Nash-Cournot and Lindahl equilibria. Specifically:

(1) Demand for agricultural research is analyzed by modeling it as a public good. Agricultural research is modeled as a pure public good and as an impure public good model and allocation rules are derived for both these formulations. Under the general impure specification two models are analyzed in particular - the joint product model and the joint-use model. In the joint product model, agricultural research is regarded as an input that gives rise to two outputs - one purely public in nature, and the other purely private. The effect of the private good, jointly produced with the public good, on equilibrium conditions is analyzed and compared to the case where there are no joint products produced. The implications for the possibility (and extent) of free riding are analyzed.

In the joint-use model agricultural research is regarded as an impure public good for which, like other impure specifications, the jointness in consumption is not complete. However, unlike other public good formulations, pure or impure, the aggregate level of the public good in the joint-use model is fixed for agents providing the good. That is, the aggregate level of (feasible) public good that can be provided is fixed. This may be viewed as a two-step optimization in which, at the first step, the aggregate amount of the public good to be provided is determined, and at the second step, the individual agents determine their own provision levels. For the case of agricultural research this occurs when Congress allocates funds for research, and thereby, determines the total level of agricultural research that may be provided. Given this fixed level of funds, each state determines its own level of provision. Analysis of this model will show how the additional constraint affects equilibrium conditions and the related provision levels. This is of particular importance to agricultural research, given the recent shift in the mix of federal funding from emphasis on formula funds to competitive grants. Formula funds are allocated to states depending on the size of the rural population and the number of farms in the state. Competitive grants, on the other hand, are fixed amount of funds for which the states (research stations) compete to finance their own research program. The results from joint-use model will show how this shift in funding will affect the provision of agricultural research. The same model would also be applicable to the provision of any other public good or service at the state or local level for which the funds are fixed by the budgeting process.

(2) The various public good formulations discussed above are analyzed for two specific games under which the various agents are hypothesized to operate. We analyze state legislature's behavior for the two polar cases of cooperative and noncooperative behavior - Nash-Cournot and Lindahl. The equilibrium conditions from each of these models are related to the optimality conditions.

(3) Most developments of public good models stop with a comparison of the equilibrium conditions and their dissimilarity with the optimal conditions. Given the different equilibrium conditions there is no way to test, empirically, the public good specification that most adequately describes demand for the public good. In this study, empirical specifications of the

reduced-form demand functions are derived for several different public good models and, econometric techniques are used to try to identify the public good model that gives the best representation for the demand for public agricultural research. The econometric procedure would distinguish between the pure public good model and the joint product model. This would also help identify the (degree) of publicness of the good without assigning any numerical measure. The empirical specification and the tests between the different specifications are carried out without specifying any functional form for the utility function.

(4) The set of demand functions derived in this study take account of the simultaneity of decisions that arises from analyzing equilibrium models. Most earlier studies do not take account of this simultaneity and derive demand functions for the equilibrium position, independent of the decisions of the other agents[1].

(5) Finally, this study uses the non-nested technique of the J test to identify the allocational behavior of the state legislatures. That is, this test will allow us to determine whether the state legislatures are engaged in a noncooperative Nash game or they use a cooperative Lindahl strategy while determining the provision of agricultural research. The presence of private aspects from research, if shown to hold by the joint product model, would lead one to suspect that decisions are made in a noncooperative environment. In general, studies analyzing demand for public goods use the Nash game as the most plausible scenario in which

[1]I am grateful to Dr. Wayne Fuller for his help in the econometric specification of the simultaneity of decisions.

decisions are made. The results from the J test will support or refute this supposition. This is important because this assumed conjecture, on the part of the agents, has not been previously tested in the literature.

The J test evaluates the adequacy of each model independently and acceptance (or rejection) of one model does not imply automatic rejection (acceptance) of the competing model. Thus, in our case, the J-test might reject (or accept) both the Nash-Cournot and the Lindahl model. This would point to the fact that more work needs to be done in the literature in modeling agent's behavior. This issue will be discussed in greater detail later in the dissertation.

C. Brief History of U.S. Agricultural Research System

Since this study focusses on the U.S. agricultural research system, a brief review of the structure of the agricultural system would be imperative to understanding of the modeling of agricultural research and its underlying assumptions. The U.S. agricultural research system is a federal-state system in which state and federal agencies are involved. The institutionalization of public-sector responsibility for research in agricultural science and technology can be dated to the 1860s. The Morrill Act of 1862 provided land-grants to states for the support of colleges where the main object was teaching courses in agriculture and the mechanic arts. It also established the Department of Agriculture which became the first federal authority under which a nationwide agricultural research system was to develop.

The institutional pattern that emerged created a dual federal-state system. The federal system developed more rapidly than the state system, but it was not until the end of the 19th century that either the state or the federal system acquired any significant capacity to provide the scientific knowledge needed to deal with agricultural development.

The demand for knowledge about relationships in agriculture grew rapidly in the states. The first state experiment station, the Connecticut State Agricultural Experiment Station, was established in 1877. Before the passage of the Hatch Act in 1887, which provided federal funding for the support of public agricultural experiment stations, only a few states were provided any significant financial support for agricultural research at the state level. It was only after the 1920s that an effective national agricultural research system at both federal and state levels had been established.

The Hatch Act of 1887 caused a significant increase in U.S. public sector funding of agricultural research. Between 1897 and 1931 there was a rapid increase in public funding, with the rate being around 8.2 percent per annum. Between 1931 and 1951, the rate of growth fluctuated with no net growth occurring over this period. From 1951-1978, the rate of growth was 6.4 percent per annum.

Public agricultural research in state agricultural experiment stations is supported by federal and nonfederal funds (Table 2). Part of the federal funds are based on a formula that depends on the number of farms in the state and the size of the nonfarm population. The nonfederal funds

Table 2. Major funding sources for public agricultural research, all SAES, 1969 and 1984 (USDA-CSRS, 1969, 1984)

	1969		1984	
Sources of Funds	$ 1984 thousands	%	$ thousands	%
Total Federal Funds	$ 231,260	31.5	$ 295,996	27.9
CSRS Administered	139,648	19.0	180,950	17.1
Other USDA	20,479	2.8	33,327	3.1
Other Federal	71,132	9.7	81,719	7.7
Total Nonfederal Funds	503,710	68.5	763,347	72.1
State Funds	400,055	54.4	591,356	55.8
Product Sales				
Industry				
Other	103,655	14.1	171,991	16.2
Total	$734,970	100.0	$1,059,343	100.0

Table 3. Private sector research expenditures in constant 1984 Dollars, 1900-1985 (Huffman and Evenson, forthcoming)

Years	Total ($ mil. 1984)	Production ($ mil. 1984)	Percent Production
1900-1909	247.2	205.6	83.2
1910-1919	347.7	268.8	77.3
1920-1929	352.1	251.4	71.4
1930-1939	749.8	475.2	63.4
1940-1949	471.0	275.3	58.5
1950-1959	890.6	575.0	58.5
1960-1969	1367.8	848.0	62.0
1970-1979	1569.6	884.2	56.3
1980-1985	2444.7	1429.5	58.5

include a state's own allocation to agricultural research plus the private funds channeled through state experiment stations. During the early years, federal funding provided a large share of the state experiment station support, i.e., 82.6 percent in 1888. Since that time nonfederal - primarily state government funds - have grown much more rapidly. In 1955, 40 percent of the support was federally provided, and this relative support fell to 27.9 percent in 1984. State governments provided about 55 percent of SAES funding in 1969, which rose to 72 percent in 1984.

Agricultural research expenditures by the private sector on its own research have exceeded those of public sector (USDA and SAES) for all decades except the 1940s. In 1984, private expenditures were 63 percent higher than public expenditures. However, for the period from 1956-1982, private expenditures were 1.3 percent higher than the public expenditures (Huffman and Evenson, forthcoming). Table 2 gives the private sector research expenditures from 1900-1985. As can be seen, private expenditures are an important source of funds for agricultural research.

In this study, however, we will focus only on state government decisions on SAES research. Decisions by USDA on its own research activities in the state and by private industry on its research expenditure are ignored. SAES research and private sector research have been shown to have different research foci (Huffman and Evenson, forthcoming). SAES research is dominated by biological sciences. The basic and applied biological science fields account for 80 percent of total SAES expenditures. Private sector research, on the other hand, has shifted from focus on technology field to emphasis on utilization-nutrition research.

The different research foci suggest that public and private research efforts might complement each other.

In Chapter II, the theoretical modeling of agricultural research as a public good is presented. Various models of public goods are examined and reduced-form demand functions for each of these models are derived. In particular, Nash-Cournot and Lindahl specifications for agricultural research are presented. Chapter III lays out the data and the empirical specification for the demand functions derived from the theoretical models in Chapter II. Also, the methodology of the J test, to test between the alternative allocation schemes, is presented. Chapter IV presents the econometric results from fitting these models to U.S. annual data. Results from the J-test will help distinguish between the two allocational schemes and show which allocational pattern is followed by the state legislatures. Finally, in Chapter V, a summary of the results will be presented and the results will be evaluated to make policy predictions; also areas for future research will be identified.

II. AGRICULTURAL RESEARCH AS A PUBLIC GOOD

A. Brief Review of Literature

This chapter investigates, with the use of a theoretical framework, the implications when agricultural research is provided by individual (public) agents. Research activity generally occurs in a mixed scenario: basic research activity is carried out at federal research institutes, whereas applied research is provided by state institutions. This, as shown by studies discussed later in the chapter, is due to differences in the public/private mix of characteristics of the two types of research.

Agricultural research has been extensively analyzed. An impressive and growing body of literature on expost studies shows high economic returns to investments in agricultural research. Ruttan (1984) cites numerous empirical studies in the United States and abroad in which annual internal rates of return to public investment have been estimated to range between 30 to 35 percent. Other studies have focussed on issues relating to the financing of agricultural research. Schultz (1971) argues that agricultural experiment stations have the attributes of an economic decision-making unit and respond to demand and supply factors. Misallocation occurs due to relatively high social rates of return and the fact that these returns are so widely diffused that they usually have effects outside the economic and political boundaries of origin.

The above way of analyzing agricultural research assigns an almost passive role to the aspect of demand. These studies assume that the relevant decision-making unit (e.g., an experiment station, a state or a country) demands some predetermined level of research. The issue of interest then is to evaluate whether this investment alternative can generate high returns, and to analyze the associated financing problem. A few studies, however, have tried to determine and test empirically factors that influence demand for agricultural research. Huffman and Miranowski (1981) use a four-equation model of resource allocation, consisting of demand and supply equations for research, an equation for allocation of government revenues and an expenditure identity. In their study, the demand for indigenous research by a state is hypothesized to be a function of the size of the agricultural sector of that state, other characteristics of a state's agricultural output, agricultural input prices, farmers' education and extension and agricultural research in other states. The last variable is included to account for two opposing effects. If new research is directly borrowable between states, it leads to "free-riding" causing demand for indigenous research to fall. If, on the other hand, new research cannot be directly applied by other states it leads to a 'competing' effect that increases the demand for indigenous research. Their empirical results indicate that states do not want to lose their comparative advantage and hence 'competing' effect dominates for subregional applied research whereas there is evidence of "free-riding" for regional basic research. Their study also indicates that wealthier states (based upon per-capita state government revenue) and more agriculturally oriented states (measured by size of agricultural output per-capita) invest heavily in public agricultural research.

A different approach is employed by Rose-Ackerman and Evenson (1985) in explaining interstate differences in demand for agricultural research. They hypothesize a political model in which politicians seek to maximize their chance of re-election, given a state tax bill of fixed size and the level of state personal income. Thus, the state legislator must decide what share of tax revenues should be allocated to agricultural research and extension. Their results indicate that state demand for research is influenced not only by level of farm income and size, as found by other studies, but also by measures of inter-governmental influence and the political effectiveness of farmers. Their study supports the finding of Huffman and Miranowski (1981) that states try to free ride on the basic research of neighboring states, and find evidence of free-riding for livestock (i.e., basic) research. Rose-Ackerman and Evenson's study is thus broader in its context and includes economic as well as political determinants of state spending on agricultural research. Guttman (1978) arrives at a similar result that lobbying activities, by increasing the political effectiveness of its constituents, influences demand for agricultural research. The results of his study show that per capita state support for agricultural research is related to the size distribution of farmers, co-operative memberships, firms producing inputs, borrowable research and the proportion of owner operators. Thus, the same conclusions emerge that demand for agricultural research is determined in an economic and political setup.

A recent study by Judd, Boyce and Evenson (1986) focusses on demand for agricultural research at the international level. In their model a social planner maximizes some measure of aggregate income, given the resource base of the economy, which includes a given stock of technical knowledge. Growth can be achieved through various alternatives ranging from additions to arable land to development of location-specific agricultural technology. Each alternative has a different cost configuration which can vary over time and space.

The empirical specification of their model includes variables for total agricultural production, those for demand conditions, possibility of arable expansion, diversity of agricultural production, scientists man-year and a proxy for the price of research. They also include variables to account for free-riding effects between countries within the same geo-climatic zone and those due to the domestic location of an International Agricultural Research Center (IARC). Their results support the findings of the earlier studies that spending on agricultural research is an increasing function of total agricultural production and its diversity, and inversely related to the cost of research. Interestingly, they find evidence of net free-riding only in the industrialized countries. This could be explained in terms of a comparable technical level of the industrialized countries and, hence, an innovation by any one country can be easily adopted by the other countries. They find no evidence of free-riding on domestic IARC spending for developing countries and, in fact, presence of IARC stimulated net national spending which in turn had a positive effect on spending by neighbors in the same geo-climatic zone. A reasonable explanation for this can be sought in that research activity of IARC is generally broad-based and basic in nature which in turn stimulates domestic research expenditure on a more 'country-specific' applied type of research. Increased spending by neighbors indicates that 'competing' effect dominates the free-riding effect.

Studies cited above have primarily an empirical form. They have not explicitly derived research expenditure decisions from models of optimal behavior. Although these studies have tested for the presence of free-riding, they have not modeled it within a theoretic framework. By obtaining reduced-form demand functions within an optimizing framework, this study, will help determine the extent of free-riding and identify conditions under which it can be reduced.

In particular, this study models agricultural research as a pure public good and an impure public good. Under the impure specification, two alternate models are analyzed - joint product and joint-use. Agricultural research, which is an input, is assumed to give rise to pure public and pure private benefits under the joint product specification. The private output refers to that part of agricultural research, produced at the state agricultural experiment stations, which is specific to that particular state and can not be used by any other state. The pure public output refers to that part of research that can flow freely across state boundaries. The joint product model has been analyzed by Cornes and Sandler (1984a) and has been applied to models of charity and national defense expenditures (Posnett and Sandler, 1986; Murdoch and Sandler, 1989). The model used in this study to analyze agricultural research draws heavily on Cornes and Sandler (1984a).

The remainder of this chapter analyzes demand for agricultural research activity by the states. Agricultural research is carried out at three institutions in a state - the state agricultural experiment stations, USDA research centers, and private research institutions. In 1969, 41 percent of total public agricultural research activity was performed by USDA agencies; by 1984 the USDA's share had fallen to 34 percent. In 1969, state institutions performed 59 percent of total public agricultural research activity, which rose to 65 percent in 1984. Thus, state agricultural research activity has been steadily increasing over the years, and at present, state research stations constitute the major providers of public agricultural research. Research activity at the private research institutions and at USDA centers will affect research activity at state experiment stations. In this study, however, we focus only on state government decisions for agricultural research carried out at the state experiment stations.

Section A considers agricultural research activity to be a pure public good. We study the allocation of resources to research by the state governments under Nash-Cournot and Lindahl assumptions. Individual optimizing behavioral rule is compared to that which would maximize society's welfare. Such a simple representation of research activity, however, hardly describes the real situation. A more realistic depiction occurs when state's research activity is modeled as an impure public good, in which either the condition of nonexludability or of nonrivalry or both do not hold strictly.

In Section B, we model research activity as an impure public good. Two cases of impurity are considered; the joint product case in which agricultural research is an input that gives rise to some output that is purely private to the state producing the research, and to some output which is purely public; and the joint-use model in which the aggregate level of (feasible) agricultural research is fixed for the states. This, we feel, is a correct representation for federal funds when aggregate research activity is determined by Congress and therefore taken as fixed or as a parameter for each state decision. Given the allocation for total research activity, each state decides how much to take out of the given pool of funds for its own research activity. Two considerations will affect the demand for an individual state's research activity - the desire to free ride when benefits are not perfectly excludable and the potential loss of spillins to the i-th state caused by its own demand. We compare individual demand functions for Nash-Cournot equilibrium under the general externality and the joint-use case and see which one is further from society's optimal demand. As our last model, we combine the joint-product specification with joint-use and derive individual (Nash) behavioral rule and the associated demand functions.

B. Pure Public Good Models

1. Pareto optimum

A widely used criterion to evaluate and compare alternative resource allocation positions is that of Pareto-optimality. A Pareto optimum is a societal equilibrium in which no one agent can be made better-off without making at least one other agent worse-off. A change in the resource allocation that raises the welfare of one agent without lowering that of any other agent is said to be a Pareto-superior move. To derive a Pareto-optimum, one agent's utility is maximized subject to some predetermined utility level of the other agents and, subject to the relevant resource constraints (Cornes and Sandler, 1986). A Pareto-optimal position is generally not unique since it depends on the preset utility levels of the other agents (i.e., the income distribution) and changing these utility levels will result in a different Pareto-optimum. Further, it is based on ordinal concept of efficiency since it does not rely on intensity of preferences or interpersonal comparisons of utility. Analyses of Pareto optimality, thus, stops short of interpersonal comparisons. If a change in an allocation improves the position of some individuals but causes a detriment in the utility level of others, then such a position cannot be evaluated in terms of efficiency. The "best" among all these optima can be chosen, however, by using a social welfare function that weights the utility levels of the agents according to some rule that does not violate Pareto-optimality (for example, Samuelson-Bergstrom welfare function).

The Pareto criterion, which involves making only Pareto superior moves, is applied to the distribution and production of goods, referred to as exchange and production efficiency, respectively. For private goods, exchange efficiency is obtained if every possible reallocation of goods that increases utility of one or more individuals causes a reduction in the utility of some others. If there are only two goods consumed, and they are x and y, then this occurs when the marginal rate of substitution (MRS) is equalized across all agents i and j:

$$MRS^{i}_{xy} = MRS^{j}_{xy} .$$

Production efficiency is attained when an increment in the quantity of one good by a reallocation of resources between goods causes a decrement in the quantity of some other good. This, like the consumption case, is achieved when the marginal rate of technical substitution (MRTS) between each pair of inputs is equated across all industries using these inputs. If production of x and y is with inputs labor (L) and capital (K), then,

$$MRTS^{x}_{LK} = MRTS^{y}_{LK} .$$

A Pareto optimum for private goods is attained when the exchange and production efficiency conditions hold simultaneously. The exchange and production sides are tied together through the top-level condition which requires

$$(MRS^{i}_{xy} = MRS^{j}_{xy}) = MRS_{xy} = MRT_{xy} ,$$

where the MRT_{xy} is the marginal rate of transformation between x and y and indicates the opportunity cost of one good in terms of the other, given inelastically supplied factors and production efficiency. The MRS in the top-level is the equalized MRS over all agents and shows the willingness of the society to transform x into y.

The conditions for Pareto optimality formulated above are not valid for public goods. Since public goods simultaneously benefit all the members of the community and it is not possible for any one individual to appropriate a public good for personal consumption, total rather than individual valuations matter in deciding the resource allocation. The production efficiency condition remains intact since publicness does not affect the need to produce efficiently. There is no exchange efficiency condition because the property of nonexcludability precludes exchange. Let q^i be i-th agent's contribution of the public good; and Q the total amount of the public good available for the community of n individuals, i.e., $\sum_{i=1}^{n} q^i = Q$. Then, the new top-level condition is

$$\sum_{i=1}^{n} MRS^i_{Qy} = MRT_{Qy} .$$

This condition is obtained by maximizing the utility of any one individual, subject to given utility levels of the others, and the economy's transformation function.

In the models that are developed below, we assume the relevant agent(s) are the state governments which make decisions on public agricultural research and other state government expenditures. A (direct) utility function is assumed to reflect the preferences of the state legislature. This function is defined over a composite private good, y^i, agricultural research, Q, and an environmental variable, E^i. The state legislature chooses the optimizing quantities of y^i, and q^i, given E^i. We impose certain regularity constraints on the utility function so that the necessary conditions we obtain are the sufficient conditions for a maximum as well. In particular, we assume that the utility function is twice continuously differentiable, strictly increasing and strictly quasi-concave in its arguments. We can represent the utility function of the i-th state's legislature as:

$$U^i = U^i(y^i, Q ; E^i).$$

The Pareto problem can be expressed as follows:

$$\max_{\{y^i, q^i\}} U^i(y^i, Q ; E^i)$$

$$\text{subject to } U^j(y^j, Q ; E^j) \geq \bar{U}^j \quad j \neq i, \quad i,j=1,\ldots,n$$

$$F(Y, Q) \leq 0 ,$$

$$\text{and } Y = \sum_{i=1}^{n} y^i . \qquad \text{(II.1)}$$

Utility of agent i (i.e., of the state legislature) is maximized subject to given utility levels of the other n-1 state legislatures and the aggregate transformation function. The transformation function can be replaced by an aggregate budget constraint to reflect the production capacity of the economy. Thus we get,

$$\sum_{i=1}^{n} I^{i} - P_y Y - P_Q Q = 0 , \qquad \text{(II.2)}$$

where I^i are the revenues of the i-th state government, and $\sum_{i=1}^{n} I^i$ is the aggregate resource endowment of all the states, P_y is the constant marginal cost of y and P_Q is the constant marginal cost of Q, agricultural research. Maximizing U^i subject to (II.2) and the given utility levels, $\bar{U}^j$, $j \neq i$, will give the following first-order condition (FOC):

$$\sum_{i=1}^{n} MRS^{i}_{Qy} = P_Q / P_y . \qquad \text{(II.3)}$$

Equation (II.3) implies that at a Pareto-optimal allocation, the sum of the marginal valuations (over all n states) should equal the price ratio. Let the optimizing quantity for the i-th state be Q^{i*} . Then at a Pareto optimum $Q^{1*} = \ldots = Q^{i*} = \ldots = Q^{n*}$. That is, the equilibrium quantities of all agents should satisfy equation II.3.

2. *Nash-Cournot model*

This is a model of noncooperative behavior in which each state legislature is engaged in self-interested utility maximization and adjusts its public good contribution independently. Formally, a Nash equilibrium is defined as a strategy profile such that no single player (e.g., state legislature) by changing its strategy can obtain higher utility if other players stick to their best strategies. In our model, each state legislature holds zero conjecture about the effects of its optimizing choice on the choice of the other states. A zero conjecture implies that each state legislature believes that its optimal choice will not influence the choice of the other state legislatures. The resulting equilibrium is typically not Pareto optimal because each state contributes to the provision of the public good up to the point where its own MRS is equal to the price ratio, whereas a Pareto optimal solution requires equating the sum of the MRS to the price ratio.

We assume each state legislature's preferences are represented by a utility function that satisfies the regularity constraints imposed earlier. Thus, the i-th state's utility function is

$$U^i = U^i(y^i, Q ; E^i) ,$$

where y^i is i-th state legislature's consumption of the private good, Q is the public good consumption level and E^i is the environmental variable. The total level of agricultural research consumed is the sum of that provided by state i ,q^i, and the amount of the spillins, which are assumed to be perfect substitutes, from the other n-1 states, $\bar{Q}^i = \sum_{j \neq i} q^j$. Each state is assumed to face a linear budget constraint

$$I^i = P_y y + P_Q q^i ,$$

where I^i are the state revenues of the state government, including intergovernmental transfers. These transfers include formula funds allocated to states for agricultural research activity in the states. The formula funds are based on the relative size of the agricultural sector in the state. The expenditures on agricultural research, thus, include the state allocations for research and the federal formula funds allocated to that state for research. In this study, however, we focus on the state's share of expenditures on research.

The state legislatures, in addition to the budget constraint, face a prevailing public good contribution constraint,

$$Q = q^{i} + \tilde{Q}^{i} . \tag{II.4}$$

The i-th state legislature maximizes its utility, U^{i}, subject to the two constraints and thereby determines its optimal agricultural research activity, i.e., q^{i*}. We can incorporate the public good constraint (II.4) into the budget constraint and redefine the i-th state's maximizing problem as a decision on the aggregate level of the public good instead of only its own contribution (for a similar treatment see Bergstrom, Blume, and Varian, 1986; Cornes and Sandler, 1986). This specification, in which each state makes its choice over the aggregate level of the public good, yields reduced-form demand functions in a form that can be readily compared with equations derived from an alternative cooperative solution to public decisions on resource allocation - Lindahl.

By adding $P\tilde{Q}^{i}$ to both the sides of the budget constraint we can express the decision problem facing the i-th state legislature as choices on y^{i} and the aggregate level of the public good Q^{i}:

$$\max_{\{y^i, Q^i\}} U^i(y^i, Q^i; E^i)$$

$$\text{subject to} \quad F^i = I^i + P_Q\tilde{Q}^i = P_y y^i + P_Q Q^i$$

$$Q^i > \tilde{Q}^i , \qquad \text{(II.5)}$$

where F^i is defined as full income. The constrained optimization, as shown in Appendix A, yields FOCs that can be expressed in terms of marginal rates of substitution as:

$$MRS^i_{Qy} = P_Q / P_y . \qquad i=1,\ldots,n \qquad \text{(II.6)}$$

Let the optimizing levels of quantities that satisfy equation (II.6) be denoted by y^{in} and Q^{in}. There exists a vector of such equilibrium quantities, each element of this vector being the equilibrium quantity of the private good and public agricultural research of each state legislature.

The above FOC implies that each state contributes to the provision of agricultural research until the marginal valuation of research equals the marginal cost. If agricultural research can potentially provide benefits to other (possibly all) states at the same time, then there is an incentive for each state legislature to understate its preferences in order to be able to free ride. This strategy by all states legislatures leads to underprovision of the public good - agricultural research.

A Nash equilibrium to (II.5) is achieved when there exists a vector of y^i's and Q^i's such that (Q^{in}, y^{in}) solves the model and Q^i is the same for each state. As noted earlier, when regularity constraints are imposed on the utility function, the FOCs are both necessary and sufficient for a maximum. If the associated bordered Hessian determinant, $|H|$, is restricted to being positive definite[1], then using the implicit rule we can write the reduced-form demand equations for y^i and Q^i as:

$$y^{in} = y^i\ (F^i,\ P_Q,\ P_y;\ E^i), \qquad i=1,\ldots,n$$

$$Q^{in} = Q^i\ (F^i,\ P_Q\ ,P_y;\ E^i). \qquad i=1,\ldots,n \tag{II.7}$$

For each state its subscription demand for the community level of agricultural research is a function of full income and the prices of y and Q. A state's own derived demand for research activity is found by subtracting the spillins from the aggregate demand:

$$q^{in} = Q^i(F^i,\ P_Q,\ P_y;\ E^i) - \tilde{Q}^i\ . \quad i=1,\ldots,n$$

3. Lindahl model

Lindahl equilibrium attempts to solve the problem of determining the levels of public goods to be provided and their financing by adapting the

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[1]A strictly quasiconcave utility function implies that the $|H| \geq 0$ which is insufficient to rule out a zero value.

price system in a way that maintains its central feature of an efficient allocation based on voluntary market activities. Instead of some political choice mechanism or coercive taxation, the Lindahl scheme has agents facing individualized prices at which they might buy the public goods. In equilibrium, these prices are such that everyone demands the same level of public good and thus agrees on the amount of the public good to be provided.

Foley (1970) derives individual demand functions for public goods that depend on the prices of both private and public goods, and defines them as choices of quantities that maximize utility subject to budget constraint defined by prices and agent's endowment. Thus, the quantity demanded of any public good at a particular price vector differs with individual preferences and endowments. However, the nature of the public goods requires that all agents' consumption of the public good be equal. If, therefore, prices are to lead to the same quantity of the public good, then the prices charged should be different across consumers so as to reflect differences in preferences and endowments. It should be noted that agents follow standard price-taking behavior as in Walrasian equilibrium. The Lindahl equilibrium establishes an analogue to competitive market equilibrium for private goods and, if attained, is Pareto efficient. There is an interesting duality here between the definition of private and public goods on one hand, and the properties of equilibrium prices on the other. In terms of quantities, for private goods the sum of individual quantities should add up to the total quantity produced, while for public goods individual consumption equals aggregate production. In terms of prices, on the other hand, for private goods each consumer's price equals the producer price, while for public goods individual consumer prices add up to the producer price. However, one of the major drawbacks of this equilibrium concept is the proclivity for strategic misrepresentation of preferences. With private goods, individuals facing given prices have clear incentive to reveal their true preferences by equating their marginal rates of substitution to relative prices. With public goods, this no longer holds. Because an individual has the same quantity of good available whether she pays or not, she has an incentive to misrepresent preferences and free ride. However, authors such as Roberts (1979), and Truchon (1986) have shown that misrepresentation need not prevent convergence to a Lindahl allocation.

In the Lindahl problem, each state legislature maximizes its utility subject to a given share of the total cost of agricultural research activity, θ^i. These cost shares sum to unity so that the full cost of (public) research is covered. The representative state legislature is assumed to choose y^i and Q^i, which is the community provision of agricultural research:

$$\max_{(y^i, Q^i)} U(y^i, Q^i; E^i)$$

$$\text{subject to } I^i = P_y y^i + \theta^i P_Q Q^i ,$$

$$\theta^i = q^i / Q^i , \qquad \text{(II.8)}$$

where θ^i is the i-th state's share of the total cost ($P_Q Q^i$) of agricultural research for the region; I^i are the state revenues of the state legislature, and P_y and P_Q are prices of the private good and agricultural research, respectively.

The FOC (Appendix A) can be written as

$$MRS^i_{Qy} = \theta^i P_Q / P_y . \qquad i=1,\ldots,n \tag{II.9}$$

Let the solution to (II.9) be y^{i1} and Q^{i1}. Because the aggregate level of the public good at the equilibrium is the same, we can sum over all the n states. This gives

$$\sum_{i=1}^{n} MRS^i_{Qy} = P_Q / P_y . \tag{II.10}$$

Equation (II.10) is the Samuelson condition for Pareto optimal provision of a public good, since $\sum_{i=1}^{n} \theta^i = 1$. This then implies that a Lindahl equilibrium is Pareto optimal.

By imposing the condition that the bordered Hessian determinant, $|H|$, is strictly positive we can transform the FOCs via the Implicit Function theorem into the following reduced-form demand equations for y and Q:

$$y^{i1} = y^i(I^i, \theta^i P_Q, P_y; E^i), \qquad i=1,\ldots,n$$

$$Q^{i1} = Q^i(I^i, \theta^i P_Q, P_y; E^i). \qquad i=1,\ldots,n \tag{II.11}$$

The Lindahl demand for agricultural research depends on the state's income, the price of y and Q, the individual cost shares, and the environmental variable. A Lindahl equilibrium is obtained when there exists a set of cost shares such that Equations (II.11) hold for each agent, and the aggregate amount of agricultural research demanded is the same; that is $Q^{11} = \ldots = Q^{i1} = \ldots = \ldots = Q^{n1}$.

C. Impure Public Good Models

In the models that we have considered in part A above, agricultural research is modeled as a pure public good. This implies that the benefits that flow from this good are, not even in any partial sense, excludable to any one state. This is a somewhat unreal representation, and as critics such as Margolis (1955) point out it is difficult to find real-life situation that fits the pure public goods model completely. The pure model has a relatively simple structure. When a state legislature increases its contribution to the public good by a unit, then each and every state's consumption of the public good rises by the same amount. Thus, the only characteristic that distinguishes the contributor from the other agents is the corresponding reduction in the consumption of the private good, given the budget constraint. However, Cornes and Sandler (1986, p. 113) note that, "It is not the purity of the model that accounts for its simplicity and for its inadequacy as a description of many real phenomena, but rather the presence of only one public good." Thus any externality situation can be modeled as one involving public goods without changing the essence of the Samuelson model.

In recent years, work in the field of public goods has focussed on extending the pure public good model to account for cases where the contributor to the public good derives benefits from the use of the public good that are exclusive to her. Thus giving to charity, which has for long been considered a pure public activity, has now been modeled differently. The pure public approach implies that as the number of potential donors increases, a utility-maximizing agent will not give to charity. Yet, we find that a considerable amount of charitable activity exists. Andreoni (1988) models charity as an impure public good, calling it impure altruism. He contends that when agents donate to privately provided public good they gain utility not only from an increase in the provision of the public good but also from the act of giving referred to as the "warm glow". Posnett and Sandler (1986) model charitable activity as a joint-supply model in which donating to charity is tied-in with the purchase of a private good. Thus joint-supply turns out, in their model, to be an effective fund-raising technique when private and public goods are Hicksian complements. Defense expenditures, considered to be one of the few examples of a pure public good, are now modeled as an impure public good (see Murdoch and Sandler 1982, 1984, and 1986).

Extensions of the pure public good model are considered next. The first model is the joint-product model. Then we will discuss the joint-use model that was first developed by Oakland (1969).

1. Nash-Cournot joint product model

Under this specification, an input produces goods having public and private characteristics. This model can refute, in some instances, the basic proposition that follows from the pure model; when the community size increases, free riding and the associated suboptimality also increase (Cornes and Sandler 1984a). In particular, the joint product model shows that the consumption relationship of the jointly produced outputs influences the departure of Nash equilibria from optimality and the slope of the reaction paths. When the jointly produced goods are complements in the Hicksian sense, an increase in the provision of the public input by one state may raise the contribution of the other states (Cornes and Sandler 1984a).

The formulation of the joint product model here directly follows the one used in Cornes and Sandler (1984a). We assume that the state legislatures provide the private final good y and the input agricultural research activity q. Each unit of the private good y gives rise to a unit of private good y. This commodity produces no other characteristic for this or any other state and hence is considered private. Agricultural research represented by q^i produces two final goods or characteristics - x and Z. A simple (but arbitrary) transformation function which relates q^i to x^i and z^i is:

$$x^i = g_i(q^i) \, , \tag{II.12}$$

$$z^i = h_i(q^i) \ , \qquad \text{(II.13)}$$

where the function g_i and h_i are assumed to be twice continuously differentiable and concave, and g_i' and h_i' are positive. We define the total public good available to the i-th state, Z^i, as the summation of the public good provided by all the n states, i.e.,

$$Z^i = z^i + \tilde{Z}^i \ , \qquad \text{(II.14)}$$

where $\tilde{Z}^i$ is the public good provided by the other n-1 states. The level of $\tilde{Z}^i$ can also be related through a production function to the amount of research activity by the other states $\tilde{Q}^i$ as:

$$\tilde{Z}^i = m(\tilde{Q}^i) \ . \qquad \text{(II.15)}$$

Thus, $\tilde{Z}^i$, is a function of aggregate research activity of all the n-1 states. Any state i can enjoy the public good produced from agricultural research (Z^i) without diminishing any other state's consumption.

Each state legislature's preferences are defined over three goods x, y and Z and the environmental variable E. The utility function of state legislature i, which satisfies all the regularity constraints imposed earlier, may be represented as follows:

$$U^i = U^i(y^i, x^i, Z^i; E^i). \qquad \text{(II.16)}$$

where a) y^i is a private good,

b) x^i is the private good produced by agricultural research,

c) Z^i is the pure public good produced by agricultural research, in the aggregate.

State i is assumed to face a budget constraint of the form

$$I^i = P_y y^i + P_Q q^i \ . \qquad \text{(II.17)}$$

Under the Nash perspective, each state legislature maximizes utility by choosing y and q, taking everything else as exogenous.

The utility function in (II.16) can also be represented in terms of y^i, q^i, and $\tilde{Q}^i$ by substituting in for x^i and Z^i, via Equations (II.12) to (II.15). This allows utility to be stated as a function of y, the private good and q, agricultural research activity:

$$U^i = U^i(y^i, x^i, Z^i; E^i) = U^i[y^i, g_i(q^i), h_i(q^i) + m(\tilde{Q}^i), E^i]. \qquad \text{(II.18)}$$

Thus, Equation (II.18) establishes a link between the final goods space and the purchased goods space.

We can relate the two spaces by differentiating the utility function with respect to y^i and q^i and expressing it as marginal rates of substitution. We obtain,

$$\frac{U^i_q}{U^i_y} = g'_i \frac{U^i_x}{U^i_y} + h'_i \frac{U^i_z}{U^i_y} \qquad \text{(II.19)}$$

or,

$$MRS^i_{qy} = g'_i \, MRS^i_{xy} + h'_i \, MRS^i_{zy} \, . \qquad \text{(II.20)}$$

Equation (II.20) shows that the MRS of q for y is a weighted sum of the MRS of x for y and the MRS of Z for y. The weights are the marginal product of the private and the pure public goods produced from research. They define the productivity of the i-th state to produce these two goods.

To enable us to derive reduced-form demand equations, comparable to those derived under the Lindahl process, we redefine the representative state legislature's utility function so that it is stated in terms of the aggregate level of the public good. This follows from the relationship

$$q^i = Q^i - \tilde{Q}^i , \qquad \text{(II.21)}$$

where Q^i is the i-th state legislature's choice of aggregate level of research activity. Thus, the Nash problem may be represented as follows:

$$\max_{\{y^i, Q^i\}} U^i[y^i, \, g_i(Q^i - \tilde{Q}^i), \, h_i(Q^i - \tilde{Q}^i) + m(\tilde{Q}^i), \, E^i]$$

$$\text{subject to} \quad F^i = I^i + P_Q\tilde{Q}^i = P_y y^i + P_Q Q^i$$

$$Q^i > \tilde{Q}^i \quad , \quad y \geq 0 \, . \qquad \text{(II.22)}$$

The FOCs of (II.22), as derived in Appendix A, can be expressed as

$$g'_i \, MRS^i_{xy} + h'_i \, MRS^i_{zy} = P_Q / P_y. \quad i=1,\ldots,n \tag{II.23}$$

Equation II.23 implies that state i will provide goods to the point where the weighted sum of the MRS between x and y and the MRS between Z and y is equal to the price ratio for Q and y. Let the solution be denoted as Q^{in}_{jp}; this a vector of equilibrium quantities of y^i's and Q^i's that satisfy Equation (II.23) for all the states in a region. The weights g'_i and h'_i are the change in the goods between x and Z as q is varied. If g'_i is greater than h'_i, then relatively more private good is produced from a unit of q; and the marginal rate of substitution between x and y is given more weight. For applied research activity private good is likely to have greater weight and this may be the reason that a positive quantity of applied research is provided by the states.

From the perspective of policy makers, it is important to know the determinants of demand for agricultural research. By changing the policy parameters, governments can influence demand. The reduced-form demand equations is derived, using the Implicit Function Theorem and by restricting the associated bordered Hessian determinant of the first-order conditions to be positive definite. A general specification of the demand functions for y^i and Q^i is:

$$y^{in}_{jp} = y^i \, (F^i, P_Q, P_y, \tilde{Q}^i; E^i, g'_i, h'_i, m'), \quad i=1,\ldots,n$$

$$Q^{in}_{jp} = Q^{i}\,(F^{i},\ P_{Q}\ ,P_{y},\ \tilde{Q}^{i};\ E^{i},\ g'_{i},\ h'_{i},\ m').\qquad i=1,\ldots,n \qquad \text{(II.24)}$$

Specific demand functions can be obtained by imposing some structure on the utility function. With joint products, a state's demand for agricultural research depends on the prices, full income, the amount of spillins, environmental variable, and the technological parameters. Spillins enter the demand function twice; once explicitly, as $\tilde{Q}^{i}$, and once through the full income term F^{i}. The inclusion of the spillin term ($\tilde{Q}^{i}$) implies that the private good(s) derived from agricultural research are important determinants of demand for the state legislatures. A change in $\tilde{Q}^{i}$ affects the level of full income and the mix between pure and private agricultural research, since no private research is obtained from $\tilde{Q}^{i}$. Only an increase in the state's own research activities will cause an increase in private agricultural research output, x. The appearance of spillins as $\tilde{Q}^{i}$ also implies that the neutrality theorem does not extend to the case of joint products; that is, a redistribution of income between the contributors will affect the Nash-Cournot equilibrium choice. A transfer of income, compensated by an equivalent transfer of the public good, will change equilibrium levels because private research output would remain uncompensated. When there are no private goods to be obtained from agricultural research, spillins enter the demand function only through the full income term and a redistribution of income does not affect Nash equilibrium (Warr, 1983; Cornes and Sandler, 1985; Bergstrom, Blume, and Varian, 1986).

The other variables in the demand function, namely the productivity factors, measure the marginal productivity of the i-th state, and other states (through m′) in producing the private and public research outputs. However, it is difficult to quantify these factors and hence cannot be used in the empirical analysis.

2. Pareto optimal joint product model

A state's optimal quantity of public research determined by Nash behavior may not be optimal from a national perspective. The Pareto-optimal quantity would be that quantity which takes into account the public benefit accruing to all the states from the production by any one state.

The Pareto-optimizing problem is set up as a maximization of state i's utility subject to every other state obtaining a given utility level, as well as the aggregate budget constraint. The problem may be written as:

$$\max_{(y^i, q^i)} U^i[y^i,\ g_i(q^i),\ h_i(q^i) + \sum_{j \neq i}^{n} h_j(q^j),\ E^i]$$

$$\text{subject to } \sum_{i=1}^{n} I^i = \sum_{i=1}^{n} [P_y y^i + P_Q q^i]$$

$$U^j[y^j, g_j(q^j), h_j(q^j) + \sum_{k \neq j}^{n} h_k(q^k),\ E^j] \geq \bar{U}^j \ , \text{ for all } j \neq i, \quad i,j=1,\ldots,n \qquad \text{(II.25)}$$

The FOCs associated with (II.25), derived in Appendix A, can be written as:

$$g'_i \, MRS^i_{xy} + \sum_{i=1}^{n} h'_i \, MRS^i_{zy} = P_Q / P_y \, . \qquad \text{(II.26)}$$

The amount of Z provided under the Nash solution is less than the Pareto-optimum. In the Nash solution of the same problem, agents engaged in a self-interested utility maximization, do not take into account the benefits to the other agents from their own demand of agricultural research. Hence, the Nash solution cannot be a societal equilibrium. Condition (II.26) shows that the sum of every state's marginal rate of substitution between the public good and the private good should be considered in order for agricultural research to be supplied optimally from a national perspective. Let the solution to the Pareto problem be denoted by Q^{i*}_{jp}; a vector of quantities of the private good, y, and the public input agricultural research, Q, that satisfies Equation (II.26). As discussed earlier, Nash demand for public goods is less than the optimal (Pareto) demand because of the possibility of free riding. However, the presence of private aspects from the provision of a public good increases the Nash provision levels from the Nash levels reached without these corresponding private aspects. Under the Lindahl process, as we show below, a Pareto-optimal solution can be achieved by calling out state tax shares.

3. Lindahl joint product model

When agricultural research produces joint products, the Lindahl problem can be depicted such that a state legislature chooses the aggregate level of agricultural research activity, given the cost share. This is similar to the pure public good case except for the complexity caused by the joint product relationships. Let,

$$x^i = R_i(Q^i)\ , \qquad R_i' = dR_i/dQ_i > 0\ ,$$

and
$$Z = G(Q^i)\ , \qquad G' = dG/dQ^i > 0\ ,$$

and, in addition, the functions R_i and G are concave. The i-th state legislature chooses y and Q so as to maximize utility:

$$\max_{\{y^i, Q^i\}} U^i[y^i,\ R_i(Q^i),\ G(Q^i),\ E^i]$$

$$\text{subject to} \quad I^i = P_y y^i + \theta^i P_Q Q^i\ ,$$

$$\theta^i = q^i / Q^i\ . \tag{II.27}$$

The FOCs (Appendix A) imply the following:

$$R_i' MRS^i_{xy} + G' MRS^i_{zy} = \theta^i P_Q / P_y\ . \quad i=1,\dots,n \tag{II.28}$$

At a Lindahl equilibrium, the cost shares sum to one, hence we can sum over all the states at the equilibrium on both sides of (II.28) and obtain the Pareto-optimal result,

$$\sum_{i=1}^{n} R_i' MRS^i_{xy} + G' \sum_{i=1}^{n} MRS^i_{zy} = P_Q / P_y\ . \tag{II.29}$$

The Lindahl process is a cooperative game which induces all agents to internalize their benefits. This is referred to as the "privatizing" effect (Murdoch and Sandler, 1986). It is this "privatizing" effect that makes the Lindahl process Pareto-optimal. By imposing the condition of a non-zero determinant on the bordered Hessian, the Lindahl demand functions are:

$$y^{iL} = y^{i}\ (I_i,\ \theta^{i}P_Q,\ P_y;\ E^{i},\ G',\ R'_i)\ ,\qquad i=1,\ldots,n$$

$$Q^{iL} = Q^{i}\ (I_i,\ \theta^{i}P_Q,\ P_y;\ E^{i},\ G',\ R'_i)\ .\qquad i=1,\ldots,n \qquad \text{(II.30)}$$

The general form of these demand functions does not differ from those derived under the pure public good model. As in the earlier case, no structure can be imposed on these technical factors. Using a specific utility function will, however, allow one to ascertain the productivity factors G', and R'_i. The existence of joint-products does not change, in the general specification of the demand function, the exogenous factors that affect demand for agricultural research.

4. Nash-Cournot joint-use good model

The model that we are going to present next follows closely the model developed in Oakland (1969). Such a specification defines the conditions for a Nash-Cournot equilibrium for collectively consumed goods for which the aggregate level of provision is fixed for agents providing the good. These goods were called joint-goods by Oakland. The jointness in consumption of these goods, like other impure public goods, is not complete. However, the distinguishing characteristic of these goods is the fixed aggregate level of the public good. This could be due to allocation of a given amount of funds for that public activity; or the quantity of the good itself is fixed, as in some natural resource. In other cases of public goods, analyzed here or elsewhere in literature, the utility-maximizing problem of the i-th agent can always be defined as choice over the aggregate level of the public good. Oakland, though introducing this concept of goods, failed to include the fixed aggregate level constraint in his derivation of the equilibrium conditions. The additional constraint of fixed aggregate level leads to vastly different normative conclusions, as will be shown in the following section.

We first present Oakland's definition of joint-goods before we formalize our model. A collection of goods $Q^1, Q^2, \ldots Q^n$, which obey the transformation function

$$Q = \sum_{i=1}^{n} Q^i$$

constitute a joint-good if for at least one pair of states s, i, and at least one use i,

$$\delta U^s/\delta Q^i \neq 0 \quad , \quad \delta U^i/\delta Q^i \neq 0 \ ,$$

where U^s and U^i are utility functions of s and i, respectively. Private goods do not satisfy the conditions for a joint-good because $\delta U^s/\delta Q^i = 0$ for all $s \neq i$. That is, consumption by the s-th state of Q does not in any way affect the utility of the i-th state legislature. In the case of pure public goods, on the other hand, for every state legislature the utility function can be represented as $U^j(Q)$, for all j, where $Q = \sum_{i=1}^{n} Q^i$. A change in the provision of Q by the i-th state will affect every other state.

A note on semantics is in order before we formally set-up the model. We refer to the model that follows as the joint-use model whereas Oakland (1969) called it a joint-goods model. We choose to label it differently because we obtain results for the Nash-Cournot model that do not coincide with those obtained by Oakland, and furthermore we augment Oakland's model at a later stage by introducing joint-products along-with joint-use. We do not have a Lindahl specification under joint-use because the aggregate level of the activity is a parameter, given the definition of joint-use. In the Lindahl model, by construction, the various agents cooperate to decide the aggregate level of the public good that they would like to provide. In the joint-use model, on the other hand, the aggregate level of the public good is not a choice variable for the agents.

The basic assumption that distinguishes the joint-use model from the other public goods model (pure and impure) is that the aggregate level of the public good activity is given for the group of states. In our model, the feasible level of agricultural research activity is, then a parameter for each state legislature. Thus, each state maximizes utility subject to this additional constraint. For each unit of the joint-use good demanded, a state loses the spillins that could have resulted from the other states' use of the joint-use good. There are, however, two parts to the spillins lost. One is due to a reduction in the amount of free-riding due to one's own contribution and is similar to the one that occurs in the other public goods model. The second part of spillins lost is due to the fact that the total amount of the public good is fixed. By demanding one unit of the good, the representative state, thus, leaves one unit less for the other states. There are, therefore, two forces that keep a state legislature from demanding the joint-use good. There is the possibility that, at the limit, no state will demand any agricultural research and wait for every other state to provide the good. This, however, will not happen because the jointness in consumption is not complete; there are some benefits of research that are exclusive to the state which is undertaking the research.

We can express the i-th state legislature's utility function as

$$U^i = U^i(y^i, Q^1, \ldots, Q^i, \ldots Q^n)$$

where y^i is the consumption of the private good by the i-th state and Q^i is the joint-use good allocated to the i-th state. As before, we assume the representative state's utility function satisfies all the regularity constraints. Under the Nash model, we make the usual zero conjecture assumption. Summarizing the i-th state's maximization problem as

$$\max_{(y^i, Q^i)} U^i(y^i, Q^1, \ldots, Q^i, \ldots Q^n, E^i)$$

$$\text{subject to} \quad I^i = P_y y^i + P_Q Q^i,$$

$$Q = \sum_{i=1}^{n} Q^{i} , \qquad (II.31)$$

where state i maximizes utility subject to the budget constraint and the joint-use good constraint. In the joint-use constraint Q is the given level of agricultural research activity for the region. We could also interpret Q as the fixed amount of research money available which has to be shared among the various states. The joint-use constraint simply asserts that all the various uses (i.e., allocations) of the joint-use good should sum to the total amount available of the good. We can rewrite the joint-use constraint as

$$Q^{-i} = Q - \sum_{j \neq i}^{n} Q^{j}$$

where Q^{-i} represents the amount of the joint-use good available to all states except the i-th state. It reflects the amount left over for the other states to use once the i-th state has made its optimal choice. We solve the maximization problem in Appendix A. The FOCs that follow can be written in terms of marginal valuations as

$$MRS^{i}_{Qiy} = MRS^{i}_{Q-iy} = P_Q / P_y , \qquad i=1,\ldots,n \qquad (II.32)$$

The FOC in (II.32) implies that every state demands the joint-use good (Q^{in}_{ju}), where Q^{in}_{ju} is a vector of y's and Q's that satisfy the necessary conditions given by Equation (II.32). These optimizing levels are so chosen so as to equate to the price ratio the difference of its marginal valuation of the joint-use good and the marginal valuation of the spillins lost from research not provided by the other states. A comparison with the FOCs obtained under the pure public good model (Equation II.6) shows that the amount equated to the relative price ratio is smaller, if the marginal valuation of the spillins is positive. In the pure public good case, under Nash assumptions, there is no interrelation between the units demanded by the i-th state and the other n-1 states. In the joint-use case, i-th state's demand for research is linked to demand of the other states through the fixed aggregate level constraint - one more unit of agricultural research funds for i-th state implies one less unit for the other n-1 states. The effect of fixed aggregate level of the public good is explored in further detail in the following paragraphs.

By imposing the additional condition that the bordered Hessian associated with the above maximization is strictly positive, we can write the reduced-form demand equations as:

$$y^{in}_{ju} = y^{i}\,(I^{i},\ P_{Q},\ P_{y};\ Q,\ Q^{1},\ldots,Q^{i-1},Q^{i+1},\ldots Q^{n},E^{i}),\qquad i=1,\ldots,n$$

$$Q^{in}_{ju} = Q^{i}\,(I^{i},\ P_{Q},\ P_{y};\ Q,Q^{1},\ldots,Q^{i-1},Q^{i+1},\ldots Q^{n},\ E^{i}).\qquad i=1,\ldots,n \quad \text{(II.33)}$$

The equilibrium amount of agricultural research demanded by state i under joint-use specification is thus a function of the prices, income, the fixed level of the joint-use good, and the (equilibrium) level of demand of all the other n-1 agents. The demand of the other agents captures the spill term for the i-th state. Since the spill term does not appear as part of income, i.e., as full income, the neutrality theorem can not be applied to this model. Similar to other impure specifications in which jointness in consumption is not complete, transfers of income between agents can not be compensated fully by corresponding changes in public godd provision levels.

5. Effect of joint-use constraint on demand for research

It would be interesting to analyze the effect of the additional joint-use constraint on the behavioral rules of the agents. This can be done by contrasting the optimal decision rule with and without the joint-use constraint. The utility function defined for the joint-use case is similar to that for general externality. Hence a comparison of the necessary conditions in these two cases will bring out clearly the effect of having the aggregate quantity of the public good as a parameter.

It has for long been established that in the presence of externalities, in a market economy, the independent adjustment mechanism produces non-Pareto optimal allocations (see for example Cornes and Sandler, 1986). Typically, state legislatures make their optimal decisions based on their personal marginal valuations whereas Pareto optimality requires otherwise. We can make a similar comparison when the good causing the externality is a joint-use good. Our interest then is to ascertain if the degree of suboptimality changes with this different specification. The i-th state's utility function in the presence of externalities is:

$$\max_{\{y^i, Q^i\}} U^i[\, y^i, Q^1, \ldots, Q^i, \ldots Q^n \,]$$

where the consumption of good Q by the i-th state and by all the other n-1 states enters the utility function of the i-th state. Maximizing this utility function subject to the standard budget constraint will yield the following FOCs:

$$MRS^i_{Q^i y} = P_Q / P_y , \quad i=1,\ldots,n \qquad (II.34)$$

Let the optimal quantity associated with (II.34) be denoted as Q^i_x and y^i_x. In contrast, the Pareto allocation requires the fulfillment of the following FOC:

$$MRS^i_{Q^i y} + \sum_{j \neq i}^{n} MRS^j_{Q^j y} = P_Q / P_y , \quad i,j = 1,\ldots,n \qquad (II.35)$$

Solving (II.35) at the Nash demands Q^i_x and y^i_x yields

$$(MRS^i_{Q^i y} - P_Q / P_y) + \sum_{j \neq i}^{n} MRS^j_{Q^j y} > 0 . \qquad (II.36)$$

Since $(MRS^i_{Q^i y} - P_Q / P_y) = 0$ (from II.34), Equation (II.36) implies that the Pareto FOC solved at the Nash demand is positive. That is, the point of a Pareto maximum which requires the FOC to be zero, has still not been attained at the Nash demand level of Q^i_x and y^i_x. Given our assumption of quasiconcave preferences this means that the Pareto optimal provision levels are higher than the Nash levels. That is,

$$Q^{i}_{x} < Q^{i*}_{x} \, , \tag{II.37}$$

where Q^{i*}_{x} is the Pareto efficient demand for the good. Carrying out a similar comparison with a joint-use good will enable us to relate the Nash demands with and without the joint-use constraint and contrast it to the Pareto optimal demand. The Pareto-optimal conditions, as we have seen earlier, remain the same except that they have to hold for each use of the joint good. That is,

$$\sum_{j=1}^{n} MRS^{j}_{Q^{i}y} = P_{Q} / P_{y}, \qquad i = 1,2,\ldots,n \tag{II.38}$$

The solution to the above, Q^{i*}_{x} is same as in the simple externality model. Rewriting the FOC for the joint-use good:

$$MRS^{i}_{Q^{i}y} - MRS^{i}_{Q^{-i}y} = P_{Q} / P_{y}. \tag{II.39}$$

Evaluating (II.39), the Nash FOC for joint-use, at the optimal Nash demand under externalities Q^{i}_{x} and y^{i}_{x} we get:

$$(MRS^{i}_{Q^{i}y} - P_{Q} / P_{y}) - MRS^{i}_{Q^{-i}y} < 0 \, , \tag{II.40}$$

since, at the equilibrium demands, Q^{i}_{x} and y^{i}_{x}, the first term equals zero, from (II.34) and we assume the i-th state to have a positive marginal valuation of the spillins (i.e., $MRS^{i}_{Q-i_y} > 0$). Condition (II.40) implies that the i-th state is not at a point of maximum when it demands Q^{i}_{x}. Further, since (II.40) is negative it implies that the state has surpassed the optimum demand level. This follows again from the assumption of a quasiconcave utility function. Thus optimal demand under the joint-use model Q^{in}_{ju} can be related to that under externalities as:

$$Q^{in}_{ju} < Q^{i}_{x} , \qquad \text{(II.41)}$$

Using (II.37) and (II.41) we can write :

$$Q^{in}_{ju} < Q^{i}_{x} < Q^{i*}_{x} . \qquad \text{(II.42)}$$

Equation (II.42) allows us to conclude that with the additional joint-use constraint the degree of suboptimality increases. A state while making the optimal choice has to appraise the benefits it will lose by demanding some given amount of the joint-use good. This is peculiar to the joint-use specification primarily because the aggregate level of the good is a parameter. In the other models of public goods previously considered, the aggregate level of the public good is not a given quantity to the utility-maximizing state. State legislatures, as we have shown, can be depicted as making their choice over the aggregate amount of the public good. The additional constraint of given amount of the aggregate level of the public good increases the degree of suboptimality in the joint-use model.

The above analysis of the optimal decision rule when the public good is a joint-use good demonstrates that the marginal valuation of the spillins plays a major role in distorting each state's optimal solution away from the Pareto-optimal one. Comparing it to the case of general externality we find that marginal valuation of the spillins, if positive, leads each state to demand fewer units of the good. Given that the independent solution under externality is already suboptimal, we conclude that jointness in consumption increases the suboptimality.

6. Joint-use model with joint products

The joint-use specification as detailed above seems to conform most closely to the situation encountered for the federal funding of agricultural research projects. Decision regarding the amount of funds to be allocated to aggregate agricultural research activity is made at an earlier stage and is exogenous to the optimization process involving individual state's decision on research. Thus, the federal budget is a parameter for all the participating states. Given this, each state determines how much to demand out of the fixed budget. A deciding factor, of course, is their individual valuation of the spillins. Up to this point, however, we have implicitly assumed that the research produced is pure public. Once the research has been produced, it can be used by all the states equally. We can revise this assumption to allow for private and public characteristics to stem from each unit of research. This is the joint-product model that we have discussed earlier. Now along with jointness in production we assume that the marketed good is a joint-use good as well.

The model that follows is similar to the earlier joint-product specification. Hence, most of the relations will simply be stated and not explained in detail. The resulting FOCs and the reduced-form equations will show the effects of the additional joint-use constraint.

The i-th state's maximization problem may be stated as follows:

$$\max_{(y^i, Q^i)} \quad U^i = U^i(y^i,\ g_i(Q^i),\ h_i(Q^i) + m(\tilde{Q}^i),\ E^i)$$

subject to

$$I^i = P_y y^i + P_Q Q^i$$

$$Q = \sum_{i=1}^{n} Q^i \,. \qquad \text{(II.43)}$$

We can rewrite the joint-use constraint as:

$$\tilde{Q}^i = Q - Q^i \,,$$

and substitute this into the utility function in the production of the public good ($\tilde{Z}^i$) to get the utility function as:

$$U^i(y^i,\ g_i(Q^i),\ h_i(Q^i) + m(Q - Q^i),\ E^i). \qquad \text{(II.44)}$$

Maximizing (II.44) with respect to the budget constraint, gives the following FOCs:

$$g'_i \, MRS^i_{xy} + (h'_i - m') \, MRS^i_{zy} = P_Q / P_y \, , \; i=1,\ldots,n. \qquad (II.45)$$

The FOCs show that the i-th state equates to the price ratio its weighted marginal valuation of the private and public aspects of research. The private characteristic resulting from research activity is weighted by the marginal product of the i-th state. The public aspect is weighted by the difference in the marginal productivity of the i-th state and the other n-1 states.

In this model, we have assumed all states except i to have the same aggregate production function, $m(\tilde{Q}^i)$ and hence an aggregate productivity coefficient. Relative productivity plays a major role in the decision process. Productivity of the other state(s) is important because decisions are being made under 'a given level of public good' constraint.

If we assume the bordered Hessian determinant associated with the above maximization to be positive definite, then the reduced-form equations implied by the FOCs are:

$$y^{in} = y^i \, (I_i, \, P_Q \, , P_y, \, Q; \, E^i, \, g'_i, \, h'_i, \, m') \quad i=1,\ldots,n$$

$$Q^{in} = Q^i \, (I_i, \, P_Q \, , P_y, \, Q; \, E^i, \, g'_i, \, h'_i, \, m') \quad i=1,\ldots,n \qquad (II.46)$$

For joint products, i-th state's Nash-Cournot demand for agricultural research, when it is a joint-use good, depends on prices, income, the exogenous level of aggregate public good, the environmental variable, and the technology parameters. Since these technology parameters can not be quantified for a general specification, demand function for joint-use goods, with or without joint products, will be identical in an empirical description of these models. However, if we impose some structure on the production functions we will be able to distinguish between the two specifications.

D. Conclusions

In this chapter, we have derived the reduced-form demand functions for agricultural research when it is alternately modeled as a pure public good and an impure public good. The various models and their associated first-order conditions and demand functions are summarized in Table II.1. The first column in Table 4 lists the utility function and the constraints associated with the maximization process for the specific model being considered. The second column lists the first-order conditions obtained from this maximization; and the third column lists the related reduced-form demand function of this model. The first set of models presented in the Table are the pure public good representations for the Nash-Cournot and the Lindahl allocation schemes. The second set of models belong to the general specification of impure public goods. Under this specification, the Nash-Cournot and Lindahl allocative behavior is studied for the joint product model, and compared to the Pareto allocation. The other impure specification presented is the Nash-Cournot joint-use model - with and without joint products.

A cursory look at Table 4 shows how the general demand functions vary across models. The joint product model under the Nash-Cournot scheme includes full income, prices, spillins, and the environmental variable. The Lindahl scheme, on the other hand, includes income, prices, the tax share, and the environmental variable. Also, the determinants of the pure public good specification form a subset of the determinants of the joint product model. Hence, the pure public good model "nests" within the joint product model. With the aggregate level of public good fixed, as in the joint-use model, the spillin variable is replaced by this fixed aggregate level parameter.

The models discussed in this chapter form a wide array, stretching from the pure public to the impure public good specification, and from cooperative to noncooperative behavior. The next step would be to distinguish between the various models using econometric techniques. Since many models have been examined analytically, only a subset of these are chosen to be fitted empirically. Hence, for empirical purposes, the joint product specification for Nash-Cournot and Lindahl allocation schemes is fitted. As discussed earlier, the pure public specification "nests" within the joint product specification. Thus, fitting the joint product specification implicitly tests for the pure public good specification. The empirical testing of the joint-use model is left for future research.

The next chapter describes the data and empirical specifications of the models that are to be fitted. The construction of variables used in the analysis is described and the problems related to the empirical analysis are investigated. The results of the empirical analysis are presented in Chapter IV.

Table 4. Summary of the models analyzed

Model	First-Order Conditions	Demand Function
I: <u>Pure Public Good Specification</u>		
1. Nash-Cournot		
$U^i(y^i, Q^i, E^i)$ s.t. $F^i = P_y y^i + P_Q Q^i$	$MRS^i_{Qy} = \frac{P_Q}{P_y}$	$Q^i(F^i, P_Q, P_y, E^i)$
2. Lindahl		
$U^i(y^i, Q^i, E^i)$ s.t. $I^i = P_y y^i + \theta^i P_Q Q^i$	$MRS^i_{Q_y} = \frac{\theta^i P_Q}{P_Q}$	$Q^i(I^i, \theta^i P_Q, P_y, E^i)$
II: <u>Impure Public Good Specification</u>		
A. Joint Product		
1A. Nash-Cournot		
$U^i[y^i, g_i(Q^i - Q^i), h_i(Q^i - Q^i) + m(Q^i), E^i]$ s.t. $F^i = P_y y^i + P_Q Q^i$.	$(g_i' MRS^i_{xy} + h' MRS^i_{zy} = \frac{P_Q}{P_y})$	$Q^i(F^i, P_Q, P_y, Q^i, g', h', m', E^i)$.

Table 4. (Continued)

Model	First-Order Conditions	Demand Function
2A. Lindahl		
$U^i[y^i, R_i(Q^i), G(Q^i), E^i]$ s.t. $I^i = P_y y^i + \theta^i P_Q Q^i$	$R'_i MRS^i_{xy} + G' MRS^i_{zy} = \frac{\theta^i P_Q}{P_y}$	$Q^i(I^i, \theta^i P_Q, P_y, R'_i, G, E^i)$.
B. Joint-Use		
1B. Nash-Cournot Joint-Use		
$U^i(y^i, Q', \ldots, Q^i, \ldots, Q^n, E^i)$ s.t. $I^i = P_y y^i + P_Q Q^i$ $Q = \sum_{i=1}^{n} Q^i$	$MRS^i_{Q^i y} = MRS^i_{Q-iy}$	$Q^i(I^i, P_Q, P_y, Q, E^i)$.
2B: Nash-Cournot Joint-Use and Joint Product		
$U^i[y^i, g_i(Q^i), h_i(Q^i) + m(Q^i), E^i]$ s.t. $I^i = P_y y^i + P_Q Q^i$ $Q^{-i} = Q - Q^i$	$g'_i MRS^i_{xy} + (h' - m') MRS^i_{zy} = \frac{P_Q}{P_y}$	$Q^i(I^i, P_Q, P_y, Q, g'_i, h'_i, m', E^i)$.

III. THE ECONOMETRIC SPECIFICATION

This chapter describes the empirical specification of the reduced-form demand functions derived in the previous chapter. These demand functions are fitted using U.S. data from the 48 contiguous states. State legislative decisions are analyzed under the Nash-Cournot allocation equilibrium and the Lindahl equilibrium. A number of alternative models of decision-making were analyzed in Chapter II. For empirical purposes, however, only the joint product specification is fitted, for both the Nash-Cournot and the Lindahl equilibrium. The joint product specification is fitted mainly for two reasons; first, the pure public good model "nests" in the more general joint product model, hence fitting the joint product model implies testing for the pure public specification as well. Secondly, empirical analysis of the joint-use model requires data on funds allocated to various regions (regions defined in terms of geoclimate considerations). Data on agricultural research is not so well disaggregated to allow one to identify funds allocated to the various regions for research. Hence, empirical testing of the joint-use model cannot be undertaken at this time.

The first section of this chapter lays out the empirical specification of the joint product model under the Nash-Cournot and the Lindahl equilibrium concepts. Empirical measures of the various factors that affect demand for research are described. We also look at the related problems of empirical specification and how they can be eliminated.

Finally, the data sources and a brief description of the variables is given.

A. Econometric Models

1. Nash-Cournot Models

Two versions of the Nash-Cournot models of state government decisions on demand for agricultural research are considered. They are the pure public goods model which has a general aggregate demand function of Equation (II.7) and the joint products model which has the general specification in Equation (II.24).

Some of the differences in arriving at an empirical specification of Nash-Cournot models can be seen by considering the following demand equation for agricultural research:

$$\ln Q_t^r = a_{0i} + a_{1i} \ln P_t + a_{2i} \ln F_{it}^r + a_{3i} \ln SP1LL_{it}^r + e_{it}^r \qquad \text{(III.1)}$$

where Q_t^r is the total quantity of public agricultural rsearch demanded by all states i $(i=1,\ldots,n_r)$ in region r $(r=1,\ldots,R)$ in year t $(t=1,\ldots,T)$, P_t is the relative price of public agricultural research in t, F_{it}^r is full income of state i in region r in year t, and $SP1LL_{it}^r$ is the potential spillin of public agricultural research from other states in region r to state i during t; and e_{it}^r is a random error term. The a_{ji}s are the unknown coefficients.

The issues involved in the empirical specification of these models are

(i) the functional form, (ii) the randomness of full income (F_{it}^{r}) and the spillin ($SPILL_{it}^{r}$) variables and their correlation with e_{it}^{r}, and (iii) autocorrelation of e_{it}^{r}s. Although a little experimenting was done with a strictly linear form, the log-linear form generally performed better. It has estimated coefficients that are elasticities and it facilitates performing some of the tests between models.

To see the randomness and the potential simultaneity in Equation (III.1), we examine more carefully the definitions of Q_{t}^{r}, $SPILL_{it}^{r}$, and F_{it}^{r}. The total quantity of research demanded in region r is

$$Q_{t}^{r} = \sum_{i=1}^{n_r} q_{it}^{r} , \qquad \text{(III.2)}$$

where q_{it}^{r} is the quantity demanded by state i in region r during year t. The research available for potentially spilling into state i in region r during year t is

$$SPILL_{it}^{r} = \sum_{l \neq i}^{n_r} q_{lt}^{r} . \qquad \text{(III.3)}$$

The full income of state i in region r is

$$F_{it}^{r} = I_{it}^{r} + SPILL_{it}^{r} = I_{it}^{r} + \sum_{l \neq i}^{n_r} q_{lt}^{r} , \qquad \text{(III.4)}$$

where I_{it}^{r} is the government revenue of state i in region r during year t. Now Equations (III.2), (III.3), and (III.4) contain common variables; they are q^r_{it}s. These q^r_{it}s are the quantities of research demanded by the state in region r. They contain a random component which is the primary source of randomness for Q^r_t and imparts randomness to $SPILL^r_{it}$ and F^r_{it}. Thus, $SPILL^r_{it}$ and F^r_{it} cannot be taken as exogenous in Equation (III.1). This is the classic multi-agent problem in which each state demand function represents a separate response function, but the outcome of each state is constrained by the equilibrium condition that the total level of agricultural research for the region be the same for all the states in the rgion. This interdependence introduces a randomness in the variables $SPILL^r_{it}$ and F^r_{it} on the right-hand side of the demand equation. Specifically, $SPILL^r_{it}$ and F^r_{it} are correlated with e^r_{it}.

An instrumental variable solution to the simultaneity problem is contained in the following model:

$$\ln Q^r_t = a_{0i} + a_{1i} \ln P_t + a_{2i} \ln F^r_{it} + a_{3i} \ln SPILL^r_{it} + e^r_{it} \qquad \text{(III.5)}$$

$$\ln SPILL^r_{it} = \beta_{0i} + \sum_{1\neq i}^{n_r} \beta_{11} \ln I^r_{1t} + \beta_2 1 \ln P_t + \omega_{it} \qquad \text{(III.6)}$$

$$\ln F^r_{it} = {}_0 + \sum_{k=1} \Omega_{1k} \ln I_{kt} + \Omega_2 \ln P_t + \varsigma_{it} \qquad \text{(III.7)}$$

where e^r_{it}, ω_{it}, and ς_{it} are random disturbance terms. Here the instruments used to predict $SPILL^r_{it}$ and F^r_{it} are the government revenues of all the states in the region (I^r_{1t}) and the relative price of agricultural research (P_t). This solution assumes that the $\ln I^r_{1t}$s and $\ln P_t$ are uncorrelated with e^r_{it}.

When Equations (III.5), (III.6), and (III.7) are fitted to annual data, the random disturbance terms e^r_{it}, ω_{it}, and ς_{it} seem likely to be autocorrelated. However, the assumption that is made here is that e^r_{it} has a first-order autocorrelation process, $e^r_{it} = \rho_i e^r_{it-1} + u^r_{it}$ where $Eu^r_{it} = 0$, and $E[u^r_{it}]^2 = \sigma^2$. The possible autocorrelation of ω_{it} and ς_{it} will be ignored. The autocorrelation of these disturbances will not affect the consistency of the estimated parameters in the demand equation.

The procedure for estimating Equations (III.5), (III.6) and (III.7) is as follows. First, a test of the null hypothesis that $\rho_i = 0$ (vs $\rho_i \neq 0$) is performed using the Durbin-Watson statistic. The Durbin-Watson test statistic is used to detect first-order autocorrelation. It is defined as

$$d = \frac{\sum_{t=1}^{n-1} (\hat{e}_t - \hat{e}_{t-1})^2}{\sum_{t=1}^{n} \hat{e}_t^2} .$$

When the hypothesis is not rejected, then Equations (III.5), (III.6), and (III.7) are to be estimated by two-stage least squares. When the null hypothesis that $\rho_i = 0$ is rejected, then Equation (III.5) is transformed as follows using the estimated value of ρ_i, that is, $\hat{\rho}_i$:

$$\ln Q^r_t - \hat{\rho}_i \ln Q^r_{t-1} = a_{0i}(1 - \hat{\rho}_i) + a_{1i} (\ln P_t - \hat{\rho}_i \ln P_{t-1})$$

$$+ a_{2i} (\ln \hat{F}^r_{it} - \hat{\rho}_i \ln \hat{F}^r_{it-1})$$

$$+ a_{3i} (\ln \hat{SPILL}^r_{it} - \hat{\rho}_i \ln \hat{SPILL}^r_{it-1}) + \nu^*_{it} , \qquad \text{(III.8)}$$

where $\nu^*_{it} = e^r_{it} - \hat{\rho}_i e^r_{it-1}$. Thus, when $\hat{\rho}_i$ is significantly different from zero, Equations (III.6), (III.7) and (III.8) are fitted by two-stage least squares.

We have some prior exceptation about the signs of the coefficients of the empirical demand function for public agricultural research. We except, based on economic theory, that the own-price elasticity of demand (a_{1i}) is negative. Earlier studied on demand for agricultural research do not use any price data, hence there are no estimates from previous studied that will refute or support our results. However, economic theory would suggest own price effects to be negatively related to demand for that good.

The full income elasticity of demand for public agricultural research (a_{2i}) could be positive or negative. Earlier studies do not use a public goods approach, hence their estimates on income elasticity are different from estimates obtained in this study. The estimates obtained here are elasticity measures on full income, which includes cash income and the level of spillins. Elasticity estimates from earlier studies measure the responsiveness to the cash income alone. Thus, these measures are partial measures compared to the elasticity measures obtained here. However, the earlier studies can give us some idea about the direction of this measure. Huffman and Miranowski (1981) and Evenson and Rose-Ackerman (1985) obtain positive income elasticities for demand for agricultural research. Based upon these studies, and the sign and magnitude of the spillin term which makes the other part of the full income elasticity measure, we do except a positive income elasticity of demand for agricultural research. If this elasticity is positive then public agricultural research is a normal good.

The coefficient on the spillin variable (a_{3i}) is of special interest in the demand function. If it is significantly different from zero, then the joint product model of agricultural research provides a significantly better explanation of demand for public agricultural research by the states than the pure public good model of agricultural research. Crop research in particular seems to produce some goods that are specific to a state performing research. These are the private goods produced from research, as described in the theoretical model. The goods produced from livestock research seem to be less geoclimatic specific and hence are likely to spill more freely to other states. These are the public goods produced by agricultural research. Because this study aggregates crop and livestock research expenditures together, we expect the joint product model to be a better explanation of demand for agricultural research than the pure public good model, i.e., the expectation is that a_{3i} will be significantly different from zero.

The sign of the spillin term depends on two parts as is explained below. The overall effect of change in spillins on demand may be split as:

$$\delta\, Q_t^r \,/\, \delta \ln SPILL_{it}^r = \delta\, q_t^i \,/\, \delta \ln SPILL_{it}^r + 1 \,.$$

Thus, the total effect of a change in spillins on demand for research depends on change in state's own demand for research plus 1. The first part, $\delta q^{i}_{t} / \delta \ln SPILL^{r}_{it}$, is greater than minus 1 for normal goods (Cornes and Sandler, 1986). Therefore, the total effect will be positive if the private good produced by agricultural research is a normal good or if the public and private goods produced by input of public agricultural research are strong complements.

2. Lindahl Model

In Chapter II, Equation (II.11) is the general form of the demand function for public agricultural research under the Lindahl model. The empirical specification of this model is as follows:

$$\ln Q^{r}_{t} = a^{*}_{0i} + a_{4i} \ln I_{it} + a_{5i} (\ln P_{t} + \ln \theta^{r}_{it}) + \varsigma^{r}_{it} \qquad \text{(III.9)}$$

$$(\ln P_{t} + \ln \theta^{r}_{it}) = \delta^{*}_{0i} + \sum_{l \neq i}^{n_r} \delta^{*}_{li} \ln I^{r}_{lt} + \delta^{*}_{i} \ln P_{t} + \psi^{r}_{it} \qquad \text{(III.10)}$$

where $\theta^{r}_{it} = P_{t} q^{r}_{it} / P_{t} Q^{r}_{t}$ is the share by state i of the total cost of public agricultural research in region r, and ς^{r}_{it} and ψ^{r}_{it} are the random disturbance terms.

The reasons for the particular empirical specification of the Lindahl model chosen in Equations (III.9) and (III.10) are basically the same as for the Nash-Cournot specification in Equations (III.5), (III.6) and (III.7). The log- linear model has estimated parameters that are elasticities and it facilitates some of the model testing that is carried out later. The cost share θ_{i} is a function of Q^{r}_{t} and q^{r}_{it} which are random and likely to be correlated with ς^r_{it}. This is the reason for Equation (III.10) which uses ln I^r_{1t} and ln P_t as instruments to predict (ln P_t + ln θ^r_{it}). Although the random disturbance terms ς^r_{it} and ψ^r_{it} seem likely to be correlated in annual data, only ς^r_{it} is examined for autocorrelation, $\varsigma^r_{it} = \rho^*_i \varsigma^r_{it-1} + u^*_{it}$.

The procedure for estimating Equations (III.9) and (III.10) is as follows. First, a test of the null hypothesis that $\rho^*_i = 0$ (vs $\rho^*_i \neq 0$) is performed. Where this hypothesis is not rejected, Equations (III.9) and (III.10) are estimated by two-stage least squares. When the null hypothesis that $\rho^*_i = 0$ is rejected, then Equation (III.9) is transformed as follows, using the estimated value of ρ^*_i, that is $\hat{\rho}^*_i$:

$$\ln Q^r_t - \hat{\rho}^*_i \ln Q^r_{t-1} = a^*_{0i} (1 - \hat{\rho}^*_i) + a_{4i} (\ln I^r_{it} - \hat{\rho}^*_i \ln I^r_{it-1})$$

$$+ a_{5i} (\ln P_t + \ln \theta^r_{it} - \hat{\rho}^*_i \ln P_{t-1} - \hat{\rho}^*_i \ln \theta^r_{it-1} + u^*_{it} \qquad \text{(III.11)}$$

Thus, when $\hat{\rho}^*_i$ is significantly different from zero, Equations (III.10) and (III.11) are fitted by two-stage least squares.

The coefficients of demand are of primary interest. Based upon the empirical results reported by others, a_{4i} is expected to be positive. Hence, agricultural research is a normal good. The coefficient a_{5i} is excepted to be negative. Holding θ^r_{it} constant, a high price is excepted to reduce the quantity of agricultural research that is demanded. Similarly, holding P_t constant, a large cost share is also expected to reduce the amount of agricultural research demanded. The cost share term is what individualizes the price of agricultural research for each state in the Lindahl model.

B. Distinguishing Between the Nash-Cournot and Lindahl Models

Both the Nash-Cournot and Lindahl models provide possible explanations for state government decisions on public agricultural research. A reasonable question to ask is which model provides the best explanation. A natural approach to the testing of a particular specification of interest is to embed it in some general model in such a way that the former model can be derived from the latter by imposing a set of parametric restrictions. The adequacy of the tentatively entertained null model can then be assessed by checking whether these restrictions are consistent with sample data. The null hypothesis is accordingly identified with these parametric restrictions.

However, in our case the alternative is fully specified and does not contain the null model as a special case; that is, it can not be derived from the null model by any parametric restrictions. This is because although Equations (III.5) and (III.9) have the same specification of the dependent variable, the regressors are different. Testing of such models is referred to in the literature as "nonnested" testing. Broadly speaking, two models are said to be nonnested if neither can be obtained from the other by the imposition of appropriate parametric restrictions or as a limit of a suitable approximation (Pesaran 1987). Nonnested models can arise from differences in the underlying theoretical paradigms or from differences in the way a particular relationship suggested by economic theory is modelled. Examples of nonnested testing abound in the literature: money demand functions (McAleer, Fisher and Volker, 1982), empirical models of exchange rate determination (Backus, 1984), Keynesian and new classical models of unemployment (Pesaran, 1982a).

Many checks of model adequacy have been derived as Lagrange multiplier tests by viewing the model under scrutiny as being a special case of a more general specification. While it is clear that these checks are helpful, a poor choice of alternative hypothesis may lead to a low probability of rejecting an inadequate hypothesis. In such cases, it is necessary to check models against each other and use these competing models to provide information about each other (Hendry and Richard, 1983, Davidson et al., 1978, Pesaran, 1982b). Tests of nonnested alternatives are, therefore, important.

The two demand functions derived from the Nash and Lindahl specification are not nested (i.e., no one model is a more general specification of any other model), hence it is not possible to use common tests based on the F statistic or the liklihood ratio. It is possible, however, to test among these nonnested models by using the J-test suggested by Davidson and Mackinnon (1981).

Davidson and Mackinnon consider the case of the single equation model, the truth of which we wish to determine. This represents our null hypothesis:

$$H_0 : y_t = f(X_t, \beta) + e_{0t} \quad \text{(III.12)}$$

where y is the dependent variable, X is the matrix of independent variables, β is a vector of parameters to be estimated and e_{0t} is the error term which is assumed to be independent and identically distributed. The alternative model is posed as the alternative hypothesis:

$$H_1 : y_t = g(S_t, \phi) + e_{1t} \quad \text{(III.13)}$$

where S is a matrix of exogenous variables, ϕ is a vector of parameters and e_{1t} is the error term which is independent and identically distributed. To test the alternative specification we construct a compound model that is a weighted average of the two competing models. That is:

$$H_c : y_t = (1-\Omega) f(X_t, \beta) + \Omega g(S_t, \phi) + \xi_{it}. \quad \text{(III.14)}$$

By itself this model is not very useful, since β, ϕ , and Ω are not identifiable. Davidson and Mackinnon suggest that if ϕ is replaced by its least squares estimate, the t-statistic on Ω is asymptotically N(0,1) when H0 is true. This is called the J-test because β and Ω are being estimated jointly.

By combining Equations (III.5) and (III.9) together we can make a compound model for testing the Nash-Cournot specification in the following way:

$$\ln Q_t^r = a_{0i} (1 - \Omega) + a_{1i} (1 - \Omega) \ln P_t + a_{3i} (1- \Omega) \ln \hat{F}_{it}^r$$

$$+ a_{4i} (1 - \Omega) \quad \hat{SPILL}_{it}^{r} + a_{5i} \Omega \ln Q_t^{rL} + \upsilon_{it} , \qquad \text{(III.15)}$$

where $\ln Q_t^{rL}$ is the predicted value from the Lindahl model obtained from fitting Equation (III.9) by least squares, and Ω is the weight given to the predicted value from the Lindahl model.

The above test assumes that the right-hand side variables are contemporaneously uncorrelated with errors of the model. They also assume that the errors are serially uncorrelated. Our demand models, however, exhibit contemporaneous correlation between the independent variables and the error term and also that the errors are serially correlated.

These issues have been addressed in literature, though separetely. Davidson and Mackinnon (1981) address the issue of correlation between the right-hand side variables and the error term. They show how the test can be adapted to handle models estimated by two stage least squares. Assuming the two competing models to be linear, they show that if there exists a matrix of instruments with the usual properties then the two stage least squares J test involves estimating the combined model given in Equation (III.14) by two stage least squares.

This test procedure assumes that both competing hypotheses specify the same set of instruments. This assumption is somewhat restrictive but is needed to identify the effect of different specifications. With different instruments the J test results might depend on which instruments were associated with each hypotheses, rather than on the specification of H0 and H1.

The issue of testing alternative hypothesis for time-series data is developed in Bernake et al. (1988). Under H0, with a first-order autoregressive scheme, Equation (IV.1) becomes

$$y_t = f(X_t, \beta) + e_{0t} ,$$

where $$e_{0t} = \rho\, e_{0t-1} + \vartheta_t ,$$

and ϑ_t is white noise. The equation for the compound model is

$$y_t = \rho\, y_{t-1}\, f(X_t - \rho\, X_{t-1}), \beta + \Omega\, \hat{g}\, (Z_t, \phi) + \zeta_t, \qquad \text{(III.16)}$$

where $\hat{g}\, (Z_t, \phi) = g(Z_t, \hat{\phi}\,)$ and $\hat{\phi}$ is the maximum liklihood estimator of ϕ obtained from the following first-order autocorrelation transformed equation

$$y_t = \rho_1\, y_{t-1}\, g(Z_t - \rho_1\, Z_{t-1}, \phi\,) + e_{1t} .$$

We correct for autocorrelation in the estimation of ϕ, but we did not use the autogressive structure to calculate the predicted value of $\hat{g}\, (Z_t, \hat{\phi}\,)$. The idea is to get efficiency in the estimation of ϕ, but not to include the autoregressive structure in the prediction of $\hat{g}$. This is because imposing the autoregressive structure to predict might result in a significant estimate of Ω, and not reflect the true prediction of g as a function of its regressors.

In our model, then, we bring together the modifications to the J test to account for the contemporaneous correlation between the errors and the regressors and the serial correlation of the errors. There are a number of ways in which the J statistic may be modified. We look at two possible methods. In the first method[1] (called JI), the predicted value from the competing model is corrected for autocorrelation by the correlation coefficient of the other model. That is, if the first model has significant autocorrelation then all the regressors, including the predicted value from the competing model, are corrected for autocorrelation. In the second method[2] (called JII), the predicted values are not corrected for autocorrelation. The results from JII will be presented here while those from JI will be presented in Appendix C.

Thus for our case we make a combined model for the Nash-Cournot and the Lindahl models. There will be two such combined models. The first combined model retains the Nash-Cournot structure and test the predictive power of the Lindahl model. This is the specification given in Equation (III.15). In the second combined model, we retain the Lindahl structure and test the additional information provided by the Nash-Cournot model. With autocorrelation, however, the equation has to be redefined by

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[1]The methodology of this test grew out of discussions with Wayne Fuller, Iowa State University, Ames, Iowa.

[2]This method is a result of discussions with Wallace Huffman, Todd Sandler, Iowa State University, Ames, Iowa, and James Murdoch, Auburn University, Montgomery, Alabama, respectively.

transforming the variables. The compound model, in the presence of correlated disturbances, becomes:

$$\ln Q_t^r = a_{0i} + a_{1i}\,(1 - \Omega)(\,1 - \hat{\rho}_i^*\,) + a_{2i}\,\hat{\rho}_i^*\,(\ln Q_{t-1}^r)$$

$$a_{3i}\,(1 - \Omega)\,(\ln P_t - \hat{\rho}_i^*\,\ln P_{t-1}\,)$$

$$+ a_{4i}\,(\,1- \Omega)\,(\ln \hat{F}_{it}^r - \hat{\rho}_i^*\,\ln \hat{F}_{it-i}^r)$$

$$+ a_{5i}(1 - \Omega)\,(\ln \hat{SPILL}_{it}^r\,\hat{\rho}_i^*\,\ln \hat{SPILL}_{it-1}^r\,)$$

$$+ a_{5i}\,\Omega\,\ln Q_t^{rL} + \upsilon_{it}\,, \qquad \text{(III.17)}$$

where $\hat{\rho}_i^*$ is the predicted value of the autocorrelation coefficient.

The J test, thus, consists of testing the hypothesis of the predicted values from the competing model. This procedure is outlined below.

Hypothesis 1

Maintain the Nash-Cournot joint product model.

This hypothesis can be tested by the following linear restriction:

$$H1_0 : Q_t^{rL} = 0\,,$$
$$H1_A : Q_t^{rL} \neq 0\,, \quad \text{for each } i.$$

Under hypothesis 1, the predicted value from the Lindahl model should have little statistical significance in the joint product model. Failure to reject $H1_0$ provides support for Nash behavior.

The methodology of the test is as follows: from the estimate of demand Equations (III.6) and (III.11) the predicted values of ln Q^{rp}_t is obtained from the Nash-Cournot and Lindahl models. Then the combined model is specified for each state in the region, which is a linear combinition of the the model to be tested and the predicted value from the other model. That is, the first combined model is a linear combinition of the Nash model and the predicted value from the Lindahl model; the second is the linear combinition of the Lindahl model and the predicted value from the Nash model. If significant autocorrelation is detected in the Nash model then all variables, except the predicted value from the Lindahl model Q^{rL}_t, are corrected for autocorrelation and the equation is refitted.

Hypothesis 2

Maintain the Lindahl model. This specification can be tested by the following linear restriction:

$$H2_0 : Q^{rN}_t = 0 ,$$
$$H2_A : Q^{rN}_t \neq 0 , \quad \text{for each i.}$$

Under hypothesis 2, we do not expect the predicted values of In Q^r_t from the Nash model to be significant. If the Lindahl model shows evidence of autocorrelation all the variables of the combined model are transformed.

We present the results of the J test in the next chapter. Before that, however, we present a brief description of the data and variables used in the estimation of these models.

C. Data

The empirical analysis uses annual U.S. data for the 48 contiguous states. Data were obtained primarily from USDA-CSRS reports and the Statistical Abstract (several years) of the United States. Variables specific to a certain model have been defined in section A while discussing the empirical specification of the models. In this section we define variables that are common to all the models analyzed in this chapter.

3. Quantity of Agricultural Research

The quantity of agricultural research is derived by dividing expenditures on research by the price for agricultural research. Thus,

$$q^i = \text{Expenditure}_i \,/\, P_Q \,,$$

where

q^i = the quantity of state agriculture experiment station research undertaken by state i,

P_Q = price of agricultural research,

Expenditure_i = expenditures on state experiment station research by state i.

The expenditure data are obtained from Funds for Research in State Agricultural Experiment Stations and Other State Institution, for 1951-1966, and Inventory of Agricultural Research, for 1967-1982. The growth of expenditures for all the states are reported in Table 5. The mean growth rate of expenditures for the U.S. as a whole over the period 1951-1982 was 8.6 percent. The mean expenditure for each state as a percent of the region total (regions being defined in terms of geoclimatic considerations) varies widely across states. State government expenditures on agricultural reesearch vary from 10 percent for Maryland to 48 percent for New York, in the Northeast region. A similar pattern holds for other regions (Table 5). This shows that we have quite disparate players in the regions, who could be characterized as small and major players. Demand decisions for agricultural research may vary between such diverse players.

4. Price of Agricultural Research

A price index for agricultural research should capture the costs of inputs into research, which includes cost of scientists' time and other inputs. Single price indices based on the implicit GDP deflator are usually used to proxy the price of agricultural research. However, an index that covers all the components of research expenditures is important if it is to depict the price of research accurately. A base weighted (Laspeyres) index is acceptable only as long as there are no significant shifts in the composition of research expenditures. Research expenditures

Table 5. State agricultural research expenditures, 1951-1982

Region/State	Growth of Research Expenditure (per annum)	Mean Research Expenditure (million $)	Mean Expenditure as percent of the region total
Northeast			
New York	7.9%	15	48%
New Jersey	6.9%	6	18%
Maryland	8.2%	3	10%
Pennsylvania	7.9%	7	21%
Delaware	7.6%	1	4%
Appalachian			
Kentucky	8.6%	5	16%
Virginia	10.4%	7	23%
West Virginia	6.0%	2	7%
Tennessee	9.0%	5	17%
North Carolina	10.0%	12	38%
Lake			
Minnesota	8.7%	9	33%
Wisconsin	8.6%	10	36%
Michigan	9.0%	9	32%
Southeast			
Alabama	0.7%	12	30%
Georgia	13.1%	10	24%
South Carolina	8.5%	4	11%
Florida	9.5%	15	36%
Corn Belt			
Iowa	8.0%	9	22%
Illinois	7.0%	8	19%
Indiana	8.5%	9	23%
Ohio	7.5%	8	19%
Missouri	10.0%	7	17%

Table 5. (Continued)

Region/State	Growth of Research Expenditure (per annum)	Mean Research Expenditure (million $)	Mean Expenditure as percent of the region total
Northern Plains			
North Dakota	9.8%	5	19%
South Dakota	9.3%	3	13%
Nebraska	10.0%	9	36%
Kansas	11.0%	8	32%
Mountains			
Montana	8.0%	4	14%
Utah	10.0%	3	11%
Nevada	10.0%	2	5%
Idaho	9.0%	3	12%
Colorado	13.0%	6	23%
New Mexico	8.4%	2	7%
Arizona	10.5%	5	20%
Wyoming	7.5%	2	7%
Delta			
Arkansas	10.0%	6	28%
Mississippi	9.0%	7	31%
Lousiana	10.0%	9	41%
Southern Plains			
Oklahoma	6.9%	5	20%
Texas	8.8%	19	80%
Pacific			
Washington	7.5%	8	17%
Oregon	8.4%	8	17%
California	9.4%	31	66%

have, however, undergone a major shift in emphasis over time, with the proportion of total expenditures going to capital rather than non-capital goods increasing steadily. Pardey et al. (1987) have shown that using the common price indices - the implicit GDP deflator, an index of university teacher salaries, and the fixed weight deflator - grossly underestimates state government expenditures on research. In this study we use the Huffman-Evenson (1988) index, which is a weighted average of an index of salaries of college and university faculty members (70%) (American Association of University Professors, various years) and the wholesale price index (30%) (Executive Office of the President, 1987), was used in the analysis. The weights between faculty salaries and other items represent the 1951-1982 period well. The wholesale price index represents prices of items that do not have a large labor cost share. The set of goods included in the index, however, is broader than the set of nonscientist goods purchased by agricultural experiment stations.

5. Price of private good

The price index representing the composite private good (P_y) is the implicit GDP deflator for goods and services purchased by state and local governments obtained from Statistical Abstract and Historical Statistics (U.S. Department of Commerce, several years). The index is not perfect because it includes state government expenditures on agricultural research. Since these expenditures are less than 1 percent of total state government expenditures, the price index for P_y covers primarily the nonresearch goods and services. The price of private good will be used to normalize all the variables of the demand equation.

6. State Revenues

State government revenues are total state government revenues, including the intergovernmental transfers (Statistical Abstract, various years).

7. Environmental Variables

The environmental variable should capture the effect of geoclimatic conditions on demand for research by each state. This could be achieved by using dummy variables to denote the geo-climate specificities. However, working in a public good framework, state legislatures are assumed to operate in a regional setting in which they take into account the amount of net spills from other states within the same geoclimatic region. Hence, the effect of geoclimate conditions is captured indirectly through a spill term. Including an explicit environmental variable should measure only the effect of geoclimate considerations that have not been included in the spill term. Since the data are not so well disaggregated we do not have a measure for this (partial) environmental variable. The environmental variable is, nevertheless, included in the analysis to show that differing climate conditions will affect demand for research. Related to these differing climate and soil conditions is the relative importance of the agricultural sector in that state's economy. That is, favorable climate conditions imply a relatively large agricultural sector in the state. Thus, the environmental variable that appears in the models includes "all the other factors" that affect demand for research.

A grouping of states into regions is, therefore, important for defining the spillin variable. The 48 states are grouped into regions so that states in a region have similar geoclimate conditions. Two different types of classification schemes are used. States grouped into USDA's Econommic Research Service (ERS) production regions is one possible grouping where similar production conditions occur (Figure 1). This grouping has the advantage of being confined to state boundaries and fits well into the framework of state legislative decision making. There are eight ERS production regions: Northeast, Appalachian, Lake, Southeast, Corn Belt, Northern Plains, Mountain, Delta, Southern Plains, and Pacific. For a list of the states in each of these regions see Table 6. With the ERS grouping, however, some regions include only two or three states. This would suggest that to make production region boundaries to coincide with state boundaries, parts of some states that have similar geoclimate conditions, were not included.

Consequently, another classification scheme based on the 1957 Yearbook of Agriculture with a system of sixteen geoclimate regions including thirty- four subregions was used (Figure 2). This groups relatively close geoclimate neighbors and less-close neighbors. This categorization is based on geoclimate considerations alone and does not follow state boundaries, so that a state could be located in two or more regions. In our application of this classification, all states in a region that have

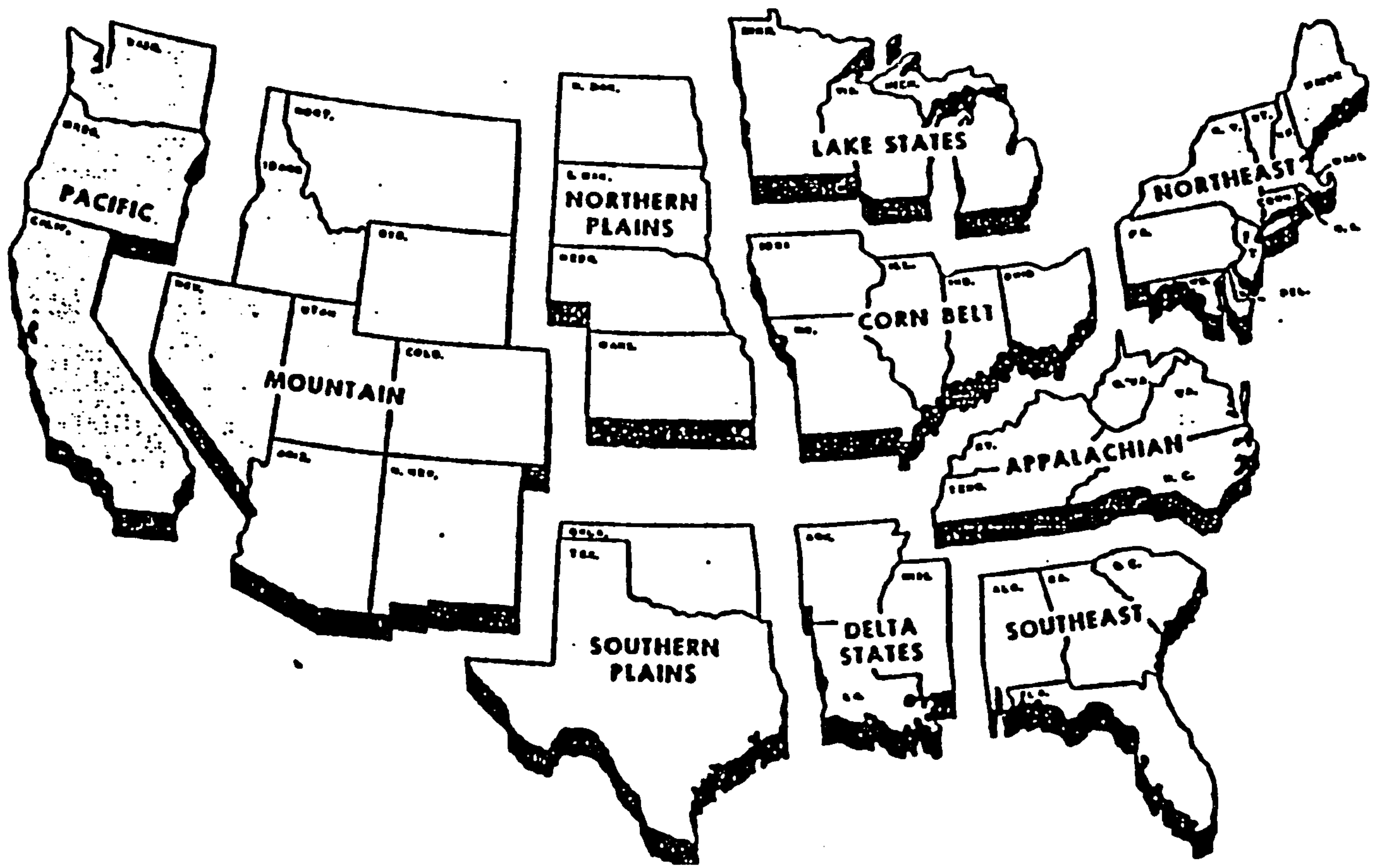

Figure 1. ERS Production Regions (USDA-CSRS, Inventory of Agricultural Research)

Table 6. List of states in the ERS production regions

Region	States	Region	States
Northeast	New York New Jersey Maryland Pennsylvania Delaware	Northern Plains	North Dakota South Dakota Nebraska Kansas
Appalachian	Kentucky Virginia West Virginia Tennessee North Carolina	Mountains	Montana Utah Nevada Idaho Colorado New Mexico Arizona Wyoming
Lake States	Minnesota Wisconsin Michigan	Delta	Arkansas Mississippi Louisiana
Southeast	Alabama Georgia South Carolina Florida	Southern Plains	Oklahoma Texas
Corn Belt	Iowa Illinois Indiana Ohio Missouri	Pacific	Washington Oregon California

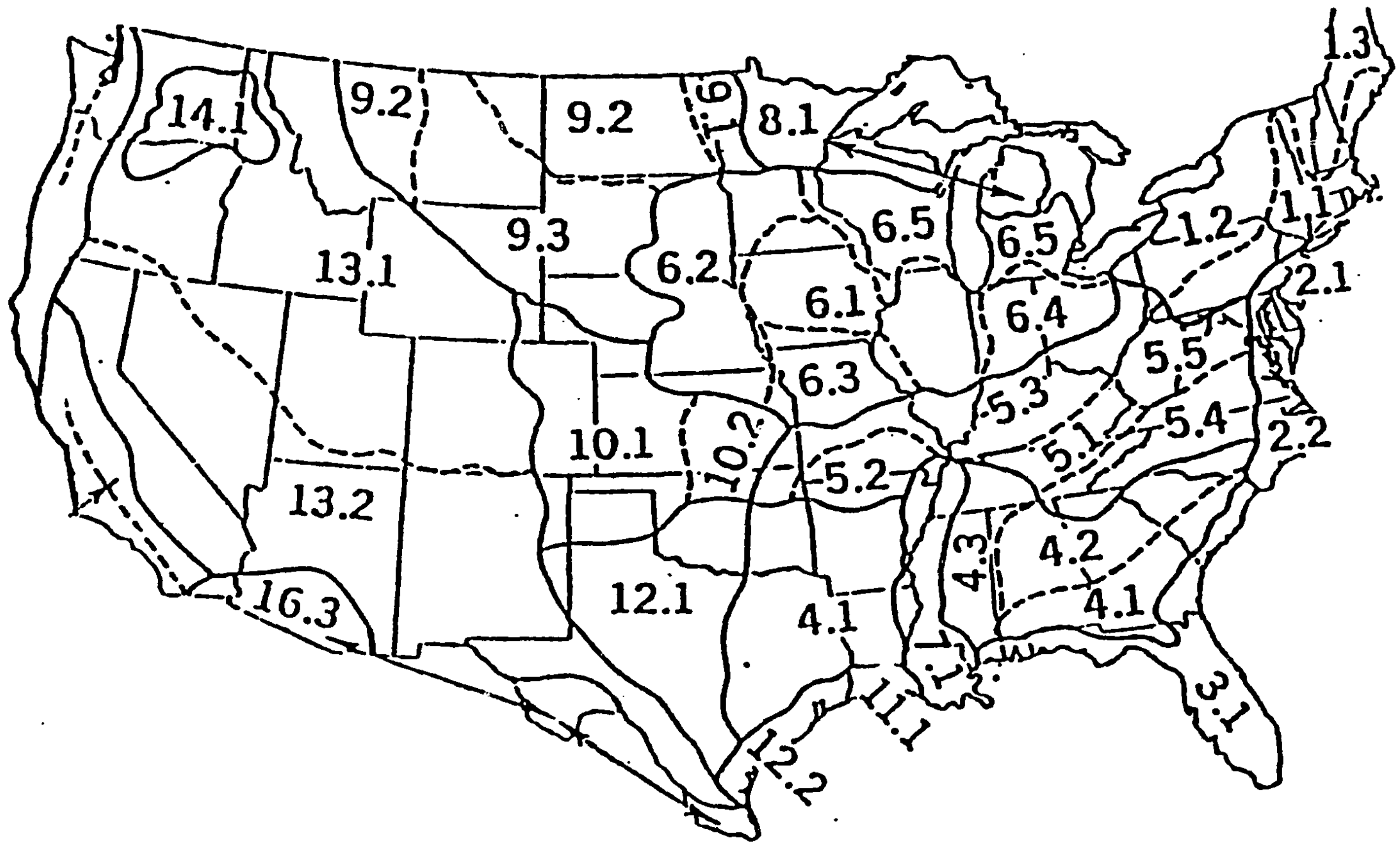

Figure 2. Geoclimatic Regions (USDA, Yearbook of Agriculture, 1957)

Table 7. List of states in the Geoclimatic regions

Upper Central Region	
Illinois	Missouri
Indiana	Nebraska
Iowa	Ohio
Kansas	South Dakota
Michigan	Wisconsin
Minnesota	
South and East-Central Uplands	
Arkansas	Missouri
Alabama	New Mexico
Florida	North Carolina
Georgia	Ohio
Illinois	Oklahoma
Indiana	South Carolina
Kansas	Tennessee
Kentucky	Texas
Louisiana	Virginia
Mississippi	
West	
Arizona	New Mexico
California	North Dakota
Colorado	Oklahoma
Idaho	Oregon
Kansas	South Dakota
Minnesota	Texas
Montana	Utah
Nebraska	Washington
Nevada	Wyoming
Northeast	
Connecticut	New Jersey
Delaware	New York
Maine	Pennsylvania
Maryland	Rhode Island
Massachusetts	Vermont
New Hampshire	

any part included in the region are counted in that region. This means in some cases a particular state is included in more than one of the regional grouping of states.

This classification scheme has several regions and subregions. Again, some of the regions are very small. For empirical purposes, we grouped together regions that were geographically close, on the assumption that if the regions are close they have somewhat similar conditions and flow of spills across these regions is possible. This alternative grouping of regions is an arbitrary procedure. Hence, several different combinations of regions were tried. For the final analysis we have four major regions: Northeast, South and East-Central Uplands, Upper Central region and West. Within each region all subregions are included; hence no state was partitioned between regions. The regions might include some states that may not seem to be geoclimatically similar. This is because in our regional groups a state is included even if only a small part of it is included in the geoclimate region. A list of all the states included in the various regions using this classification scheme are reported in Table 7.

D. Conclusion

This chapter has described the empirical specification of the joint product model for the Nash-Cournot and the Lindahl allocation schemes. The problems involved in the empirical specification of these models are discussed. Also, the theory and procedure of the non-nested J test to distinguish between the Nash and Lindahl models is given. Finally, the data and variables used in the empirical models was briefly discussed. In the next chapter results from fitting these empirical relations will be presented which will show if the relations obtained from theoretical considerations can be validated by the data.

IV. ECONOMETRIC ESTIMATES OF DEMAND FOR AGRICULTURAL RESEARCH

Chapter IV presents econometric estimates from the empirical models described in Chapter III, using U.S. annual data for state agricultural experiment stations, from 1951-1982. These estimates provide support for the determinants of demand derived from theoretical models in Chapter II. Also, the results from these models help identify the public good formulation that "best" describes demand for agricultural research. Further, results from the nonnested J test, designed to distinguish between the competing Nash-Cournot and Lindahl models, are presented.

This chapter is laid out as follows. Section A presents results from fitting the Nash-Cournot model of demand for agricultural research. As discussed in Chapter III, two classification schemes are used to group states into regions. This grouping of states is needed to define the public good - that is, agricultural research. Hence, agricultural research is a public good for states within a region but a private good with respect to other regions. That is, agricultural research from one region is exclusive to states in that region and can not be used by states in other regions. This arises from the geoclimatic specificity of agricultural research. The degree of publicness of agricultural research diminishes as geoclimatic conditions change.

The two classification schemes used are the geoclimatic regions and the ERS production regions. Nash-Cournot estimates are presented for both these classification schemes. Results from these two schemes are evaluated to see which classification scheme gives the better set of results. We expect the classification scheme that measures the spillin variable most accurately (that is, takes account of all the possible spillins) to give the best results.

In Section B, results for the Lindahl model of demand for agricultural research are presented. Fitting the Nash-Cournot model for both the classification schemes identifies the classification method that gives better estimates of demand. Hence, the Lindahl model was fitted for only one classification scheme - the geoclimatic regions. Finally, in Section C, results from the J test to determine the adequacy of the two competing models are presented.

A. Nash-Cournot Model of Demand for Agricultural Research

The empirical specification of the Nash-Cournot model for joint products is given by Equation (III.1). The right-hand side variables of this equation, that is F^r_{it} and $SPILL^r_{it}$, exhibit randomness. Hence, this equation is fitted as a system, using two-stage least squares estimation, whose specification is given by Equations (III.5), (III.6), and (III.7). When significant first-order autocorrelation is present in the disturbances of Equation (III.5), then Equations (III.6), (III.7), and (III.8) are fitted to the data.

1. Nash-Cournot results for geoclimatic regions

The Nash-Cournot model was fitted for the 48 states, grouped into regions using the geoclimatic classification scheme. This scheme demarcates several regions and subregions. However, for the final empirical analysis we identified 4 major regions: Upper Central, Northeast, South and East-Central Uplands, and the West region. The demand equation was fitted for all the states in each of these regions. In some cases, states that accounted for a very small share of the total agricultural research expenditures in a region had exceptionally large t-ratios for the coefficient of the spillin variable. These states, for which the share of agricultural research expenditures accounted for less than 4 percent of the total level for the region, were excluded from the final analysis. Results for the regions, when no state was excluded, are reported in Appendix C.

Tables 8-11 report two-stage least squares estimates of demand for agricultural research. Data for equations in which rho (ρ) are found to be significantly different from zero are transformed and the equation refitted to give two-stage least squares estimates, adjusted for autocorrelation. The estimated autocorrelation coefficients ($\hat{\rho}$) are reported in the second column in the tables. The estimated coefficients on the variables represent the demand elasticities for research.

The price elasticity of demand for agricultural research (given by coefficient on $\ln P_t$) is negative and statistically significant for all the states. Earlier studies on demand for agricultural research do not use any

Table 8. Corn Belt: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q^r_t$ and t-ratios are in parentheses)[a]

		Regressors			
States	ρ^b	Constant	$\ln P_t$	$\ln F^r_{it}$	$\ln SPILL^r_{it}$
Illinois	0.596	1.277 (2.74)	-1.176 (-10.42)	0.027 (0.87)	0.958 (16.78)
Indiana	0.702	0.483 (0.79)	-1.479 (-10.23)	0.011 (0.15)	1.002 (8.82)
Iowa	-	0.171 (0.74)	-1.238 (-10.10)	-0.046 (-0.66)	1.091 (11.02)
Michigan	-	-0.303 (-1.19)	-1.153 (-11.92)	0.011 (0.28)	1.067 (14.44)
Nebraska	-	-0.423 (-1.83)	-1.259 (-11.16)	0.116 (2.57)	0.949 (14.28)
Ohio	-	0.844 (2.41)	-1.264 (-9.41)	0.127 (2.29)	0.798 (7.91)
Wisconsin	-	0.522 (1.91)	-1.357 (-8.54)	0.017 (0.69)	0.975 (20.58)

[a]The smallest player in the region, South Dakota, with share of agricultural research of 3.7% has been excluded.

[b]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table 9. Northeast: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is lnQ^r_t and t-ratios are in parentheses)[a]

States	ρ[b]	Regressors			
		Constant	lnP_t	lnF^r_{it}	$lnSPILL^r_{it}$
Connecticut	-	0.972 (2.46)	-0.838 (-7.04)	0.037 (0.76)	0.879 (9.44)
Maryland	0.483	0.312 (0.57)	-0.856 (-6.41)	0.027 (0.60)	0.957 (9.34)
New Jersey	-	1.283 (1.29)	-0.645 (-2.95)	0.081 (1.36)	0.813 (5.00)
New York	-	-0.053 (2.66)	-1.731 (-9.43)	-0.101 (0.95)	1.149 (4.50)
Pennsylvania		0.024 (0.08)	-0.867 (-10.58)	0.042 (1.28)	0.971 (13.82)

[a]Six players with share of agricultural research of less than 4% has been excluded.

[b]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table 10. South and East-Central Uplands: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q^r_t$ and t-ratios are in parentheses)

		Regressors			
States	ρ[a]	Constant	$\ln P_t$	$\ln F^r_{it}$	$\ln SPILL^r_{it}$
Arkansas	.717	-0.486 (-0.50)	-1.197 (-6.75)	0.098 (3.16)	0.959 (18.86)
Alabama	.645	3.752 (3.63)	-1.169 (-3.81)	-0.207 (-2.20)	0.918 (9.48)
Florida	-	0.341 (0.81)	-1.279 (-6.43)	0.088 (3.90)	0.921 (16.89)
Georgia	-	-0.164 (-0.44)	-1.216 (-6.66)	0.083 (3.01)	0.971 (18.11)
Illinois	.619	0.722 (0.77)	-1.158 (-6.81)	0.046 (2.30)	0.979 (21.62)
Indiana	.498	-0.329 (-0.31)	-1.343 (-7.07)	0.054 (1.76)	0.998 (17.83)
Kansas	.351	-0.883 (-0.95)	-1.267 (-7.43)	0.119 (3.33)	0.945 (17.98)
Kentucky	.435	0.238 (0.23)	-1.196 (-6.89)	0.051 (2.22)	0.989 (19.90)
Louisiana	-	-0.416 (-1.26)	-1.198 (-6.95)	0.125 (3.49)	0.942 (18.85)
Mississippi	-	-0.225 (-0.57)	-1.327 (-6.57)	0.071 (1.97)	0.987 (16.55)
Missouri	-	-0.141 (-0.45)	-1.111 (-7.17)	0.089 (3.44)	0.968 (20.57)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table 10. (Continued)

States	ρ^a	Regressors: Constant	lnP_t	lnF^r_{it}	$lnSPILL^r_{it}$
N. Carolina	-	-0.309 (-0.82)	-1.203 (-6.61)	0.109 (4.13)	0.953 (18.14)
New Mexico	-	0.031 (0.09)	-1.179 (-7.01)	0.089 (2.76)	0.951 (17.31)
Ohio	-	0.101 (0.27)	-1.249 (-6.73)	0.054 (2.26)	0.978 (18.14)
Oklahoma	-	-0.205 (-0.69)	-1.177 (-7.29)	0.114 (3.19)	0.940 (19.56)
S. Carolina	.603	0.347 (0.34)	-1.159 (-6.44)	0.093 (3.22)	0.937 (17.57)
Tennessee	-	-0.224 (-0.64)	-1.204 (-6.89)	0.068 (2.32)	0.995 (18.98)
Texas	-	-0.223 (-0.13)	-1.344 (-2.24)	0.127 (1.24)	0.914 (3.61)
Virginia	-	-0.010 (-0.02)	-1.257 (-6.71)	0.054 (2.33)	0.991 (17.93)
West Virginia	-	-0.019 (-0.05)	-1.236 (-6.89)	0.048 (1.56)	1.000 (17.57)

Table 11. West: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q^r_t$ and t-ratios are in parentheses)

		Regressors			
States	ρ^a	Constant	$\ln P_t$	$\ln F^r_{it}$	$\ln SPILL^r_{it}$
Arizona	.706	0.048 (0.97)	-1.000 (-60.12)	0.027 (5.76)	0.967 (223.62)
California	-	0.515 (2.06)	-0.949 (-4.23)	0.147 (4.50)	0.839 (16.13)
Colorado	-	0.183 (0.65)	-1.133 (-4.46)	0.177 (3.49)	0.839 (12.66)
Idaho	-	0.261 (1.11)	-1.167 (-5.61)	0.152 (2.79)	0.872 (13.23)
Kansas	.310	-1.326 (-1.51)	-1.193 (-6.23)	0.196 (3.72)	0.869 (16.63)
Minnesota	.588	1.213 (1.32)	-1.249 (-5.20)	0.079 (2.47)	0.938 (22.53)
Montana	-	0.192 (0.89)	-1.125 (-5.78)	0.174 (3.24)	0.855 (13.96)
Nebraska	-	-0.244 (-1.12)	-1.118 (-5.87)	0.189 (4.17)	0.876 (17.41)
Nevada	-	0.695 (2.29)	-1.087 (-5.49)	0.124 (3.18)	0.869 (13.85)
New Mexico	-	0.086 (0.44)	-1.047 (-5.85)	0.181 (4.08)	0.849 (16.25)
North Dakota	-	-0.630 (-2.69)	-0.995 (-5.76)	0.315 (5.39)	0.774 (14.14)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table 11. (Continued)

States	ρ^a	Regressors			
		Constant	lnP_t	lnF^r_{it}	$lnSPILL^r_{it}$
Oklahoma	-	-0.448 (-1.63)	-1.074 (-6.15)	0.200 (4.11)	0.867 (19.87)
Oregon	-	0.476 (2.25)	-1.002 (-5.20)	0.121 (3.39)	0.887 (18.26)
South Dakota	-	-0.301 (-1.05)	-1.189 (-6.28)	0.082 (2.17)	1.000 (30.76)
Texas	-	0.414 (0.43)	-0.884 (-1.19)	0.437 (2.28)	0.472 (1.73)
Utah	-	0.351 (1.29)	-1.231 (-5.57)	0.066 (1.71)	0.957 (16.95)
Washington	-	0.407 (1.78)	-1.192 (-5.76)	0.097 (2.35)	0.911 (17.08)
Wyoming	-	0.151 (0.82)	-0.986 (-5.81)	0.204 (4.99)	0.832 (18.04)

price data in their analysis, hence there are no other results to corroborate (or refute) our finding. Economic theory, however, would dictate that own-price elasticity be negative.

The estimated price elasticity varies over the four geoclimatic regions. For the Upper-Central region the price elasticity of demand lies between -1.087 and -1.479. In South and East-Central Uplands, the elasticity ranges between -1.111 and -1.344; for West it lies between -0.884 and -1.249. For the Northeast region, the absolute value of price elasticity, except for New York, is less than 1, lying between -0.645 and -0.867. For New York, it is -1.731. Thus, the Northeast region is the only group indicating an inelastic price response to demand for research. For all the states, the price elasticity measure is significantly different from zero.

Since the geoclimatic grouping of states does not coincide with the state boundaries, some states appear in two or more regions; e.g., Minnesota is included in the Upper Central region and the West region. The elasticity measures for price, full income, and spillin differ for the same state when included in different regions. This is because the value of the spillin variable changes with a different grouping of states. This different spillin measure, and consequently the full income measure, gives different price elasticity, and different full income and spillin elasticities. However, these elasticity measures for the same state differ slightly with different groupings, and the sign of the elasticities remains unchanged.

The next set of elasticity measures presented in the Tables are the full income elasticities, given by the coefficient on ln F^r_{it}. The full income elasticities vary considerably over regions. In general, full income elasticity is positive, but there are some states for which it is negative. In the Upper Central region, the elasticity measure lies between 0.011 and 0.127. States where full income elasticity is negative, the value of this elasticity is not significantly different from zero. For Nebraska, Ohio, and Kansas, in the Upper Central region, the full income elasticity is positive and significantly different from zero.

In the Northeast region, the full income elasticities are positive, but not significantly different from zero, for all states, except New York. For New York the full income elasticity is negative, though not different from zero.

The West region and South and East-Central Uplands exhibit positive and statistically significant full income elasticities. In South and East-Central Uplands, the elasticity is positive for all states, except Alabama. However, the absolute value of these elasticities is small ranging between 0.046 and 0.207. For West, this elasticity ranges between 0.027 and 0.437.

Thus, demand for agricultural research exhibits a positive response to full income. This implies that, other things being equal, wealthier states will spend more on agricultural research. This supports earlier research by Huffman and Miranowski (1981) who report an income elasticity estimate of about 0.18. This also supports Schultz's (1971) results that spending by state experiment stations on research increases with revenues of the state.

In our study, however, the full income elasticity measure is not exactly comparable to income elasticity measures obtained in the earlier studies. Full income includes the spillin term which will change the elasticity measure obtained. Since the spillin elasticity, based on theoretical considerations discussed earlier, can be positive or negative, it is difficult to isolate the income (or revenue) effect from the total full income measure. Positive full income elasticity, which is obtained for most states, implies that agricultural research is a normal good for the state legislatures making decisions for demand for agricultural research.

The third elasticity measure in our study is the spillin elasticity. This elasticity picks up the change in demand for research due to a change in the level of spillins. The spillin elasticity is important for two reasons. First, if this elasticity measure is significantly different from zero, then the joint product model is a better explanation of demand for agricultural research compared with the pure public good model. Second, a positive and statistically significant spillin elasticity implies that the private outputs (benefits) obtained from providing agricultural research are important determinants of demand for research.

The spillin elasticity is positive and significantly different from zero for all states. For Upper Central region, the elasticity measure lies between 0.798 and 1.091. In the Northeast, the spillin measure lies between 0.813 and 1.149; for South and East-Central Uplands the elasticity measure ranges between 0.90 and 1.0; and for West region between 0.774 and 1.0. Demand for agricultural research, thus, shows strongest response to a change in the level of spillins. Statistically significant estimates of the spillin elasticity also provide strong support for the Nash-Cournot joint product model as against the pure public good model. The private goods (or benefits) obtained from providing agricultural research are important in a state's decision on demand for research. These private goods may include specific type of research that is only applicable to the state in which it is produced; or it may include some indirect benefits obtained from engaging in research activity like "prestige" among other states in the same region; support of farmers' lobby for other issues; increase in chances of reelection of the state legislatures, etc.

2. Nash-Cournot model for ERS production regions

The ERS classification scheme also groups states by geoclimatic considerations, but in this classification the region and state boundaries coincide. We first present the results from using this scheme and then, in the following section, evaluate the two sets of results to determine which classification gives the best results. The grouping of states is crucial in a public goods framework, as is discussed later.

There are 9 ERS production regions: Appalachian, Corn Belt, Delta, Lake States, Mountain, Northeast, Northern Plains, Pacific, and Southeast. Some of these regions are very small containing only three or four states; e.g., Northern Plains has only 4 states and Pacific region has only 3 states. The ERS regions provide an alternative arbitrary grouping of states into regions where spillover benefits from agricultural research might be expected to occur. The most likely deficiency with this

Table 12. Appalachian: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)

	Regressors			
States	Constant	$\ln P_t$	$\ln F_{it}^r$	$\ln SPILL_{it}^r$
Kentucky	0.489 (1.41)	-1.290 (-2.20)	-0.624 (-1.01)	1.811 (2.21)
N. Carolina	-1.169 (-9.39)	-0.873 (-8.00)	0.321 (7.27)	0.708 (13.34)
Tennessee	0.443 (1.36)	-0.942 (-6.16)	-0.052 (-0.43)	1.053 (8.36)
Virginia	0.023 (0.19)	-1.158 (-12.73)	-0.017 (-0.35)	1.030 (14.52)
West Virginia	0.647 (20.63)	-0.931 (-41.13)	0.004 (0.37)	0.32 (7.27)

Table 13. Corn Belt: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)[a]

States	ρ^a	Regressors			
		Constant	$\ln P_t$	$\ln F^r_{it}$	$\ln SPILL^r_{it}$
Illinois	0.486	2.210 (6.68)	-0.719 (-15.34)	0.025 (1.37)	0.912 (23.24)
Indiana	0.712	1.049 (1.59)	-1.184 (-15.29)	0.057 (0.98)	0.876 (8.50)
Iowa	-	0.238 (0.83)	-0.769 (-10.20)	-0.021 (-0.34)	1.055 (10.18)
Missouri	0.528	-0.913 (-1.64)	-1.390 (-11.34)	-0.114 (-1.00)	1.222 (6.36)
Ohio	-	0.321 (0.59)	-0.999 (-10.05)	0.028 (0.41)	0.949 (6.64)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table 14. Delta: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)[a]

		Regressors			
States	ρ[a]	Constant	$\ln P_t$	$\ln F_{it}^r$	$\ln SPILL_{it}^r$
Arkansas	0.669	-0.088 (-0.32)	-1.124 (-5.76)	0.039 (0.45)	0.974 (11.47)
Mississippi	-	-0.603 (-2.92)	-0.117 (-0.78)	0.257 (3.31)	0.839 (8.97)
Louisiana	-	-3.852 (-0.87)	-0.005 (-0.01)	0.837 (1.22)	0.303 (0.67)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table 15. Lake States: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)[a]

States	ρ[a]	Regressors			
		Constant	$\ln P_t$	$\ln F_{it}^r$	$\ln SPILL_{it}^r$
Michigan	-	1.789 (0.61)	-0.772 (-1.15)	0.497 (1.19)	0.105 (0.10)
Minnesota	0.475	-1.049 (4.09)	-1.387 (-10.18)	0.046 (0.874)	0.819 (9.86)
Wisconsin	-	1.267 (4.72)	-1.185 (-8.43)	-0.014 (-0.45)	0.914 (15.25)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table 16. Mountain: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)[a]

States	ρ^a	Regressors			
		Constant	$\ln P_t$	$\ln F_{it}^r$	$\ln SPILL_{it}^r$
Arizona	0.585	-0.319	-0.674	0.079	0.983
		(-1.56)	(-8.02)	(2.56)	(16.09)
Colorado	-	-0.745	-1.937	-0.14	1.191
		(-2.71)	(-9.22)	(-1.68)	(10.62)
Idaho	-	0.393	-1.060	-0.014	0.985
		(6.95)	(-26.95)	(-0.85)	(47.55)
Montana	-	0.680	-0.912	0.032	0.915
		(9.23)	(-19.18)	(1.39)	(34.59)
New Mexico	-	0.253	-0.821	0.063	0.918
		(3.89)	(-18.35)	(1.90)	(23.60)
Nevada	-	0.053	-0.880	0.029	0.978
		(0.878)	(-45.07)	(3.69)	(65.06)
Utah	-	0.391	-1.035	-0.003	0.972
		(7.08)	(-30.22)	(-0.28)	(59.34)
Wyoming	0.462	0.537	-0.986	-0.022	0.982
		(10.96)	(-18.11)	(-0.66)	(28.14)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table 17. Northeast: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q^r_t$ and t-ratios are in parentheses)

	Regressors			
States	Constant	$\ln P_t$	$\ln F^r_{it}$	$\ln SPILL^r_{it}$
Connecticut	0.419 (1.92)	-0.967 (-14.84)	-0.014 (-0.56)	0.988 (21.09)
Delaware	0.138 (2.88)	-0.980 (-64.01)	-0.004 (-1.24)	0.996 (141.26)
Maine	-0.196 (-0.65)	-1.012 (-88.48)	0.017 (4.76)	0.984 (160.76)
Maryland	-0.107 (-0.63)	-0.965 (-22.02)	-0.007 (-0.49)	1.031 (33.88)
Massachusetts	0.170 (2.88)	-1.039 (-43.24)	-0.024 (-3.32)	1.018 (78.35)
New Hampshire	-0.111 (-2.69)	-1.017 (-95.55)	-0.011 (-3.08)	1.025 (142.5)
New Jersey	0.433 (1.05)	-0.838 (-8.75)	0.029 (1.22)	0.949 (14.83)
New York	0.939 (2.66)	-1.159 (-9.43)	0.032 (0.95)	0.881 (11.92)
Pennsylvania	0.131 (0.96)	-0.867 (-21.89)	0.044 (3.17)	0.953 (32.54)
Rhode Island	-0.063 (-2.72)	-1.016 (-126.99)	-0.001 (-0.75)	1.009 (280.19)
Vermont	-0.015 (-0.34)	-0.998 (-107.68)	0.003 (0.63)	1.001 (120.97)

Table 18. Northern Plains: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)

	Regressors			
States	Constant	$\ln P_t$	$\ln F^r_{it}$	$\ln SPILL^r_{it}$
Kansas	1.475 (0.56)	-1.328 (-2.46)	-0.184 (-0.34)	1.107 (2.53)
Nebraska	-1.071 (-7.49)	-0.806 (-8.90)	0.269 (5.11)	0.814 (15.09)
North Dakota	-0.187 (-0.40)	-0.906 (-5.74)	0.143 (1.37)	0.87 (11.75)
South Dakota	0.451 (4.69)	-0.680 (-11.45)	0.002 (0.29)	1.003 (86.74)

Table 19. Pacific: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)[a]

States	ρ^a	Regressors			
		Constant	$\ln P_t$	$\ln F_{it}^r$	$\ln SPILL_{it}^r$
California	-	4.776	-0.604	0.954	-0.821
		(0.96)	(-0.44)	(1.39)	(-0.54)
Oregon	-	0.804	-0.764	0.074	0.867
		(4.03)	(-5.77)	(1.36)	(11.43)
Washington	0.493	1.114	-0.914	0.120	0.753
		(5.29)	(-10.11)	(2.89)	(12.57)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table 20. Southeast: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)[a]

		Regressors			
States	ρ[a]	Constant	$\ln P_t$	$\ln F^r_{it}$	$\ln SPILL^r_{it}$
Alabama	0.632	11.769 (8.95)	-3.39 (-4.03)	0.408 (0.44)	-0.983 (-0.77)
Florida	-	1.815 (1.41)	-1.451 (-4.96)	0.101 (1.96)	0.665 (7.57)
Georgia	-	0.474 (0.33)	-0.902 (-2.85)	0.136 (2.31)	0.801 (8.33)
S. Carolina	0.469	1.096 (1.81)	-1.209 (-8.08)	0.016 (0.73)	0.859 (18.53)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

classification is that research benefits generally spillover a larger geographic area than for states in one of these regions.

Econometric estimates for the Nash-Cournot model for ERS production regions are presented in Tables 12-20. The tables list the states in the region; the estimated autocorrelation coefficient; and the estimated elasticities of demand for price, full income and spillin.

The price elasticity is negative and statistically significant for all the states. This elasticity measure, however, shows considerable variation across states. The lowest price elasticity is obtained for Mississippi at -0.005 and the highest for Alabama at -3.39. For other states it ranges between -0.70 and -1.39.

The full income elasticity measure is positive for some states while negative for other states. Delta, Pacific, and Southeast are the only regions with positive full income elasticities for all the states in the region. The value of the elasticity, in cases where it is negative, is not significantly different from zero. Only for New Hampshire and Massachusetts the full income elasticity is negative and significant. This implies that agricultural research is an inferior good for these states. However, for most cases, we may conclude that agricultural research is a normal good. Where the elasticity is negative, but not different from zero, the effect of full income on demand for research is small or negligible.

Spillin elasticity, given by coefficient on ln $SPILL_{it}^{r}$ term, is generally positive and significant. The value of this elasticity ranges between 0.105 and 1.811. This elasticity is negative for California and

Alabama, but for both cases it is not significantly different from zero. The statistically significant measure of elasticity, once again, provides support for the joint product model. For Louisiana and Michigan, however, this elasticity measure, though positive, is not significantly different from zero. This would imply that the pure public good model is a better explanation of demand for research for these two states. Nevertheless, we still find strong support for the joint product model of demand for agricultural research.

3. Geoclimatic regions vs ERS production regions

Both the geoclimatic regions and the ERS production regions provide reasonable estimates for elasticities of demand for agricultural research. The ERS production regions are, however, somewhat ad hoc in their grouping because of the requirement that regional boundaries coincide with state boundaries. Such a grouping implies that a state is included in only one region, even if the state (or a part of this state) is geoclimatically similar to some other state in an adjoining region. This is of particular importance in a public goods framework because of the importance to measure the spillin variable correctly. Correct regional grouping will define the public good properly for states within a region; if some states are left out for which spillins (or spill-outs) occur from this region, the spillin measure will be incorrectly defined and the elasticities will not capture the publicness of the good.

This will be clear if we compare the estimates of elasticities obtained from the two classification schemes. With the geoclimatic regional grouping, the full income elasticity is positive and statistically significant for 35 states. For 4 states the full income elasticity is negative, though statistically not different from zero. With the ERS production region grouping, on the other hand, only 8 states have positive and significant full income elasticities. There are 17 negative full income elasticities. For the spillin elasticity, all states grouped according to the geoclimatic scheme, have positive and statistically significant values. For the ERS production region scheme, 6 states have elasticity values that are not different from zero.

Thus, the geoclimatic grouping provides estimates that are what we would expect from theoretical considerations. The signs of the elasticity are correct and their statistical properties are better. This occurs because the spillin variable, fundamental to the public goods framework, is correctly measured in the geoclimatic grouping. Thus, geoclimatic regions group states in accordance wih requirements for a public goods approach to demand for research. Therefore, we fit Lindahl model of demand for agricultural research using the geoclimatic regional grouping only.

B. Lindahl Model of Demand for Agricultural Research

The Lindahl model of demand for agricultural research was fitted for all the states grouped into regions using the geoclimatic classification scheme. Equations (III.11) and (III.12) summarize the Lindahl model of demand. When statistically significant first-order autocorrelation is detected, equations III.12 and III.13 are fitted to the data to give two-stage least squares estimates, corrected for autocorrelation.

Tables 21-24 present the results from fitting these equations for all the states. The second column in the Tables lists the autocorrelation coefficients when they were found to be significantly different from zero; otherwise they were not listed. The other columns give the estimated demand elasticities for income and the cost share of the state.

The income elasticity is positive and statistically significant for all states in all the four regions. This elasticity measure ranges between 0.001 and 0.889 for the Upper Central region; between 0.089 and 0.650 for the Northeast. For the South and East-Central Uplands this measure lies between 0.319 and 0.837 and for West between 0.342 and 1.037. For South Dakota the income elasticity is negative, indicating that agricultural research is an inferior good. For all the other states, positive income elasticities indicate that wealthier states spend more on agricultural research.

The other regressor of the Lindahl model is ($\ln P_t + \ln \theta^r_{it}$). This term picks up the price effect on demand for agricultural research. There are two prices that the agent faces - the normalized price ($\ln P_t$) and the individualized price or the cost share of the state, given by $\ln \theta^r_{it}$. Theory would suggest the total price effect be negative for the states.

The total cost elasticity (including price and share terms) is found to be negative for most of the states. In the Upper Central region this elasticity is negative and statistically significant for all the states,

Table 21. Upper Central Region: Two-stage least squares estimates of the Lindahl demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)[a]

		Regressors		
States	Constant	ρ^a	$\ln I_{it}$	$\ln P_t + \ln \theta_{it}^r$
Illinois	0.602	5.353 (7.99)	0.289 (5.06)	-0.729 (-6.16)
Indiana	0.505	0.879 (0.68)	0.518 (5.30)	-1.191 (-2.74)
Iowa	-	2.019 (4.29)	0.657 (12.92)	-0.356 (-2.53)
Kansas	-	-0.685 (-0.58)	0.889 (20.59)	-0.286 (-2.17)
Minnesota	-	3.518 (5.44)	0.604 (10.58)	-0.052 (-0.19)
Missouri	-	2.969 (3.36)	0.796 (20.48)	0.496 (2.57)
Nebraska	-	0.989 (0.68)	0.814 (11.59)	-0.228 (-1.31)
Ohio	0.506	2.994 (4.93)	0.521 (12.97)	-0.416 (-5.73)
S. Dakota	0.907	12.059 (11.75)	0.001 (0.07)	-0.046 (-0.20)
Wisconsin		4.868 (6.66)	0.376 (5.24)	-0.613 (-1.91)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform data.

Table 22. South and East-Central Uplands: Two-stage least squares estimates of the Lindahl demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)[a]

		Regressors		
States	ρ[a]	Constant	$\ln I_{it}$	$\ln P_t + \ln\theta_{it}^r$
Arkansas	-	1.998 (1.89)	0.687 (11.22)	-0.389 (-4.31)
Alabama	-	3.654 (2.69)	0.698 (6.14)	0.135 (2.12)
Florida	-	1.816 (2.54)	0.553 (18.51)	-0.854 (-8.11)
Georgia	-	3.613 (3.25)	0.588 (9.31)	-0.231 (-2.41)
Illinois	-	5.593 (14.60)	0.319 (11.38)	-0.599 (-8.99)
Indiana	0.656	1.445 (0.94)	0.511 (5.12)	-1.048 (-7.56)
Kansas	-	-0.873 (-0.85)	0.837 (14.70)	-0.599 (-6.10)
Kentucky	-	4.828 (8.21)	0.449 (12.70)	-0.394 (-5.91)
Louisiana	-	-1.309 (-1.75)	0.809 (18.52)	-0.658 (-8.52)
Mississippi	-	0.174 (0.12)	0.715 (10.28)	-0.620 (-3.87)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform data.

Table 22. (Continued)

States	ρ^a	Regressors		
		Constant	lnI_{it}	$lnP_t + ln\theta^r_{it}$
Missouri	-	2.872	0.630	-0.337
		(3.66)	(13.52)	(-5.16)
N. Carolina	-	5.639	0.388	-0.506
		(7.29)	(12.28)	(-4.72)
New Mexico	-	3.957	0.510	-0.392
		(5.85)	(11.43)	(-4.73)
Ohio	-	2.817	0.452	-0.788
		(3.81)	(12.41)	(-6.21)
Oklahoma	-	2.639	0.543	-0.598
		(4.03)	(9.97)	(-6.94)
S. Carolina	-	3.333	0.538	-0.454
		(3.44)	(11.88)	(-3.37)
Tennessee	-	4.302	0.562	-0.158
		(4.21)	(8.50)	(-1.88)
Texas	0.432	7.148	0.444	0.275
		(5.90)	(5.74)	(3.78)
Virginia	-	1.999	0.565	-0.671
		(2.57)	(16.35)	(-7.42)
W. Virginia	-	5.162	0.349	-0.552
		(11.62)	(9.22)	(-7.60)

Table 23. West: Two-stage least squares estimates of Lindahl demand for SAES research, 1951-1982. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)

States	ρ^a	Regressors: Constant	$\ln I_{it}$	$\ln P_t + \ln\theta_{it}^r$
Arizona	-	2.707 (3.43)	0.646 (17.41)	-0.286 (-2.93)
California	-	1.641 (2.52)	0.620 (15.72)	-0.424 (-3.39)
Colorado	-	1.791 (2.07)	0.756 (15.39)	-0.125 (-1.23)
Idaho	0.400	1.348 (1.55)	0.591 (8.52)	-0.807 (-6.39)
Kansas	-	-2.907 (-3.53)	0.977 (18.16)	-0.618 (-4.73)
Minnesota	0.565	3.23 (2.59)	0.342 (4.50)	-1.208 (-10.23)
Montana	-	1.848 (3.42)	0.583 (9.09)	-0.746 (-5.24)
Nebraska	0.401	-4.014 (-3.22)	1.023 (13.20)	-0.904 (-7.17)
Nevada	-	3.749 (4.70)	0.559 (18.14)	-0.348 (-3.37)
New Mexico	-	1.614 (2.50)	0.731 (10.59)	-0.259 (-1.99)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table 23. (Continued)

States	ρ^a	Regressors		
		Constant	$\ln I_{it}$	$\ln P_t + \ln\theta^r_{it}$
North Dakota	-	-2.339 (-2.32)	1.037 (15.24)	-0.444 (-2.74)
Oklahoma	0.476	3.052 (2.28)	0.402 (3.46)	-0.926 (-8.26)
Oregon	-	2.989 (5.67)	0.578 (11.57)	-0.442 (11.58)
South Dakota	0.777	12.328 (8.23)	-0.103 (-2.56)	-0.317 (-1.42)
Texas	-	1.871 (3.39)	0.785 (21.47)	0.299 (4.79)
Utah	0.273	2.866 (4.60)	0.354 (7.50)	-1.046 (-8.02)
Washington	0.498	3.093 (4.12)	0.436 (7.49)	-0.841 (-11.28)
Wyoming	0.630	3.982 (3.43)	0.355 (3.45)	-0.811 (-8.24)

Table 24. Northeast: Two-stage least squares estimates of Lindahl demand for SAES research, 1951-1982. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)

		Regressors		
States	ρ[a]	Constant	$\ln I_{it}$	$\ln P_t + \ln\theta_{it}^r$
Connecticut	-	5.214 (12.87)	0.465 (9.27)	0.024 (0.19)
Delaware	-	5.348 (4.03)	0.089 (1.15)	-1.122 (-3.58)
Maine	0.540	2.795 (1.56)	0.508 (7.20)	-0.540 (-2.04)
Maryland	-	6.277 (12.37)	0.412 (15.46)	0.145 (1.08)
Massachusetts	-	4.398 (7.79)	0.650 (6.96)	0.547 (2.14)
N. Hampshire	-	7.652 (11.42)	0.442 (14.17)	0.325 (2.08)
New Jersey	0.384	7.146 (13.06)	0.330 (10.57)	0.130 (0.84)
New York	0.402	5.064 (6.99)	0.349 (7.39)	-0.439 (-1.28)
Pennsylvania	-	4.349 (6.39)	0.456 (15.95)	-0.092 (-0.56)
Rhode Island	-	10.389 (6.95)	0.358 (10.45)	0.733 (2.52)
Vermont	-	5.811 (5.42)	0.435 (15.45)	-0.086 (-0.44)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

except Missouri. The value of this elasticity ranges between -0.046 and -1.191. For the Northeast, it lies between -0.086 and -1.122. However, this elasticity is positive, and significant, for Massachusets, New Hampshire, and Rhode Island in the Northeast region. In the South and East-Central Uplands the total cost elasticity lies between -0.158 and -1.048, except Alabama and Texas, where it is positive. In the West, the total cost elasticity elasticity lies between -0.125 and -1.208, but is positive for Texas. Thus, the total cost elasticity measure is negative, for most of the states, which is what we would expect from theoretical considerations.

The Lindahl model also seems to explain well the demand decision for research by the state governments. However, given these two models - Nash-Cournot and Lindahl - it is difficult to say, based on these demand estimates, which model outperforms the other. For this, we have to use hypothesis testing which is discussed in the following section.

C. Nash-Cournot vs Lindahl: Results from the J Test

As is evident from discussion in Sections A and B, both the Nash-Cournot joint product model and the Lindahl model provide reasonable explanation of demand for agricultural research. Earlier studies on demand for public goods assume one of these conjectures to hold, and given these conjectures, determine the factors that influence demand. However, it may be the case that one of these models provides a significantly better explanation than the other; or that both the conjectures are not appropriate to model agents' behavior in the presence of public goods. The validity of these conjectures as against other possible conjectures is, therefore, important. One method for examining this issue is the non-nested J test that was discussed in Chapter III and summarized by hypotheses 1 and 2.

The results from the J test are presented in Tables 25 and 26. This test was carried out for two regions - Upper Central and South and East-Central Uplands. The results are presented for hypotheses 1 and 2. For each hypothesis, the coefficient on the predicted value from the competing model, the associated t-ratio, and the resulting conclusion are listed.

In performing the J test, the conclusions are to reject the Lindahl model for all the states in the Upper Central region and the South and East-Central Uplands. This implies that the state legislatures are not engaged in a cooperative solution while determining demand for agricultural research. Thus, the provision levels are not Pareto optimal, which is to be expected, given the persistently high rates of return to agricultural research.

Support for the Nash-Cournot model is "weak" and inconclusive. The results from the J test reject the Nash-Cournot conjecture for all states, except Illinois, in the Upper Central region. In the South and East-Central Uplands, the Nash-Cournot model is accepted for Missouri and Minnesota. For all the other states, the Nash-Cournot model is rejected.

The results from the J test, thus, conclusively reject the Lindahl model and provide "weak" support for the Nash-Cournot model. These results

Table 25. J Test Results: South and East-Central Uplands Region

	Hypothesis 1			Hypothesis 2		
States	$\ln Q_t^{rL}$	t-ratio	Conclusion	$\ln Q_t^{rN}$	t-ratio	Conclusion
Arkansas	-0.024	-4.13	Reject	1.014	250.33	Reject
Alabama	0.321	2.20	Reject	0.967	14.30	Reject
Florida	-0.091	-20.84	Reject	1.061	176.41	Reject
Georgia	-0.164	-11.83	Reject	1.035	150.68	Reject
Illinois	-0.022	-1.85	Unable to Rej.	1.013	113.32	Reject
Indiana	-0.047	-11.79	Reject	1.033	286.10	Reject
Kansas	-0.051	-5.39	Reject	1.074	133.11	Reject
Kentucky	-0.049	-5.91	Reject	0.980	14.71	Reject
Louisiana	-0.076	-22.54	Reject	1.049	181.64	Reject
Mississippi	-0.071	-37.41	Reject	1.104	82.56	Reject
Missouri	-0.123	-14.57	Reject	1.041	156.57	Reject
N. Carolina	-0.123	-9.77	Reject	1.003	114.04	Reject
New Mexico	-0.035	-20.76	Reject	1.017	714.89	Reject
Ohio	-0.066	-14.08	Reject	1.048	239.39	Reject
Oklahoma	-0.060	-23.74	Reject	1.027	197.92	Reject
S. Carolina	-0.019	-3.61	Reject	1.012	385.70	Reject
Tennessee	-0.114	-12.95	Reject	1.015	249.08	Reject
Texas	0.887	6.91	Reject	1.059	10.88	Reject
Virginia	-0.033	-5.46	Reject	1.028	237.71	Reject
W. Virginia	-0.027	-11.92	Reject	1.009	392.59	Reject

Table 26. J Test Results: Upper Central Region

States	Hypothesis 1			Hypothesis 2		
	$\ln Q_t^{rL}$	t-ratio	Conclusion	$\ln Q_t^{rN}$	t-ratio	Conclusion
Illinois	0.263	3.33	Reject	0.958	26.05	Reject
Indiana	-0.088	-7.91	Reject	1.049	100.28	Reject
Iowa	-0.336	-23.14	Reject	1.010	45.42	Reject
Kansas	-0.335	-20.70	Reject	1.002	54.15	Reject
Michigan	-0.495	-28.16	Reject	1.023	45.58	Reject
Minnesota	-0.005	-0.16	Unable to rej.	1.005	100.64	Reject
Missouri	-0.012	-0.80	Unable to rej.	0.976	83.53	Reject
Nebraska	-0.362	-13.88	Reject	1.005	83.82	Reject
Ohio	-0.219	-2.70	Reject	1.142	20.19	Reject
S. Dakota	-0.058	-2.84	Reject	1.011	150.68	Reject
Wisconsin	-0.191	-19.77	Reject	1.036	309.32	Reject

are not definitive and do not allow us to accept one model in favor of the other model. This apparent "inconclusive" situation needs to be interpreted with caution. First, in public goods literature the Nash-Cournot model is assumed to hold almost axiomatically. However, the results from this study indicate that this conjecture may not be an appropriate description of agents' behavior. The presence of public goods in the utility function implies that agents do not engage in a purely self-interested utility maximization. On the other hand, they do not even engage in a fully cooperative solution. The results indicate that we need to look at other possible conjectures in the presence of public goods. We may take our cue from the growing literature in oligopoly theory. One possible alternative strategy would be to look at consistent conjectures equilibrium in which the reaction functions are equated to the conjectural variation of the agents.

Another reason to interpret the results from the J test with caution arises from earlier studies that have used this test, and from the growing econometric literature in this field. Most studies that have used this test do not find any conclusive evidence to reject or accept one of their models (see Deaton, 1978; Pesaran, 1982a; Backus, 1984; Antonovitz and Green, 1989). Pesaran (1986) notes that since the competing models in a non-nested hypothesis testing can not be ranked by their level of generality, it is very common that both the models are rejected by such tests. Small sample studies by Pesaran (1982b), Godfrey and Pesaran (1983), and Davidson and MacKinnon (1982) show that the J test rejects the true model too frequently with the estimated significance levels very large. Some authors have suggested that the test variable of the J-procedure be adjusted to improve its significance levels. However, attempts to adjust the test variable while preserving its ease of implementation have not been successful (Godfrey and Pesaran, 1983).

The seeming inadequacy of the J test arises from it being a partial test, as has been shown by a recent study by Mizon and Richard (1986). They appeal to the encompassing principle while formulating a test for rival models. According to this principle, a model M should be able to explain the characteristics of rival models and, encompassing tests should embody this principle. The J test uses this principle, but partially. A complete encompassing test (CET) considers all the unknown parameters. That is, if H_0 and H_1 constitute the two rival models, as given by equations III.12 and III.13, then a CET should compare $\hat{\phi}$ with plim $\hat{\phi} | H_0$ and $\hat{\sigma}_1^2$ with $\hat{\sigma}_1^2 | H_0$. Comparing $\hat{\phi}$ with plim $\hat{\phi} | H_0$ gives the mean encompassing test and comparing $\hat{\sigma}_1^2$ with $\hat{\sigma}_1^2 | H_0$ gives the variance encompassing test. Mizon and Richard show the F test is a mean encompassing test and the J test is a variance encompassing test. This explains why the J test is a one-degree-of-freedom test no matter how many explanatory variables are in the models given by H_0 and H_1. The CET is a joint test that compares $\hat{\phi}$ and $\hat{\sigma}_1^2$ with their probability limits under H_0. There is no empirical evidence, however, on how the joint test performs and the properties of the asociated test statistic (Maddala, 1988).

D. Conclusions

This chapter has presented the empirical results from fitting the demand functions for agricultural research. Demand functions from two theoretical specifications were chosen. These were the Nash-Cournot joint product model and the Lindahl joint product (or the pure public good) model. These models were fitted for the 48 contiguous states using U.S. annual data from 1951-1982. In the Nash-Cournot specification, demand for agricultural research is a function of normalized prices, full income and the level of spillins. In the Lindahl model, demand for agricultural research is a function of the agent's share of total cost of agricultural research for the region, and the income of the state. The empirical results show the price elasticity of demand for research in the Nash model to be negative; the full income elasticity to be positive; and the spillin elasticity to be positive, indicating the private aspects (or outputs) from research to be important determinants of demand.

In the Lindahl model, the total cost elasticity, which is the individualized price for the state plus the normalized price, is negative for a large number of states. The income elasticity is positive, indicating that agricultural research is a normal good.

The results from the J test reject the Lindahl model for all the states, but provide some support for the Nash-Cournot model. The "weak" support for the Nash-Cournot model points to the fact that more work needs to be done in modeling agent's conjectures about the response of other agents participating in the game, than the simple Nash assumptions. The "weak" results should not be taken as evidence that no model is appropriate, in light of the econometric discussion in the earlier section. The J test is a partial construct to test rival models. However, the ease of implementing this test and the fact that there is no (operational) more powerful test justifies the use of the J test. The results from this test should serve as a guide to future modeling. Also, as Deaton (1978) notes, it may be possible, in some cases, that economists do not possess the "true" model and thus, can arrive at the most appropriate specification by testing such tentative models.

V. SUMMARY AND CONCLUSIONS

This chapter presents a summary of the results obtained in this study and analyzes these results for their implications for the provision of public goods, in general, and agricultural research in particular. Also, results from the test of Nash and Lindahl conjectures will be evaluated. Any policy implications that can be drawn, given the empirical estimates of demand for research, will be discussed.

A. Summary of Results

This study has modeled the demand for public goods, in general, and focussed on the demand for agricultural research, in particular. There are two methods that have been used in the literature to model demand for public goods. The nonmarket (direct) method generates demand data through the use of surveys, experiments, or voting results. The market (indirect) method uses market data from private goods to infer about demand for public goods (see Cornes and Sandler, 1986). The technique used in this study is a nonmarket evaluation for estimating demand for agricultural research. This technique has been used earlier by Murdoch and Sandler (1984) to analyze defense expenditures. This method is based on utility maximization subject to a resource constraint. Unlike other procedures, this method identifies the utility function of the decision maker and not of a "representative" agent, as in the median voter model.

This method of deriving demand functions was used to analyze demand for agricultural research. Two general specifications of public goods were used - the pure public good formulation and the impure public good formulation. Under the impure public good formulation, the joint product model and the joint-use model were analyzed. The joint product model exploits the geoclimatic specificity of agricultural research by considering the private as well as public outputs (benefits) that result from research.

The joint-use model analyzes the effect of the changing mix of federal funds for state agricultural experiment stations from formula funds to competitive grants. The equilibrium conditions obtained from this model show that the aditional 'fixed-aggregate-level' constraint lowers the provision of agricultural research by the states. This is because the fear of (potential) loss of spillins, caused by an agent's own demand, induce agents to demand fewer units of research, than they would demand in absence of the fixed aggregate level of agricultural research. Given the already low level of investment in agricultural research, well documented by the underinvestment literature, this shift in funding will further aggravate the low level of provision of agricultural research. The predictions from this model do not imply that there is no way of determining the total amount of funds for a particular public project. This model only suggests that total allocations be made after the various agents have determined their own provision levels. The total allocation for the provision of a public good then is the sum of individual provision levels. For the specific case of agricultural research, this model suggests that federal support should remain in the form of formula funds rather than move to competitive grants.

The various formulations of agricultural research as a public good were analyzed for two possible allocation schemes for the agents - the Nash-Cournot and the Lindahl. Empirical results from both the allocation strategies were presented. In the Nash-Cournot model, agricultural research depends on prices, full income, and the level of spillins from the other states. The empirical results from this model indicate that price and income elasticities are of the expected signs; the price elasticity is negative and the full income elasticity is positive. These elasticity measures are, however, small indicating an inelastic response to income and prices. Because we have full income rather than only income (or revenues) of the state, the full income elasticity includes the effect of spillins, in addition to the effect of income on demand for research. Positive full income elasticity implies that agricultural research is a normal good for the state legislatures. The spillin elasticity captures the presence of private benefits (outputs) from agricultural research. Significantly different from zero value of this elasticity indicates that the joint product model outperforms the pure public good model as an "appropriate" specification of demand for agricultural research. This lends support to the notion of geoclimatic specificity of research - that is, there are some private benefits (outputs) from research that are exclusive to the state undertaking the research. This can also be seen as support for the interest group theory if the benefits from meeting the demands of the interest group are seen as private benefits from research.

In the Lindahl model, agricultural research is found to be a function of income, prices, and the individualized cost share of the state in providing research for the region. The prices and the cost share appear in a multiplicative form, which in the log-linear specification becomes additive. The empirical results indicate that the income elasticity is positive and the total cost elasticity is negative. Thus, agricultural research is a normal good for the state legislatures.

Both the Nash-Cournot and the Lindahl model provide reasonable explanations of demand for agricultural research. To test the possibility of one allocation strategy outperforming the other, the two strategies were tested against each other. For this we used the nonnested technique of the J test. The results from the J test, however, failed to support any one model. The Lindahl model was rejected for all the states, thereby implying that the state legislatures are not engaged in a cooperative game. The Nash-Cournot model was found to be valid for three out of twenty-two states. This small evidence does not allow us to conclude, definitively, that the Nash-Cournot strategy is the appropriate strategy. The somewhat "inconclusive" result has to be understood in light of the weaknesses of the J test, and the methodology behind any nonnested test.

The two rival models to be tested by any nonnested technique specify the conditional distribution of the dependent variable, given the independent variables of *that* particular model. That is, equation III.12 specifies the conditional distribution of *y given X*. Similarly, equation III.13 specifies the condition distribution *y given S*. Comparing these two conditional distributions implies comparing the role of S under H_0 and comparing the role of X under H_1. Thus, to compare the two models we should be able to derive conditional distributions of $f(y|X)$ and $g(y|S)$ under both H_0 and H_1. This is what is suggested by the complete encompassing test of Mizon and Richard. The J test compares only the variance of the disturbances from one model with the disturbances under the rival specification.

Given the problem of testing nonnested models, the "weak" support for the Nash-Cournot model suggests that state legislative decisions are noncooperative. However, we can look at some other noncooperative conjectures suggested in the literature. One possible alternative would be to generalize the model to look at a continuum of strategic responses. The Nash-Cournot model would be at the noncooperative end of this continuum with a conjectural variation of zero; the Lindahl model would be the cooperative strategy with a conjectural variation of one. We could have positive and negative values for the conjectural variation.

B. Conclusions

This study has looked at the determinants of demand for agricultural research in a public goods framework, for different possible strategies of the agents. The methodology of the study allows one to distinguish between the public and private aspects of research. The study also helped identify the public good formulation that "best" describes demand for agricultural research. The econometric results from the study imply that agricultural research is a normal good for the state legislatures, with positive income elasticity and negative price elasticity. Also, the positive and statistically significant spillin elasticity implies that the private outputs from research are important determinants of demand for research, and that these private outputs are normal goods.

The results from the J test opened a Pandora's box of issues, and pointed to some possible weaknesses in modeling agent's behavior in the public goods framework. The Nash conjecture has been used in all studies for modeling agent's behavior in a noncooperative environment. However, results from our study indicate that this may not be an appropriate conjectural assumption. Future work in this area should look at some other possible conjectures for the agents.

Another problem identified by the results relates to econometrics. Various studies, already cited in Chapter IV, have pointed to some weaknesses in the J test, arising from its partial testing of the paramaters of interest. However, in absence of a more powerful test with known empirical properties of how it performs, the J test should be used to identify areas of possible weaknesses. The results from this test should provide guidance for future research.

Various interesting research issues emerge from this study. The joint public good model can be applied to international agricultural research to determine the flow of research across international borders. It would be interesting, in this context, to study the effect of International Agricultural Research Centers on the research effort of the developing countries. Another issue would be to look at the private research effort, and to incorporate this into the public goods model to test if there is any crowding-out of public expenditures. The issues arising from the J test would be to look at the behaviorial strategies of the agents, in the presence of public goods.

VI. APPENDIX A. UTILITY MAXIMIZATION

The utility maximization problem for the i-th state under Nash-Cournot assumptions for the pure public good model is:

$$\max_{\{y^i, Q^i\}} U^i(y^i, Q^i; E^i)$$

$$\text{subject to} \quad F_i = I^i + P_Q\tilde{Q}^i = P_y y^i + P_Q Q^i$$

$$Q^i > \tilde{Q}^i .$$

The Lagrangian associated with the problem, when $Q^i > \tilde{Q}^i$, is

$$\pounds = U^i(y^i, Q^i; E^i) + \lambda\,[F_i - P_y y^i - P_Q Q^i] ,$$

and the resulting first-order conditions are:

(1) $U^i_y - \lambda P_y = 0$,

(2) $U^i_Q - \lambda P_Q = 0$, and

(3) $F_i - P_y y^i - P_Q Q^i = 0$.

Solving for λ from equation (1) and substituting the value in equation (2) gives:

$$MRS^{i}_{Qy} = P_Q / P_y , \quad i=1,\ldots,n.$$

The utility maximizing problem of i-th state for the Lindahl allocation scheme for pure public good case is:

$$\max_{\{y^i, Q^i\}} U^i(y^i, Q^i; E^i)$$

$$\text{subject to } I^i = P_y y^i + \theta^i P Q^i$$

$$\theta^i = q^i / Q^i .$$

The Lagrangian associated with the problem is:

$$\pounds = U\,(y^i, Q^i;\ E^i) + \lambda\,[I^i - P_y y^i - \theta^i P Q^i] ,$$

and the resulting first-order conditions are:

(1) $U^i_y - \lambda P_y = 0$,

(2) $U^i_Q - \lambda \theta^i P Q^i = 0$,

(3) $I^i - P_y y^i - \theta^i P Q^i = 0$.

The first-order conditions can be expressed as:

$$MRS^i_{Qy} = \theta^i \, P_Q \,/\, P_y \,, \quad i=1,\ldots,n.$$

The i-th state's maximization problem for the joint product model, defined in terms of marketed goods y and Q, under Nash-Cournot assumptions is:

$$\underset{\{y^i, Q^i\}}{\text{Max}} \; U^i(y^i,\; g_i(Q^i\text{-}\tilde{Q}^i),\; h_i(Q^i\text{-}\tilde{Q}^i)+ m(\tilde{Q}^i),\; E^i)$$

$$\text{subject to} \quad I^i + P_Q\tilde{Q}^i = P_y y^i + P_Q Q^i$$

$$Q^i > \tilde{Q}^i \;,\; y \geq 0 \,.$$

The Lagrangian associated with the problem is:

$$\pounds = U^i(y^i, g_i(Q^i\text{-}\tilde{Q}^i), h_i(Q^i\text{-}\tilde{Q}^i)+ m(\tilde{Q}^i), E^i) + \lambda\; [F_i - P_y y^i - P_Q Q^i] \;,$$

and the first-order conditions are:

(1) $U^i_y - \lambda P_y = 0$,

(2) $g'_i \, U^i_x + h'_i \, U^i_z - \lambda P_Q = 0$, and

(3) $F_i - P_y y^i - P_Q Q^i = 0,$

where, $g'_i = \partial g_i / \partial (Q^i - \tilde{Q}^i)$, and $h'_i = \partial h_i / \partial (Q^i - \tilde{Q}^i)$.

The first-order conditions can be expressed as:

$$g'_i \, MRS^i_{xy} + h'_i \, MRS^i_{zy} = P_Q \, / \, P_y \, , \quad i=1,\ldots,n.$$

The Pareto optimal joint product model is:

$$\max_{\{y^i, q^i\}} U^i(y^i, g_i(q^i), h_i(q^i) + \sum_{j \neq i}^{n} h_j(q^j), \; E^i)$$

$$\text{subject to } \sum_{i=1}^{n} I^i = \sum_{i=1}^{n} (P_y y^i + P_Q Q^i)$$

$$U^j(y^j, g_j(q^j), h_j(q^j) + \sum_{k \neq j}^{n} h_k(q^k), E^j) \geq \bar{U}^j \text{ , for all } j \neq i \text{ .}$$

The Lagrangian associated with the problem is:

$$\pounds = U^i(y^i, \; g_i(q^i), \; h_i(q^i) + \sum_{j \neq i}^{n} h_j(q^j), \; E^i)$$

$$\sum_{j \neq i} \sigma_j \; (U^j [y^j, g_j(q^j), h_j(q^j) + \sum_{k \neq j}^{n} h_k(q^k), E^j] - \bar{U}^j) \quad +$$

$$\mu\ [\sum_{i=1}^{n} I^i - \sum_{i=1}^{n} (P_y y^i + P_Q Q^i)]\ .$$

The first-order conditions are:

(1) $U_y^i - \mu P_y = 0$,

(2) $\sigma_j U_y^j - \mu P_y = 0$,

(3) $g'_i U_x^i + h'_i U_z^i + \sum_{j \neq i} h_j\ U_z^j - \mu P_Q = 0$,

(4) $[\sum_{i=1}^{n} I^i - \sum_{i=1}^{n} (P_y y^i + P_Q Q^i)] = 0$, and

(5) $U^j[y^j, g_j(q^j), h_j(q^j) + \sum_{k \neq j}^{n} h_k(q^k), E^j] - \bar{U}^j\} = 0$.

The first-order conditions can be expressed as:

$$g'_i\ MRS_{xy}^i + h'_i\ MRS_{zy}^i + m' \sum_{j \neq i}^{n} MRS_{zy}^j = P_Q\ /\ P_y\ ,\ i=1,\ldots,n.$$

The maximization problem under the Lindahl scheme for the joint product model is:

$$\max_{\{y^i, Q^i\}} U^i\ \{y^i,\ R_i(Q^i),\ G(Q^i),\ E^i\}$$

subject to $I^i = P_y y^i + \theta^i P_Q Q^i$

$$\theta^i = q^i \,/\, Q^i \,.$$

The Lagrangian associated with the problem is:

$$\pounds = U^i\ (y^i,\ R_i(Q^i),\ G(Q^i),\ E^i) + \lambda\ [I^i - P_y y^i - \theta^i P_Q Q^i]$$

The first-order conditions are:

(1) $U^i_y - \lambda P_y = 0$,

(2) $R'_i\ U^i_x + G' U^i_z - \lambda\theta^i P_Q = 0$, and

(3) $I^i - P_y y^i - \theta^i P_Q Q^i = 0$.

The FOCs imply the following:

$$R'_i MRS^i_{xy} + G' MRS^i_{zy} = \theta^i P_Q \,/\, P_y \ , \ i=1,\dots,n.$$

The Nash-Cournot joint-use model is:

$$\underset{(y^i,Q^i)}{\text{Max}}\ U^i[y^i,\ Q^1,\dots,Q^i,\dots Q^n,\ E^i]$$

subject to $I^i = P_y y^i + P_Q Q^i$

$$Q = \sum_{i=1}^{n} Q^i .$$

We can rewrite the joint-use constraint as

$$(Q - \sum_{j \neq i}^{n} Q^j) - Q^i = 0 ,$$

or,

$$Q^{-i} - Q^i = 0 ,$$

where

$$Q^{-i} = (Q - \sum_{j \neq i}^{n} Q^j) .$$

The Lagrangian associated with the above is:

$$\pounds = U^i[y^i, Q^1,\ldots,Q^i,\ldots Q^n, E^i] + \lambda [I^i - P_y y^i - P_Q Q^i]$$

$$+ \omega [Q^{-i} - Q^i] .$$

The first-order conditions are:

(1) $U^i_y - \lambda P_y = 0$,

(2) $U^i_{Qi} - \lambda P_Q - \omega = 0$,

(3) $I^i - P_y y^i - P_Q Q^i = 0$, and

(4) $Q^{-i} - Q^i = 0$.

The Lagrangian multiplier associated with the joint-use constraint, ω , can be interpreted as the marginal utility of an additional unit of Q^{-i} and hence, can be denoted as $U^i_{Q^{-i}}$. Dividing equation (2) λ and gives:

$$U^i_{Q^i} / \lambda - P_Q - \omega / \lambda = 0 .$$

The above expression, after substituting for the value of λ , from equation (1), and ω becomes,

$$MRS^i_{Q^i y} - MRS^i_{Q^{-i} y} = P_Q / P_y , \quad i=1,\ldots,n.$$

The Nash-Cournot joint-use - joint product model, defined for marketed goods, may be represented as:

$$\max_{\{y^i, Q^i\}} U^i = U^i(y^i, x^i, Z^i, E^i)$$

subject to $\quad I^i = P_y y^i + P_Q Q^i$

$$Q = \sum_{i=1}^{n} Q^i$$

where $x^i = g_i(Q^i)$, $z^i = h_i(Q^i)$,

$$Z^i = z^i + \tilde{Z}^i \text{ , and } \tilde{Z}^i = m(\tilde{Q}^i) .$$

The utility function can be defined over the marketed goods as:

$$U^i(y^i, g_i(Q^i), h_i(Q^i)+ m(\tilde{Q}^i), E^i)$$

We can decompose the total amount of agricultural research as being made up of that demanded by the i-th state (given by Q^i), and that demanded by the other n-1 states ($\tilde{Q}^i$). That is:

$$Q = Q^i + \tilde{Q}^i .$$

Using this relation we can substitute for $\tilde{Q}^i$ in the utility function

$$\tilde{Q}^i = (Q - Q^i)$$

where $$\tilde{Q}^i = \sum_{j \neq i}^{n} Q^j .$$

The associated Lagrangian, after substituting for $\tilde{Q}^i$ in the utility function, is:

$$\pounds = U^i(y^i, g_i(Q^i), h_i(Q^i)+ m(Q - Q^i),E) +$$

$$\lambda[\; I^i - P_y y^i - P_Q Q^i] \; ,$$

and the corresponding first-order conditions are:

(1) $U_y^i - \lambda P_y = 0$,

(2) $g'_i \; U_x^i + (h' - m') \; U_z^i - \lambda P_Q = 0$, and

(3) $I^i - P_y y^i - P_Q Q^i = 0$.

Substituting for λ in equation (2) gives:

$$g'_i \; MRS_{xy}^i + (h'_i - m') \; MRS_{zy}^i = P_Q \,/\, P_y \; .$$

VII. APPENDIX B. TWO-STAGE LEAST SQUARES ESTIMATES

Table B.1 Upper Central Region: Two-stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and r-ratios are in parentheses)

		Regressors			
States	ρ[a]	Constant	$\ln P_{xt}$	$\ln F_{it}$	$\ln SPILL_{it}^r$
Illinois	.581	1.406 (3.44)	-1.177 (-10.90)	0.041 (1.45)	0.929 (18.33)
Indiana	.700	0.954 (1.95)	-1.454 (-11.05)	0.088 (1.48)	0.878 (9.92)
Iowa	-	0.319 (1.57)	-1.248 (-10.85)	0.011 (0.19)	1.004 (12.23)
Kansas	-	-0.138 (-0.77)	-1.277 (-11.08)	0.172 (2.69)	0.845 (10.44)
Michigan	-	-0.088 (-0.39)	-1.168 (-12.28)	0.043 (1.19)	1.000 (15.60)
Minnesota	.493	0.357 (2.71)	-1.088 (-28.49)	0.006 (0.62)	0.960 (47.19)
Missouri	.478	0.121 (0.23)	-1.429 (-9.57)	0.087 (1.05)	0.919 (8.06)

[a]When statistically significant first-order autocorrelation occurs, ρ is used to transform the data.

Table B.1 (Continued)

States	ρ^a	Regressors			
		Constant	lnP_{xt}	lnF_{it}	$lnSPILL^r_{it}$
Nebraska	-	-0.297 (-1.44)	-1.244 (-11.49)	0.135 (3.33)	0.914 (15.73)
Ohio	-	0.896 (3.04)	-1.240 (-9.69)	0.136 (2.93)	0.781 (9.46)
South Dakota	-	-0.137 (-0.78)	-1.248 (-12.25)	0.009 (0.53)	1.042 (44.09)
Wisconsin	-	0.600 (2.34)	-1.383 (-9.06)	0.023 (0.99)	0.957 (21.77)

Table B.2. Northeast region: Two stage least squares estimates of the demand for SAES research, 1951-82. (Dependent variable is $\ln Q_t^r$ and t-ratios are in parentheses)

	Regressors			
States	Constant	$\ln P_t$	$\ln F_{it}^r$	$\ln SPILL_{it}^r$
Connecticut	0.419 (1.92)	-0.967 (-14.84)	-0.014 (-0.56)	0.988 (21.09)
Delaware	-0.980 (2.88)	-0.980 (-1.24)	-0.004 (-1.24)	0.996 (141.26)
Maine	-0.019 (-0.65)	-1.012 (-88.47)	0.017 (4.76)	0.984 (160.76)
Maryland	-0.107 (-0.63)	-0.965 (-22.02)	-0.006 (-0.49)	1.031 (33.88)
Massachusetts	0.170 (2.88)	-1.039 (-43.24)	-0.024 (-3.32)	1.018 (78.35)
New Hampshire	-0.111 (-2.69)	-1.017 (-95.55)	-0.011 (-3.08)	1.025 (142.50)
New Jersey	0.433 (1.05)	-0.838 (-8.75)	0.029 (1.22)	0.949 (14.83)
New York	0.939 (2.66)	-1.160 (9.43)	0.032 (0.95)	0.881 (11.92)
Pennsylvania	0.131 (0.96)	-0.867 (3.17)	0.044 (3.17)	0.953 (32.54)
Rhode Island	-0.063 (-2.72)	-1.016 (-126.99)	-0.001 (-0.75)	1.009 (280.19)
Vermont	-0.015 (-0.34)	-0.998 (-107.68)	0.003 (0.63)	1.001 (120.97)

VIII. APPENDIX C. ALTERNATIVE J-TEST METHODOLOGY

The methodology of the JII test is the same as that of JI, except that the predicted value from the competing model is also corrected for autocorrelation in the model to be tested. The compound model for testing the Nash-Cournot model is:

$$\ln Q^r_t = a_{0i} + a_{1i}(1 - \Omega)(1 - \hat{\rho}^*_i) + a_{2i}\hat{\rho}^*_i(\ln Q^r_{t-1})$$

$$a_{3i}(1 - \Omega)(\ln P_t - \hat{\rho}^*_i \ln P_{t-1})$$

$$+ a_{4i}(1 - \Omega)(\ln \hat{F}^r_{it} - \hat{\rho}^*_i \ln \hat{F}^r_{it-1})$$

$$+ a_{5i}(1 - \Omega)(\ln \hat{SPILL}^r_{it} - \hat{\rho}^*_i \ln \hat{SPILL}^r_{it-1})_1$$

$$+ a_{5i}\,\Omega\,(\ln Q^{rL}_t - \hat{\rho}^*_i \ln Q^{rL}_t) + \upsilon_{it}, \qquad \text{(III.17)}$$

where $\hat{\rho}^*_i$ is the predicted value of the autocorrelation coefficient.

The hypothesis of the J test remain the same as in method JI. Results from using the JII procedure are presented in Tables C.1 and C.2.

Table C.1. JII Test Results: South and East-Central Uplands Region

	Hypothesis 1			Hypothesis 2		
States	$\ln Q_t^{rL}$	t-ratio	Conclusion	$\ln Q_t^{rN}$	t-ratio	Conclusion
Arkansas	-0.085	-18.14	Reject	0.765	11.71	Reject
Alabama	1.369	15.73	Reject	0.884	12.75	Reject
Florida	-0.091	-20.84	Reject	1.061	176.41	Reject
Georgia	-0.164	-11.83	Reject	1.035	150.68	Reject
Illinois	-0.162	-13.80	Reject	1.026	52.93	Reject
Indiana	-0.047	-11.79	Reject	1.033	286.10	Reject
Kansas	-0.051	-5.39	Reject	1.074	133.11	Reject
Kentucky	-0.095	-14.33	Reject	1.037	213.45	Reject
Louisiana	-0.076	-22.54	Reject	1.049	181.64	Reject
Mississippi	-0.071	-37.41	Reject	1.104	82.56	Reject
Missouri	-0.123	-14.57	Reject	1.041	156.57	Reject
N. Carolina	-0.123	-9.77	Reject	1.003	114.04	Reject
New Mexico	-0.035	-20.76	Reject	1.017	714.89	Reject
Ohio	-0.066	-14.08	Reject	1.048	239.39	Reject
Oklahoma	-0.060	-23.74	Reject	1.027	197.92	Reject
S. Carolina	-0.058	-33.49	Reject	1.012	657.58	Reject
Tennessee	-0.114	-12.95	Reject	1.015	249.08	Reject
Texas	1.174	18.53	Reject	1.295	21.18	Reject
Virginia	-0.033	-5.46	Reject	1.028	237.71	Reject
W. Virginia	-0.027	-11.92	Reject	1.009	392.59	Reject

Table C.2. JII Test Results: Upper Central Region

	Hypothesis 1			Hypothesis 2		
States	$\ln Q_t^{rL}$	t-ratio	Conclusion	$\ln Q_t^{rN}$	t-ratio	Conclusion
Illinois	0.263	3.33	Reject	0.958	26.05	Reject
Indiana	-0.089	-24.86	Reject	1.055	235.73	Reject
Iowa	-0.336	-23.14	Reject	1.010	45.42	Reject
Kansas	-0.335	-20.70	Reject	1.002	54.15	Reject
Michigan	-0.495	-28.16	Reject	1.023	45.58	Reject
Minnesota	-1.904	-12.12	Reject	1.032	280.28	Reject
Missouri	0.148	24.68	Reject	0.801	16.56	Reject
Nebraska	-0.362	-13.88	Reject	1.005	83.82	Reject
Ohio	-0.219	-2.70	Reject	1.142	20.19	Reject
S. Dakota	-0.058	-2.84	Reject	1.011	150.68	Reject
Wisconsin	-0.191	-19.77	Reject	1.036	309.32	Reject

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