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INDUCEMENTS TO PUBLIC RESEARCH: RICE AND WHEAT IN INDIA

Keijiro Otsuka*

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Notes: * Tokyo Metropolitan University. The research for this paper was performed while the author was a Postdoctoral Fellow at Yale University.

I. Introduction

Although much has been written about the rapid diffusion of the modern varieties (MVs) and the high growth performance of agricultural sector in India since the mid-1960s, in particular in the rice and wheat sectors, no systematic inquiry has been made as to how this revolutionary change took place.[1/] Was it simply a result of the direct transfer of the improved seeds of rice from the Philippines and wheat from Mexico? If not, what was the mechanism through which India could attain its unprecedentedly high growth of agricultural productivity?

Figure 1 compares the trends of rice and wheat yields since 1960 with the diffusion rates of the MVs (ratio of cropped area covered by the MVs to total cropped area). Excepting the poor crop years of the mid-1960s and the early 1970s due to unfavorable weather, the yield growth coincided with the growing adoption of the MVs. There seems to be no doubt that the diffusion of the MVs contributed to the productivity growth of the rice and wheat sectors.[2/] At the same time, however, it is untenable to totally attribute these productivity gains to the diffusion of MVs developed abroad and imported into India. As a matter of fact, a few years before 1970 the diffusion of the imported MVs began declining and were being replaced by new MVs locally developed by indigenous breeding efforts using foreign MVs as parental varieties [Dalrymple, 1978]. Public sector research played a substantial role in this growth process. Figure 2 supports our contention, where the number of the rice- and wheat-oriented publications by Indian scientists working for the public research institutions, which are abstracted in the relevant journals,[3/] are shown, together with the number of the cotton- and sugar-oriented research publications. The growth of rice and wheat research during the late 1960s is quite impressive. One of the key issues we will explore in this analysis is the relative contribution of the imported MVs without adaptational research, and of domestic research efforts, to productivity growth in the rice and wheat sectors. Separate production function analysis on these crop sectors will be employed for this purpose, using the number of rice- and wheat-oriented research publications as an index of public sector research outputs. Given the uncertain nature of the research publications as a technology index, we will first test their usefulness by attempting the statistical analysis relating the number of total field crop-oriented publications to aggregate research expenditures before proceeding to the production function analysis of the specific crop sectors.

It is not legitimate, however, to evaluate the impact of the imported technology only in terms of its direct effect on productivity. There are many indications that the foreign MVs induced domestic research concerned with adaptation of technological knowledge embodied in those MVs to the Indian local conditions.[4/] Let us again take a look at Figure 2, noting that there is about a 3 to 5 year lag between the actual period of research and the date of the published research outcome being abstracted, and that the import of improved rice seeds began in 1960 and that of wheat in 1962 [Dalrymple, 1978 and Huang et al., 1972]. The fact that the abstracted rice and wheat research publications increased greatly during the late 1960s clearly suggests the pervasive effect on indigenous research efforts of the new research possibility opened up by the advent of the semi-dwarf rice and wheat varieties. Moreover, comparison of the growing trends of the rice and wheat research with the essentially stagnant trends of the cotton and sugar research, for which no substantial borrowable stock of knowledge existed in foreign countries, provides additional evidence of the positive interaction between borrowed technology and adaptive research.

However, this does not tell the whole story. Rice and wheat research began declining, with peaks in 1972 and a resumed upswing in the late 1970s. It appears that one of the critical factors responsible for this decline in research is diminishing returns to domestic research as a result of intensive previous research efforts. The individual state research publication data shown in Table 1 for rice and in Table 2 for wheat reveal the tendency that those states in which the growth rates of research publications were high during the early two periods (1963-66 and 1967-70) witnessed either a negative or only slightly positive growth of publications during the later periods (1971-74 to 1975-78). On the other hand, the critical factor which led to the increasing research in the 1975-78 period appears to have been increasing crop prices during the food "crisis" in the 1973-74 period (see Figure 1). Since research knowledge is a useful input of production, the derived demand for it arises from the profit-seeking motives of producers. Such derived demand should positively depend on the real output price, for the economic value of a given productivity increment resulting from research activity will be greater, the higher the output price is relative to input prices. While it is true that research information supplied by public institutions is characterized by the nature of public goods and thus non-marketable, the increased crop prices in recent years may well have caused the increased appropriations of public funds for research through non-market interactions between farm producers and research entrepreneurs.[5/] The same economic logic also points to the causation running from crop prices to research publications in the earlier years. Indeed, growth curves of both the publications shown in Figure 2 and the prices shown in Figure 1 follow bell-shaped paths, with some time lags. The price changes appear to have helped launch a substantial number of research projects and deter their continuation or implementation of new projects.

In sum, public sector research in India appears to have been responsive to shifts in research supply, as suggested by the positive relationship between the discovery of the MVs and domestic research efforts, and in research demand, as exemplified by the cyclical changes in both output prices and crop research publications. What economic factors influenced the research decisions in India represents another major issue to be resolved in this analysis. In the final section we will test if public sector research behavior is guided by changes in variables affecting the profitability of research production.

II. Estimation of Research Publication Function

While the common measure of agricultural research activity is the amount of research inputs measured by real research expenditures, the research expenditure data in India are available only in the aggregate form,including costs of resources spent for a variety of crop production purposes. In order to explore the cause and the effect of public sector research in the rice and wheat sectors in India, we will use the number of research publications specifically oriented to rice and wheat production as an index of research outputs. Although variations in quality among published articles represent the prime difficulty in the interpretation of publication data,[6/] they have certain advantages as a research measure; they are a real measure free from the problem of appropriate deflator, and the selection process employed by abstracting journals provides a quality standard.

Since we will exclusively rely on such data in the following analyses, it seems of utmost relevance to clarify the nature of publication data in relation to available, though limited, expenditures data of the aggregate magnitudes. The overall picture of changes in publications and expenditures at the all-India level is shown in Figure 3.[7/] The broad consistency of the historical trends of the two series can be observed at a first glance. Let us further pursue this issue by undertaking a statistical analysis of the "research production function" at the state level.

We will postulate that the quality-adjusted number of publications produced depends on the amount of research resources employed and the stock of knowledge useful for research activity in the same way as in the ordinary production function, where the quality-adjusted output depends on the amount of input resources employed and technological knowledge. More specifically, we will assume the following functional relation:

$$P = g(Q) \cdot f(I;S),$$

where P stands for the number of publications in a state at a given year, g for the quality adjustment function with variable Q for the average quality factor of publications, and f for the production function relation with real research inputs of I and a shift parameter of S.

In practice, we will assume that the ratio of rice cum wheat publications to the total publications is a reasonable proxy for Q in view of the relatively greater scientific quality of published articles concerned with those crops. Q is supposed to have a negative effect on P because larger amounts of inputs are required for the publication of higher-quality articles.

The following variables are introduced for the shift parameter S: the neighborhood effect of technological knowledge captured by past research conducted in surrounding states with similar agro-climatic environments; the borrowable stock of the most advanced applied research knowledge in India approximated by the ratio of the total factor productivity of a state to the highest state total factor productivity in India; and the stock of the relatively basic research knowledge estimated by past research undertaken at Delhi and New Delhi, where the central research institution of the Indian Agricultural Research Institute is located. All these variables are expected to enhance the efficiency of research production, thereby raising the input productivity.

The estimated equations in logarithmic form are shown in Table 3. The most remarkable result should be the firm statistical relationship found between the publications and real expenditures as revealed by the t-values of more than 5.0. Moreover, the estimated expenditure elasticity of 0.8 is highly reasonable: a 1% increase in the research input mix increases the number of research publications by less than 1% due to the diminishing return in the state research activity.[8/] Significant effects of past research in surrounding states and at Delhi support the hypothesis that state technology production is more efficient when there is a greater stock of research knowledge relevant to state research. Supposed effects of other variables, however, are not revealed statistically.

In the light of the above statistical analysis, we may conclude that research activity is amenable to ordinary production function analysis. More importantly, it appears reasonable to regard the publication data as a good proxy for research outputs. This does not imply, of course, that publication data are a perfect substitute for expenditures as a technology index; the number of publications reflects the efficiency of research production, whereas the amount of expenditures simply measures the direct inputs of production, with no regard to research productivity. Statistical evidence that basic as well as applied research conducted outside the states positively affected the number of state research publications supports the hypothesis that publication data embody research production efficiency as well as direct research efforts.

III. Effect of Research on Productivity

A. Specification of Production Function

This section turns to a statistical analysis of the effect on productivity of public sector research in the rice and wheat sectors in India, using a state as an observation unit. The following functional relation serves as a framework for the analysis:

(1) $$Y_{ti} = F(A_{oi}, A_{ti}, CI_{ti}, QF_{ti}, SC_i),$$

Y = Yield

A_o = Research Capital in 1955

A_t = Research Capital Accumulated since 1956

CI = Conventional Input-Land Ratios

QF = Quality Factor of Inputs

SC = State Characteristics

t = t-th Period

i = i-th State.

A_o stands for the research knowledge accumulated before 1955, while A_t represents the research knowledge created since then. Considering the wide variability of annual state yields and state research publications, we will use four-year periods from 1959-62 to 1975-78 as a time unit (i.e., 1959-62, 1963-66, 1967-70, 1971-74 and 1975-78) to reduce the problem of measurement errors. Therefore, where relevant, the four-year average figures of variables are employed. This procedure, however, leads to the loss of degrees of freedom in the regression analysis, which makes it difficult to handle the unobservable variables of A_o and SC by the state dummy techniques.

We assume that the yield function is of the Cobb-Douglas form and that A_t, which is largely based on the modern agricultural science, is separable from A_o, which results essentially from less scientific research endeavors of the prewar years.[9/] The yield functions in 1955 and t-th period are

(2) $$Y_{ti} = (A_{oi})^{\beta_1}(A_{ti})^{\alpha_1}(CI_{ti})^{\alpha_2}(QF_{ti})^{\alpha_3}(SC_i)^{\beta_i}$$

and

$$(3) \qquad Y_{oi} = (A_{oi})^{\beta_1}(CI_{oi})^{\alpha_2}(QF_{ti})^{\alpha_3}(SC_i)^{\beta_i}.$$

Then A_{oi} and SC_i can be suppressed by dividing equation (2) by equation (3). The estimated yield relation is, therefore, of the following form:

$$\frac{Y_{ti}}{Y_{oi}} = (A_{ti})^{\alpha_1}\left(\frac{CI_{ti}}{CI_{oi}}\right)^{\alpha_2}\left(\frac{QF_{ti}}{QF_{oi}}\right)^{\alpha_3}.$$

We have considered three variables constituting the A_t variable: past state research, past regional research, and the superiority of the imported modern varieties. Past state research is defined as the cumulated simple sum of rice- or wheat-oriented publications abstracted for the years from 1951 to t-th period. Given the roughly four years' time lag between the period of research conducted and the date of published outcome abstracted, the diffusion periods are assumed to be about 4 years.[10/] Past regional research is the sum of research publications outside the state but within the same major agro-climate region.[11/] This variable is expected to reflect the free, spill-over benefits of research from other Indian states. The superiority of the imported MVs is estimated by the average ratio of yields with the high-yielding varieties to those with local varieties under the irrigated field conditions for 1967 and 1968, when most of the high-yielding varieties consisted of imported MVs. This variable purports to capture the free, international spill-over benefits to India.

It must be noted at this point that even if those variables defined above are good proxies for the stock of knowledge, they are not necessarily appropriate arguments in the production function. That is, unless each state is homogeneous so that the same knowledge is of equal practical value throughout a state, the production effects of a given percentage progress in knowledge would vary among states. Actually it is well-known that crop technology under consideration is location-specific to varying degrees within a state because of the diverse production environments of India. To take account of the heterogeneous production effects of knowledge, all three of the knowledge-related variables are "deflated" or multiplied by the agro-climate homogeneity index of state, defined as the squared sum of the ratios of different agro-climate rice or wheat sub-regions in the state.[12/] To put it shortly, we assume that the productivity effect of a given knowledge depends on how homogeneous a state is in terms of its environmental characteristics.

Due to the unavailability of input data specific to rice and wheat production except for the cropped area, input-land ratios considered were merely fertilizer- and labor-cropped area ratios, both for the total crop production. The quality elements of land and labor inputs are taken care of by the modern irrigation rate (ratio of irrigated cropped areas by tube-well and government canal to the gross cropped areas, separately for rice and wheat) and the literacy ratio of agricultural workers.

B. Statistical Results

The regression estimates reported in Table 4 for rice show positive and significant past state research coefficients. However, the externality expected to be captured by the initial yield effect of the MVs and by past regional research performed poorly. Taken literally, this implies that a state cannot attain the productivity growth in the rice sector unless it allocates its own resources to rice research. It was not the simple transfer of the MVs to India, but India's, or, more accurately, the states' research efforts which directly brought about the remarkable growth of rice production.

Statistical results for the wheat sector, shown in Table 5, are wholly different with respect to the knowledge-related variables. First of all, although the sign is as expected, the effect of past state research is not statistically significant. Does this imply that state research did not contribute much to wheat productivity improvements, in spite of the fact that the yield growth of wheat was far greater than that of rice? Indefinite as it is, it appears that as far as wheat is concerned the external effects across states are so substantial that the relationship between state research and state productivity is not as direct as in the case of rice. Region rather than state may be a more appropriate unit area served by state research. The substantial spill-over benefits to a state wheat sector were not confined to those from other Indian states: the significant coefficients of the initial yield effect of the MVs are suggestive of the direct applicability of the imported MVs over wide areas. These results are in accord with the observation that a few imported MVs were much diffused throughout India [Dalrymple, 1978]. The issue of "internal" vs. "external" sources of productivity growth will be a clue to proper understanding of the differential growth rates of rice and wheat yields.

The labor-land and fertilizer-land ratios do not show significant effects, in contrast to the positive and mostly significant effects of the input quality-related variables--irrigation rate of cropped area and literacy ratio of agricultural workers. Given the fact that the input-land ratios are for the total agricultural sector, the insignificant results are not too disappointing. Rather, it is encouraging for us to have confirmed the alleged complementarity between irrigation and modern technology [International Rice Research Institute, 1975] and between education and production efficiency [Chaudhuri, 1973].

IV. Determinants of Research Publication

A. Specification of Research Determination Function

Evenson and Kislev (1975) estimate that the marginal internal rates of return to state agricultural research in India were on the order of 30 to 50%, the margin being due to the specification of spill-over benefits from one state to another, which would imply that state funds have been socially underinvested in research. A crude calculation based on our production function analysis indicates a marginal rate of return of the same magnitude. Therefore, the research "market" appears to have worked inefficiently from a social welfare point of view.

This would not imply, however, that no economic forces were at work to guide research investment decisions in India toward a more efficient direction. Indeed, without activated research during the years of price hikes and the burgeoning stage of MV imports, the rate of return to research must have been much higher. It is rather remarkable to observe that public sector research appears to have been responsive, for whatever reasons, to changes in research demand and supply, in view of the fact that research information under consideration is neither priced nor transacted at the market place. Furthermore, as far as state research is financed by state budget, a part of the excessively high return must be attributed to the spill-over effect of research among states but not to the inefficient state research policy. We will explore in this section if and to what extent the actual behavior of the research publications across states and over time is consistent with the profit-seeking behavior of research planning by states. A simple dynamic optimization problem will be formulated and the implication of the solution for the determinants of the number of current research publications will be tested.

Particular focus will be placed on the possible effect of market crop prices on state research. Due to the procurement program of major crops, internal movements of wheat and rice across state borders, as well as international movements, have been regulated so that both states and the nation as a whole are partially segregated from other markets. Moreover, crop prices are set by the state governments such that prices in "surplus" states are depressed and in "deficit" states are supported, with a downward bias from world prices in both cases [Lele 1971 and Mellor 1972]. Needless to say, such price distortion will lead to the misallocation of private resources. The question of interest is a step further: Does the price distortion bring about the distorted allocation of public resources? The issue will be of wide relevance in view of the ubiquitous downward distortions of agricultural prices in many developing countries.

We will assume, for simplicity, that state research does not affect market prices of outputs and inputs, except for land resources, i.e., only land input is inelastically supplied.[13/] Then, viewed from each state, which is assumed to be a maximizer of the state welfare, all future benefits accrue to state producers as a capitalized value of land inputs.[14/] The dynamic maximization amounts to the maximization of discounted value of all future returns to land minus current research costs: i.e.,

$$\text{Maximize } \int_s^\infty [P_t Q_t - P_t^F F_t - W_t L_t] e^{-rt} dt - V_s R_s,$$

where

P = Rice (or Wheat) Price

Q = State Rice (or Wheat) Outputs

P^F = Fertilizer Price

F = Fertilizer Inputs

W = Farm Wage Rate

L = Labor Inputs

V = Unit Average Cost of Publication

R = Number of Publications

r = Discount Rate .

The control variables are R_s, F_t, and L_t, and the constraint of this maximization problem is the following technology production function derived from the yield regression analysis;

$$\frac{d(\text{Technology})_t}{dt} = A_o^{\beta_1} \alpha_1 A_t^{\alpha_1 - 1} \frac{dA_t}{dt}$$

$$\simeq A_o^{\beta_1} \alpha_1 A_t^{\alpha_1 - 1} R_t,$$

where A_t is a function of past state research, yield effect of foreign MVs, and past research in the same agro-climate region.

Manipulation of the first-order necessary conditions of this maximization problem shows that the optimum magnitude of R is a non-linear function of expected values of all future exogenous variables and the research knowledge accumulated in the past;

$$(1) \qquad R_t = \int_t^\infty G(\underset{(+)}{P}, \underset{(-)}{V}, \underset{(-)}{P_F}, \underset{(-)}{W}, \underset{(+)}{A_o}, \underset{(?)}{A_t}, \underset{(+)}{IR}, \underset{(+)}{LR}) e^{-rs} ds$$

where

IR = Irrigation Rate

LR = Literacy Rate,

and the signs under variables show the direction of the partial effects of variables in the optimum research publication determination function.

We again suppress the A_o variable and introduce the shifters of research publication function into equation (1) by use of the functional relation between the research publication and research inputs analyzed in section II:

$$(2) \qquad R_t = f(I; S) \quad ,$$

where S is a catch-all variable including the whole range of variables affecting the efficiency of rice or wheat research publications; the variables constituting S are general research knowledge, yield effect of MVs, past research in a similar region, and initial research capital A_o. The problem here is the lack of and endogenous nature of the crop research input data, I. We assume that I is equal to total state research expenditures multiplied by the ratio of rice- or wheat-oriented publications to total state publications, i.e.,

$$(3) \qquad I = \left(\frac{\text{Number of a Specific Crop-Oriented Publications}}{\text{Number of Total Publications}}\right)\cdot(\text{Real Research Expenditures})$$

$$= (\text{Number of a Specific Crop-Oriented Publications})\cdot(\text{Average Unit Cost of Publication})$$

$$= R\cdot V.$$

Solving equation (2) for A_o and substituting it into equation (1) with the use of equation (3) yield the reduced form research publication function without unobservable variable A_o.

B. Statistical Results

Since the exact form of the research publication determination function thus derived is not known, various specifications of the regression equation have been attempted. The "best" statistical results are reported in Table 6 for rice and in Table 7 for wheat, where some of the variables which did not show any significant effects in unreported regressions are deleted, and the future expectations are assumed to be dependent on past data and time. In the case of rice almost all variables have expected signs and more than four coefficients are significant. Particularly noticeable are the positive effect of the rice price on research when it is deflated by the unit cost of research publication, the rice cropped-area, and the irrigation ratio. These are the variables determining the gross profits of research accrued from state research to the state rice producers. These statistical results support the hypothesis that state research is motivated to promote the welfare of farmers residing in the state.

A similar, though less clear-cut, observation can be made as to wheat-oriented publications. Coefficients of wheat prices and cropped area have positive signs with t-values of more than unity. Moreover, the effect of the wheat price-fertilizer price ratio is significant. It appears that the research demand of state wheat producers affected, to a lesser extent, state wheat research decisions. This is consistent with our earlier finding that the relationship between state research and state productivity in wheat is not as close as in rice.

The evidence that market prices govern resource allocation in the public sector for agricultural growth measures is not new. Hayami and Kikuchi (1978), taking the case of irrigation in the Philippines, find that rice prices manipulated by the government affected the rate of return to irrigation investment, which in turn guided public sector irrigation programs. Otsuka (1979) reveals that the highly supported rice prices in Japan had an appreciable impact on rice research investments made by the central as well as local governments. Changes in the market prices in India, too, should have induced changes in state research policy by affecting the payoff of research investment.

On the other hand, the initial yield effect of the MVs does not show any expected positive effects on state publication in either crop case. We do not regard this result as evidence of the negligible effect of imported technology on domestic Indian research. For one thing, the MVs would have affected the allocation of resources to general research, thereby inducing the current research publication in an indirect fashion; and for another, past state and regional research is likely to have been induced to increase by the introduction of MVs. The statistical results are supportive of such a hypothesis. Although we are unable to detect the favorable effects of the MVs on domestic state research statistically, our analysis suggests the importance of the indirect route through which scientific breakthroughs made abroad affected the Indian agricultural growth.

What implications can we draw from our analysis of the causes of Indian agricultural growth? It will certainly be true that the semi-dwarf high-yielding varieties imported to India during the early

1960s were instrumental not only in raising the productivity directly but also in inducing indigenous research, thereby raising the pro-uctivity indirectly. Also, there appears to be no denying that increases in the market rice and wheat prices have affected productivity growth by stimulating state research investments. The process of Indian agricultural growth must be understood in the light of the intricate mechanism of research inducement, in responding to the market price as well as research efficiency changes.

V. Concluding Remarks

We have empirically revealed the significant role played by public sector research in the productivity growth of Indian agriculture. For productivity growth in each state, the state's own research is most critical for rice, and the spill-over effects of research knowledge from other states as well as from abroad are of utmost importance for wheat. Therefore, rice-growing states are handicapped in comparison to wheat-growing states, as rice-growing states which do not appropriate public resources for rice research cannot realize technological progress, whereas wheat-growing states can enjoy a great deal of external benefits. The growing disparity between rice and wheat yields in India will be partially accounted for by this differential applicability of technological knowledge across areas.

The handicaps are artificially made even more serious by the "cheaper" price of rice than that of wheat because of discriminatory government intervention in these grain markets.[15/] Statistical results indicate that research planners are well aware of the profitable opportunity for research projects and the price is a major component of profitability. Huge downward price distortions of both crops, especially for rice, are harmful for Indian agricultural growth because of the induced underinvestment of public funds in agricultural research.[16]

The active response of Indian domestic research to the MV technology developed at international research centers provides significant implications for international technology transfer in agriculture. Successful technology transfer requires the adaptive research to modify foreign technology so as to be consistent with environmental and economc conditions of the importing region. Our analysis suggests that adaptive research will be induced if the international technology gap represents the unexploited research opportunity. In other words, if it is profitable to borrow foreign technology, scarce resources will be allocated to research for the sake of adaptation.

The clear recognition of the effect on research of price and foreign technology would widen the scope of our understanding of the process of agricultural growth. There has been wide variability in rice prices in Asian countries. In recent decades, considerable differences in rice yields have emerged as a result of different growth of rice yields. As has been indicated by Timmer and Falcon (1977), the yield differences are so substantial that short-run movements along the same production function can hardly explain them. Thus, current yield differences are likely to be largely attributable to the differences in past investments in adaptive research, which in turn will be explainable if we realize the stimulus of price to the development of technology. The focus on the distortion of market prices will provide the key to gaining deeper insights into the different experiences of the "Green Revolution" among poor countries.

Footnotes

[1]The literature on Indian agricultural growth is by now profuse. See, among others, Rao [1975].

[2]Sukhatme [1977] observes that where the yield growth was the largest, the rate and level of MV adoption were the greatest.

[3]Three abstracting journals are used for counting the number of publications: Indian Science Abstracts, Plant Breeding Abstracts, and Biological Abstracts. Indian Science Abstracts is the most comprehensive and consistent in the coverage of journals, but its first volume was published in 1965. Therefore, for the years before 1965, the number of articles abstracted in the Plant Breeding Abstracts and Biological Abstracts are counted without double-counting. Consistency of the two methods is checked for some of the years after 1965.

[4]A close investigation of the abstracted articles shows that the most common research subjects in the earlier periods were on the comparative yield tests between imported MVs and local varieties, but research on the new hybridization gradually dominated the scene. Also Hargrove [1978] and Vyas [1975] report that many of the local semi-dwarfs were developed from crosses between the two types of varieties and later used for breeding programs as parents in place of the original semi-dwarfs.

[5]The importance of dialectic interactions between farmers and researchers in research resource allocation is highlighted by Hayami and Ruttan [1971]. It must be noted, however, that while they essentially inquired into the process of allocating given research budget for the development of different forms of technology in relation to the relative input price changes, what we would like to clarify is determinants of the amount of the research budget in relation to relative output price changes.

[6]The quality problem of publication data is similar in nature to that of patent data. In this regard, Schmookler [1966] contends that the value of patent data can be judged only in terms of their usefulness for the understanding of technological change. Moreover, as will be discussed in this section, expenditure data implicitly assume away the "quality" problem in the sense that the productivity of research inputs is disregarded. See Griliches [1979] for other difficulties of the use of research expenditures.

[7]The research expenditure data in India are scattered and, more often than not, unavailable for certain states and years. The only available time-series data by states are those estimated by Mohan et al. [1973] up to 1968.

[8] This proposition must be qualified to the extent that states which produced the largest number of publications are those which undertook more sophisticated, high-quality research projects.

[9] As far as rice research is concerned, the modern crosses between the Indica and Japonica varieties were first initiated in 1950. See Parthasarathy [1972].

[10] Several ad hoc lag structures are imposed in the unreported regressions with no major differences in statisitcal results.

[11] Easter [1972] classified both rice and wheat cropped areas into three major regions. Increment in regional research knowledge each year is estimated by the following formula:

(i-th Regional Research) = $\sum_j$(The number of j-th State Research Publications)·(Ratio of Cropped Area Belonged to i-th Region to Total Cropped Area in j-th State).

The regional research relevant for j-th states is

(Regional Research for j-th State) = $\sum_i$(Ratio of Cropped Area Belonged to i-th Region in j-th State)·(i-th Regional Research minus j-th State Contribution to i-th Regional Research).

[12] In total,there are twenty-seven sub-rice regions and eighteen sub-wheat regions in India,as defined by Easter [1972].

[13] For a more detailed specification of this maximization problem, see Otsuka [1979].

[14] Note that if the output demand curve facing the nation is inelastic, as probably is in the case of India because of the crop trade regulation, research accrues benefits to consumers at the sacrifice of producers through market price reductions. The implicit assumption underlying the maximization problem in the text is that a state is a "competitive" unit of research production faced by the fixed market price. In consequence, the maximizing decision amounts to the maximization of the producers' surplus in the state output market.

[15] Sukhatme [1977] finds that the effective rates of protection tended to be negative, but much less so for wheat than for rice.

[16] The under-investment in research because of the downward distortion of output prices is one of the major themes of the distorted incentives for the agricultural sector in developing countries discussed by T. W. Schultz [1979].

TABLE 1

RICE-ORIENTED INDIAN RESEARCH PUBLICATIONS
BY STATES, 1955-78

	1955-58	1959-62	1963-66	1967-70	1971-74	1975-78	Total
Andhra Pradesh	9	4	26	37	36	34	146
Assam	0	1	1	1	4	12	19
Bihar	9	7	16	18	20	22	92
Gujarat	3	0	4	2	2	4	15
Karnataka	12	14	9	7	34	57	133
Kerala	2	6	14	10	25	8	65
Madhya Pradesh	3	1	4	12	25	6	51
Maharashtra	2	10	7	10	29	20	78
Orissa[1)]	12	15	10	14	29	22	102
Punjab-Haryana	2	7	12	21	34	37	113
Rajasthan	0	1	2	5	13	9	30
Tamil Nadu	25	22	37	57	101	64	306
Uttar Pradesh	8	7	16	21	49	78	179
West Bengal	19	31	43	61	100	89	343
Delhi	5	20	31	30	57	50	193
Central Rice Research Inst.[1)]	17	46	56	46	54	93	312
All India[2)]	128	194	295	349	534	625	2,126

NOTES: 1) Publications in Orissa do not include those by researchers at the Central Rice Research Institute in Orissa operated by the central government.

2) All India figures include states other than fifteen major states.

SOURCE: 1955-64; Plant Breeding Abstracts and Biological Abstracts.

1965-78; Indian Science Abstracts.

TABLE 2

WHEAT-ORIENTED INDIAN RESEARCH PUBLICATIONS
BY STATES, 1955-78

	1955-58	1959-62	1963-66	1967-70	1971-74	1975-78	Total
Andhra Pradesh	2	0	0	4	2	1	9
Assam	0	0	0	1	2	1	4
Bihar	2	4	10	12	24	25	77
Gujarat	2	0	6	3	10	11	32
Karnataka	2	4	1	6	16	19	48
Kerala	0	0	0	1	0	0	1
Madhya Pradesh	2	5	9	21	55	24	116
Maharashtra	3	3	3	11	19	28	67
Orissa	1	1	0	0	0	0	2
Punjab-Haryana	7	13	10	44	109	111	294
Rajasthan	0	13	9	27	39	41	129
Tamil Nadu	1	1	4	0	8	0	14
Uttar Pradesh	18	17	8	43	89	95	270
West Bengal	5	2	6	2	7	14	36
Delhi	32	60	78	88	116	91	465
All India[1)]	77	122	143	271	507	492	1,612

NOTE: 1) All India figures include states other than fifteen major states.

SOURCE: 1955-64; Plant Breeding Abstracts and Biological Abstracts.

1965-78; Indian Science Abstracts.

TABLE 3

ESTIMATES OF PUBLICATION PRODUCTION FUNCTION

Intercept	-1.008 (-.927)	-.101 (-.027)	5.213 (1.596)	.238 (.063)
Current State Research Expenditures	.807 (5.805)	.803 (5.687)	.839 (5.530)	.790 (5.601)
Past Research Expenditures in Surrounding States	.136 (2.464)	.140 (2.421)	.153 (2.167)	.210 (2.533)
Past Research Expenditures on Basic Research a/	.710 (2.689)	.684 (2.381)		.687 (2.402)
Relative State Productivity b/		-.181 (-.250)	-.786 (-1.084)	-.241 (-.334)
Wheat and Rice Oriented Publication Ratio c/			.040 (.306)	-.144 (-1.175)
Regional Dummy (North and West = 1)	.041 (.122)	.089 (.209)	.011 (.262)	.024 (.431)
R^2	.726	.726	.688	.736

Notes: t-values are in parentheses.

Specification of the estimated function is

$$\text{Log(Number of Research Publications)}_{it} = \sum_j a^j \text{ Log}(X)^j_{it-4}$$

t = year(1966, 69, 72)

i = states(15) .

Four years lag is imposed on the research expenditure variables to take account of the gestation periods of research.

a/ Sum of past years of research expenditures in Delhi and New Delhi since 1955.

b/ Ratio of a state total factor productivity to the highest total factor productivity in India.

c/ Ratio of the number of wheat and rice oriented research publications to the total number of commodity specific research publications.

Source: Appendix.

TABLE 4

ESTIMATES OF RICE YIELD FUNCTION

Intercept	4.487 (7.723)	4.554 (7.860)	4.358 (7.425)	4.448 (7.633)
Past State Research	.154 (2.364)	.150 (2.303)	.155 (2.309)	.134 (2.110)
Past Regional Research	-.147 (-1.250)	-.033 (-.547)	-.015 (-.237)	
Initial Yield Effect of Foreign MVs	.173 (1.130)			.009 (.114)
Fertilizer-Land Ratio	.003 (1.063)	.032 (1.135)	.036 (1.231)	.031 (1.073)
Labor-Land Ratio	-.011 (-.095)	-.026 (-.237)	.169 (.160)	-.009 (-.080)
Irrigation Rate	.004 (2.876)	.004 (3.622)	.004 (3.270)	.004 (3.424)
Literacy Ratio	.001 (1.803)	.001 (2.120)		.001 (1.969)
Trend	-.006 (-.382)	-.016 (-1.075)	-.003 (-.254)	-.014 (-.917)
Regional Dummy (South and East = 1)	-.006 (-.165)	-.007 (-.222)	-.030 (-.910)	-.008 (-.249)
R^2	.766	.762	.745	.761

Notes: Observations are on 15 states for 1959-62, 1963-66. 1967-70, 1971-74, and 1975-78 periods, totally 75.

Past State Research = the number of rice-oriented state research publications cumulated from 1951-55 period to t-th period and multiplied by the state agro-climate homogeneity index of rice production.

Past Regional Research = the number of rice-oriented research publications outside the state but within the same major agro-climate region, multiplied by the state agro-climate homogeneity index.

Initial Yield Effect of Foreign MVs = unity for the pre-green revolution period of 1959-66 and ratio of MV to local variety yields in 1967 and 1968 for the later periods. Note that most of the MVs adopted by farmers in 1967 and 1968 are those developed in foreign countries.

Fertilizer-Land Ratio = ratio of state application of fertilizer in terms of nitrogen contents to state total cropped area.

Labor-Land Ratio = ratio of the number of agricultural workers to state total cropped area.

Irrigation Rate = ratio of gross irrigated paddy area by government canal and tube-well to rice cropped area.

Source: Appendix.

TABLE 5

ESTIMATES OF WHEAT YIELD FUNCTION

Intercept	2.953 (1.950)	2.857 (1.937)	3.330 (2.336)
Past State Research	.008 (.173)	.001 (.035)	.001 (.001)
Past Regional Research	.074 (1.800)	.075 (1.846)	.089 (2.481)
Initial Yield Effect of Foreign MVs	.158 (1.618)	.169 (1.853)	.176 (1.875)
Fertilizer-Land Ratio	.041 (.768)	.039 (.734)	
Labor-Land Ratio	.288 (.915)		.233 (.780)
Irrigation Rate	.003 (2.510)	.003 (2.525)	.004 (3.526)
Literacy Ratio	.001 (1.056)	.001 (1.043)	.001 (1.440)
Trend	.216 (3.117)	.210 (3.160)	.208 (3.047)
Regional Dummy (North and West = 1)	.223 (2.404)	.229 (2.539)	.250 (2.910)
R^2	.822	.821	.819

Notes: t-values are in parentheses.

Observations are on 10 states for 1959-62, 1963-66, 1967-70, 1971-74, and 1975-78 periods, totally 50.

Definitions of variables are the same as in the case of rice yield function except for differences in crops. See footnotes in Table 4.

Source: Appendix.

TABLE 6

ESTIMATES OF RICE-ORIENTED PUBLICATION DETERMINATION FUNCTION, FIFTEEN STATES FOR FIVE PERIODS

Intercept	1.598 (.291)	-.886 (-.215)	-.099 (-.020)
Rice Price-Unit Publication Cost Ratio	.641 (3.150)	.625 (3.104)	.641 (3.164)
Rice Price-Fertilizer Price Ratio	.339 (.336)	-.078 (-.097)	.113 (.118)
Rice Cropped Area	.318 (2.493)	.328 (2.603)	.362 (3.244)
Irrigation Rate	.005 (2.052)	.005 (1.940)	.005 (1.919)
Past State Rice Research	.365 (2.250)	.322 (2.160)	.306 (2.173)
Past General Research	.308 (.769)	.450 (1.310)	.472 (1.411)
Past Regional Rice Research	.483 (1.411)	.528 (1.578)	.592 (1.922)
Initial Yield Effect of Foreign MVs	-.487 (-.690)		-.324 (-.484)
Trend	-.198 (-.610)	-.325 (-1.226)	-.320 (-1.150)
Regional Dummy (North and East = 1)	-.003 (-.015)	.006 (.033)	
R^2	.819	.818	.818

Notes: t-values are in parentheses.

Rice Price = nominal wholesale rice price in state.

Unit Publication Cost = total state research expenditures divided by the total number of state research publications.

Fertilizer Price = wholesale fertlizer price index, common to all states.

Past General Research = the number of state non-commodity specific research publications plus rice-oriented research publications at Delhi and at the Central Rice Research Institute in Orissa, cumulated from 1951.

Source: Appendix.

TABLE 7

ESTIMATES OF WHEAT-ORIENTED PUBLICATION DETERMINATION FUNCTION, TEN STATES FOR FIVE PERIODS

Intercept	-3.811 (-1.758)	-4.262 (-2.066)	-3.877 (-1.807)
Wheat Price-Unit Publication Cost Ratio	.329 (1.338)	.250 (1.110)	.310 (1.286)
Wheat Price-Fertilizer Price Ratio	.661 (1.614)	.662 (1.625)	.716 (1.821)
Wheat Cropped Area	.150 (1.095)	.167 (1.239)	.161 (1.195)
Irrigation Rate	-.004 (-.992)	-.003 (-.687)	-.003 (-.879)
Past State Wheat Research	.395 (2.216)	.431 (2.468)	.401 (2.273)
Past General Research	-.067 (-.268)	-.067 (-.272)	-.130 (-.591)
Past Regional Wheat Research	.527 (1.373)	.555 (1.446)	.610 (1.752)
Initial Yield Effect of Foreign MVs	-.267 (-.819)		-.226 (-.719)
Trend	-.032 (-.111)	-.114 (-.414)	
Regional Dummy (North and West = 1)	.573 (1.797)	.539 (1.653)	.522 (1.726)
R^2	.856	.853	.855

Notes: t-values are in parentheses.

Definitions of variables are the same as in the case of rice publication function except for differences in crops. See footnotes in Table 6.

Source: Appendix.

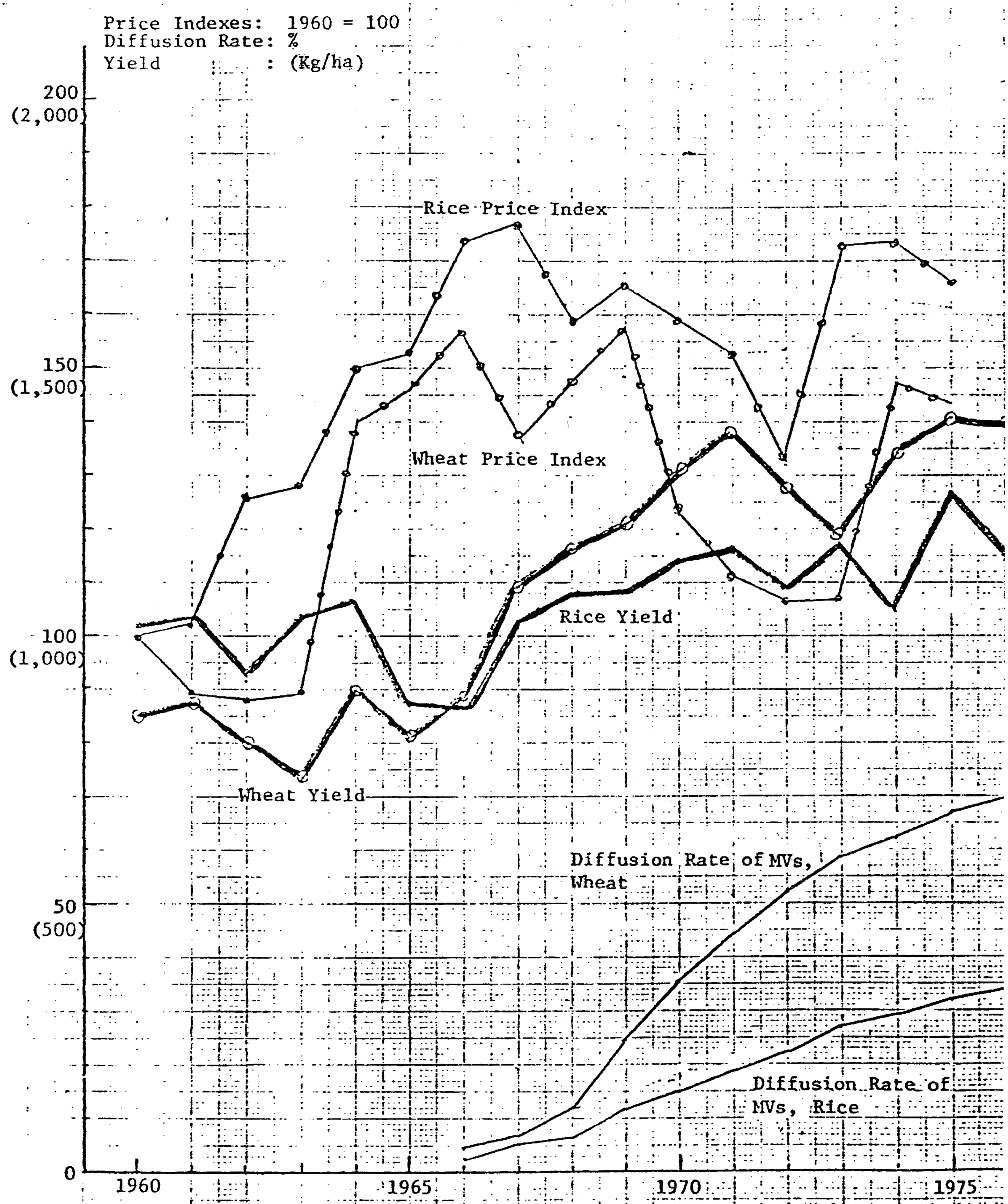

Fig.1.--Real Price Indexes (1960=100), Diffusion Rate of Modern Varieties, and Yield of Rice and Wheat.

Note: Deflator of rice and wheat prices is fertilizer price index.

Source: Appendix.

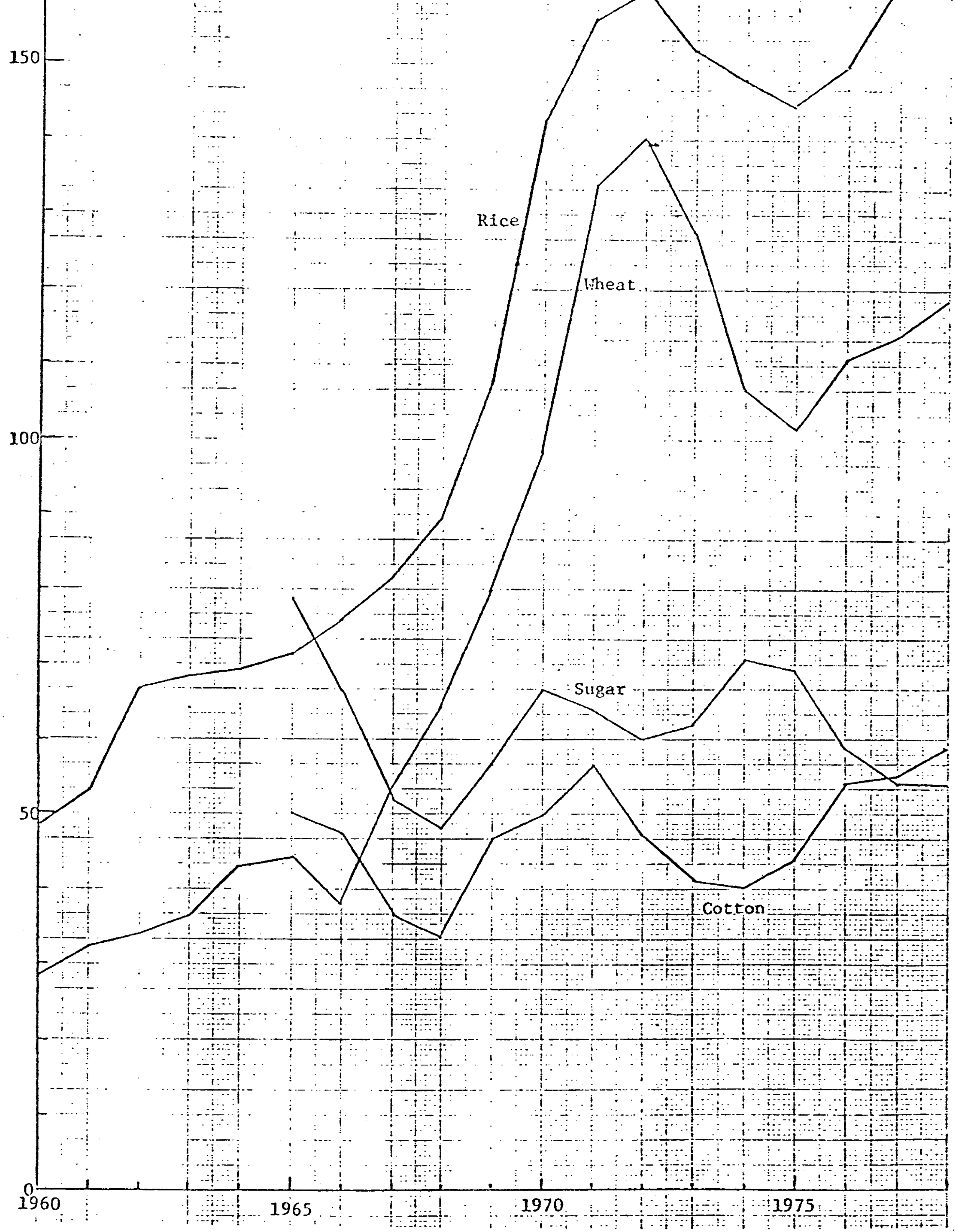

Fig.2.-- The Number of Annual Research Publications Abstracted, Three-year Average; Rice, Wheat, Sugar, and Cotton

Source: See footnotes in Table 1.

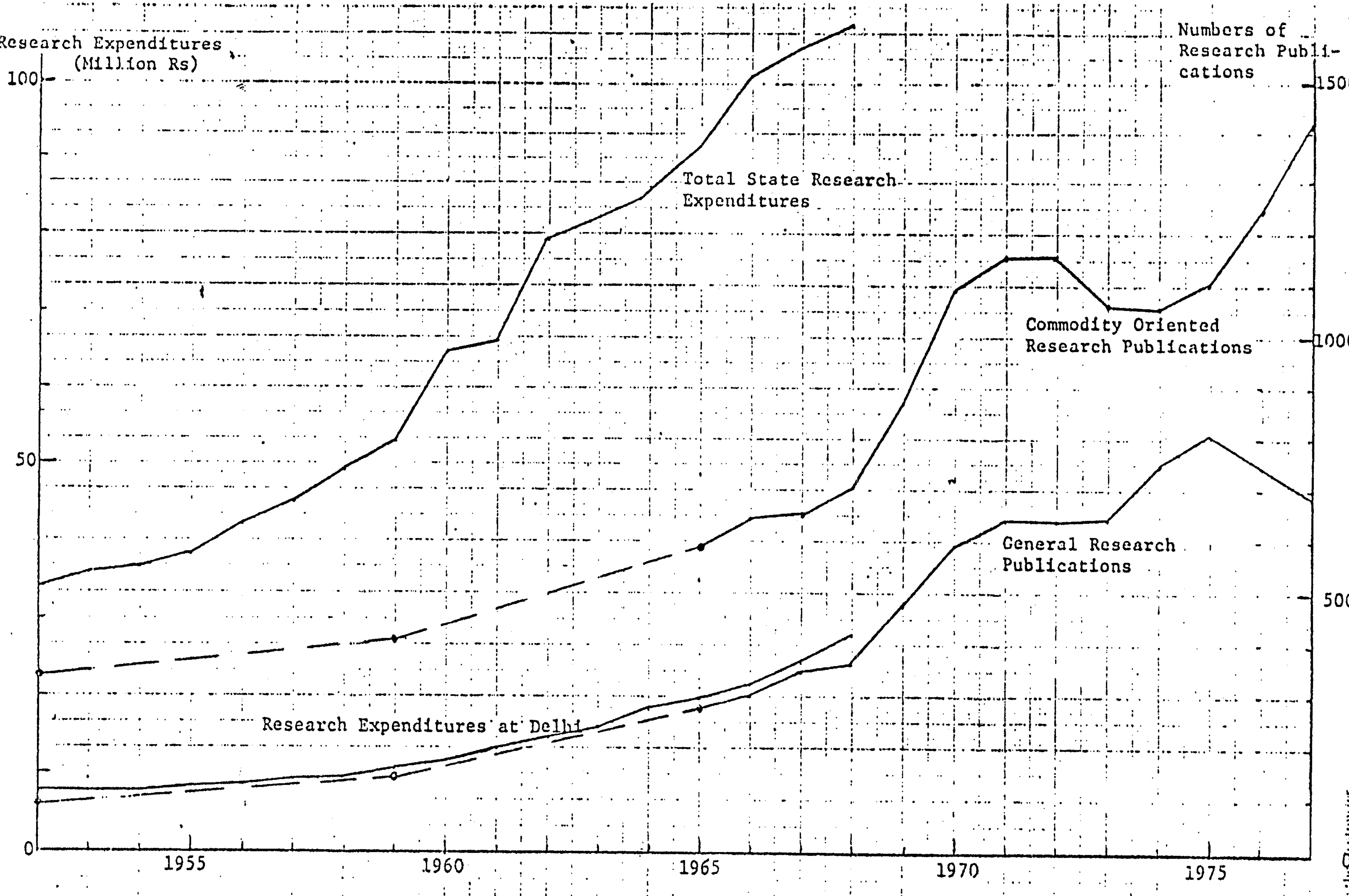

Fig. 3.--Research Expenditures and Publications.

Source: Research expenditures, Mohan et al. (1973).
Publications, see footnotes in Table 1

Appendix: Data Source

Research Publication: Biological Abstracts and Plant Breeding Abstracts for the years before 1964 and Indian Science Abstracts for the years after 1965.

Research Expenditure: Rakesh Mohan, D Jha, and Robert Evenson, "The Indian Agricultural Research System," Economic and Political Weekly 8, No.13 (March 1973):21-26.

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Fertilizer Input and Fertilizer Price: Fertilizer Statistics, Fertilizer Association of India.

Output, Cropped Area (Land), and Irrigated Area: Estimates of Area and Production of Principal Crops in India, Ministry of Food and Agriculture.

Labor Input and Literacy Rate: Census of India.

Rice and Wheat Wholesale Price: Economic Survey of Indian Agriculture, Department of Economics and Statistics.

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