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Agricultural Research Productivity in Pakistan

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Introduction and Overview

Productivity growth is an important component of economic growth in agriculture. Agricultural research programs have been shown in a number of studies to have contributed to productivity growth (see Evenson and Pray 1990 for a summary). This study is one of the first to quantify the economic impacts of agricultural research in Pakistan.

Nagy (1990) reports a study of the impacts of wheat research from 1964-81 and maize research from 1967-81 and an aggregate productivity study for the 1959-60 to 1978-79 period. The latter study was based on a productivity measure by Wizarat (1981). No previous studies have developed productivity measures on a district basis for Pakistan agriculture (Wizarat 1981 reports a national series). The only prior study estimating the contribution of crop research program to productivity change in Pakistan's agriculture is the Nagy (1990) study. This volume reports a new analysis of the contribution of agricultural research to crop productivity growth and to aggregate productivity growth.

Chapter I presents an overview of the research institutions in Pakistan and documents changes in the system associated with the development of the Pakistan Agricultural Research Council (PARC). Characteristics of the system are discussed, and some of these are subjected to further analysis in later chapters.

Chapter II develops and reports both Partial Factor Productivity (PFP) and Total Factor Productivity(TFP) indexes for Pakistan agriculture. These indexes are computed for most districts for the 1955-56 to 1985-86 period. This chapter also reports a comparison of TFP changes in the Indian state of Punjab and the Pakistan provinces utilizing comparable computational methods and data. Chapter III reports a statistical analysis of the determinants of TFP change at the district level. This analysis is comparable to studies in other countries usually referred to as "TFP decomposition" studies. The analysis estimates the contribution of research and infrastructure investments to productivity growth.

Chapter IV reports statistical analysis of PFP indexes (yields) for several crops. This analysis is more complex than the TFP analysis and requires more complex methodology. This

analysis provides additional insight into the role of research programs because differences between crop research programs can be observed.

Chapter V reports another approach to the analysis of farm production data. It utilizes the basis "duality" relationship between production and maximized profits to specify and estimate a "meta profits function" system of product supply and factor demand equations. The term "meta" is used to indicate that the research and infrastructure variables are directly incorporated into a specification that normally treats them as constant.

The final chapter analyzes the economic implications of the estimated parameters. Estimates of benefits based on total (i.e., producer plus consumer) surplus are utilized to compute marginal internal rates of return (MIRRs) to investment in research. International comparisons with other studies are also provided.

The findings of this study are summarized in the following table which reports the estimated Marginal Internal Rates of Return (MIRR's) to investment in agricultural research in Pakistan. These returns to investment are, in general, extraordinarily high. The PFP decomposition estimates based on Chapter IV allow us to compare returns for different commodity research programs. Of the major commodity research programs in Pakistan, significant research impacts and high returns were estimated for all programs except sugarcane. We were unable to address the question of returns to livestock research.

Estimated Marginal Internal Rates of Return to
Agricultural Research in Pakistan Agriculture
1956-1986

Source	Methodology	Coverage	Estimated MIRR
Chapter IV	PFP decomposition	Wheat research	76 percent
Chapter IV	PFP decomposition	Rice research	84-89 percent
Chapter IV	PFP decomposition	Maize research	46 percent
Chapter IV	PFP decomposition	Bajra research	44 percent
Chapter IV	PFP decomposition	Jowar research	52 percent
Chapter IV	PFP decomposition	All cereals research	81-84 percent
Chapter IV	PFP decomposition	Cotton research	102 percent
Chapter IV	PFP decomposition	Sugarcane research	n.s.
Chapter III	TFP decomposition	Applied research (excl HYV)	57-63 percent
Chapter III	TFP decomposition	Applied research (incl HYV)	82 percent
Chapter III	TFP decomposition	General research (excl HYV)	46 percent
Chapter III	TFP decomposition	General research (incl HYV)	56 percent
Chapter III	TFP decomposition	All agricultural research	57-65 percent

We were, however, able to obtain estimated impacts and rates of return for both the highly applied commodity focused research in the system and the more "general" research which included more basic research and some livestock research. These estimates were made in Chapter III and summarized in Chapter IV and in the summary table above. Computations were made including and excluding the direct contribution of high-yielding varieties (HYVs). We note that the inclusion of the HYV effects did result in higher returns to investment. However, it is pertinent to note that even when these are excluded, returns to investment in research have been extremely high.

In Chapter VI these estimates are compared with approximately 75 other estimates obtained in studies in other countries using similar methodologies. The Pakistan estimates compare favorably, - not only against an objective standard for returns to investment, but compare favorably with results obtained in other countries as well.

This study thus reports evidence that has strong statistical support to the effect that Pakistan's agricultural research system has been productive. It has produced high rates of return to investment. It has produced economic growth in agriculture at low cost and that growth has been vital to Pakistan with its rapidly growing population. There is little doubt that investments in agricultural research programs have been among the most productive investment in Pakistan over the past 40 years.

It does not follow, however, that the research system has been as productive as it could have been. This study has noted problems with "congruence", i.e., with the commodity mix (particularly serious for rice). Currently there are serious problems with the provision of operational support to allow scientists to get their work done. The system has a weak basic research support system.

Nor does it follow that the system has solved all or even some of the major problems of Pakistan. Soil salinity has probably worsened. Our data show severe problems in the NWFP province, and these will have to be addressed. It, however, is important to note that agricultural research programs cannot solve all problems. They are designed to develop technology to enable

farmers to achieve better productivity and to enable the economy to get more production from the resources at hand.

And this they have done in Pakistan. It is clear that even given the flaws in the system (and these are probably not too serious) Pakistan has under-invested in agricultural research. It should have invested more. Among the alternatives by which an economy can increase output (land expansion, irrigation, more fertilizer), research as been a "bargain" in terms of growth achieved relative to cost. For an economy like Pakistan's, the biggest bargains in the process of achieving economic growth are probably its agricultural scientists. Not only are they productive, but they are low cost. (This study has documented the fact that the real cost of supporting a scientist relative to the costs of irrigation equipment, fertilizer, etc., are probably one-tenth of their level in developed countries.)

Pakistan faces challenges in the future. Its population will double in the next few years. It must double food production merely to maintain per capita food production. It has brought most cultivable land under cultivation now. If Pakistan is to meet this challenge, it must realize gains in productivity. To do this it must expand and strengthen its agricultural research system as well as its extension and farmer education programs. The evidence for high returns to agricultural research from this study is strong. Research contributes to productivity. Numerous other studies reveal the same conclusions. Agricultural research programs will have to play a larger role in the future. Countries such as Pakistan cannot afford to continue to underinvest in their research system and to provide inadequate support to agricultural scientists.

Chapter I Agricultural Research: Institutional Development In Pakistan

During the past four decades of planned economic development in Pakistan, significant structural changes have taken place in the economy. Nevertheless, agriculture remains the largest sector of the economy in terms of output, employment and contribution to exports. As in most other developing countries, the share of agriculture in GDP has declined over recent years, from 32% in 1975-76 to 22% in 1988-89[1], indicating higher growth rates in other sectors of the economy. Many of these sectors, however, depend directly or indirectly on agriculture sector.

Pakistan's current population of 103.8 million is increasing at the rate of around 3% per annum and will be about 148 million by the turn of this century. Thus, to sustain this population at current rates of consumption, agricultural production will have to be increased at least by 50% over the next 10 years. In fact, even higher production will be required to meet the growing needs of the high income groups of the society, of industries and of export markets. This by no means is an easy task because the country has almost reached its extensive margin of cultivation of available land resources. Existing agricultural land resources, apart from being afflicted with desertification, soil erosion, salinization and water logging, are being diverted rapidly for non-agricultural uses such as residential accommodation, industrial estates and recreation parks. On a per capita basis, cropped area and area under food grains have decreased by 13% and 9% during the last decade.

Agricultural policy in the 1960's was directed primarily towards increasing agricultural production through the expanded use of subsidized inputs, namely fertilizer, pesticides and tubewell water. In the middle of the decade, high yielding varieties of wheat and rice became available. During the later part of the 70's and the early parts of 80's, growth in agriculture resulted largely from strong emphasis on agricultural research programs and modification of agricultural policies i.e., increased availability of agricultural credit and irrigation facilities as well as pricing and procurement policies.

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[1] Government of Pakistan., Pakistan Economic Survey 1988-89

Agricultural production growth stems basically from two sources: (1) that due to increased input use (land, fertilizer, water, etc.), and (2) that due to productivity growth or growth in product per unit of input. In countries such as Pakistan where the options for low - cost expansion of cropped area have largely been exhausted, most production growth typically comes from the second source; i.e., growth in productivity.

Productivity growth is not realized spontaneously or without purposive investment. It requires investment in research programs to produce (and adapt) improved technology, in extension programs to facilitate adoption and use of improved technology, in the education of farmers to facilitate response to technological opportunities, and in infrastructure to facilitate more efficient markets for products and inputs. In addition, it requires an economic environment conducive to appropriate investments in capital by farmers. In this introductory chapter we review the development of the agricultural research system in Pakistan. In section I, we review existing institutions. In section II, quantitative indicators of investment and manpower are developed. Comparisons with other countries are made. In section III, we report data that indicate qualitative dimensions of the program. Section IV reports further detailed data from the MART-WINROCK survey undertaken as part of this study. Section V reports extension and schooling data. The final section summarizes the state of research institutions in Pakistan.

I. Institutional Development of the Agricultural Research System of Pakistan

Since 1920, agriculture has been a subject that was constitutionally assigned to the provincial governments, and agricultural research, education and extension were carried out almost exclusively by the provincial governments. In the mid 1920's, the Government of British India realized the need for a central body that would at least make sure that there was coordination of the provincial scientific research. The Imperial Council of Agricultural Research (ICAR) was thus established in 1929. The ICAR, which established a number of world famous institutions in India, went through several transformations in its scope, structure and organization in the 1930's and 1940's. Unfortunately, all the central research institutions of the ICAR were located in India at the time of partition. Not a single central institute of ICAR was located in the territories that constituted Pakistan. The only research establishments in Pakistan at the time of independence were

the provincial research stations, that were established in the undivided India to undertake applied and adaptive research on certain agricultural commodities. The development of a centralized research system to cover the major agro-ecological regions and important commodities became the responsibility of the new government.

After Independence in 1947, Pakistan established the Food and Agriculture Council, but it had little power and little funding. The Agriculture Research Council (ARC) was formed in the mid-1960's. In 1978, the ARC was reconstituted as an autonomous body at federal level and renamed the Pakistan Agricultural Research Council (PARC). PARC was given a mandate to work in close coordination with the Ministry of Food and Agriculture, provincial agricultural departments, agricultural research institutes and agricultural universities.

A. Pakistan Agriculture Research Council (PARC)

PARC now, with its revised charter, has inter-alia the authority to conduct, promote and coordinate agricultural research in the country. In order to strengthen the national agricultural research network, PARC has its own research centers: National Agricultural Research Center (NARC), Islamabad; Arid Zone Research Institute (AZRI), Quetta; Crop Diseases Research Institute (CDRI), Islamabad; Pesticides Laboratories and Vertebrate Pest Control Laboratory (VPCL), Karachi.

B. Federal Institutions other than PARC

There are a number of federal research organizations other than PARC that are involved in agricultural research and development. These are as follows:

> Pakistan Central Cotton Committee (PCCC); Pakistan Tobacco Board; Pakistan Atomic Energy Commission Agricultural Research Centers; Forest Research Institute; Department of Plant Protection, Karachi; Center of Excellence in Water resources Engineering, Lahore; Center of Excellence, Marine Biology, University of Karachi.

Although PARC has been established as an apex body in agricultural research, it is not the only federal institution who undertake conducts research in the field of agriculture. There are a number of federal institutions that conduct research on cotton, tobacco, and forestry. The research on land reclamation and water management is conducted by the Water and Power Development

Authority (WAPDA), the Soil Survey Department conducts soil surveys, and the Nuclear Institutes for Agriculture conducts research on various aspects of agriculture.

C. Other Federal Research Institutions

A number of other federally funded research institutes conduct research on agricultural issues including the Pakistan Council of Scientific and Industrial Research (PCSIR); the Irrigation Drainage and Flood Control Research Council (now Pakistan Council of Research in Water Resources); the Leather Board; the Pakistan Science Foundation (PSF); the Zoological Survey Department, Karachi; and the Directorate of Marine Fisheries, Karachi.

All these federal institutions are supervised by various ministries/divisions and their research programs and projects are not coordinated by any one organization. PARC supports some research in most of these institutions through cooperative research programs. However, the annual work plans and research programs of these institutions are not dovetailed into the total research system of the country, and efforts made by them are isolated, not known to others nor coordinated by a research agency at the federal level.

D. The Provincial Agricultural Research Institutions

Each province has an agricultural research institute on crops with sub-stations. There are a number of commodity-oriented institutes, which are part of the main provincial institute. Punjab, Sind and NWFP have agricultural universities, all of which are involved in limited agricultural research programs. Research on crops is mainly looked after by the provincial agriculture departments whereas research on livestock and fisheries is looked after by the provincial departments of livestock, fisheries, poultry and dairy development. Some research on forestry is carried out by the provincial forest departments. Research on land and water use is carried out by the provincial departments of agriculture or irrigation and by the universities.

Punjab

The Ayub Agricultural Research Institute (AARI) was evolved in 1961 from the Punjab Agriculture College and Research Institute which had been established in 1909. In 1962, the college was upgraded to university level and the institute was started on a new campus. The main institute is located at Faisalabad and there are 18 stations/substations at different locations in the province.

Some commodity research stations are located in different ecological zones. The following original sections have attained institute status:

> Wheat Research Institute; Vegetable Research Institute; Sugarcane Research Institute; Oilseed Research Institute; Cotton Research Institute; Plant Protection Research Institute, located at Faisalabad and Rice Research Institute located at Kala Shah Kaku and Maize and Millet Research Institute, located at Yousufwala.

There are a number of other research institutions located in Punjab that are not governed by or affiliated with AARI. The Rapid Soil Fertility and Soil Testing Institute, Lahore, is administered by the provincial department of agriculture , though it is a part of AARI. The Directorate of Land Reclamation, Punjab, which conducts research on soil alkalinity and waterlogging is controlled by the Punjab Irrigation Department. The Punjab Irrigation Research Institute, Lahore, serves the entire country for hydraulic model studies on large structures.

The research needs of the livestock industry are the responsibility of the Livestock Production Research Institute, Bahadurnager; Livestock Experiment Station, Qadirabad; and Veterinary Research Institute, Lahore. There are 16 livestock experiment stations and laboratories that deal research on livestock production, poultry and fisheries. The Agricultural Research Mechanization Institute, Multan (AMRI) conducts research on the design and development of agricultural machinery and maintenance.

The University of Agriculture, Faisalabad (UAF) has six faculties, one division and the College of Veterinary Sciences, Lahore. It is supported by the federal grants received through the University Grants Commission (UGC). Previously, it was administered by the Provincial Education Department. Recently, it has been transferred to the Provincial Department of Agriculture in an attempt to strengthen the association between teaching, research and extension and to ensure that the students have adequate contact with practical agriculture.

Within the total agricultural research system in Punjab, there is some dispersal of effort, not only among the provincial institutions but also among the federal institutions. There are, for instance, <u>four agencies involved in cotton research in Punjab and five others elsewhere in Pakistan</u>, with little or no coordination among their individual programs. A provincial Coordination Board exists under the chairmanship of the Vice-Chancellor of the UAF. The Board has 67 members and

five executive directors; in charge of agriculture, livestock, economics, engineering, and information and logistics. All research institutions are represented on the Board, including PARC. The Board has been given financial as well as planning authority. It monitors and evaluates research projects financed by the province.

Sind

The Agricultural Research Institute (ARI) at Tando Jam, which mainly deals with crops and allied disciplines, was established in 1926 at Sakrand. It was shifted to Tando Jam in 1955. It has eight sub-stations and five research farms. In addition, the province supports the Rice Research Institute, Dokri , which was founded in 1938 as a general crop research station, but gradually concentrated on rice in response to changes in cropping patterns and an increase in the area under rice. ARI was considerably expanded in 1977 and maintains linkage with PARC and the International Rice Research Institute (IRRI), Philippines.

The Silviculture Division of Forest Department, Government of Sind, deals with all silvicultural problems that arise in the management of forests, raising and maintaining nurseries, carries out experiments with exotic as well as inland forest plants and also collects data on growth studies and related studies.

There are four livestock experiment stations which carry out research and development on Red Sindhi cattle, Kundi buffaloes and other breeds of cattle. The Poultry Research Institute at Karachi develops vaccines for the local poultry industry.

Sind Agriculture University, Tando Jam was established in 1977 by upgrading the College of Agriculture at Tando Jam. The University is administered by the Sind Department of Education and has no linkage with the provincial Department of Agriculture or ARI, Tando Jam, except through the Provincial Coordination Board.

Agricultural research at the University of Karachi is supported by grants from a number of sources including the University Grants Commission, PARC, and the Pakistan Science Foundation (PSF). The Center of Excellence in Marine Biology is located at Karachi University and is funded by the federal government through the Ministry of Education. Some fisheries investigations are also conducted by the provincial Department of Fisheries.

North-West Frontier Province

The Agricultural Research Station at Tarnab was established in 1910, and a network of sub-stations was added subsequently in response to the needs of various agro-ecological zones. The station became an institute in 1962. More recently, some regional stations have been upgraded and some specialized institutes have been established: Sugar Crops Research Institute for research on sugarcane and sugar beet at Mardan; and the Cereal Crops Research Institute for research on cereal crops at Pirsabak (Nowshera); Gram and Pulses research Institute, at Ahmed Wala (Kark); Fruits and Vegetable Research Institute at Mingora (Swat) with sub-stations at Abbottabad, Dhodial and Batakundi.

The Veterinary Research Institute, Peshawar, is mainly concerned with the production of sera and vaccines and providing with timely diagnosis service to cut down losses due to contagious and parasitic animal diseases. The NWFP University of Agriculture has recently been established by upgrading the Faculty of Agriculture, University of Peshawar. The government has executed an agreement with the U.S. Government for launching a project entitled: "Transmission and Integration of Provincial Agricultural Research Network (TIPAN)". The main purpose of this project is to establish a unified system of agricultural research, education and extension in the province.

An agricultural research coordination board has also been set-up recently for coordination of research in the province.

Baluchistan

This province has only one major agricultural research institute located at Sariab near Quetta. This institute was established in early 1960 as a research station and was elevated to institute status in 1970. It concentrates on horticultural crops, although research is also carried out on wheat and pulses. The Veterinary Research Institute (VRI), Quetta, established in 1979, carries out research on animal diseases and produces vaccines. The Beef Production Center was established at Sibi in 1969. An agriculture college has recently been initiated. Prior to that, students from the province used to receive formal training in agriculture at Sind Agriculture University, Tandojam.

The Arid Zone Research Institute (AZRI) of PARC is also located in Baluchistan at Quetta. It has three sub-stations in other provinces (Umarkot in Sind, Bahawalpur in Punjab and Dera

Ismail Khan in NWFP). PARC also supports some research in the ARI at Sariab and VRI, Quetta. An agricultural research coordination board has been established in Baluchistan, but has not started functioning yet.

E. Role of The Federal Government

Six ministries have some responsibility for research that impinges on agriculture in Pakistan. Relations between Ministries and research organizations are shown in the following table.

Table 1.1 Ministries and Their Responsibilities.

MINISTRY	RESPONSIBILITIES
MINISTRY OF FINANCE, PLANNING & COORDINATION	PROVINCIAL DEPARTMENTS OF AGRICULTURE AND THEIR RESEARCH INSTITUTES.
MINISTRY OF SCIENCE & TECHNOLOGY	IRRIGATION DRAINAGE AND FLOOD CONTROL; PAKISTAN SCIENCE FOUNDATION; PAKISTAN COUNCIL FOR SCIENTIFIC & INDUSTRIAL RESEARCH.
MINISTRY OF FOOD, AGRICULTURE & COOPERATIVES	PAKISTAN CENTRAL COTTON COMMITTEE AND LINKED THROUGH ITS AGRICULTURAL RESEARCH DIVISION (ARD) WITH THE PARC.
MINISTRY OF COMMERCE	PAKISTAN TOBACCO BOARD
MINISTRY OF WATER & POWER	WATER & POWER DEVELOPMENT AUTHORITY (WAPDA).
MINISTRY OF EDUCATION	UNIVERSITY GRANTS COMMISSION (UGC)

In addition to the above, the Pakistan Atomic Energy Commission (PAEC) which reports directly to the President through the President's Secretariat has three institutes devoted to the use of nuclear energy in agriculture research. The ministries are responsible for financing the institutes within their control and for the determination of research policy, priorities and programs.

F. Role of Provincial Departments

Agriculture is constitutionally a provincial matter. That is to say, the provincial departments of agriculture are responsible for the implementation of the national policies for agriculture in all its manifestations. Specifically, they are in control of higher agricultural education (through their agricultural universities) except in Baluchistan which shares the facilities of the other provinces; agricultural research (through their provincial agricultural research institutes); and extension (through their extension departments). While provincial research is generated in and controlled by the provinces, not all requests for development funds for research from federal government are routed through the Agricultural Research Division (ARD).

G. Role of Agricultural Universities

The universities can be divided into two categories, general and agricultural. General universities, which contain departments of basic sciences, also undertake research in specific areas relating to the broad field of agriculture. The work is carried out using in-house funds or funds for cooperative programs from outside agencies; U.S.D.A. (under Public Law 480 (PL-480) program), PARC or other donor funds. In addition, PARC has set up in these universities some units that carry out specific research in applied fields (e.g., nematology and vertebrate pest control at Karachi University). Agricultural universities contain facilities for teaching and, with the interests of their well trained staff, undertake applied agricultural research. They receive grants from outside agencies and PARC, and members of the staff take part in coordinated programs of PARC.

H. Administrative Comparisons with Agricultural Research System In Other Countries

A study conducted by the International Services for National Agricultural Research (ISNAR) reports that there are a number of developing countries which have agricultural research as a central or federal responsibility, have been able to minimize duplication and wastage of their scarce resources. In most of these countries, including Brazil, Indonesia, and Argentina, agricultural production is a provincial responsibility whereas scientific and technological research, including policy planning and coordination comes under federal purview. In India, the Indian Council for Agricultural Research (ICAR), as the central lead organization, is responsible for organizing, directing, coordinating, and promoting agricultural research. It operates more than 34 national

agricultural research institutes, 4 bureaus and 6 research centers on agricultural commodities and disciplines. ICAR also acts as the University Grants Commission (UGC) for 23 agricultural universities in India. In the United States, the Department of Agriculture (USDA) has one of the most extensive and vigorous federal agricultural research organizations. It has central and regional research centers to tackle the problems of major agricultural commodities in cooperation with local scientists.

Agricultural research system responsibilities in selected countries are summarized in Table 1.2.

Table 1.2 Agricultural Research System In Selected Countries.

COUNTRY	RESPONSIBILITY FOR AGRICULTURAL RESEARCH			
	CENTRAL	SINGLE MINISTRY	VARIOUS MINISTRIES	SEMI-AUTONOMOUS AGENCIES
ALGERIA	X	-	X	-
BURMA	X	X	-	X
BRAZIL	X	X	-	X
EGYPT	X	X	...	...
INDONESIA	X	X	X	-
KENYA	X	-	-	-
NIGERIA	X	X	...	-
PAKISTAN	-	-	X	X
PERU	X	X	-	X
SENEGAL	X	X	-	X
TANZANIA	X	-	-	X
THAILAND	X	X	X	-

(...= PARTIAL OR INTERMEDIATE SITUATION)

Source: ISNAR Annual Report.

It is evident from the table that Pakistan is unusual in that agricultural research in Pakistan is not a federal responsibility.

II. Investment in Agricultural Research

It has long been recognized in Pakistan and elsewhere that the private sector-even in the most capitalistic economies-does not provide sufficient incentives to develop technology for agricultural production. In highly developed economies the private sector does invest significantly in research and development to improve farm machinery, chemicals and animal health products because there are large farm input markets and because they can obtain Intellectual Property Rights (IPRs) such as patents, copyrights for their inventions. However, even in these economies, the private sector invests little in the biological improvement of crops and animals. In a country such as Pakistan, where input markets are small and IPR protection is weak, there is very little private sector R&D directed toward agriculture (Evenson 1990).

The remedy for this situation in most countries has been the development of a public sector research systems as well as public sector education and extension programs. These systems have been supported by and located in different political units. Pakistan is typical of most countries in having provincial and federal research units as well as having access to International Agricultural Research Center (IARC's) resources. It is also typical of many countries in that the provincial (state) units were developed long before strong federal units were developed. In Pakistan, the PARC programs (including NARC) were not developed until after considerable development of provincial research centers, especially in the Punjab. It is also typical of such systems that they do not develop information systems enabling a complete accounting of research resources for the economy by commodity and disciplinary focus and by the skill and training level of the research staff. Pakistan is only now moving towards the development of a national research information system.

In compiling the data presented here, the information from the current Management of Agricultural Research and Technology (MART) Directory Project as well as from the previous directory compiled by the National Sciences Council (NSC) of Pakistan have been utilized. In addition to this, experiment station reports and returns from a recently conducted have been used. (Azam 1988).

A. Data Issues and Problems

Before turning to a data summary, it will be instructive to discuss some of the problems requiring decisions in developing these data bases (with references to sources).

1. Distinguishing Between Researchers or Scientists and Technicians and Assistants

In highly developed research systems it is convenient to argue that status as a scientist requires the Ph.D. (or equivalent) degree with, of course, a few exceptions. That standard can not be applied to Pakistan or to similar systems where many, perhaps most, research programs are effectively managed by scientists with considerable experience, but not always with Ph.D. or even M.S. degrees. An alternative criterion for identifying the critical research manpower stocks is to include as scientists those researchers who have full research project responsibility. This generally means a GS rating of 16 or above for public sector employees. It is also critical for meaningful policy comparison that a distinction be made between research scientists, technical assistants and other field staff. The latter category (other staff) is often so affected by local bureaucracy as to render total staff counts to be meaningless as indicators of research staff.

A similar distinction between financial resources to support these three types of staff as well as other financial support (chemical, etc.) is also useful to policy makers because research systems often drift into very inefficient factor proportions (e.g., using the budget from salary and providing too few resources for research conduct). See section III of this Chapter for a further discussions.

2. Separating the True Research Component of Programmes from Other Components

For institutions set up to conduct research as their primary objective it is relatively easy to associate the budget with research (and sometime with extension) programs. Thus for provincial research units (e.g. the rice research station at Kala Shah Kaku) the identification of research activities is straight-forward.

For universities where faculty are engaged in both research and teaching, the allocation is more complex. It is usually conceptually possible to identify the relative proportion of faculty time expended on research and technology, but often the appropriate data are not available. It clearly is a mistake to attribut- the entire budget of the various provincial universities to research. We have attempted to include only the research unit budgets in our research data plus 20% of university

budget and staff. A better estimate of the proportion of university faculty time expended on research is called for.

The problem is more serious where research activities are only one (usually minor) of several activities of an institution. The Livestock and Dairy Development Department of the Punjab, for example, engages in many activities, including some animal breeding and animal improvement research. The budget of this unit is large. Indeed, if one were to consider this breeding work as "research," it would constitute the bulk of agricultural and livestock research in Pakistan. Thus it is critical that this budget be carefully examined and that a distinction between normal production work and actual research activity be made. The production of breeding herds is generally not research. Provincial budgets in Pakistan generally do not make such distinction and are thus of little value for research investigation.

3. Achieving Consistency Over Time

Research units may be combined at certain periods. New units may be created. Accounting procedures may change. Provincial budgets in Pakistan, for example, do not provide consistent accounting categories between development and non-development expenditures.

Budget choices differ by province, and it appears that many non-research activities are included in research and extension categories.

These problems render provincial budgets almost useless as indicators of research activities. The PARC budget is also of limited usefulness in this respect because it cover only a proportion of the agricultural research activities in Pakistan, and this proportion varies over time. We have thus developed our budget and staff estimates from the following sources:

1) The NSC Directory of Agricultural Scientists (1982).

2) The NSC Directory of Agricultural Research Establishments in Pakistan (1982).

3) Results of a PARC-MART survey of research institutions.

4) Provincial data from the MART-ARM institutional data set.

5) Estimates of expenditure-by year from growth of R & D manpower and expenditure in Pakistan, Pakistan Council for Science and Technology (PCST) 1985.

B. Research Investment --- A Summary

From these sources we have compiled three tables providing estimates of agricultural research manpower and expenditures in Pakistan. Table 1.3 reports a summary of research expenditures in current Rupees (Rs) for crop, livestock and irrigation research by the region of conduct of the research for selected years. Our procedure for constructing Table 1.3 was to treat the 1978 data from the NSC Directory of Agricultural Research Establishments as the most comprehensive and complete available. We compiled both expenditure and staff data from this source. For years prior to 1975 (i.e. for 1950, 1960 and 1970) we had two sources. For 1960 and 1970 expenditures we used the comparative data in the PCST report,"Growth in R&D Manpower and Expenditures". This source provides data for 1977-78 and although these differ from the NSC data slightly we consider them to be reliable indexes of spending in one period relative to another. Accordingly we extended the 1978 NSC data backward to 1970 and 1960 using the PCST 1970/1978 and 1960/1970 ratios for the relevant categories. We had a second source of data on staff from the NSC Directory of Agricultural Scientists (1982) where the data are for the 1978 year. These data allowed us to compute the number of staff in previous years. The data indicate the years in the present and prior institution and years of total research by the researchers. Utilizing these data we were able to check them against the PCST data. We considered the NSC Directory data to be better estimates of staff for earlier years.

To update the 1978 data we needed better data than currently are available. Budget data for PARC are readily available. However we have only partial data for other research institutions. For these, however, we have a survey conducted in 1988 in which we attempted to update the 1978 NSC Directory data (Appendices A 1.1, and A 1.2). A second source is the MART-ARM survey currently in a preliminary stage.

The MART-WINROCK 1988 survey was sent to the 65 institutions included in the NSC Directory. Useable returns for 50 institutions were received. For several other institutions we obtained data from the MART-ARM survey for expenditures (The staff data reported in the ARM data at this point include total staff and thus are not useful as measures of research staff,further compilation should correct this). From these sources we were able to obtain reliable estimate of

both research staff and expenditures for 1988 for most institutions. For those units for which data were not obtained we assumed expenditure changes proportional to those for which we did have data.

Table 1.3 thus reports current expenditure data. Table 1.4 reports the same data in 1988 constant rupees (using the General WPI index as a deflator). These data will be discussed further in the indicators section, but we will note at this point that, in spite of very substantial program efforts in the past decade, growth in real expenditures and in staff has not been rapid.

Table 1.3 Agricultural Research Expenditures
1950, 1960, 1970, 1978, 1988

(MILLION Rs.)

RESEARCH/ PROVINCE	1950	1960	1970	1978	1988
CROP RESEARCH					
FEDERAL	1.50	10.00	13.41	63.9	93
PUNJAB	0.33	2.19	8.41	73.4	285
SIND	0.27	1.79	6.93	25.1	117
NWFP	0.25	1.09	6.53	22.9	43
BALUCHISTAN	-	-	0.68	5.4	15
TOTAL	2.35	15.66	35.96	191.0	552
LIVESTOCK RESEARCH					
FEDERAL	-	-	-	8.89	27
PUNJAB	-	0.90	3.46	15.49	39
SIND	-	-	-	7.6	32
NWFP	-	-	0.09	1.9	6
BALUCHISTAN	-	-	-	0.1	1
TOTAL	-	0.90	3.54	33.8	105
IRRIGATION RESEARCH					
FEDERAL	-	-	0.93	5.4	25
PUNJAB	-	-	-	5.9	25
SIND	-	-	-	7.6	30
NWFP	-	-	-	-	3
BALUCHISTAN	-	-	-	-	2
TOTAL	-	-	0.93	18.2	85
GRAND TOTAL	2.35	16.56	43.98	243	743

20'

Table 1.4 Agricultural Research Expenditures Deflated By Wholesale Price Index (1988 Rupees).

(MILLION Rs.)

RESEARCH/ PROVINCE	1950	1960	1970	1978	1988
CROP RESEARCH					
FEDERAL	21.40	69.20	70.26	113.10	93
PUNJAB	4.71	15.08	44.07	130.57	285
SIND	3.85	13.14	36.31	44.43	117
NWFP	3.56	7.54	34.21	40.53	43
BALUCHISTAN	-	-	3.56	9.56	15
TOTAL	33.52	104.96	148.74	338.19	552
LIVESTOCK RESEARCH					
FEDERAL	-	-	-	15.57	27
PUNJAB	-	6.23	18.13	27.42	39
SIND	-	-	-	13.45	32
NWFP	-	-	0.47	3.36	6
BALUCHISTAN	-	-	-	0.17	1
TOTAL	-	6.23	18.6	59.97	105
IRRIGATION RESEARCH					
FEDERAL	-	-	4.87	9.55	25
PUNJAB	-	-	-	10.44	25
SIND	-	-	-	13.45	30
NWFP	-	-	-	-	3
BALUCHISTAN	-	-	-	-	2
TOTAL	-	-	4.87	33.44	85
GRAND TOTAL	33.52	111.19	172.21	431.6	743

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C. Research Intensities: International Comparisons

A comparative index widely used to assess relative investment levels is the "intensity" indicator. This is the ratio of investment in research to the value of the commodity or commodities where research is directed. Table 1.5 reports intensity indicators for Pakistan and for other regions.

Panel I reports the ratio of annual spending on research programs to the value of agricultural product for several periods for all research. Comparative data for South Asia, Southeast Asia, and Low-income Developing and Middle-Income Developing countries are provided.

In 1960, by this measure, Pakistan was more research intensive than other countries in South and Southeast Asia and other Low Income developing countries. By 1970, the South Asian and Low-Income developing countries were on par with Pakistan. By 1978, all developing countries had expanded their research investment. Pakistan made a major advance in the 1970's with modest increases in the 1980's. Today, with approximately half of one percent of agricultural product expended on research, Pakistan ranks a little below the level for all Low-Income Developing countries and is at about half of the level achieved by the Middle Income Developing countries.

Crop specific data (Panel II) show that Pakistan spends only half as much on rice as do most other countries. For wheat its intensity is similar to the South Asian standard, but below the level for all developing countries. For maize, Pakistan may be spending more than most other developing economies. In general, Pakistan has a low level of "congruence" between its research programs and its commodity values.

Table 1.5 Research Expenditure Intensities Indicators

I. Total Agricultural Research Expenditures / Value of Agricultural Product

YEAR	PAKISTAN	SOUTH ASIA	SOUTH EAST ASIA	LOW INCOME DEVELOPING	MIDDLE INCOME DEVELOPING
1960	.00216	.0012	.0010	.0015	.0029
1970	.00275	.0019	.0028	.0027	.0057
1978	.00486	.0043	.0052	.0050	.0081
1988	.00519	NA	NA	NA	NA

II. Research Spending on Commodity / Value of Commodity (1980).

COMMODITIES	PAKISTAN	ASIA	ALL DEVE. COUNTRIES	IARC's/TOTAL
BAJRA	.0081			
JOWAR	.0081			
MAIZE	.0080	.0021	.0025	-------
COARSE CEREALS	.0084	.0021	.0023	.11
RICE	.0010	.0021	.0025	.07
WHEAT	.0033	.0032	.0051	.04
SAR	.0026	.0013	.0027	
TTON	.0040	.0017	.0021	
THER COMMODITIES	.0081			

III. Qualitative Indicator for Pakistan Agricultural Research

We note turn to several indicators of the qualitative aspects of Pakistan's research program. these data deal with the basic-applied mix of research in the system and with staffing mixes and staffing support. Most of the data utilized in this section were collected from research institutions as part of this study (the MART-WINROCK survey).

A. Basic and Applied Research

We can obtain indicators for the basic-applied mix of research from publications data. Table 1.6 reports ratios of basic to applied publications abstracted in the Commonwealth Agricultural Bureau (CAB) abstracting; annals. This source is quite comprehensive and comparisons among countries are reasonably valid. The table notes show the definition of the division between basic and applied in terms of abstracting journal. Ratios are reported from three periods for both crop and animal research for 25 developing countries.

Table 1.6 Ratios of Basic to Applied Research

ITRIES	CROP RESEARCH			ANIMAL RESEARCH		
	1972-75	1976-79	1980-83	1972-75	1976-79	1980-83
ENTINA	.13	.16	.08	.33	.59	.90
IL	.18	.19	.17	.66	.97	.91
E	.13	.13	.14	.38	.47	.59
MBIA	.15	.17	.22	.34	.61	.90
CO	.16	.10	.07	.32	.61	.90
	.25	.49	.26	.23	.15	.44
ZUELA	.18	.14	.12	.51	.95	1.40
A	.12	.07	.12	.25	.48	.53
A	.15	.16	.18	.23	.71	.96
RIA	.14	.22	.19	.32	.59	.64
N	.12	.04	.13	.58	.53	.60
ANIA	.04	.07	.13	.93	1.11	1.11
SIA	.09	.05	.07	.57	1.18	2.10
DA	.10	.06	.23	.29	.97	1.79
T	.14	.16	.16	.30	.41	.50
LANKA	.08	.09	.09	.33	.36	.26
A	.21	.27	.26	.29	.43	.38
NESIA	.05	.10	.08	.64	.92	.43
H KOREA	.14	.15	.19	.58	.43	.61
YSIA	.22	.21	.17	1.07	.61	.51
STAN	.10	.08	.09	.36	.43	.43
IPPINES	.19	.16	.15	.51	.37	.30
AN	.17	.29	.27	.76	.42	.30
LAND	.17	.16	.18	1.37	1.97	2.68
EY	.41	.40	.28	.47	.73	.50
EVELOPING ITRIES	.18	.22	.21	.37	.52	.54
DEVELOPING ITRIES	.16	.15	.16	.23	.34	.30

Note: Ratios are based on counts of abstracted publications by class of journal defined as follows:

Basic Crop Journals: Helminthological Abstracts (B); Rev. Plant Pathology.

Applied Crop Journals: Field Crop Abstracts: Herbage Abstracts: Horticultural Abstracts: Review of Applied Entomology; Soils and Fertilizers Abstracts; Wood Abstracts.

Basic Animal Journals: Helminthological Abstracts; Protozoologist Abstracts; Review of Med. & Vet. Mycology.

Applied Animal Journals: Animal Breeding Abstracts; Dairy Science Abstracts; Nutrition Abstracts (Land and Feeding); Rev. Applied Entomology (A); Vet. Bulletin and Index Vet.

It is quite clear from this comparison that the Pakistan system is on the applied end of the spectrum. Only 3 of the 25 countries had lower crop basic-applied ratios than Pakistan, and Pakistan was well below the average from the 25 advanced developing countries and was also well below the average for all developing countries. For animal research, only 5 of the 25 countries had lower basic-applied ratios. Pakistan did have somewhat higher ratios than the average for all developing countries. Thus, Pakistan's research system is a highly applied system. It is not likely to be on "exporter" of scientific findings.

B. Staff Training Levels

The preparation of research staff with Ph.D and M.S. degrees is another indicator of research depth and quality. Training at the Ph.D. level is costly and few developing countries achieve high proportions of staff with Ph.D. training until they are quite advanced. Table 1.7 reports staffing data by training level. As can be seen the proportion with Ph.D. level training is quite low by international standards. In addition, many Ph.D. level scientists have been drawn into administration. This low proportion of Ph.D. researchers is consistent with the low basic-applied ratios reported in Table 1.6.

The proportion of staff with graduate training has risen since 1960, but has not risen markedly since 1977. It should perhaps be noted that the Bachelors level degree in Pakistan is only a three years degree and cannot be considered fully comparable to the four and five year Bachelors degrees in many other countries. These data show that Pakistan is building research program under severe skill constraints.

Table 1.7 Staff of Agricultural Research

(NUMBER)

STAFF	YEAR 1960	1970	1978	1988
DERAL	-	-	175	1460
JAB	170	625	1080	1483
D	37	175	347	246
	-	-	381	390
UCHISTAN	-	-	77	85
AL	300	1140	2059	3664
h.D	-	-	0.062	0.076
S	-	-	0.483	0.632
RADUATE	0.24	0.44	0.455	0.292

TES: **1977 data compiled from 1982 NSC Directory of Agricultural Research Establishments**

1960 and 1970 data based on extrapolations from Directory of Scientists NSC considering length of time calendar.

1988 estimates based on MART-WINROCK survey returns from 50 comparable institutions. Twenty percent of university staff is counted as research staff.

C. Support Per Scientist

Table 1.8 reports expenditures per research staff member. These data show that expenditures per staff member rose after 1970 and have risen further during the 1978 but has declined during 1980's inn comparison to 1978. The International Agricultural Research Centers (IARC's) of the Consultative Group on International Agricultural Research (CGIAR) system, located in selected parts of the world, conduct research on fewer than 20 commodities but had a budget of US $ 160 million (Rs.3200 million) during 1984. Per scientist expenditures in these institutions come to about $ 0.2 million, whereas per scientist expenditures in Pakistan are less than 4% of this amount.

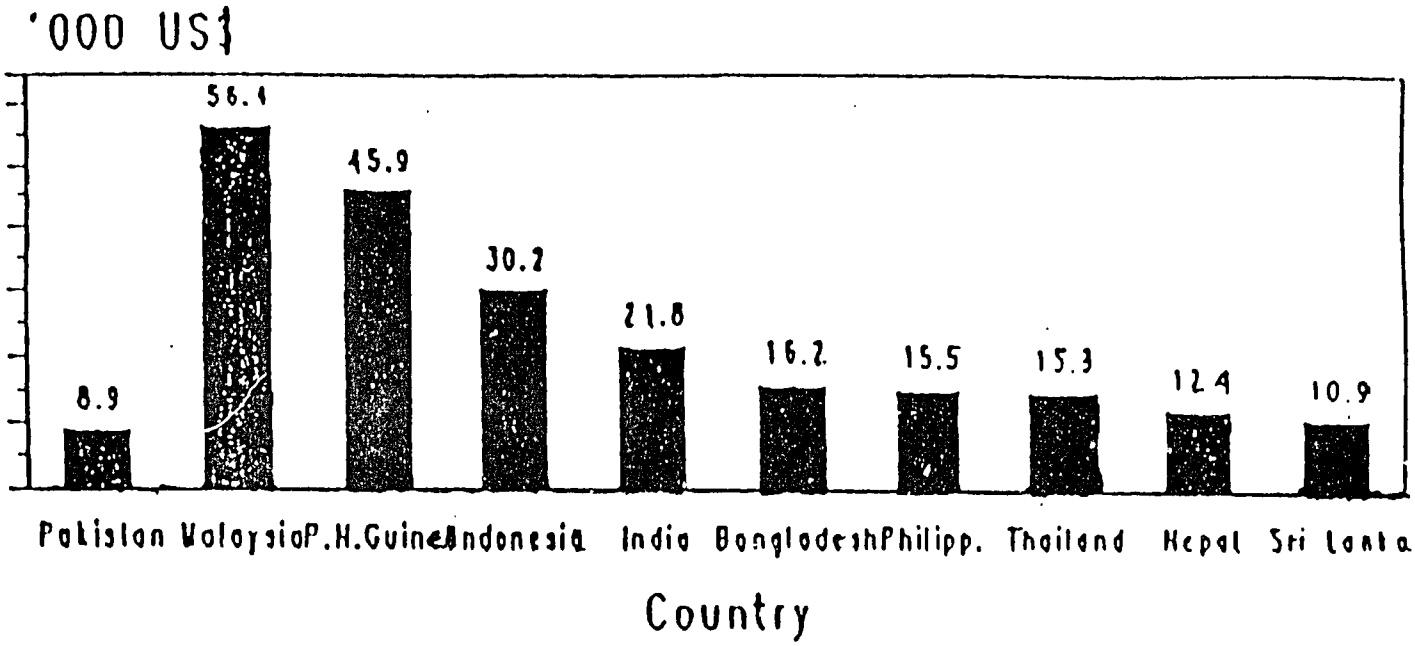
Table 1.8 Agricultural Research Expenditures Per Staff Member

(MILLION Rs.)

PROVINCE	1960	1970	1978	1988
FEDERAL	-	-	0.65	0.06
PUNJAB	0.08	0.07	0.12	0.19
SIND	0.35	0.21	0.13	0.48
NWFP	-	-	0.11	0.11
BALUCHISTAN	-	-	0.12	0.18
TOTAL	0.35	0.13	0.16	0.15

A World Bank mission to Pakistan in its 1987 report analyzed the recent cost and budgets for agricultural research and recommended an appropriate level of operational funding for Pakistan of US $ 8000 per scientist. This level, however, is lower than the amount observed in a number of other countries examined by the mission. Average expenditures per scientist (salaries, operations and development) in Pakistan, however, are extremely low. Figure 1.1 reports comparative data for several countries (see also Appendix A 1.1).

Figure 1.1 Agricultural Research Expenditures per Scientist (Selected Countries in Asia, 1980)



D. Operational Support

A commonly used mechanism for measuring operational support to staff is the ratio of salaries to total funds. It was calculated in 1980[2] that a ratio of about 70% on salaries and 30% on operational expenses was optimal for U.S. conditions. The National Commission on Agriculture in Pakistan (NCA) recommended this ratio to be 60:40 for Pakistan. At 1987-88 salary scales, this ratio for Pakistan was actually 84:16. This ratio is much too high. It shows that many individual research organizations at present do not have adequate operational support for research on numerous agricultural commodities.

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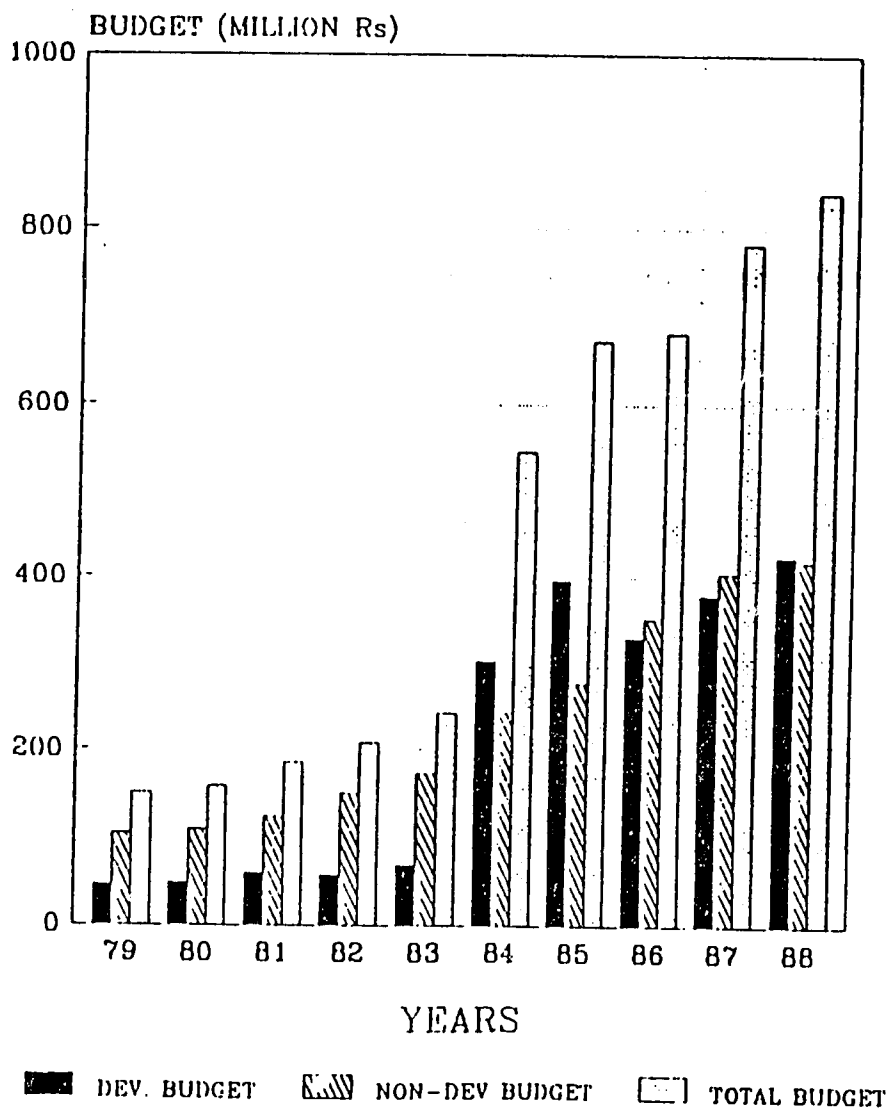
[2] World Bank Report, 1988.

III. The MART-WINROCK SURVEY: FURTHER EVIDENCE

In order to examine further the status of funding, ratio of salaries and operational expenses, and the availability of manpower in agricultural research, time series data were collected from 50 of the 65 agricultural research institutions in Pakistan. Analysis of these data reveals that the total budget (development + non-development) increased by 461% (in nominal terms) between 1978-79 and 1987-88 (figure 1.2). The increase in real terms was 189% percent (Appendix 1.2 and 1.4).

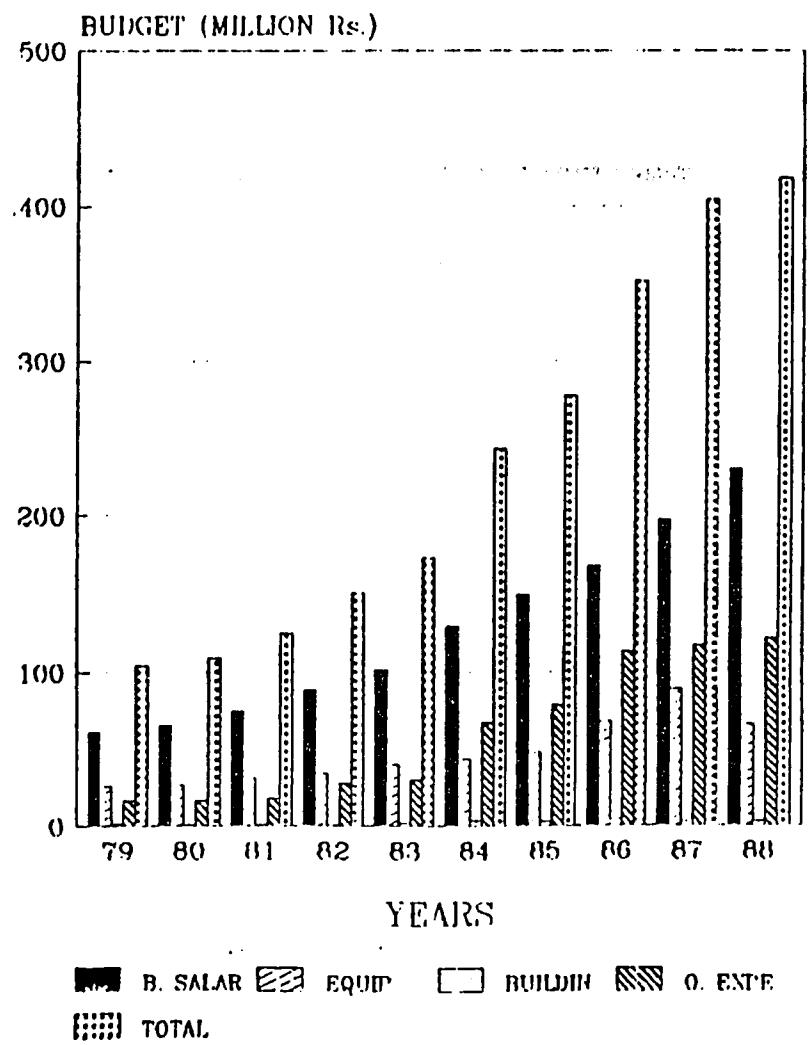
Figure 1.2 Development and Non-Development Budget of 50 Agricultural Research and Educational Establishments



The non-development budget of these institutions increased by 301% in nominal terms during 1987-88 over 1978-79 (Figure 1.3). The increase in real terms was 108% percent (also see Appendix 1.5).

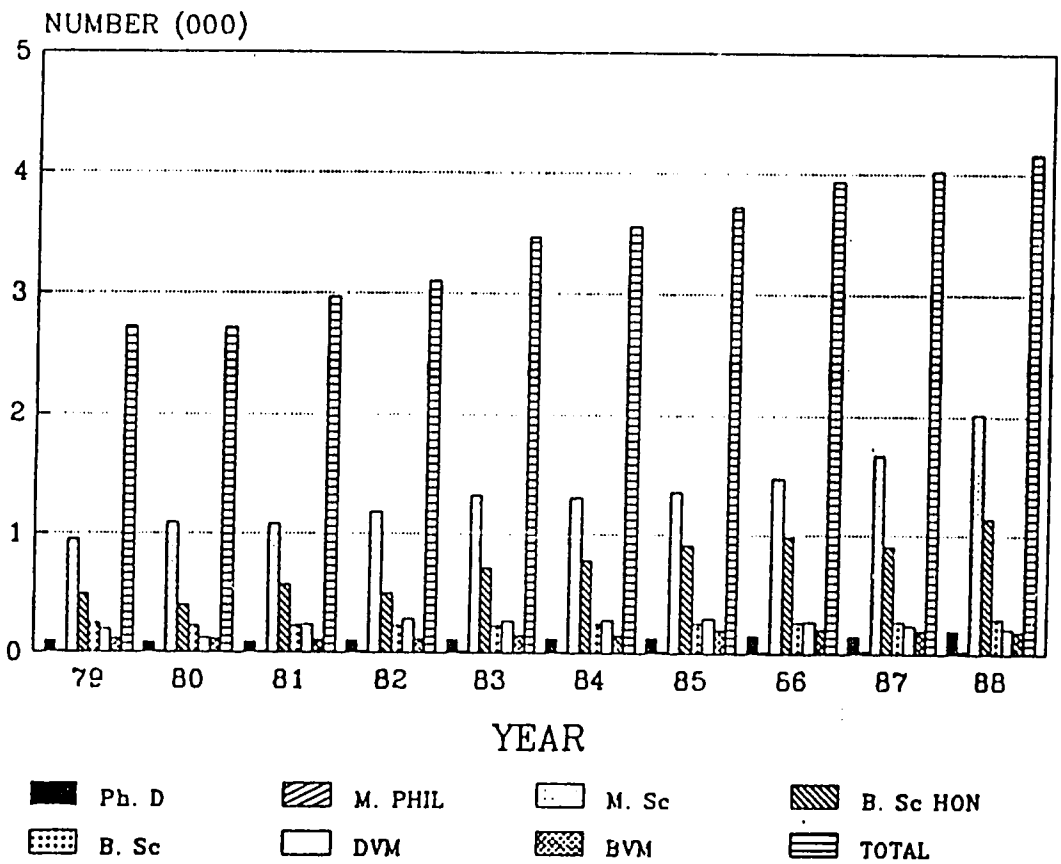
Figure 1.3 reveals that salaries and allowances increased by 350% (134% in real terms) between 1978-79 and 1987-88, whereas operational expenses increased by only 150% (32% in real terms) during the same period. The increase in operational expenses was less than the increase in prices of supplies and materials essential for research purposes. The ratio of salaries to operational expenses during 1987-88 was 84:16. This ratio means that the operational expenses need to be enhanced by at least by 24 percent in order to be proportional and to conform to the NCA recommended ratio of 60:40.

Figure 1.3 Non-Development Budget of 50 Agricultural Research and Educational Establishments



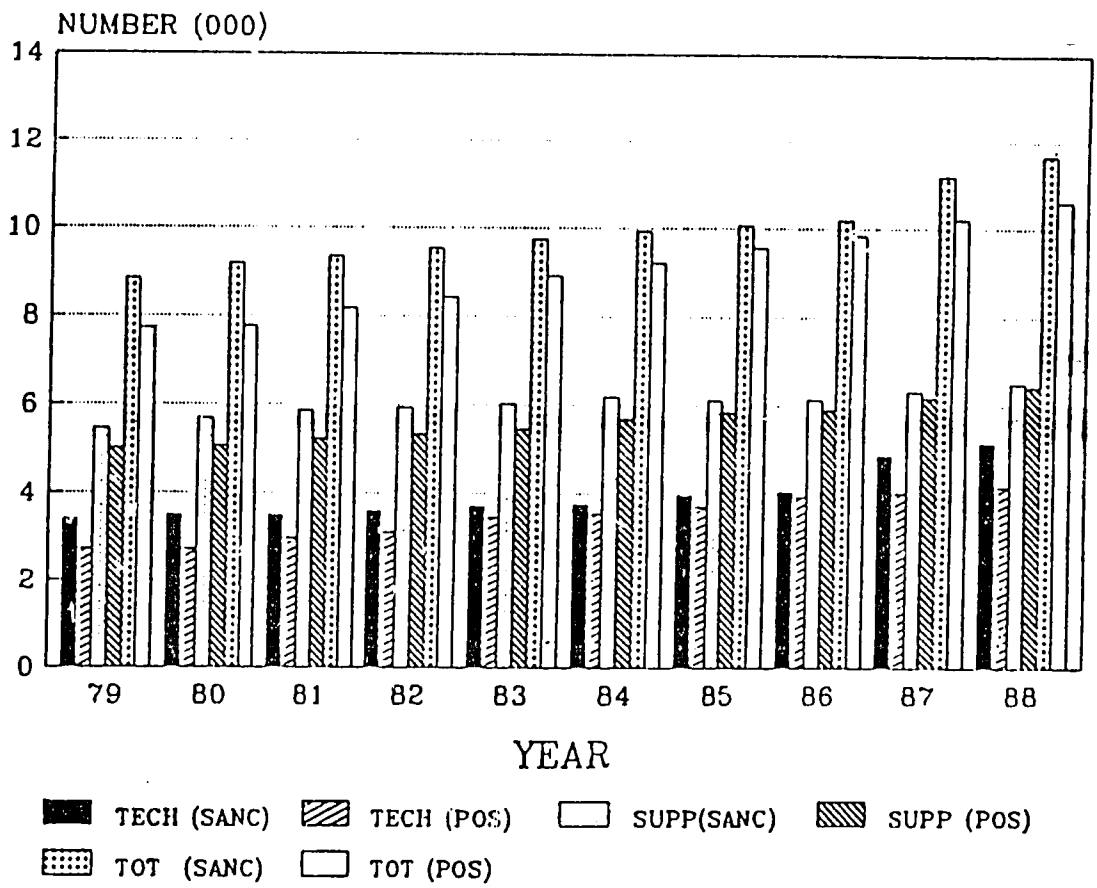
Although the overall agricultural research budget increased by 460% (189% real) the trained manpower in these institutions increased only by 53% (Figure 1.4, also see Appendices A 1.3 and A 1.7).

Figure 1.4 Trained Manpower in Agricultural Research and Educational Establishments



The total staffing position of the research organization is evident from the Figure 1.5 (Appensix A 1.6). This figure indicates that during 1978-79, about 87% of the sanctioned staff members were in position. The situation improved by about 4% during 1987-88 over 1978-79 but actual staffing levels were still lower by about 9% than sanctioned levels.

Figure 1.5 Sanctioned Staff And Staff in Position in Agricultural Research and Educational Establishments

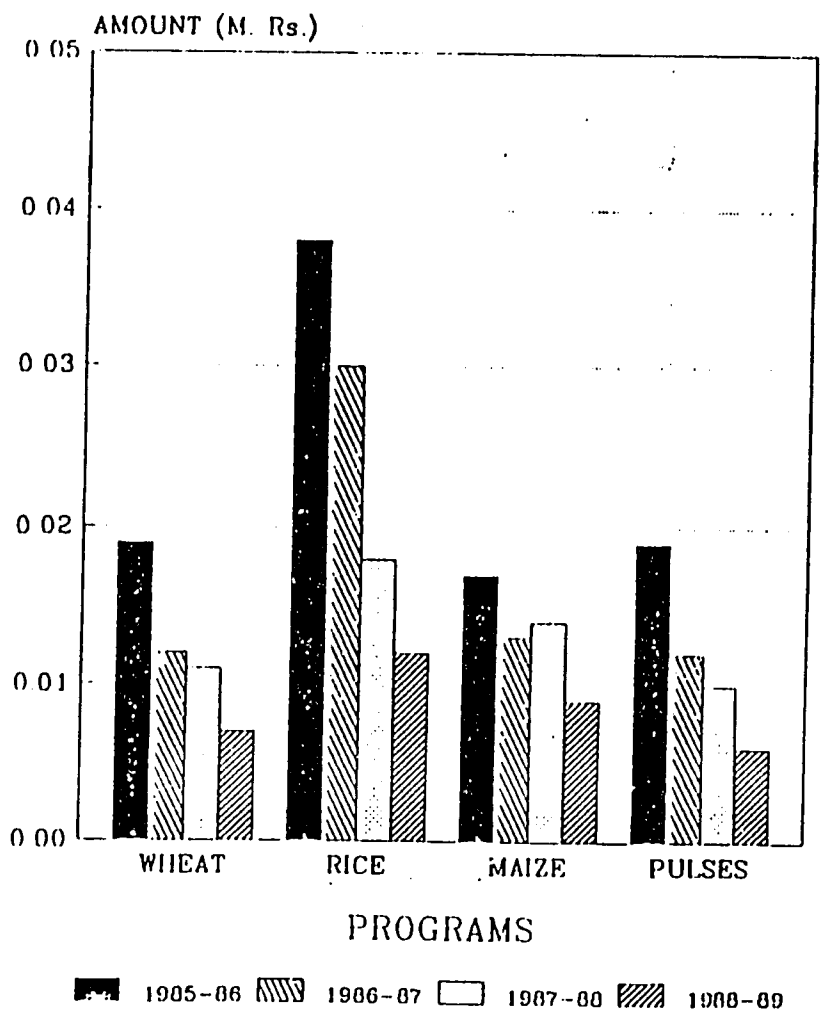


In order to visualize the financial crises faced by individual research organizations/centers, an analysis of budget data from the National Agricultural Research Center (NARC), one of the most important research establishments, was also undertaken. This budget analysis revealed that the ratio

of salaries to operational funds was 55:45 during 1985-86, 58:42 during 1986-87, 66:34 during 1987-88 and 73:27 during 1988-89. The analysis further reveals that operational funds available to each scientist Rs. 84,000 during 1985-86 were about 40 percent less than the World Bank recommended level of Rs. 1,40,000. There has been a continuous decline in operational research funding per scientist. The funding level decreased from Rs. 84,000 to Rs. 42,000 per scientist during the four years 1985-86 to 1988-89, whereas total staff costs (salaries, allowances, etc.) increased by about 100% for the same period. The total NARC budget increased by about 36% during 1985-86 to 1988-89.

The condition of research programs in terms of operational expenses is shown in Figure 1.6 (also see Appendix A 1.8).

Figure 1.6 Operational Expenditure Per Scientist of Selected Research Programs (NARC)



Analysis of 36 research programs of NARC (in wheat, rice, maize, and pulses) reveals that although the operational expenses of the wheat program were at the World Bank recommended level in 1985-86, the situation deteriorated and funding level declined by 78, 85, and 87% respectively in the next three years (see Appendices A 1.9, A 1.10, A 1.11 and A 1.12).

While PARC has during last decade, developed a hard core of highly qualified and adequately trained scientists, their precious expertise can only be utilized if they are provided with adequate financial resources to carry out research of vital national importance.

IV. Extension, Schooling and Infrastructure

A. Extension

Expenditures data on agricultural extension by province as summarized from provincial "Budget" books are presented in Table 1.9.

Table 1.9 Province Wise Expenditure on Agricultural Extension in Pakistan (1980-81 To 1987-88)

(Million Rupees)

YEAR	PUNJAB	SIND	NWFP	TOTAL
1980-81	30.6	17.6	22.7	70.9
1981-82	32.8	18.4	34.2	85.4
1982-83	43.5	20.9	34.4	98.8
1983-84	56.1	22.2	122.1	200.4
1984-85	74.9	25.5	193.4	293.8
1985-86	117.6	27.5	198.5	343.3
1986-87	134.1	28.8	199.5	362.4
1987-88	265.5	29.0	215.3	509.8

Source: Compiled from the provincial budget books.

Table 1.9 shows that expenditures on agricultural have increased considerably but it requires further analysis to find out its availability per extension staff and per unit of area.

B. Schooling

In Pakistan the rural literacy rate is only 17 percent. Table 1.9 shows the literacy ratios of population by sex, region and urban/rural areas during 1981 and 1972. It is interesting to note that while the literacy rate increased in the rural areas of Punjab and NWFP by 5.3% and 2.2% respectively, it has declined in rural areas of Sind Province by 2%. The literacy in the Rural Sind declined more in the case of the rural male population than the rural female population.

Table 1.10 Literacy Ratios By Sex, Region And Urban/Rural Area 1981 And 1972 Census.

(PERCENT)

REAS/ EX	RURAL		URBAN		TOTAL	
	1981	1972	1981	1972	1981	1972
PUNJAB						
MALE	29.6	22.9	55.2	47.8	36.8	29.1
FEMALE	9.4	5.2	36.7	28.0	16.8	10.7
TH SEXES	20.0	14.7	46.7	38.9	27.4	20.7
ND						
MALE	24.5	27.5	57.8	54.5	39.7	39.1
FEMALE	5.2	5.8	42.2	38.4	21.6	19.2
TH SEXES	15.6	17.6	50.8	47.4	31.5	30.2
FP						
MALE	21.7	19.0	47.0	44.7	25.9	23.1
FEMALE	3.8	2.2	21.9	19.9	6.5	4.7
TH SEXES	13.2	11.0	35.8	33.7	16.7	14.5
KISTAN						
MALE	26.2	22.6	55.3	49.9	35.0	30.2
FEMALE	7.3	4.7	37.3	30.9	16.0	11.6
TH SEXES	17.3	14.3	47.1	41.5	26.2	21.7

V. Summing up: Institutional Development

Pakistan was faced with a difficult institutional challenge after independence. It inherited little research capacity from its colonial past. It has, on the whole, responded quite effectively to this challenge. It has built and strengthened a large number of research institutions. Most have been developed as part of the provincial systems. Federal coordination and national research centers are of recent origin.

Quantitative investment indicators show that Pakistan has expanded its system approximately to the level that most other low-income developing countries have attained. It now spends a little over one half of one percent of its agricultural product on research. This, however, is well below the .8 to 1 percent standard that advanced developing countries have achieved in recent years.

Pakistan's system today, however, does exhibit several weaknesses that require further development and expansion. The most immediate problem is that it has an improper balance between staff funding and operational support. This is a problem that is wide spread in the developing world and is not specific to Pakistan. It is also relatively easy to remedy.

Pakistan's research system also exhibits relatively poor "congruence" in its commodity orientation. The most obvious manifestation of this is that it spends far too little on rice research relative to the economic importance of this commodity. Further analysis of the mismatch between the economic importance of commodities and research emphasis is clearly called for. Again, however, it may be noted that Pakistan is not alone in having this problem.

Pakistan's research system is highly applied, particularly in crop research. India, for example, has a ratio of basic research to applied research that is more than twice that of Pakistan. This is consistent with the fact that Pakistan has not achieved a high ratio of Ph.D. level scientists. Pakistan also suffers from an inadequate data base on all research programs, not simply on PARC institutions (where data are adequate), to effectively manage the system.

APPENDIX Table A 1.1 **Research Expenditure per Scientist in Selected Asian Countries (1980)**

(000 US $)

COUNTRY	RESEARCH EXPENDITURES PER SCIENTIST
MALAYSIA	56.4
PAPUA NEW GUINEA	45.9
INDONESIA	30.2
INDIA	21.8
BANGLADESH	16.2
PHILIPPINES	15.5
THAILAND	15.3
NEPAL	12.4
SRI LANKA	10.9
PAKISTAN	8.9

Source : World Bank Report 1988

PENDIX Table A 1.2 **BUDGET OF RESEARCH ESTABLISHMENTS IN AGRICULTURE IN PAKISTAN IN ALPHABETICAL ORDER 1977-78 AND 1988-89**

(MILLION Rs.)

NAME OF THE INSTITUTE	1977-78	1988-89	% CHANGE
A. R. I. Sariab, Quetta Baluchistan.	3.61	10.40	188.1
A. R. I. Tandojam, Sind	5.60	14.09	151.6
A. R. I. Tarnab, Peshawar, NWFP.	11.67	21.63	187.4
Animal Husbandry Lab. Karachi, Sind.	0.04	0.10	150.0
A. Z. R. I. Quetta, Baluchistan.	1.75	6.08	247.4
Atomic Energy Agricultural Research Center, Tandojam, Sind	4.29	17.00	296.3
Cereal Diseases Research Institute, Islamabad	1.39	2.01	44.6
College of Veterinary Sciences, Lahore, Punjab	4.07	1.11	-72.7
Commonwealth Institute of Biological Control, Rawalpindi, Punjab	2.24	2.17	- 3.1
Cotton Research Institute Multan, Punjab	1.75	6.83	290.3
Cotton Research Institute Sakrand, Sind	6.09	6.09	---
Directorate of Land Reclamation, Lahore, Punjab	4.85	22.67	367.4
Directorate of Marine Fisheries, Karachi, Sind	3.04	3.04	---
Directorate of Soil Conservation, Rawalpindi, Punjab	16.47	16.49	0.1
Directorate of Wool/Hair and Mutton Production, Multan, Punjab	1.29	6.92	436.4

Drainage and Reclamation Institute of Pakistan, Hyderabad, Sind	6.50	4.94	-24.0
N.W.F.P Agriculture University, Peshawar, NWFP	3.32	108.59	3170.8
Fine Wool Sheep Farm Sarai Krishna, Mianwali, Punjab	0.42	1.80	328.6
Fisheries Research Institute Qadirabad,Gujranwala, Punjab	0.42	1.23	192.8
Institute of Cotton Research and Technology, Karachi, Sind	1.90	4.30	126.3
Kamori Goat Farm, Khudabad Dadu, Sind	0.23	0.39	69.5
Livestock Development Research Farm for Kundi Buffaloes, Rohri, Sind	0.35	1.29	268.6
Livestock Experiment Station Jaba, Mansehra, N.W.F.P	0.08	1.21	1412.5
Livestock Experiment Station Karachi, Sind	0.34	1.34	294.1
Livestock Experiment Station Khushab, Punjab	1.38	2.18	57.9
Livestock Experiment Station Nabisar Road, Tharparkar, Sind	0.43	2.06	379.1
Livestock Experiment Station Qadirabad, Sahiwal. Punjab	0.86	2.79	224.4
Livestock Production Research Institute, Bahadurnagar, Okara, Punjab	7.03	8.69	23.6
Cereal Crops Research Institute, Pirsabak Nowshera, N.W.F.P	2.34	6.78	189.7
Maize and Millet Research Institute, Yousufwala, Punjab	1.94	6.51	235.5

National Agriculture Research Center, Islamabad	1.45	48.28	3229.6
Nuclear Institute Of Agriculture and Biology Faisalabad, Punjab	4.99	21.00	320.8
Nuclear Institute Of Food and Agriculture, Tarnab, Peshawar, N.W.F.P	2.20	7.50	240.9
Oilseed Research Institute Faisalabad, Punjab	1.41	4.67	231.2
Pakistan Agricultural Research Council, Islamabad	62.46	464.46	643.6
Pakistan Forest Institute, Peshawar, N.W.F.P	4.90	28.20	475.5
Plant Protection Institute Faisalabad, Punjab	1.60	4.10	156.2
Ayub Agricultural Research Institute, Faisalabad, Punjab	29.35	122.09	315.9
Rapid Soil Fertility Survey and Soil Testing Institute, Lahore, Punjab	4.80	7.93	65.2
Rice Research Institute, Kala Shah Kaku, Punjab	1.75	3.74	113.7
Sericulture Research Laboratory, Lahore Punjab	0.50	0.56	112.0
Silvicultural Research Division, Hyderabad, Sind	0.18	1.00	455.5
Sind Agriculture University Tandojam, Sind	11.50	109.54	852.5
Soil Survey of Pakistan Lahore.	4.88	9.83	101.4
University of Agriculture Faisalabad	28.20	119.53	322.5
Vegetable Research Institute Faisalabad	3.75	1.59	-57.6

48	Veterinary Research Institute Lahore	5.22	17.18	229.1
49	Veterinary Research Institute Peshawar, N.W.F.P	1.85	8.42	355.1
50	Wheat Research Institute, Faisalabad	1.20	3.15	162.5
	TOTAL	267.88	1273.13	375.3

Source: PARC Survey 1988

'ENDIX Table A 1.3 STAFF OF RESEARCH ESTABLISHMENTS IN AGRICULTURE IN PAKISTAN IN ALPHABETICAL ORDER 1977-78 AND 1988-89

(NUMBER)

NAME OF THE INSTITUTE	1977-78				1988-89			
	PhD	M.Sc	B.Sc	TOTAL	PhD	M.Sc	B.Sc	TOTAL
Ayub Agricultural Research Institute, Faisalabad, Punjab	18	299	187	504	25	501	294	820
A. R. I. Sariab, Quetta, Baluchistan.	3	29	34	66	1	25	18	44
A. R. I. Tandojam, Sind	1	86	44	131	1	88	15	104
A. R. I. Tarnab, Peshawar, NWFP.	5	75	178	258	4	104	99	207
Animal Husbandry Lab. Karachi, Sind.	-	-	2	2	-	2	-	2
A. Z. R. I. Quetta, Baluchistan.	-	8	3	11	1	35	5	41
Atomic Energy Agricultural Research Center, Tandojam, Sind	15	25	3	43	13	40	17	70
Cereal Diseases Research Institute, Islamabad	3	13	6	22	3	16	1	20
College of Veterinary Sciences, Lahore, Punjab	2	30	11	43	8	46	6	60
Commonwealth Institute of Biological Control, Rawalpindi, Punjab	4	19	2	25	1	7	1	9
Cotton Research Institute Multan, Punjab	4	19	15	38	2	33	5	40
Cotton Research Institute Sakrand, Sind	1	17	6	24	3	28	3	34
Directorate of Land Reclamation, Lahore, Punjab	-	15	82	97	-	20	57	77
Directorate of Marine Fisheries, Karachi, Sind	-	9	11	20	-	15	20	35
Directorate of Soil Conservation, Rawalpindi, Punjab	-	9	32	41	-	23	34	57
Directorate of Wool/Hair and Mutton Production Multan, Punjab	-	1	22	23	-	1	13	14
Drainage and Reclamation Institute of Pakistan, Hyderabad, Sind	-	8	5	13	1	11	20	32
N.W.F.P Agriculture University, Peshawar, NWFP	-	13	46	66	14	111	-	125
Fine Wool Sheep Farm Sarai Krishna, Mianwali, Punjab	-	1	2	3	-	1	2	3

20	Fisheries Research Institute Qadirabad, Gujranwala, Punjab	1	4	9	14	1	14	10	25
21	Institute of Cotton Research and Technology, Karachi, Sind	1	10	24	35	-	11	17	28
22	Kamori Goat Farm, Khudaabad Dadu, Sind	-	-	2	2	-	-	1	1
23	Livestock Development Research Farm for Kundi Buffaloes, Rohri, Sind	-	-	1	1	-	1	1	2
24	Livestock Experiment Station Jaba, Mansehra, N.W.F.P	-	-	2	2	-	-	2	2
25	Livestock Experiment Station Karachi, Sind	-	-	3	3	-	-	2	2
26	Livestock Experiment Station Khushab, Punjab	-	-	2	2	-	1	2	3
27	Livestock Experiment Station Nabisar Road, Tharparkar, Sind	-	-	5	5	-	-	5	5
28	Livestock Experiment Station Qadirabad, Sahiwal. Punjab	-	-	5	5	-	-	6	6
29	Livestock Production Research Institute, Bahadurnagar, Okara, Punjab	3	12	26	41	-	21	24	45
30	Cereal Crops Research Institute, Pirsabak Nowshera, N.W.F.P	2	7	19	28	2	25	21	48
31	Maize and Millet Research Institute, Yousufwala, Punjab	2	11	12	25	1	32	2	35
32	National Agriculture Research Center, Islamabad	1	2	1	4	46	207	90	343
33	Nuclear Institute Of Agriculture and Biology Faisalabad, Punjab	20	55	17	92	21	53	26	100
34	Nuclear Institute Of Food and Agriculture, Tarnab Peshawar, N.W.F.P	3	14	8	25	5	30	10	45
35	Oilseed Research Institute Faisalabad, Punjab	2	23	6	31	2	37	2	41
36	Pakistan Agricultural Research Council, Islamabad	17	75	52	144	82	471	103	656
37	Pakistan Forest Institute, Peshawar, N.W.F.P	5	34	25	64	10	48	11	69
38	Plant Protection Institute Faisalabad, Punjab	1	42	1	44	1	25	2	28
39	Rapid Soil Fertility Survey and Soil Testing Institute, Lahore, Punjab	1	30	19	50	1	56	16	83
40	Rice Research Institute, Kala Shah Kaku, Punjab	4	21	11	36	2	20	3	25

;ericulture Research .aboratory, Lahore ?unjab	-	2	3	5	-	2	1	3
;ilvicultural Research)ivision, Hyderabad, ;ind	-	1	4	5	-	2	1	3
;ind Agriculture University 'andojam, Sind	16	123	23	162	46	121	-	167
;oil Survey of Pakistan .ahore.	3	42	26	71	-	42	17	59
Iniversity of Agriculture 'aisalabad	95	219	47	361	120	267	-	387
'egetable Research Institute 'aisalabad	-	33	1	34	1	32	2	35
'eterinary Research Institute ahore	1	16	45	62	-	32	59	91
'eterinary Research Institute eshawar, N.W.F.P	1	7	16	24	1	14	24	39
heat Research Institute, aisalabad	2	31	3	36	3	34	1	38
'TAL	237	1490	1109	2836	422	2715	1071	4208
: CHANGE	(-)	(-)	(-)	(-)	78.0	82.2	-3.4	48.4

: PARC Survey 1988

APPENDIX Table A 1.4 DEVELOPMENT AND NON-DEVELOPMENT BUDGETS OF 50 AGRICULTURA RESEARCH AND EDUCATIONAL ESTABLISHMENTS (1978-70 TO 1987-88)

(MILLION Rs.)

YEAR	DEV. BUDGET	NON-DEV. BUDGET	TOTAL
1978-79	46.0	104.2	150.2
1979-80	48.5	109.1	157.6
1980-81	60.5	124.5	185.0
1981-82	57.8	150.6	208.4
1982-83	69.6	172.8	242.4
1983-84	302.9	243.2	546.1
1984-85	396.4	277.6	674.0
1985-86	331.0	351.8	682.8
1986-87	379.2	404.1	783.3
1987-88	424.1	418.0	842.1

Source: PARC Survey 1988

ENDIX Table A 1.5 NON-DEVELOPMENT BUDGETS OF 50 AGRICULTURAL RESEARCH AND EDUCATIONAL ESTABLISHMENTS (1978-79 TO 1987-88)

(MILLION Rs.)

ARS	SALARIES			OPERATIONAL EXPENSES			TOTAL
	BASIC SALARIES	ALLOWANCES MISC EXP	TOTAL	EQUIP-MENT	BUILD-ING	TOTAL	
-79	61.2	16.5	77.7	25.3	1.1	26.4	104.1
-80	65.8	16.1	82.4	26.2	0.95	27.1	109.5
-81	74.8	17.9	92.7	31.1	0.65	31.8	124.5
-82	88.1	27.8	115.9	34.2	0.53	34.7	150.6
-83	100.9	29.8	130.7	40.2	1.86	42.1	172.8
-84	129.2	67.5	196.7	43.1	3.79	46.9	243.6
-85	149.3	78.2	227.5	47.6	2.44	50.0	277.5
-86	166.8	112.9	279.7	67.9	4.17	72.1	351.8
-87	196.8	115.9	312.7	88.5	2.74	91.2	404.9
-88	229.7	120.1	349.8	65.5	2.67	68.2	418.0

ENDIX Table A 1.6 SANCTIONED AND ACTUAL STAFF POSITIONS OF 50 AGRICULTURAL RESEARCH AND EDUCATIONAL ESTABLISHMENTS (1978-79 TO 1987-88)

(NUMBER)

YEARS	SANCTIONED STAFF			STAFF IN POSITION		
	TECHNICAL STAFF	SUPPORT STAFF	TOTAL	TECHNICAL STAFF	SUPPORT STAFF	TOTAL
1978-79	3396	5461	8857	2718	5010	7728
1979-80	3504	5687	9191	2707	5058	7765
1980-81	3502	5862	9364	2964	5217	8181
1981-82	3600	5932	9532	3101	5347	8448
1982-83	3713	6024	9737	3462	5448	8910
1983-84	3753	6182	9935	3554	5677	9231
1984-85	3957	6117	10074	3716	5844	9560
1985-86	4046	6131	10177	3929	5916	9845
1986-87	4877	6321	11198	4023	6188	10211
1987-88	5155	6513	11668	4162	6436	10598

Source: PARC Survey 1988

PPENDIX Table A 1.7 DEGREE WISE STATUS OF TECHNICAL MANPOWER IN 50 AGRICULTURAL RESEARCH AND EDUCATIONAL ESTABLISHMENTS 1978-79 TO 1987-88)

(NUMBER)

YEAR	PhD	M. PHIL	M. Sc	B. Sc. H	B. Sc.	DVM	BVM	OTHER	TOTAL
1978-79	99	11	952	494	246	199	118	678	2718
1979-80	93	10	1090	406	231	126	116	797	2707
1980-81	89	12	1058	578	234	241	107	538	2964
1981-82	111	21	1181	503	235	293	115	499	3101
1982-83	115	15	1325	719	234	274	150	251	3462
1983-84	127	14	1303	785	247	282	153	199	3554
1984-85	137	15	1352	916	256	297	199	241	3716
1985-86	156	17	1471	987	268	269	208	117	3929
1986-87	148	26	1666	907	272	240	198	54	4023
1987-88	199	28	2014	1144	299	217	194	67	4162

Source : PARC Survey 1988

APPENDIX Table A 1.8 Analysis of Current Expenditures of NARC (1985-86 to 1988-89)

(MILLION Rs.)

DETAILS	1985-86 (ACTUAL)		1986-87 (ACTUAL)		1987-88 (REVISED)		1988-89 (BUDGET)	
	AMOUNT	%	AMOUNT	%	AMOUNT	%	AMOUNT	%
1) STAFF COST	13.633	48.7	16.525	53.0	21.58	60.8	26.789	70.6
%	(100.0)		(121.2)		(158.3)		(196.5)	
2) OPER. EXP.	10.803	38.6	12.149	38.9	11.426	32.2	9.491	25.0
%	(100.0)		(112.5)		(105.7)		(87.8)	
3) CAPITAL EXP.	3.535	12.7	2.520	8.1	2.465	7.0	1.656	4.4
%	(100.0)		(71.3)		(69.7)		(46.8)	
TOTAL	27.971	100.0	31.194	100.0	35.472	100.0	37.936	100.0
%	100.0		111.5		126.8		135.6	
TOTAL STAFF (#)	629		801		787		857	
TOTAL SCIENTIST (#)	129		203		200		224	
OPERATIONAL EXP./SCIENTIST	.084		.060		.057		.042	
%	100.0		70.9		68.0		50.2	

APPENDIX Table A 1.9 Analysis of Current Expenditures of Wheat Research Program of NARC (1985-86 to 1988-89)

(MILLION Rs)

DETAILS	1985-86 (ACTUAL)		1986-87 (ACTUAL)		1987-88 (REVISED)		1988-89 (BUDGET)	
	AMOUNT	%	AMOUNT	%	AMOUNT	%	AMOUNT	%
1) STAFF COST	0.603	55.6	0.556	59.9	0.743	72.5	1.192	82.8
%	(100.0)		(92.2)		(123.2)		(197.7)	
2) OPER. EXP.	0.420	38.8	0.369	39.7	0.277	27.0	0.239	16.6
%	(100.)		(87.8)		(65.9)		(56.9)	
3) CAPITAL EXP.	0.062	5.7	0.003	0.3	0.005	0.5	0.008	0.6
%	(100.0)		(4.8)		(8.1)		(12.9)	
TOTAL	1.085	100.0	0.928	100.0	1.025	100.0	1.439	100.0
%	100.0		85.5		94.5		132.6	
TOTAL STAFF (#)	60		80		70		70	
TOTAL SCIENTIST (#)	22		31		25		32	
OPERATIONAL EXP./SCIENTIST	0.019		0.012		0.011		0.007	

APPENDIX Table A 1.10 Analysis of Current Expenditures of Rice Research Program of NARC (1985-86 to 1988-89)

(MILLION Rs)

DETAILS	1985-86 (ACTUAL)		1986-87 (ACTUAL)		1987-88 (REVISED)		1988-89 (BUDGET)	
	AMOUNT	%	AMOUNT	%	AMOUNT	%	AMOUNT	%
1) STAFF COST	0.671	49.7	0.744	55.6	1.098	73.9	1.166	80.1
%	(100.0)		(110.9)		(163.6)		(173.8)	
2) OPER. EXP.	0.642	47.6	0.572	42.8	0.381	25.6	0.277	19.0
%	(100.0)		(89.1)		(59.3)		(43.2)	
3) CAPITAL EXP.	0.037	2.7	0.021	1.6	0.006	0.4	0.013	0.9
%	(100.0)		(56.7)		(16.2)		(35.1)	
TOTAL	1.350	100.0	1.337	100.0	1.485	100.0	1.456	100.0
%	100.0		99.0		110.0		107.8	
TOTAL STAFF (#)	55		58		59		58	
TOTAL SCIENTIST (#)	17		19		21		23	
OP. EXP./SCIENTIST	0.038		0.030		0.018		0.01[illegible]	

APPENDIX Table A 1.11 Analysis of Current Expenditures of Maize Research Program of NARC (1985-86 To 1988-89)

(MILLION Rs)

DETAILS	1985-86 (ACTUAL)		1986-87 (ACTUAL)		1987-88 (REVISED)		1988-89 (BUDGET)	
	AMOUNT	%	AMOUNT	%	AMOUNT	%	AMOUNT	%
1) STAFF COST	0.584	68.1	0.567	71.0	0.497	66.8	0.757	79.2
%	(100.0)		(97.1)		(85.1)		(129.6)	
2) OPER. EXP.	0.251	29.3	0.232	29.0	0.236	31.7	0.194	20.3
%	(100.0)		(92.4)		(94.0)		(77.3)	
3) CAPITAL EXP.	0.022	2.6	-----	---	0.011	1.5	0.005	0.5
%	(100.0)		---		(50.0)		(22.7)	
TOTAL	0.857	100.0	0.799	100.0	0.744	100.0	0.956	100.0
%	100.0		93.2		86.8		111.5	
TOTAL STAFF (#)	54		52		51		59	
TOTAL SCIENTIST (#)	15		18		17		21	
OP. EXP./SCIENTIST	0.017		0.013		0.014		0.009	

APPENDIX Table A 1.12 Analysis of Current Expenditures of Pulses Research Program of NARC (1985-86 to 1988-89)

(MILLION Rs.)

DETAILS	1985-86 (ACTUAL)		1986-87 (ACTUAL)		1987-88 (REVISED)		1988-89 (BUDGET)	
	AMOUNT	%	AMOUNT	%	AMOUNT	%	AMOUNT	%
1) STAFF COST	0.613	61.3	0.677	71.3	0.854	80.5	0.971	87.9
%	(100.0)		(110.4)		(139.3)		(158.4)	
2) OPER. EXP.	0.349	34.9	0.258	27.2	0.206	19.4	0.129	11.7
%	(100.0)		(73.9)		(59.0)		(36.9)	
3) CAPITAL EXP.	0.038	3.8	0.014	1.5	0.001	0.1	0.005	0.4
%	(100.0)		(36.8)		(2.6)		(13.1)	
TOTAL	1.000	100.0	0.949	100.0	1.061	100.0	1.105	100.0
%	100.0		94.9		106.1		110.5	
TOTAL STAFF (#)	38		40		40		41	
TOTAL SCIENTIST (#)	18		21		21		21	
OP. EXP./SCIENTIST	0.019		0.012		0.010		0.006	

Chapter II. Crop Production and Productivity in Pakistan Agriculture

Agricultural production is constrained by the skills of farmers, by technology available to the farmer, and by infrastructure in the form of roads, communication facilities, and marketing and processing facilities. When these constraints are binding and fixed, it is possible to characterize production in any period in terms of: a) production or transformation functions, and b) the "dual" maximized profits function (and its derivative functions, see Chapter V). When these constraints are binding and do not change over time it is also possible to express changes in production as a simple function of changes in quantities of factors (or of changes in prices).

However, when the technology (or infrastructure) available to farmers changes (as it is expected to as a result of research programs and extension programs) the simple expressions for changes in production no longer hold. The analyst essentially has two choices in measuring and analyzing such changes. The first choice is to engage in a two-stage procedure. In the first stage Total Factor Productivity (TFP) or Partial Factor Productivity (PFP) measures are computed for the relevant units under study (e.g., a farm or an aggregate of farms over time). This essentially divides the change in production into two parts; one part is the output change predicted by changes in factor quantities (or prices) computed as though technology and infrastructure had not changed. The second part is the residual TFP (PFP) part and is attributable to changes in technology and infrastructure.

In the second stage of this analysis, the TFP (PFP) part is then subjected to a statistical "decomposition" analysis in that TFP indexes are regressed on variables that are designed to measure the flow of new technology or infrastructure that is occurring over the periods observed. This two stage approach is taken in Chapters III and IV.

The second choice open to the analyst is to incorporate the variables measuring technology and infrastructure directly into the production or transformation functions and/or the dual profits function systems. This choice can be described as the "meta" function approach because it specifically attempts to characterize the technology and infrastructure environment as part of the

production environment (the conventional analysis treats technology and infrastructure as fixed and given). This approach is pursued in Chapter V.

In this chapter, TFP and PFP measures are defined and measured at the district level in Pakistan. Section I of the chapter discusses methods. Section II reports PFP indexes by state for Pakistan agriculture. Section III reports TFP indexes. Section IV develops a comparison of TFP growth in the Indian Punjab with TFP growth in Pakistan.

I. Measurement Methodology

There are two basic procedures for deriving Total Factor Productivity (TFP) change indexes. They are the accounting and production (or transformation) function approaches. With the accounting procedure, receipts are assumed to equal expenditures, but no knowledge of the production function is presumed. All of the early productivity measures for the aggregate U.S. economy were of this type (Kendrick 1962). With the production function approach, the producing unit of analysis is assumed to transform inputs into output subject to a production function. Index numbers must be used to aggregate quantities into output and input indexes, and a specific index number formula is associated with a specific form of the production function. For example, the Laspeyres index number is an "exact" index for the Leontief fixed-coefficient production (or transformation) function, and the Geometric function index is exact for the Cobb-Douglas production function. However, when these indexes are "chained", and weights are allowed to change from period to period, the Divisia index or the Fisher-Chained index are good approximations for any production function form.

A. The Accounting Approach to TFP Measurement

The accounting approach is based on the proposition that receipts or income for a firm equal its expenditures when all factors are properly priced. Assume an economic sector that is in long-run equilibrium. Firms may be minimizing costs and maximizing profits, but they need not be. They need not even be technically efficient. In equilibrium, firms will not be making profits (i.e., abnormal profits) because, if such profits existed, other firms would enter until profits were reduced. Thus, equation (2.1) holds:

$$(2.1) \quad \sum_i P_i Y_i = \sum_j R_j X_j$$

where the Y_i are outputs with prices P_i, and the X_j are inputs with prices R_j. (Note that "quasi-fixed" factors such as land or buildings are treated as having a "rental" or service price.)

Now differentiate (2.1) totally with respect to time, t:

$$(2.2) \quad \sum_i Y_i \partial P_i/\partial t dt + \sum_i P_i \partial Y_i/\partial t dt = \sum_j X_j/\partial R_j/\partial t dt_t + \sum_j R_j \partial X_j/1 \partial t dt$$

This expression is exact for infinitely small changes. (For discrete or finite changes, index number problems must be dealt with, see below.) Divide the left-hand side of (2.2) by $\sum_i P_i Y_i$ and the right-hand side by $\sum_j R_j X_j$ - the two sums are equal, then multiply the first term of (2.2) by P_i/P_i, the second by Y_i/Y_i, the third by R_j/R_j, and the fourth by X_j/X_j. Define $Y_i P_i/\Sigma P_i Y_i = S_i$, the output share of the ith output, and $X_j R_j/\Sigma X_j R_j = C_j$, the input cost share of the j input.

Define $\hat{X} = 1/X_j \partial X_j/\partial t \quad dt$ as the rate of change of X.

Transforming equation (2.2), we obtain:

$$(2.3) \quad \sum_i S_i \hat{P}_i + \sum_i S_i \hat{Y}_i = \hat{P} + \hat{Y} + \sum_j C_j \hat{R}_j + \sum_j C_j \hat{X}_j = \hat{R} + \hat{X}$$

where $\hat{P}$, $\hat{Y}$, $\hat{R}$ and $\hat{X}$ are rates of change of aggregated output prices, output quantities, factor prices, and factor quantities, respectively. The rate of change in total factor productivity T is defined as:

$$(2.4) \quad \hat{T} = \hat{Y} - \hat{X} = \hat{R} - \hat{P}$$

This is the difference between the rate of growth of the index of output and the index of inputs or between the rate of growth of input prices and output prices. The motivation for this "residual" definition is that $\hat{T}$ measures gains made possible by efficiency improvements. The following interpretation of these gains can be given:

(a) If all inputs are unchanged (i.e., $\hat{X} = 0$), then total factor productivity, $\hat{T} = \hat{Y}$ the increase in output (or output index) achievable at constant input levels.

(b) If all outputs are unchanged, $\hat{Y} = 0$, then $\hat{T} = \hat{X}$ -- the rate of reductions in input usage at given output levels.

where the Y_i are outputs with prices P_i, and the X_j are inputs with prices R_j. (Note that "quasi-fixed" factors such as land or buildings are treated as having a "rental" or service price.)

Now differentiate (2.1) totally with respect to time, t:

$$(2.2) \quad \sum_i Y_i \partial P_i/\partial t dt + \sum_i P_i \partial Y_i/\partial t dt - \sum_j X_j/\partial R_j/\partial t dt_t + \sum_j R_j \partial X_j/1 \partial t dt$$

This expression is exact for infinitely small changes. (For discrete or finite changes, index number problems must be dealt with, see below.) Divide the left-hand side of (2.2) by $\sum_i P_i Y_i$ and the right-hand side by $\sum_j R_j X_j$ - the two sums are equal, then multiply the first term of (2.2) by P_i/P_i, the second by Y_i/Y_i, the third by R_j/R_j, and the fourth by X_j/X_j. Define $Y_i P_i/\Sigma P_i Y_i = S_i$, the output share of the ith output, and $X_j R_j/\Sigma X_j R_j = C_j$, the input cost share of the jth input.

Define $\hat{X} = 1/X_j \partial X_I/\partial t \quad dt$ as the rate of change of X.

Transforming equation (2.2), we obtain:

$$(2.3) \quad \sum_i S_i \hat{P}_i + \sum_i S_i \hat{Y}_i = \hat{P} + \hat{Y} + \sum_j C_j \hat{R}_j + \sum_j C_j \hat{X}_j = \hat{R} + \hat{X}$$

where $\hat{P}$, $\hat{Y}$, $\hat{R}$ and $\hat{X}$ are rates of change of aggregated output prices, output quantities, factor prices, and factor quantities, respectively. The rate of change in total factor productivity T is defined as:

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(a) If all inputs are unchanged (i.e., $\hat{X} = 0$), then total factor productivity, $\hat{T} = \hat{X}$ the increase in output (or output index) achievable at constant input levels.

(b) If all outputs are unchanged, $\hat{Y} = 0$, then $\hat{T} = \hat{X}$ -- the rate of reductions in input usage at given output levels.

(c) If both inputs and outputs change, then $\hat{T} = \hat{Y} - \hat{X}$ is the increase in total factor productivity. Note that the change in the output/input ratio (or factor productivity) for single factors is: $\hat{Y} - \hat{X}_j$, where X_j is the jth input. Thus, the rate of productivity growth is the rate of change in the ratio of output to input or in the ratio of an output index to an input index.

(d) If all output prices are fixed, e.g., this arises when all goods are traded internationally and their prices cannot change or when we consider an individual firm in a large market, then $\hat{T} = \hat{R}$. Total factor productivity growth equals the rate of increase in factor prices or factor incomes made possible by efficiency gains.

(e) If all input prices are constant, i.e., $\hat{R} = 0$, which might occur when all inputs are traded internationally but goods are not, then $\hat{T} = -\hat{P}$. The rate of total factor productivity change is measured by the reduction in output prices made possible by the efficiency gains.

(f) If both input and output prices are changing, then $\hat{T} = \hat{R} - \hat{P}$ = $\hat{R}$ /P). Total factor productivity change is the increase in real factor incomes deflated by the output price (or an index thereof). These interpretations provide general content to the TFP index. Note that the TFP index cannot be described as a technology change index. Public sector infrastructure investments and human capital changes also produce TFP changes.

B. The Transformation Function Approach

With this approach, the measure of productivity is derived from the transformation function relating outputs and inputs. Let multiple outputs be positive quantities $Y_1 \ldots, Y_m$. These are produced using several inputs ($X_1 \ldots\ldots, X_n$) which are also positive quantities, and let the technology be described by a transformation function:

$$(2.5) \quad Y_1 = F(Y_2, \ldots, Y_m, X_1, \ldots, X_n, t)$$

Equation (2.5) is an asymmetric representation of the transformation function giving output of Y1 as a function of the other outputs and the inputs. Assume (2.5) is a linear homogeneous function. Several things are "held constant" in the background behind this expression including the technology set available to farmers, the existing infrastructure (roads, markets) and transactions costs (legal system, etc.). One of the purposes of productivity analysis is to infer from data only on Y's and the X's the probable contributions to output that changes in these factors in the background contribute.

Equation (2.5) can be converted into a form that summarizes relationships among growth of inputs and outputs. Differentiate (2.5) totally with respect to time to obtain:

$$(2.6) \quad \sum_{i=1}^{m} F_i \frac{\partial Y_i}{\partial t} dt + \sum_{j=1}^{n} F_j \frac{\partial x_i}{\partial t} dt + F_t dt = 0$$

where Fi and Fj are first derivatives of the production function F, and Ft is the derivative with respect to t. The first-order conditions for profit maximization are:

$$P_i = \lambda F_i \text{ and } -R_j = \lambda F_j;\ i = 2, \ldots, m;\ j = 1, \ldots, m,$$

where P_i and R_j are prices of outputs and inputs and λ is a Lagrange multiplier. Substituting $F_i = P_i/\lambda$ and $F_j = -R_j/\lambda$ in for the F_i and F_j and multiplying by $\lambda/\Sigma P_i Y_i$ or $\lambda/\Sigma R_j X_j$, we obtain:

$$(2.7\quad \sum_i \frac{P_i Y_i}{\Sigma P_i Y_i} \frac{\alpha Y_i}{\partial t} \frac{1}{Y_i} dt - \sum_j \frac{P_j X_j}{\Sigma R_j X_j} \frac{\partial X_j}{\partial t} \frac{1}{X_j} dt + \frac{\lambda Y_1}{\Sigma P_i Y_i} \frac{F_t}{Y_1} dt = 0$$

or

$$(2.8)\quad \sum_i S_i \frac{\partial Y_i}{\partial t} \frac{1}{Y_i} dt - \sum_j C_j \frac{\partial X_j}{\partial t} \frac{1}{X_j} dt + \frac{\partial Y_1}{\Sigma P_i Y_i} \frac{F_t}{Y_1} dt = 0$$

where S_i is the revenue share for each output and C_j is the cost share for each input and we make use of the property that $\sum_j R_j X_j = \Sigma P_i Y_i$, i.e., that the value of total inputs equals the value of output (this is the "no profit" condition that holds in a competitive economy). This expression holds for small changes when the "background variables" are unchanged. It relates growth in output to growth in factors or inputs. When this equation does not hold, the logic of this development tells us that the background variables have changed. This is the basis for definition of total productivity change, $\hat{T}$, as:

$$(2.9)\quad \hat{T} = \sum_i S_i \frac{\partial Y_i}{\partial t} \frac{1}{Y_i} dt - \sum_j R \frac{\partial X_j}{\partial t} \frac{1}{X_j} dt = \hat{Y} - \hat{X}$$

This development of TFP growth from the production decisions leads to the same expression as did the accounting expression. Constant scale economies were imposed to obtain this relationship. Technical errors by farmers in obtaining maximum output, profit maximizing errors and scale economics may in practice be included in measures of $\hat{T}$.

C. The Dual Function Approach to TFP Measurement

Variable profits associated with (2.5) are defined as:

(2.10) $\pi = \sum_i P_i Y_i - \sum_i R_i X_i$

Maximizing (2.10) subjects to (2.5) and solving for profit maximizing levels of Y_i (Y_i*) and X_j (X_j*) yields - the maximized profits function

(2.11) $\Pi^* = \sum_i P_i Y_i^* - \sum_i R_j X^*_j$

which can also be expressed as:

(2.12) $\Pi^* = \Pi\ (P_i \cdot\cdot P_m,\ R_i \cdot\cdot R_n, T)$

(because Y_i* and X_j* are functions of prices and T).

It is readily seen that (Shepherd-Hotelling Lemma) the derivatives of (11) and (12) with respect to prices yield the output supply

(2.13) $\partial\pi/\partial/dP_i = Y_i^* = Y_i\ (P_i - P_m R_j Rm.\ T)$

and factor demand equation,

(2.14) $\partial\pi^*/\partial R_i = X_i^X = X_j\ (P_i P_m\ R_j Rn,\ T)$

as long as appropriate "curvature" conditions are met.

Differentiating (2.13) and (2.14) with respect to time and defining:

(2.15) $\partial Y_i/\partial_\tau\ d\tau = \hat{E}_i$ as an output rate of productivity change and

(2.16) $\partial X_i/\partial_\tau\ \ d\tau = \hat{A}_j$ as a factor rate of productivity change one obtains after substitution:

(2.17) $\hat{T} = \sum_i S_i\ \hat{E}_i + \sum_i C_j\ \hat{A}_j$

This shows TFP as a weighted average of output and input rates of productivity change.

D. Index Numbers and Functional Forms

The basic TFP indexes derived as,

(2.18) $\hat{T} = \hat{Y} - \hat{X} = \hat{R} - \hat{P}$

requires index numbers for aggregate outputs and inputs or for output prices and input prices. The Tornqvist-Theil discrete approximation to the Divisia index is a good approximation when small changes in quantities occur.

This approximation to the Divisia index uses chain-linked weights. Cost or revenue weights for all years are constructed, and the weights used in the index are obtained by averaging the weights for the current and preceding year for all years. The quantity output and input indexes are given in equations (2.19) and (2.20):

$$(2.19) \quad \hat{y} = \ln (Y_t/Y_{t-1}) = \frac{1}{2} \Sigma(S_{it} + S_{it-1}) \ln (Y_{it}/Y_{it-1})$$

$$(2.20) \quad \hat{x} = \ln (X_t/X_{t-1}) = \frac{1}{2} \Sigma_j(C_{jt} + C_{jt-1}) \ln (X_{jt}/X_{jt-1})$$

When changes are large any index number formula will impose implicit "curvature" on production technology. This comes about because the index number for a quantity aggregate is designed to "purge" the aggregate of price change effects. If prices do not change or if all prices change proportionately this does not become a problem. In practice, of course, prices do change from one period to the next. The Fisher index when chained is also an appropriate index for these purposes.

In practice, not only is the Tornqvist-Theil index a discrete approximation to a Divisia index and the appropriate index when technology is linear homogeneous translog, but it is also the appropriate index for a second-order differential approximation to any arbitrary non-homothetic production technology. This is because the translog function is a "flexible" function form in the sense that it is a good approximation to any arbitrary production (cost or profit) function.

E. PFP Measurement

Partial Factor Productivity (PFP)measures relate output (a single output or an aggregate index) not to a weighted aggregate of all inputs, but simply to a single input. These indexes are widely used for two reasons. First, they are easy to calculate (no price weighting is required). Second, they have a clear physical interpretation as opposed to the economic interpretation of the TFP indexes.

Labor productivity indexes, i.e., output per worker, are widely used in descriptions of general economic activity. Land productivity indexes, i.e., output per unit land or yields, are widely used

for agriculture. The indexes, as noted, have a clear physical interpretation, and this is often useful in comparing economic conditions over time or across regions. Changes in PFP indexes have two sources. One source is from changes in other inputs (e.g., fertilizer or labor). The second source is the same set of factors that change TFP indexes.

In interpreting PFP indexes it is thus important to bear in mind that changes due to other inputs, particularly to increased fertilizer use or irrigation, are not "real" changes in productivity as noted above for TFP indexes. This consideration also has to be incorporated into statistical decomposition analyses as in Chapter III.

II. PFP Indexes for Pakistan Agriculture

It is useful to begin the reporting of productivity measures with the more familiar PFP or yield measures. These have been calculated for the following crops: wheat, rice, maize, bajra, jowar, cotton, barley, gram, mung and sugarcane. Table 2.1 reports yield levels for two periods, the 1956 to 1966 period, and the 1971-1985 period, for each of the three Pakistan states. The first period is the pre-green revolution period. The second is the post-green revolution period. In general, yields were higher for all crops in the 1972-85 period than in the 1956-66 period. Rice yields increased most in percentage terms followed by cotton yields. Wheat and maize yields increased at a modest rate. Yields of gram, barley, sugarcane, bajra and jowar increased at a slow rate.

Table 2.1 Average Crop Yields: 1956-66 and 1972-85

(TONNES PER HA)

	PUNJAB		SIND		NWFP		ALL PAKISTAN	
	1956-66	1972-85	1956-66	1972-85	1956-66	1972-85	1956-66	1972-85
	2.79	3.30	3.43	3.37	2.82	3.25	2.99	3.31
	0.96	1.23	0.52	0.54	1.03	1.33	0.88	1.09
	0.52	0.58	0.46	0.51	0.38	0.44	0.48	0.55
	0.49	0.61	0.56	0.62	0.54	0.50	0.52	0.59
	1.62	1.62	0.70	1.61	0.59	1.03	1.18	1.52
	0.82	1.36	0.83	1.74	0.72	1.42	0.81	1.49
N	0.18	0.23	0.21	0.33	0.72	1.14	0.24	0.38
Y	0.64	0.72	0.55	0.58	0.62	0.76	0.62	0.69
	0.57	0.59	0.65	0.73	0.43	0.36	0.57	0.59
	0.44	0.59	-	-	0.32	0.52	0.44	0.58

Table 2.2 reports estimated time trends in yields (PFP) for the eight commodities for the pre-green revolution period (1956-66), the green revolution period (1966-72), and the post-green revolution period (1972-86). For comparison purposes, Table 2.2 also reports trends in the TFP measure (discussed below in more detail). All trends are estimated by a regression of the form:

(2.21) $\ell n(x_t) = a + \hat{b}Year + \sum_i C_i D_i$

where the Di are district dummy variables. In this specification bB^ is an estimate of the geometric or percentage rate of change per year within the districts in the state. These estimates show that yields generally did increase most rapidly in the green revolution period and that rates of change were highest for rice and wheat in this period. Rates of yield change in the post-green revolution period have generally been low, although most have been positive.

Table 2.2 Estimated Time Trend in Yield By Crop

(PERCENTAGE CHANGE BY YEAR)

CROPS	PUNJAB			SIND			NWFP			ALL PAKISTAN		
	56-66	66-72	72-85	56-66	66-72	72-85	56-66	66-72	72-85	56-66	66-72	72-85
SUGAR-CANE	0.0154	0.0082	0.0012*	0.0158	-0.0052*	0.0185	0.0277	0.0088	-0.0050*	0.0172	0.0043*	0.0049
MAIZE	0.0140	0.0144	0.0015	0.0297	-0.0371*	-0.0092*	0.0024*	-0.0110*	0.0160	0.0147	0.0027*	0.0017
BAJRA	0.0178	0.0072	0.0076	0.0350	-0.0026*	0.0001*	0.0375	-0.0161*	0.0329	0.0248	0.0016*	0.0090
JOWAR	0.0170	0.0210	0.0040	0.0158	0.0199	-0.0074*	0.0433	-0.0029*	0.0015*	0.0211	0.0172	0.0003
WHEAT	0.0130	0.0390	0.0198	0.0123	0.0906	0.0259*	0.0022*	0.0319	0.0310	0.0109	0.0524	0.0235
RICE	0.0394	0.0646	-0.0119*	0.0068	0.1227	-0.0042*	0.0302	0.0963	0.0198	0.0275	0.0886	-0.0035
COTTON	0.0185	0.0323	0.0108	0.0385	0.0334	-0.0038*	0.0753	0.0127*	-0.0092*	0.0305	0.0304	0.0042
BARLEY	-0.0067*	0.0228	0.0057	0.0164	0.0044*	-0.0117*	-0.0137*	0.0356	0.0220	-0.0034*	0.0201	0.0048
GRAM	0.0047	0.0175	-0.0122*	0.0046*	0.0216	0.0119	0.0668	-0.0263*	0.0094*	0.0155	0.0116	-0.0021*
MUNG	0.0317	0.0117	-0.0000*	-	-	-	-	0.0731	0.0249	0.0317	0.0171	0.0033
TFP(FC)	0.0172	0.0253	0.0025	0.0233	0.0725	0.0097	0.0272	-0.0125*	-0.0128*	0.0206	0.0231	0.0019
TFP(TQ)	0.0074	0.0170	-0.0043*	0.0129	0.0628	0.0008*	0.0193	-0.0235*	-0.0184	0.0110	0.0231	0.0086

*"t" > 1.7 and < 2.0.
**"t" > 2.0.

6c

III. TFP Indexes for Pakistan Agriculture

Equations (2.19) and (2.20) define the quantity aggregates for the Tornqvist-Theil TFP index (2.18). An alternative index number that is also a flexible and "superlative" index number is the Fisher-Chained index. The Fisher index is the square root of the product of the Laspeyres and the Paasche indexes. Chain linking it refers to the practice of shifting price weights each period to the previous period (in contrast to an average of the previous period and the current period as in (2.19) and (2.20)) and then "linking" changes to produce a cumulated index.

Table 2.3 shows output and variable factor shares for the pre- and post-green revolution period by province. It is noteworthy that the shares of wheat, sugarcane and cotton rose over the period. The share of rice declined in spite of improved varieties.

Table 2.3 Output And Variable Factor Share

(PERCENT)

OPS	PUNJAB		SIND		NWFP		ALL PAKISTAN	
	1956-66	1972-85	1956-66	1972-85	1956-66	1972-85	1956-66	1972-85
TPUT SHARE								
GAR-NE	1.150	1.184	0.080	0.125	0.179	0.196	0.135	0.169
IZE	0.030	0.029	0.001	0.002	0.184	0.154	0.048	0.043
JRA	0.041	0.027	0.033	0.014	0.031	0.152	0.037	0.021
JAR	0.020	0.017	0.042	0.015	0.014	0.128	0.025	0.016
EAT	0.393	0.413	0.165	0.254	0.356	0.355	0.321	0.338
CE	0.125	0.106	0.403	0.325	0.024	0.034	0.187	0.157
CTON	0.110	0.132	0.169	0.208	0.009	0.014	0.108	0.134
RLEY	0.006	0.004	0.003	0.003	0.020	0.011	0.007	0.005
AM	0.064	0.043	0.038	0.031	0.067	0.054	0.057	0.042
IG	0.009	0.009	-	-	-	0.008	0.005	0.006
BACCO	0.025	0.009	-	-	0.084	0.116	0.028	0.025
E & TARD	0.028	0.022	0.065	0.020	0.028	0.027	0.039	0.022
IABLE FACTOR SHARE								
OR	0.561	0.519	0.526	0.621	0.559	0.626	0.551	0.567
MAL OR	0.419	0.268	0.463	0.262	0.429	0.267	0.433	0.266
CTOR	0.018	0.150	0.009	0.049	0.010	0.070	0.015	0.108
TI-ER	0.002	0.062	0.001	0.067	0.001	0.035	0.001	0.059

Variable factor shares show that fertilizer use increased rapidly and that tractor power was rapidly replacing animal power in Pakistan agriculture. (Appendix Table A 2.1 shows annual quantity indexes for each output and variable input). Figures 2.1, 2.2 and 2.3 depict the Tornqvist-Theil index for the average district in the Punjab, Sind and NWFP respectively. The base period for each district is the 1956-1960 averages. This procedure eliminates much of the early period weather variation and affords a better basis for comparison among states. Figures 2.1a, 2.2a and 2.3a depict Fisher-Chained TFP indexes on the same basis. Table A 2.2 reports a comparison of Laspeyres, Fisher-Chained and Tornqvist indexes. Table A 2.3 report Fisher-Chained and Tornqvst TPF indexes by province.

Figure 2.1 Tornqvist Index : Punjab, Pakistan

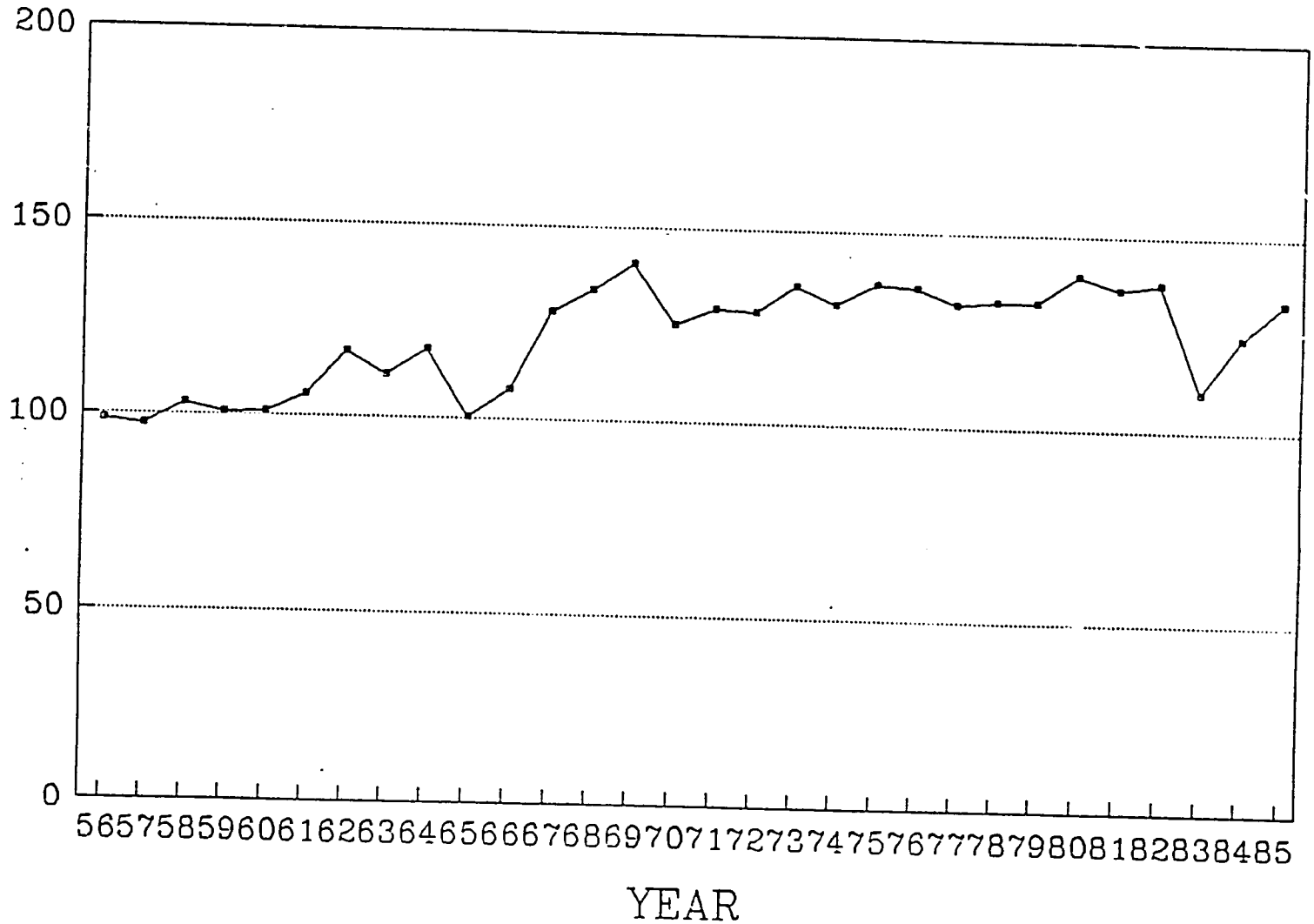


Figure 2.2 Tornqvist Index : Sind, Pakistan

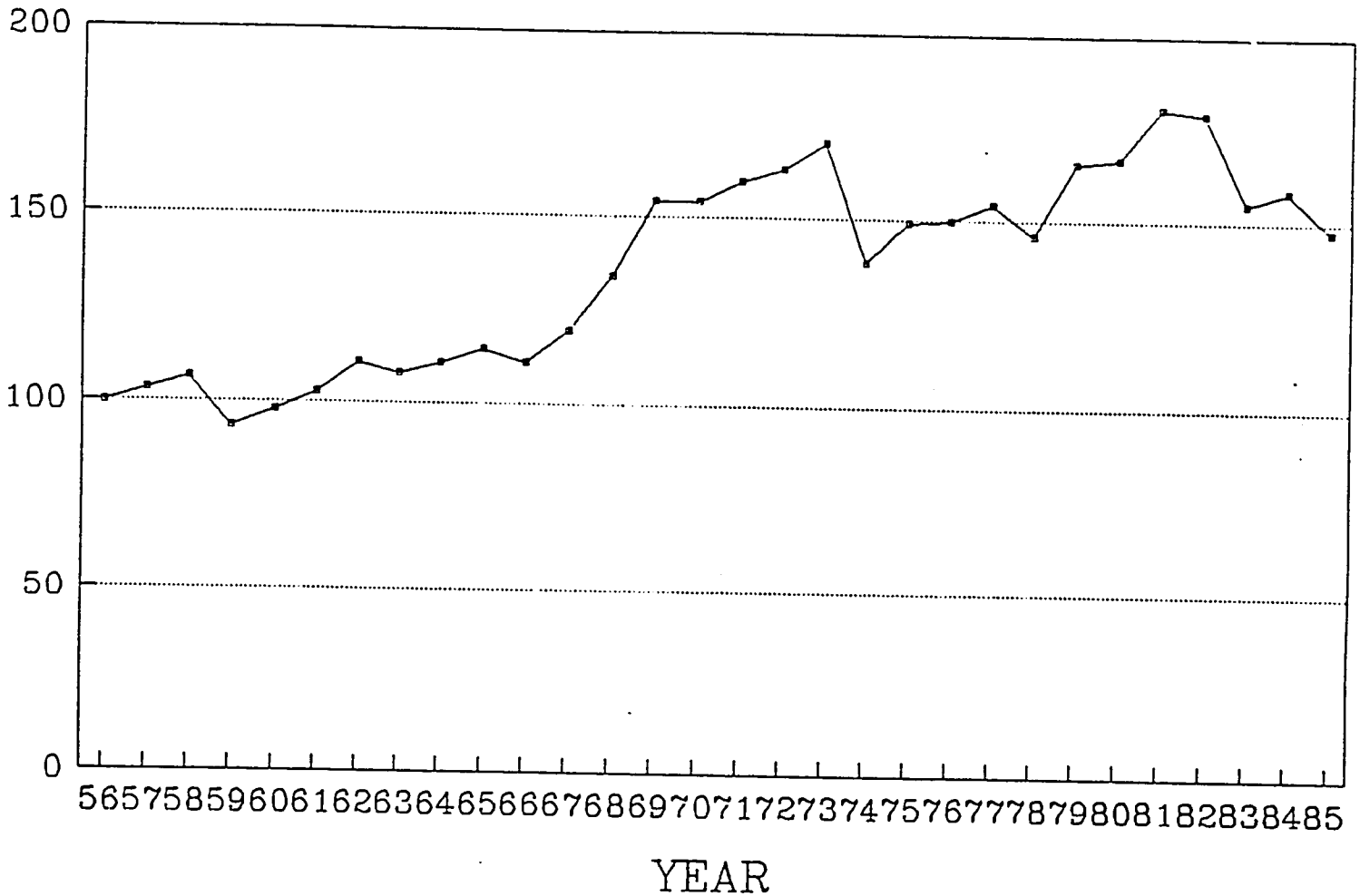


Figure 2.3 Tornqvist Index : NWFP, Pakistan

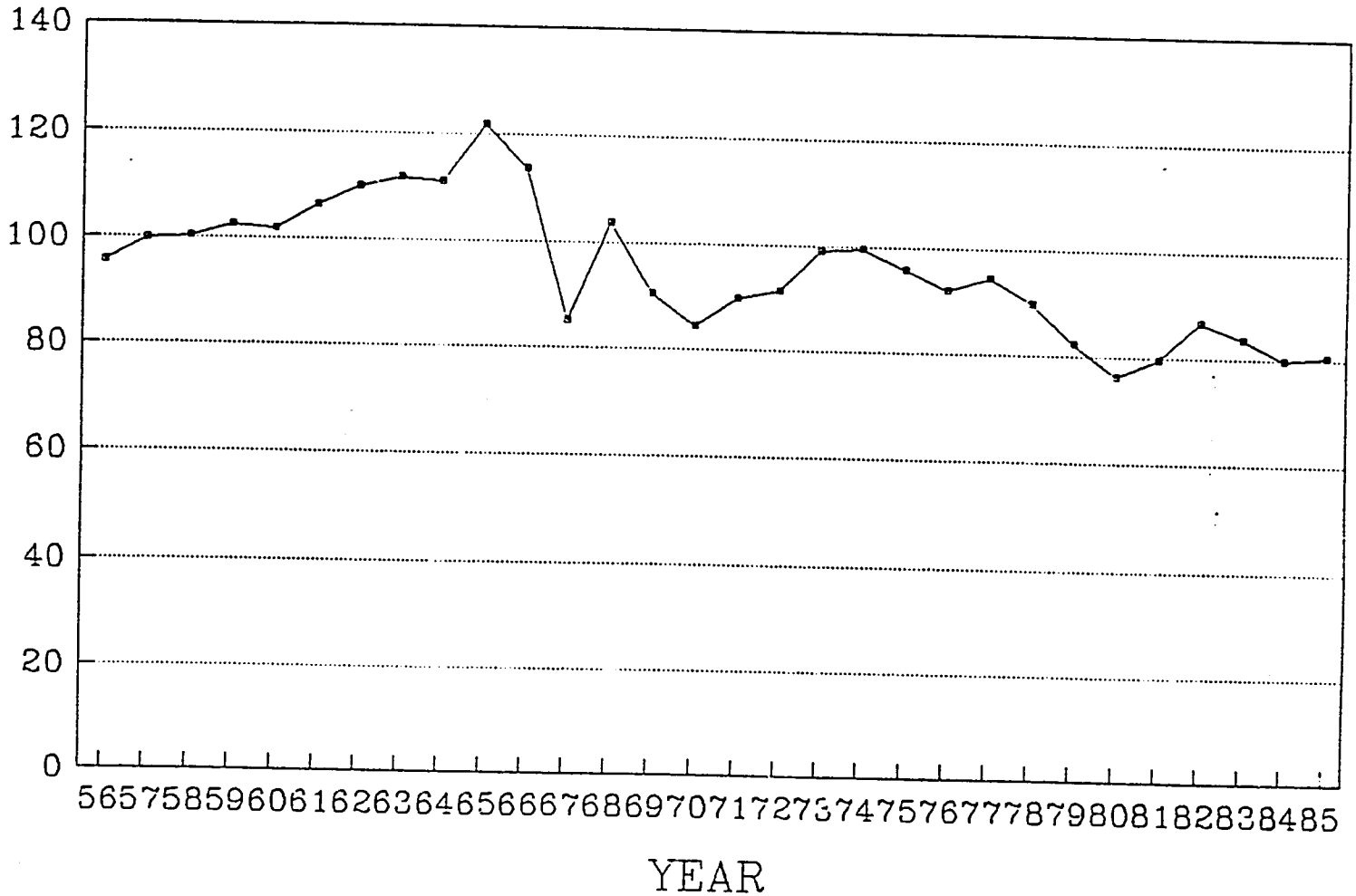


Figure 2.1 a Fisher-Chained Index : Punjab, Pakistan

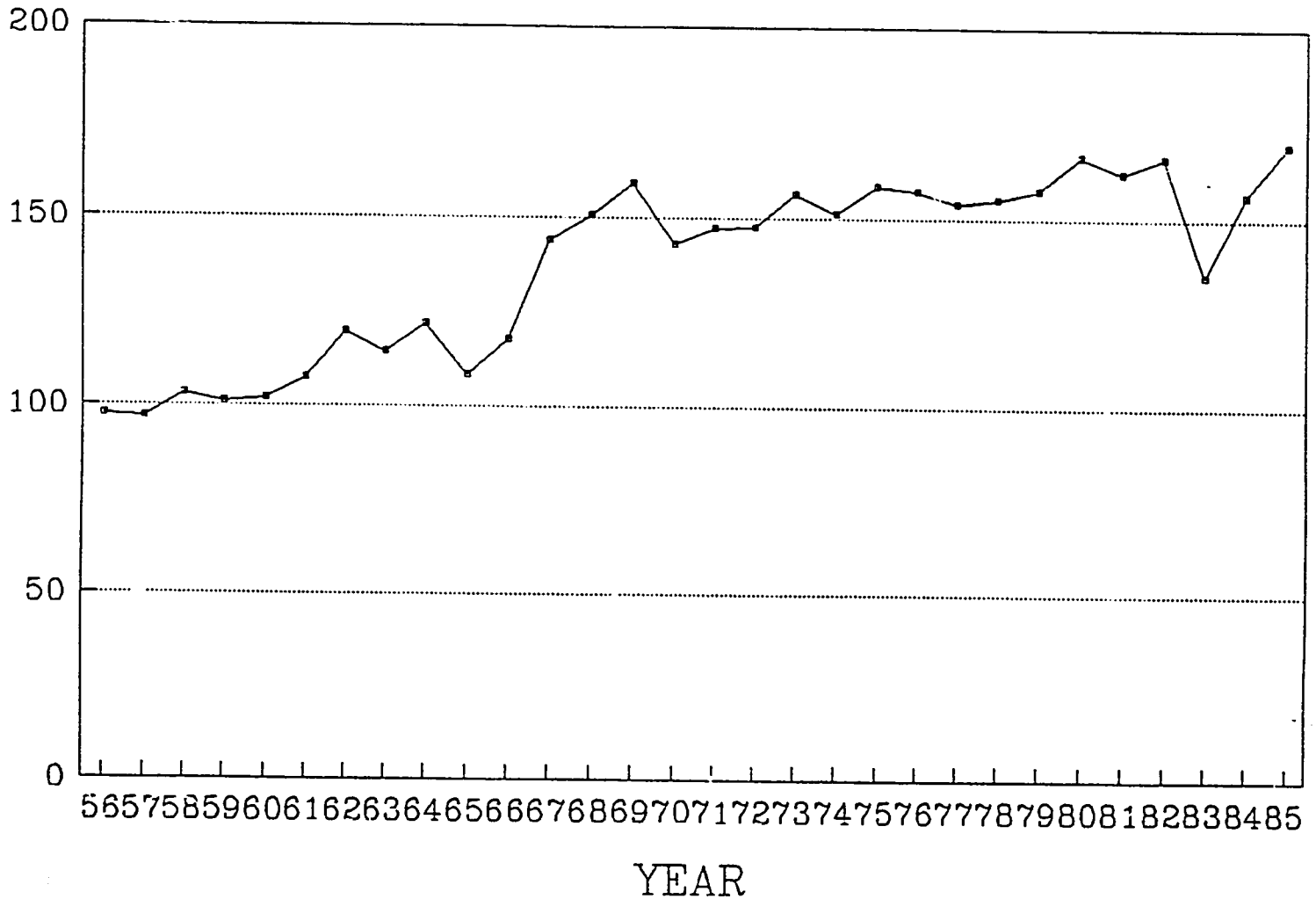


Figure 2.2 a Fisher-Chained Index : Sind, Pakistan

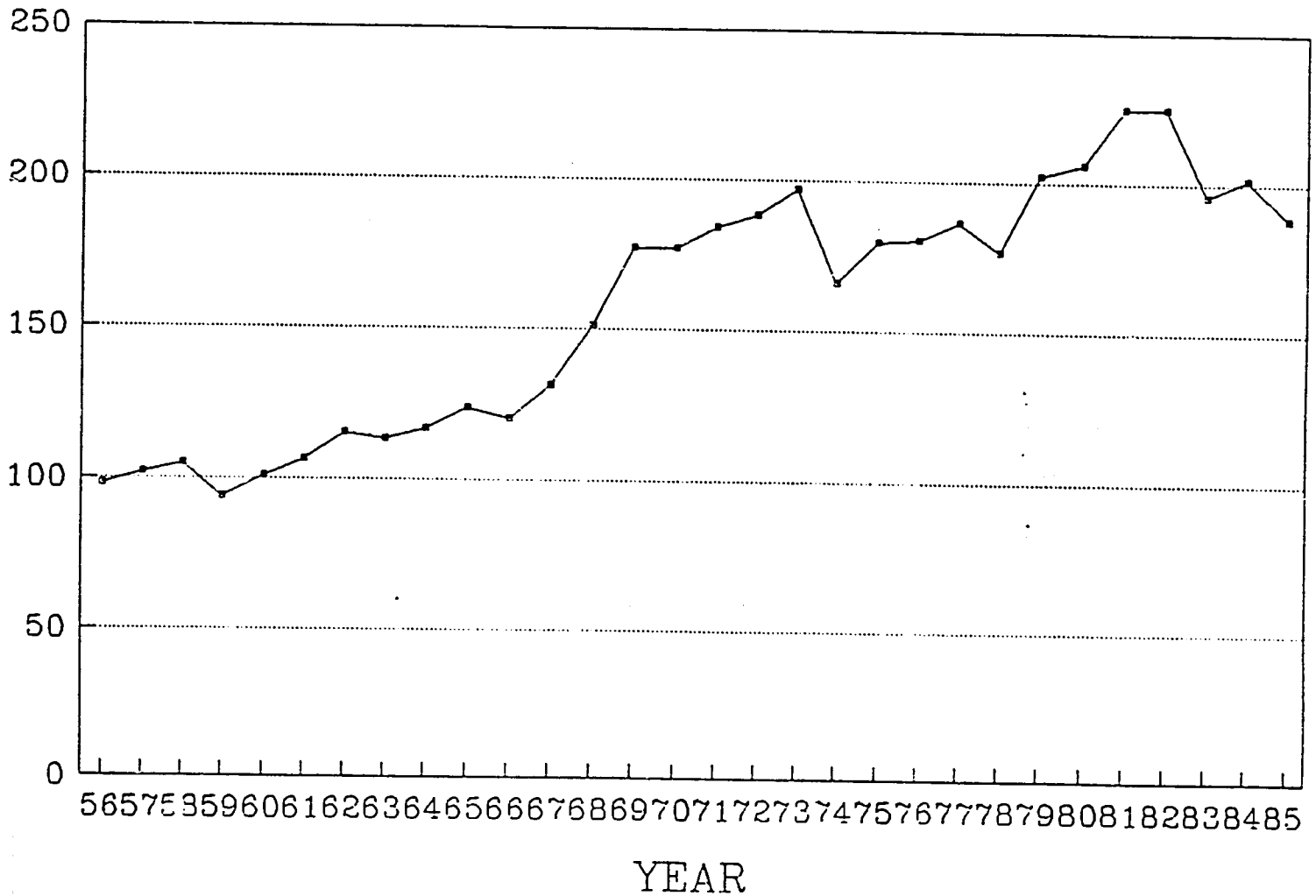
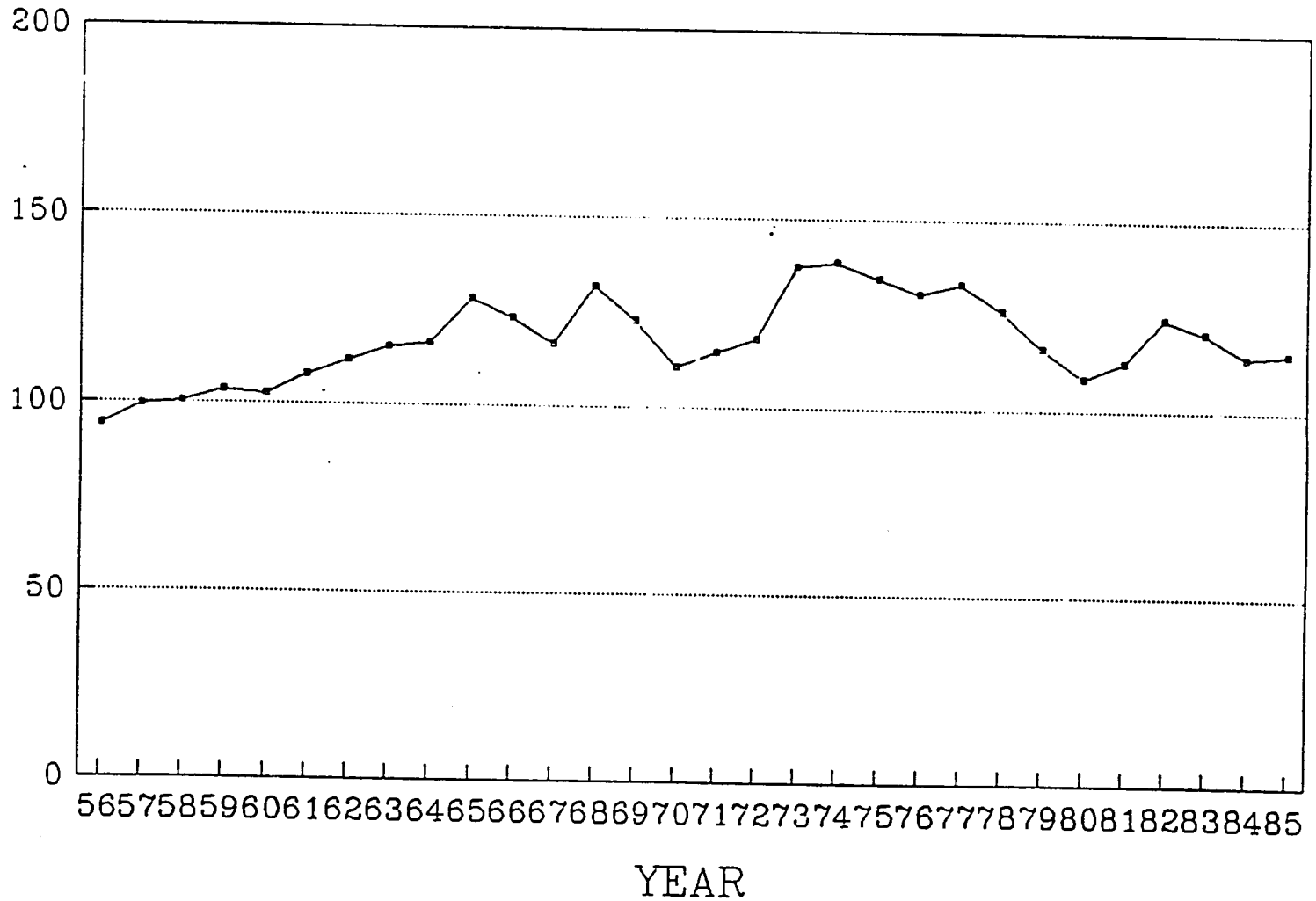


Figure 2.3 a Fisher-Chained Index : NWFP, Pakistan



It is readily obvious from these figures that marked differences in TFP growth by region have characterized Pakistan's agricultural sector. In the pre-green revolution period, 1956-66, TFP growth was clearly most rapid in the province of Punjab. The TFP index had risen to 120 by 1962 and remained at that level until 1966. In the province of Sind, the TFP index had risen to only 117 or so by 1966. Interestingly, the NWFP index had also risen to 120 by 1966.

During the green revolution period, 1966-1971, TFP rose rapidly in the Punjab from 120 to 150 or so. TFP rose even more rapidly in Sind (from 117 to 155 or so). TFP declined in the NWFP.

In the post-green revolution years, 1971 to 1985, there was little further TFP growth in the Punjab. The Sind, however, continued to realize relatively rapid TFP growth over this period. TFP growth in the NWFP continued to decline and was well below the 1956-60 level by the early 1980's. The Fisher-Chained indexes (Figures 2.1a, 2.2a and 2.3a) show essentially the same patterns as are apparent in the Tornqvist indexes. (These patterns are not the result of weather "shocks", when poor weather occurs; the return to normal weather restores the indexes back to their original path).

These results may appear to be somewhat puzzling to many observers. The Punjab is normally regarded to have the richest resource base in Pakistan. The Sind is more dependent on irrigation. The NWFP is a region of relatively poor and "fragile" soil resources. Soil salinity problems have been more severe in the Punjab than in other states. It is also regarded to be the case that the high yielding wheat variety (HYV) impact was confined to the early years of the green revolution. Chapter III is dedicated to a more formal analysis of the factors underlying these TFP changes.

IV. A Comparison of TFP Growth in Pakistan and the Indian Punjab State

Since we have comparable data for districts in the Indian Punjab state it is instructive to compare TFP growth under the Indian system with TFP growth in Pakistan. The Indian Punjab is generally regarded to be advantaged relative to the Pakistan Punjab in terms of water quality. Salinity problems have been more severe in Pakistan. Research institutions in the Indian Punjab have also

been regarded to be stronger. More wheat and rice varieties were developed in India during the post-green revolution period, for example.

Figures 2.4 and 2.4a depict the comparable Tornqvist and Fisher-Chained TFP indexes for the average district in the Indian Punjab (the districts later to be incorporated into the state of Haryana were not included in this figure). These figures show that the Pakistan Punjab outperformed the Indian Punjab in the pre-green revolution period (1956-66).

Both Punjabs performed well during the green-revolution period. The Indian Punjab clearly outperformed the Pakistan Punjab in the post-green revolution period. In fact, the TFP performance of the Indian Punjab more closely resembles that of the Sind than of the Pakistan Punjab.

Figure 2.4 Tornquist TFP Index: Punjab, India
1950-1960 = 100

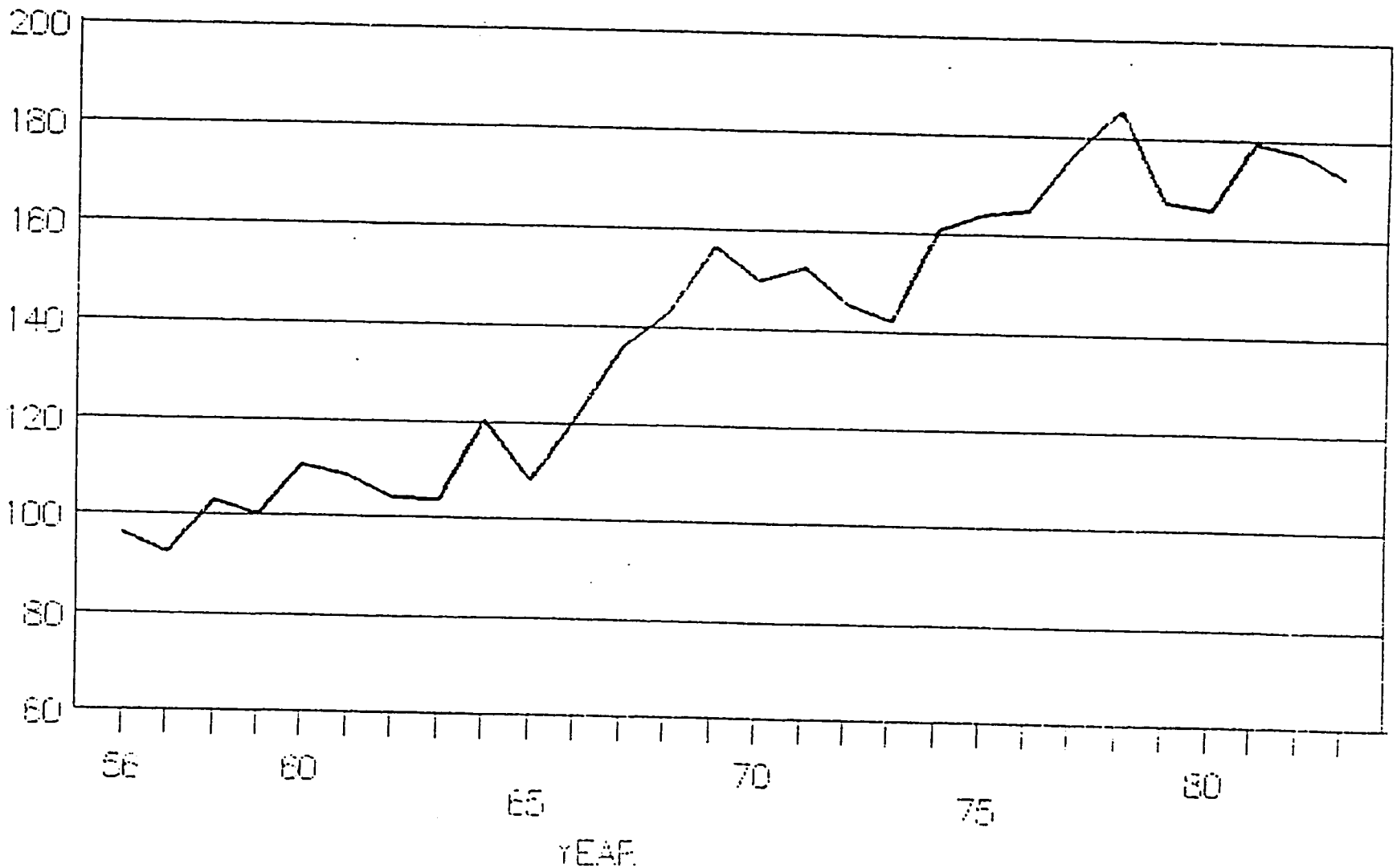
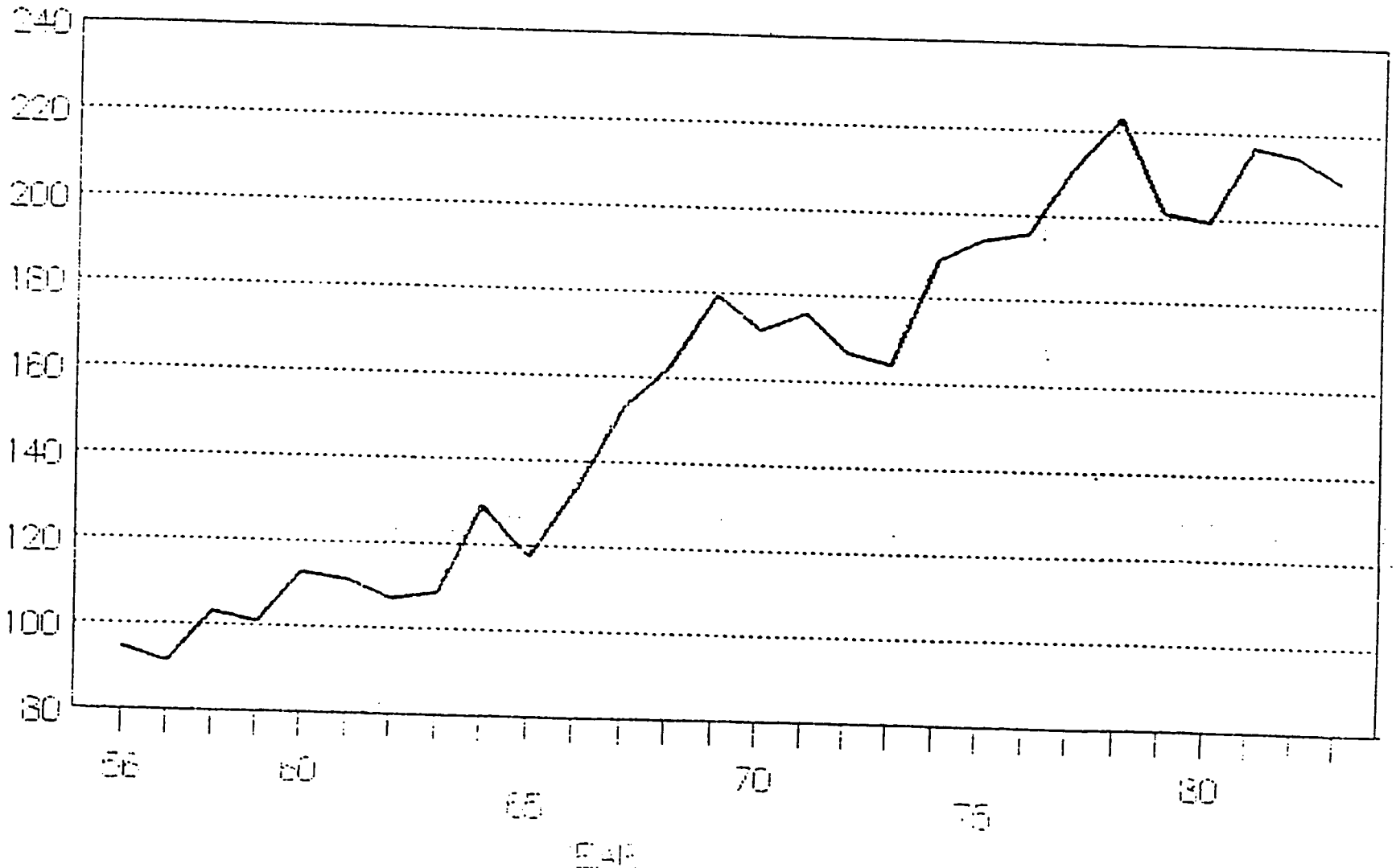


Figure 2.4 a

Fisher-Chained TFP Index: Punjab. India
1950-1960 = 100



This is shown more clearly in Figures 2.5 and 2.5a where all 4 indexes are plotted on a common scale. This shows very clearly that the NWFP series departed sharply from the other series after 1966. The Pakistan Punjab series departed from the Sind and Indian Punjab series after the early 1970's.

Figure 2.5 Tornqvist TFP Indices (1950-1960 = 100)

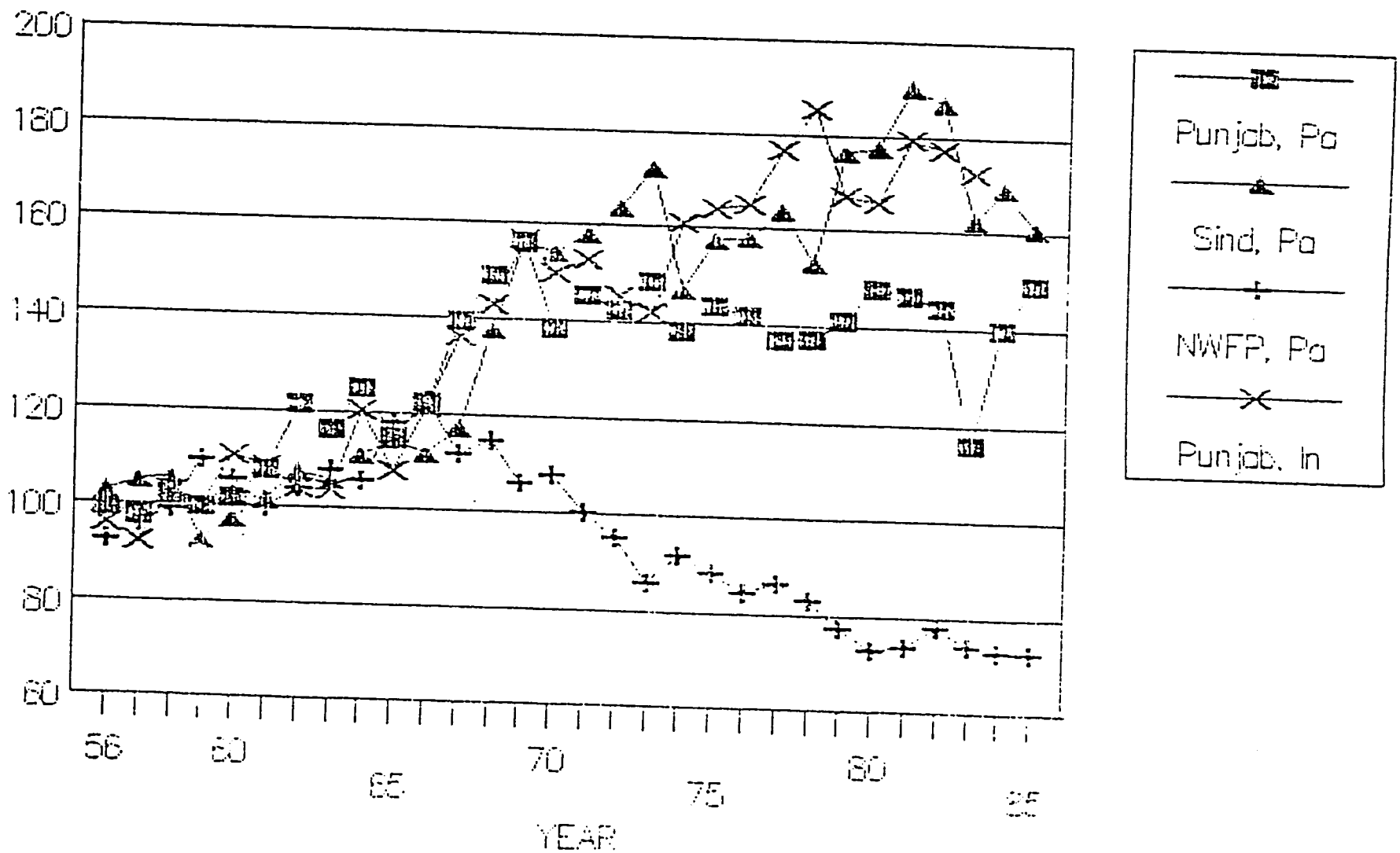
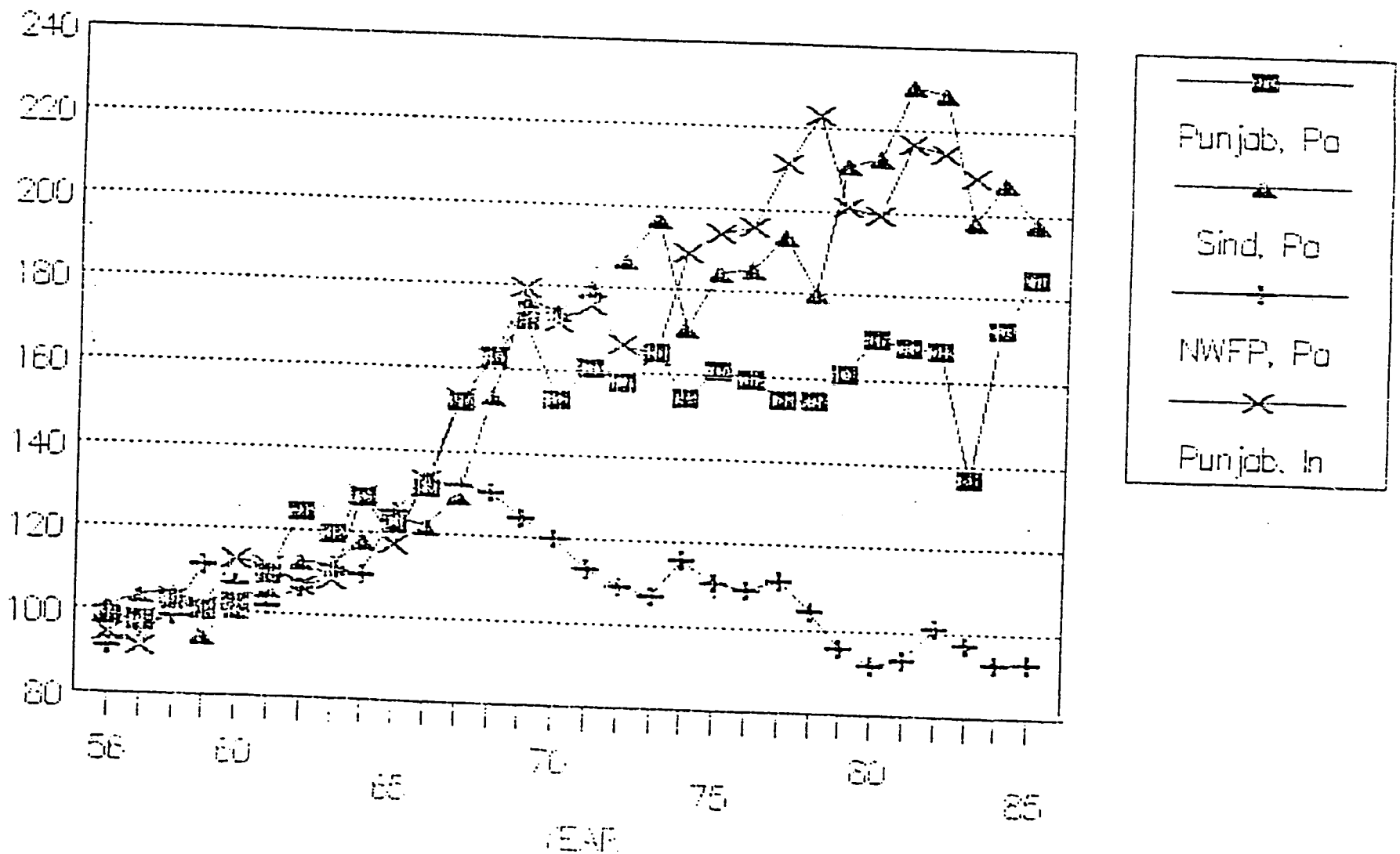


Figure 2.5 a Fisher-Chained TFP Indices (1950-1960 = 100)



V. Conclusion

These TFP calculations are of interest because they raise questions as to the factors underlying their movements. The indicators presented in this chapter were constructed using the most appropriate methods available, and comparable methods were utilized for each district. This does not rule out the existence of measurement problems in the basic data series, of course, but the resultant series provides food for thought. Succeeding chapters provide a more systematic analysis of factors contributing to these series.

APPENDIX Table A 2.1 Output And Input Quantities By Year

OUTPUT (000 TONNES)											
WHEAT	RICE	COTTON	SUGAR	BAJRA	MAIZE	JOWAR	GRAM	R & MUSTARD	TOBACCO	BARLEY	MUNG
94.08	23.76	8.23	23.61	9.72	12.01	6.61	19.54	6.16	1.87	3.11	0.71
100.73	23.90	8.37	24.76	10.52	12.80	7.38	20.09	6.32	1.20	3.76	0.62
100.94	24.58	8.36	31.28	8.45	12.85	5.54	18.41	6.53	1.32	3.18	0.54
111.31	28.25	8.09	33.59	9.96	13.41	6.11	16.22	6.18	1.32	3.65	0.56
105.24	25.74	7.81	32.64	9.57	13.16	6.57	17.27	7.41	1.50	4.66	0.66
107.52	29.16	8.26	34.04	8.39	12.51	6.11	16.88	6.23	1.56	4.22	0.59
111.40	32.02	8.88	40.69	10.22	13.14	6.95	16.67	6.10	1.73	3.16	0.60
118.12	33.80	9.99	49.80	11.78	14.28	7.24	19.54	9.17	1.95	3.16	0.52
117.22	35.16	11.35	47.52	10.31	14.03	6.76	17.47	6.03	1.81	2.92	0.44
128.71	39.16	10.37	49.90	13.49	14.84	7.68	19.40	5.11	2.16	3.07	0.62
109.18	36.26	11.35	62.66	10.90	14.55	6.51	16.15	4.83	2.18	2.36	0.52
121.32	37.36	12.75	61.95	10.61	15.64	7.19	18.62	6.68	3.11	2.27	0.62
176.18	41.87	14.13	53.08	11.89	18.96	7.93	15.26	8.15	3.42	2.51	0.56
185.95	56.98	14.47	62.43	10.36	19.77	7.68	14.73	6.45	3.45	2.63	0.63
203.76	66.45	14.70	74.45	8.96	18.87	6.89	14.72	6.42	3.17	1.96	0.50
182.58	60.65	14.88	66.39	10.11	17.88	8.19	13.79	6.77	2.95	2.75	0.61
189.68	62.13	19.39	55.76	10.18	17.99	7.25	14.52	8.08	2.87	2.75	0.71
205.01	64.01	19.22	56.88	8.70	17.23	7.10	15.37	7.51	2.35	2.56	0.57
211.50	67.70	18.06	67.26	9.89	18.44	7.53	17.43	7.80	1.51	3.05	0.61
212.20	63.47	17.40	59.68	7.39	18.91	6.54	15.47	6.82	1.80	2.96	0.66
237.51	71.86	14.13	72.23	8.97	20.28	7.02	17.13	7.28	1.78	2.94	0.67
251.94	75.65	11.95	83.58	8.88	19.88	6.58	18.36	7.75	1.59	2.72	0.57
231.07	81.35	15.79	85.16	9.07	19.39	6.17	16.78	6.46	2.03	2.56	0.64
272.07	89.40	13.00	77.58	9.10	19.84	5.95	15.81	6.50	2.07	2.86	0.53
295.01	86.94	19.96	78.34	8.01	20.31	6.15	9.78	6.75	1.74	2.63	0.68
311.58	83.81	20.45	91.18	6.24	21.89	5.69	9.88	6.78	2.03	3.89	0.64
324.02	87.34	21.43	102.16	7.70	21.36	5.50	7.87	6.33	1.91	3.53	0.59
335.01	85.54	23.61	91.90	6.32	22.64	5.47	13.50	6.59	1.74	3.60	0.75
294.54	83.31	14.20	96.83	7.31	22.99	5.28	14.08	5.68	1.78	2.78	0.78
314.61	83.10	28.88	91.74	8.08	23.46	5.65	14.22	6.06	2.16	2.29	0.88
377.82	73.66	34.83	79.03	7.39	22.05	5.40	15.88	6.76	2.94	2.38	0.99

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PENDIX Table A 2.1 Output And Input Quantities By Year (Continued).

AR	INPUTS					
	FERTILIZER (000 TONNES)			LABOR	ANIMAL LABOR	TRACTOR
	NITROGEN	P_2O_5	K_2O	(000 NUM)	(000 NUMBER)	(000 NUMBER)
55	-	-	-	44601.8	135.7	0.080
56	-	-	-	45614.0	136.9	0.084
57	-	-	-	46626.3	138.1	0.088
58	-	-	-	47638.5	139.2	0.092
59	-	-	-	48650.8	140.4	0.097
60	-	-	-	49663.1	141.5	0.103
61	-	-	-	50675.3	144.24	0.126
62	-	-	-	50887.5	146.88	0.148
63	-	-	-	51099.8	149.53	0.172
64	-	-	-	51312.1	152.18	0.199
65	2.09	0.04	-	51524.3	154.8	0.225
66	3.13	0.12	0.003	51736.5	157.5	0.309
67	4.95	0.36	0.006	51948.8	160.1	0.393
68	5.70	1.09	0.062	52161.1	162.77	0.477
69	7.90	0.96	0.03	52373.3	165.4	0.557
70	7.58	0.92	0.03	52585.6	168.1	0.637
71	9.77	1.06	0.019	82797.8	170.7	0.717
72	10.92	1.39	0.037	53010.0	173.4	0.786
73	9.78	1.67	0.072	53222.33	170.80	0.850
74	10.29	1.73	0.058	55345.7	168.24	0.924
75	12.55	2.95	0.083	57469.1	165.7	0.994
76	14.47	3.33	0.071	59592.4	163.11	1.293
77	15.53	4.46	0.165	61715.8	160.96	1.578
78	19.22	5.29	0.130	63839.1	158.81	1.87
79	22.91	6.45	0.262	65962.5	156.65	2.17
80	22.85	6.39	0.275	68085.89	154.50	2.47
81	23.42	6.36	0.59	70209.2	152.3	2.74
82	26.59	7.46	0.70	72332.6	150.2	3.10
83	25.62	7.30	0.82	74455.98	148.05	3.75
84	26.19	8.83	0.71	76579.3	145.9	4.30
85	32.99	9.82	0.93	78702.72	143.75	4.75

ENDIX Table A 2.2 Output, Input Productivity In Pakistan Agriculture

OUTPUT INDEXES			INPUT INDEXES			TFP INDEXES		
LASP	FISHER	T.Q	LASP	FISHER	T.Q	LASP	FISHER	T.Q
-	-	-	-	-	-	-	-	-
94.15	97.04	95.57	96.87	97.05	97.16	97.30	97.04	98.44
97.39	97.13	97.75	98.35	98.32	98.36	99.02	98.76	99.37
104.02	103.83	104.00	100.69	100.67	100.65	103.31	103.14	103.32
100.78	100.93	100.28	101.61	101.57	101.52	99.18	99.35	98.76
103.64	104.00	102.39	102.47	102.38	102.30	101.16	101.60	100.13
111.50	112.07	109.58	104.88	104.78	104.64	106.39	107.04	104.85
123.54	124.12	120.36	106.29	106.12	106.33	116.43	116.90	113.65
121.45	122.16	117.49	107.20	107.12	106.79	113.30	114.09	110.07
128.87	129.97	124.24	109.03	109.01	108.69	118.24	119.22	114.46
127.06	127.54	120.07	110.19	109.59	110.79	114.93	115.93	107.90
132.64	134.29	132.64	113.13	112.28	113.47	116.85	119.16	109.59
152.80	157.44	139.18	116.97	115.94	117.15	130.44	135.52	118.08
169.99	175.09	155.02	142.12	147.39	128.69	119.12	118.08	119.33
185.82	190.77	166.74	121.20	119.74	120.99	152.26	157.81	135.93
173.86	179.04	156.67	122.23	120.76	122.01	141.34	146.94	126.51
181.41	188.69	165.03	124.59	122.72	123.97	144.45	152.11	131.06
188.21	194.01	168.77	147.77	154.12	132.03	126.61	124.73	125.97
200.81	208.20	179.10	127.22	125.84	127.02	157.69	164.62	139.37
190.83	195.86	166.10	128.42	127.29	128.46	148.62	153.18	127.69
206.05	211.96	178.91	132.89	131.89	133.01	155.24	160.25	133.12
215.82	222.05	186.84	139.42	138.47	139.43	154.57	159.48	132.27
222.07	230.19	192.51	144.39	143.20	144.07	153.29	159.55	131.72
228.06	233.57	195.34	150.65	148.87	149.60	151.43	156.12	128.79
246.62	253.82	210.06	157.46	154.51	155.14	156.86	163.16	133.29
256.13	267.07	220.21	161.06	157.92	158.52	159.21	167.77	136.52
272.03	281.94	231.42	165.90	162.73	163.91	164.11	171.64	139.23
282.35	297.33	240.91	172.23	167.81	168.23	164.51	175.68	140.80
249.54	258.55	205.68	178.79	173.12	173.37	141.96	149.93	118.31
271.44	292.33	229.24	184.66	177.96	178.12	147.19	161.88	126.21
284.27	308.74	240.97	193.50	183.59	183.62	147.17	165.39	128.27

= Laspeyres; FISHER = Fisher-Chained; T.Q = Tornqvist

PENDIX Table A 2.3 T.F.P Indexes By Province

AR	PUNJAB		SIND		NWFP	
	F.C	T.Q	F.C	T.Q	F.C	T.Q
55	-	-	-	-	-	-
56	97.41	98.64	98.12	99.86	94.07	95.47
57	96.77	97.21	102.18	103.27	99.39	99.72
58	103.02	102.79	105.15	106.27	100.16	100.09
59	100.91	100.46	94.02	93.30	103.29	102.45
60	101.76	100.80	100.79	97.86	102.44	101.76
61	107.14	105.45	106.52	102.75	107.58	106.41
62	119.38	116.53	115.40	110.42	111.53	109.90
63	114.07	110.81	113.52	107.68	115.08	111.69
64	121.37	117.62	116.99	110.53	116.18	111.01
65	108.04	100.21	123.71	114.27	127.89	121.65
66	117.46	107.67	120.32	110.82	122.89	113.63
67	143.77	127.85	131.36	119.32	116.31	85.11
68	150.54	133.74	150.91	134.09	131.58	103.69
69	158.91	140.68	176.82	154.13	122.66	90.53
70	142.83	125.20	176.85	154.24	110.49	84.41
71	147.32	129.15	183.89	159.50	114.31	89.68
72	147.54	128.55	188.32	163.03	117.97	91.34
73	156.19	135.81	197.09	170.27	137.21	99.17
74	151.22	130.90	165.79	138.45	138.38	99.59
75	158.47	136.56	179.33	149.02	134.07	95.69
76	157.22	135.81	180.25	149.76	130.09	91.94
77	153.75	131.67	186.44	154.22	133.07	94.36
78	154.96	132.62	176.40	145.92	125.99	89.73
79	157.44	132.62	202.21	165.18	116.18	82.28
80	166.43	139.68	205.91	166.67	108.45	76.27
81	162.09	136.32	225.15	180.52	112.68	79.60
82	166.04	137.90	224.92	178.77	124.12	86.70
83	135.15	110.07	195.60	154.87	120.62	83.50
84	156.23	124.01	201.31	158.21	114.03	79.83
85	169.39	133.15	188.03	147.65	115.00	80.49

F = Fisher-Chained Index; T.Q = Tornqvist Index

Chapter III. Research and Productivity in Pakistan Agriculture

In this chapter we address the question of the determining factors of TFP growth in Pakistan agriculture. The methodology for analyzing TFP growth is quite simple. It entails defining "appropriate" independent variables (research and infrastructure) in a regression in which the dependent variable is the cumulated TFP index for the district. In addition, since there is some possibility of simultaneity bias, the estimating procedure must take this into account.

In Section I of this chapter we discuss methodological issues in developing TFP decomposition variables. Section II reports the results of the TFP decomposition analysis. The concluding section summarizes the estimates.

I. Methods and Variable Definition

Recall that TFP measurement procedures separate output changes into changes due to input changes and changes due to changes in technology infrastructure and skills (i.e TFP changes,. see Chapter II). TFP decomposition specifications essentially relate TFP growth to changes in technology, infrastructure and skills by developing variables that measure the "flows" of new technology, infrastructure services and skill changes. For technology this requires that variables based on past research and extension programs be developed. For infrastructure, measures of road and communication infrastructure must be developed. In general, there are no strong functional form implications to be derived from optimization theory to be imposed on this specification unless there is reason to believe that governments actually choose TFP growth-producing projects in an optimizing fashion. It is highly unlikely that the public agencies providing technologies and infrastructural services in Pakistan are doing so in a truly optimizing fashion.

"Appropriate" independent variables in a regression set-up where cumulated TFP indexes are the dependent variable should meet two conditions. First they should be "exogenous" in the context of the system under analysis. If not strictly exogenous, they should at least be "predetermined." Techniques exist for correcting for endogeneity bias, and these should be used where required. Second, the form of the variable should be such that there is consistency with the dependent variable over time and across cross-sections.

Consider first the consistency problem. The dependent variable in this case is defined as a cumulated index number with a base of one in the period 1956-60 in each district. This means that it does not depend on the size of the district and that it measures TFP change after the base period. The level of the index in time t is the cumulated change since the base period. The appropriate research variable should, therefore, reflect this cumulation in its timing weights. In addition it should reflect technological spill-in from outside the district.

The general form for the research variable is:

$$(3.1) \quad R^*_{if} = \sum_j G_{ij} \sum_k W_{ik} r_{ijt-k}$$

where r_{ijt-k} is research investment in commodity i, region j in period t-k. The research stock is thus based on cumulated past investments and weighted by two sets of weights. The first set, G_{ij}, are "spill-in" weights measuring the degree to which research conducted in location j is productive in location i relative to the productivity of research conducted in location i. For Pakistan these weights are based on geo-climate regions. The second set of weights are the "time-shape" weights, W_k,. These weights reflect the lag between research expenditure and the ultimate productivity impact. They can also reflect real "depreciation" of research impacts. These weights are estimated using an iterative procedure (see below).

There is also a "deflation" issue that must be dealt with in cases where research variables must be aggregated over commodities, (i.e., over i). For cases where the dependent variable is cumulated TFP, each commodity research variable RiB* could be included as a regression. However, this often results in high multicollinearity and aggregation is desirable. The aggregation

$$(3.2) \quad R^*_t = \Sigma S_i R_{it}^*$$

is a reasonable aggregation if one presumes no spill-over between research programs, (i.e., research on commodity j does not contribute to productivity for commodity i).

In the analysis undertaken in this chapter, we have defined three variables designed to characterize the cumulated flow of new technology to a district:

APPLIED RESEARCH:	An aggregate cumulated commodity research stock. The time weights estimated (see below) are: 0 for K = 0 to 4, .2 for k = 5, .4 for k = 6, .6 for k = 7, .8 for k = 8, and 1 for k = 9 and greater. Research expenditures are associated with geo-climate regions and presumed to spill freely within the region. Commodity shares are used to form the aggregate variable (as in (3.2)).
GENERAL RESEARCH:	A cumulated research stock based on expenditures that are not commodity specific. It is constructed in the same manner as TRES.
SHHYV:	The proportion of wheat, rice and cotton area planted to "high yielding Varieties."

The variables are not directly "deflated" by the number of farms, but the commodity weighting implicitly deflated by the number of commodities. The time weighting is consistent with the cumulated form of the TFP index (as opposed to an annual change form).

The specification also includes several infrastructure or skill level variables:

MKTDISTANCE:	A measure of market investment. This is the average distance for farms in a district from major market centers.
FARMSIZE:	Crop Area/Number of Farms. Average farm size in the district.
IRRIGSH:	Share of the cropped area that is irrigated.
CANALSH:	Proportion area irrigated by canal.
TUBEWSH:	Proportion area irrigated by tubewells.
RAIN:	Rainfall in cropping month.
ROADS:	Km's of paved roads/cropped area.
POPDENSITY:	Rural population 1960/cropped area 1985.

The simultaneity problem is likely to affect the variables FARMSIZE, IRRIGSH and TUBEWSH most severely. They are likely to respond to TFP growth, although usually with a lag. In the estimation they are treated using simultaneous equation methods.

Table 3.1 reports a summary of the variables utilized in this analysis. Means for the variables are also reported. All variables are measured at the district level for the years 1956 to

1988. The data appendix to this study provides further details. We have two alternative measures of TFP to be analyzed, the Tornqvist-Theil approximation to the Divisia index (TFP-TQ) and the Fisher-Chained index (TFP-FC). The indexes are based on the 1956-60 period in each district. They are cumulated over time.

To explore the question of simultaneity, we test to see whether markets, farm size and tubewell irrigation investment may be simultaneously determined with TFP growth. (See Table 3.2 for the full specification). Several of these variables are transformed into natural logrithums as indicated.

Table 3.1: Variable Definitions and Means: TFP Decomposition

Variable	Definition of variable	Mean
Endogenous		
*TFP-TQ:	District cumulated TFP index, 1956-60 = 100, Tornqvist	4.757
*TFP-FC:	District cumulated TFP index, 1956-60 = 100, Fisher-Chained	4.895
MKTDISTANCE:	Average distance from a major market center (kms)	18.203
FARMSIZE:	Cropped area/number of farms	3.070
TUBEWSH:	Percent of irrigated area under tubewells	.114
Exogenous		
I. Technology		
SHHYV:	Percent of cropped planted to high yielding varieties (IRRI wheat, Maxipak wheat, Pakcotton)	.302
*APPRES:	A cumulated stock of applied research investment weighted by commodity shares (see text)	3.805
GENRES	A cumulated stock of general research investment unweighted (see text)	1430
SHGRAD:	The share of research personnel with graduate degrees	.39
II. Skills		
LITERACY:	Percent of rural adult males literate	20.66
III. Infrastructure		
IRRIGSH:	Percent of cropped area irrigated	.686
CANALSH:	Percent of irrigated area irrigated by canal	.728
TUBEWSH:	See above	.114
ROADS:	Km of paved roads/1985 cropped area	1.846
MKTDISTANCE:	See above	
FARMSIZE:	See above	
POPDENSITY:	Rural Population in 1960/1985 cropped area	3.305
RAIN:	Rainfall in growing season (mm).	394

* variables are transformed to natural logarithms.

II. TFP Decomposition estimates

A. Estimates of Timing Weights

The first step in the TFP decomposition is to estimate the timing weights for the research variable. This was done by an appropriate non-linear least squares procedure. This entailed constructing alternate time weights for the three variables measuring research, APPRES, GENRES and the interaction APPRES* GENRES (see Table 3.3). The non-system TFP-TQ specification in Table 3.3 (column 8) excluding the HYV variables was utilized for estimation of the weights. Since the research system itself produces some of the HYV's, it was concluded that the best time weight would be obtained using a specification excluding the HYV variable. This allows the research variables to pickup the combined effect of varietal and non-varietal research contributions.

Table 3.2 reports the mean square errors (MSE) for alternate weighting schemes. As the table shows, the MSE is lowest for weight set 3 for APPRES and weight set 4 for GENRES. These time weights were utilized in the further estimates reported in Table 3.3.

Table 3.2 Time Weight Estimates

ATIVE	t - 1	t - 2	t - 3	t - 4	t - 5	t - 6	t - 7	t - 8	t - 9	t - 10	t - 11	t - 12	t - 13
	0	.2	.4	.6	.8	1	---------->						
	0	0	.2	.4	.6	.8	1	---------->					
	0	0	0	.2	.4	.6	.8	1	---------->				
	0	0	0	0	.2	.4	.6	.8	1	---------->			
	0	0	0	0	0	.2	.4	.6	.8	1	---------->		
	0	0	0	0	0	0	.2	.4	.6	.8	1	---------->	
	0	0	0	0	0	0	0	.2	.4	.6	.8	1	-------->
	0	0	0	0	0	0	0	0	.2	.4	.6	.8	1
	0	0	0	0	0	0	0	0	0	.2	.4	.6	.8

ALTERNATIVE

APPRES	GENRES	MSE
0	1	.033291
1	1	.032779
1	2	.032824
2	2	.032319
2	3	.032229
3	3	.032021
3	4	.031951
4	4	.031960
5	5	.032405
6	6	.032724
7	7	.032866
8	8	.032731

B. TFP Decomposition Estimates

Table 3.3 reports 2 stage Least Square coefficient estimates for a 4 equation system and its reduced form TFP-TQ equation. In addition, non-system OLS estimates for both the TFP-TQ and TFP-FC indexes are reported. These TFP measures are indexed to equal 100 in the 1956-60 period. Thus there are no beginning period differences in these indexes. However, to control far "fixed effect" environmental factors, district dummy variables are included in all TFP equations. This means that any systematic district level factors are taken out of the estimates. In addition, all equations reported included time and time-squared variables to control for any systematic trend factors. Thus the resultant estimates are based on "within district" TFP changes and TFP changes that are not with time.

Consider first the system estimates. In this system, MKDIST, FARMSIZE and TUBEWSH are treated as endogenous and simultaneously determined with TFP changes. Population density is the key identifying variable. The estimates indicate that there is some simultaneity between TFP and FARMSIZE and TUBEWSH. TFP growth does appear to have stimulated larger form sizes and more investment in tubewells. larger form in turn does appear to have stimulated TFP growth. Tubewell investment has not.

Roads and population density appear to be associated with higher distance to grain markets. The distance to grain markets, however, is not negatively related to TFP growth as expected. (This may be due to the "fixed effects" procedure-results without the fixed effects do share negative impacts).

Farm size is positively associated with TFP growth and is higher in the regions with high HYV adoption. The effect of literacy on farm size is negative. Tubewell shares are higher in high literacy districts.

A comparison of the TFP-TQ coefficients in column 4 of the system with the non system estimates in column 6 shows, that there are few large differences. Farm size has a larger input in TFP in the system estimates, but must other estimates are similar, particularly these estimating technology inputs.

Table 3.3 TFP Decomposition Estimates

ependent iable	MKtDISTANCE	System FARMSIZE	TUBEWSH	TFP-TQ	Reduced Form TFP-TQ	Non-System TFP-TQ	TFP-FC
-TQ	-0.6260	1.5784**	0.0712**	-	-	-	-
IST	-	-0.0846**	-	0.0079**	-	0.0111*	0.00026
MSIZE	-	-	-	0.0130**	-	0.0056*	0.00034
EWSH	-	-	-	-0.0777	-	-0.1077	0.0587
ſV	-	-2.8372**	0.0627	-0.0468	-0.0678	0.0678	-0.0991
RES	-	-	-	-0.0222	-0.0211	-0.0139	0.0930**
RES	-	-	-	0.0240	0.0292	0.0283	0.1151**
ſV*APPRES	-	-	-	0.1633**	0.1758**	0.1455**	0.1269**
ſV*IRRIGSH	-	-	-	-0.5725**	-0.6038**	-0.6525**	-0.3984**
ſVSQ	-	1.6924*	-0.0279	1.6788**	1.7185**	1.7217**	1.5834**
ſVSQ*APPRES	-	-	-	-0.3378**	-0.3433**	-0.3335**	-0.2973**
RES*GENRES	-	-	-	-0.0000018	-0.0000035	-0.0000031	0.000008
RES*SHGRAD	-	-	-	-0.0193	-0.0213	0.0002	-0.1071
RES*SHGRADSH	-	-	-	.1233	0.1225	0.1089	0.2514**
RES*SHIRR	-	-	-	.1515**	0.1498**	0.1570**	0.0581**
RES*LITERACY	-	-	-	-0.0015*	-0.00086	-0.0019**	-0.0027**
GSH	-	-	-	0.0545	0.0410	0.0641	.2870**
LSH	-	-	-	-0.0107	0.0208	-0.0058	0.0587
RACY	-	-0.0396**	0.0076**	0.0183**	0.0102*	0.0202**	0.0223**
S	0.8672**	-	-	-0.0658**	-0.0312*	-0.0244	0.0233
ENSITY	0.8271**	-	-0.0067*	-	-0.0489**	-0.0574**	-0.1086**
	-	-	-	-0.000032	-0.000017	-0.00002	-0.000036

- 1.7 and < 2.0.
> 2.0.

A comparison of the results for TFP-TQ, the Tornqvist-Divisia indexes, and TFP-FC, the Fisher-Chained indexes, also show little difference due to the specific form of the index measuring TFP. The variables of most interest are the research and HYV variables. Because of interactions it is difficult to interpret these effects directly. Marginal products (discussed below) calculations show these effects more clearly. The interactions themselves are of some interest.

It first merits noting that applied research does not generally interact positively with the more general research. It does interact positively with the level of HYV use when HYV use is low, but not when HYV use is high (The SHHYVSQ*APPRES variable has negative signs while SHHYV*APPRES has positive signs). Applied research does interact positively with the share of irrigation, i.e., it is more valuable in districts with more irrigation. There are weak indications that the higher the share of graduate research, the more productive is applied research. Applied research appears to have a much stronger impact on TFP than does general research.

High yielding varieties are partly imported and partly the product of domestic research. The negative SHHYVSQ*APPRES interaction may be reflecting imported varieties that tend to substitute for domestic research. This variable is probably picking up the early dominance of imported HYV's especially for wheat. The positive SHHYVSQ term is probably also reflecting this.

Interestingly the interaction of HYV's with the share of land irrigated is negative indicating that irrigation has tended to favor domestically produced technology over imported (i.e., APPRES*IRRIGSH is positive).

III. Marginal Products and Marginal Internal Rates of Return

The estimated TFP decomposition equation can be used to compute "marginal products" of the independent variables. The research variables are of special interest in this context. This requires attention to three problems:

1) The timing and spill-in weights must be used to relate units of product to the research variable.

2) HYV and research variables must be interpreted in a general and consistent context. This is because research programs themselves produce HYV technology.

3) General and applied research contributions must be consistently computed.

The methodology for calculating marginal products is based on evaluating the partial derivatives of the estimated functions. Since these derivatives are themselves functions of other variables, we must choose a particular level of these interactive variables to evaluate effects. The level used in most studies is the mean of the interactive variable.

The basic concept behind the partial derivative is that this derivative is the calculated change in the dependent variable (in this case the TFP index) due to a one unit change in the variable in question, holding constant the level of all other variables in the expression. Thus, for the analysis of research impacts two further calculations are required to actually compute a rate of return to the investment in research. First, the relationship between investment in one period (t) and the subsequent change in the research stock variable must be determined. Second the change in TFP must be given an economic value.

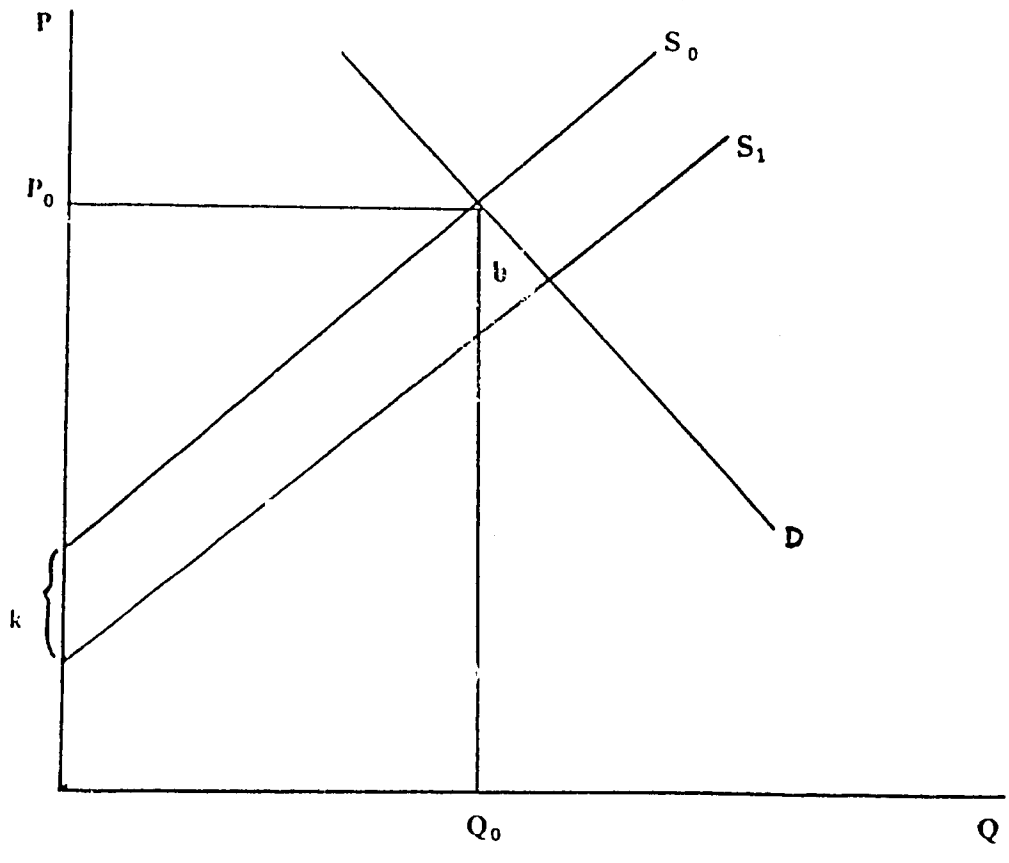
Consider the first calculation. An investment of, say, 1000 rupees in a particular region on a particular commodity will ultimately affect the research variable in one or more districts. The timing is governed by the time weights. No effect occurs in the first four years after the spending, 200 rupees (.2 x 1000) in the fifth year, 400 by the sixth year, 600 by the seventh year, 800 by the ninth year and 1000 for the tenth and later years. These weights thus define a future time profile of benefits associated with the investment in time t.

The number of districts affected will depend on the spill-in specification. In the Pakistan case this is governed by the size of the geo-climate regions. Applied research conducted in a region is specified to spill throughout the region, but not outside the region. Applied research is also specified to produce productivity impacts only on the commodity towards which it is directed. This implicitly deflates the research. This deflator must be used to calculate marginal products. For general research, spill-over occurs across all commodities in all regions. This research is not deflated.

The second calculation requires placing a value on the TFP change. Since the TFP index measures output per unit of input, a change in TFP is equivalent to an increase in output holding inputs constant. This output increase is approximately the increase in consumers plus producers surplus in a market setting. Figure 3.1 illustrates this.

Initial production is Q_0 and price is P_0. A productivity impact increasing output per unit by k percent will shift the supply curve to S_1. The change in total surplusis the area a which is k. Q_0 plus the area b which depends on the elasticity of demand. However, since b is small relative to a we can approximate total surplus as k (marginal product) times Q_0 - orignal production times P_0 initial prices.

Figure 3.1 Consumers and Producers Surplus



It is actually easier and more straightforward to compute marginal products in two stages. In the first, the marginal product elasticity is evaluated or computed by evaluating $\partial \ell(\text{TFP})/\partial \ell n$ APPRES, etc., from the estimated equation. Then, in a second step, the marginal product can be evaluated by multiplying the elasticity by the ratio of the value of output to the value of the investment in the research program involved.

Table 3.4 reports estimates of both marginal production elasticities (MPEs) and marginal products (MPs). The marginal products are interpretable as the added value of production or farm output (i.e., the consumers' plus producers' surplus) associated with a one rupee investment after its full impact is realized. The table also reports Marginal Internal Rates of Return (MIRRs) to these investments.

Table 3.4 reports calculations for four specifications for the TFP-TQ index and one for the TFP-FC index. The four TFP-TQ specifications include both the structural and reduced form equations for the system and OLS single equation estimates. The reader can quickly verify that these three specifications yield almost identical results for the MPEs and MPs (and for MIRR's see Chapter VI). Thus it is reasonable to conclude that little simultaneity bias is affecting the results. The fourth equation is the OLS equation used to estimate the timing weights. It excludes HYV variables and is intended to provide an indirect way of attributing varietal improvements to applied research APPRES.

Table 3.4: Estimated Research and HYV Marginal Product Elasticities and Marginal Products

DETAILS	Dep Variable TFP-TQ				TFP-FC
	System Structure	System Reduced Form	OLS Including HYV	OLS Excluding HYV	OLS Including HVY
Marginal Productive Elasticities					
PPRES	.056687	.07313	.05457	.16330	.07663
HHYV = 0	.04964	.06894	.04272	n.r.	.06535
ENRES	.018424	.018755	.018458	.0532	.14157
HHYV	.135803	.14264	.13214		.11697
LITERACY	.18863	.27740	.274778	-.0288	.27398
RRGSH	.26746	.26486	.24013	.19509	.24688
Marginal Products					
PPRES (128)	7.25	9.36	6.99	20.90	9.81
ENRES (192)	3.53	3.60	3.54	10.21	27.18
HHYV (38)	5.21	5.478	5.074		4.49
LLRESEARCH	10.96	12.53	10.68	16.61	21.25
Marginal Internal Rate Of Return					
PPRES	58	64	58	82	65
ENRES	39	40	39	56	75
HHYV	52	52	51	--	49
RESEARCH	57	60	57	65	70

TES: n.r = Not relevant
Numbers in parenthesis are the ratios of agricultural product to investment.

The fifth equation is for the TFP-FC index and is intended to show whether the index number construction affects the results. The reader can verify that this specification attributes a larger contribution to general research than other specifications. In Chapter II we argued that the most natural index number specification is the TFP-TQ index, and we prefer to base our interpretation on these specifications. The elasticity estimates are intended to show the percent change in product or output holding conventional inputs constant. This is the basis for interpreting them as measures of economic surplus.

There is a strong suggestion that irrigation makes a contribution over and above its normal production contribution. Each elasticity also holds other variables constant. Thus the elasticity for APPRES shows its impact holding constant HYV use even though most HYV usage is itself the product of applied research. One could consider adding these two contributions.

The marginal product (MP) calculations entail multiplication of the elasticities (MPEs) by the ratio of agricultural product to investment. These ratios (reported in parenthesis) are calculated as follows:

1. The 1987 ratio of research spending to agricultural product (.0052, see Chapter I) was the starting point.
2. Eighty percent of total product was presumed to be affected by research and extension.
3. In the absence of an extension variable it was assumed that one rupee investment in research required one rupee investment in extension.
4. The total spending on applied research was estimated to be .6 of the total. For general research this was .4 of the total.
5. The equivalent expenditure to achieve a change in HYVs was assumed to be the mean HYV level (.303). Thus a ten percent increase in APPRES leads to a 3 percent expansion of HYV acreage.

With these rules, marginal products, i.e., rupees product per rupee investment (after full realization), were computed separately for APPRES, GENRES and HYV associated research. These estimated marginal products imply high marginal interest rates of return to all forms of investment (see Chapter 6).

It was also possible to calculate the marginal product for a combined investment in applied and general research by using the .6 and .4 weights and adding the associated HYV contribution (i.e., .6 APRRES + .4 GENRES + HYVMP's). The estimated MP from the equation excluding HYV's was higher (16.61) than the calculated MP (10.68) suggesting that we may have understated the HYV contribution. However, since some of the HYV contribution is imported the calculation is probably the more reasonable estimate.

The Marginal Internal Rates of Return (MIRRs) are computed from the marginal product estimates. An investment in time t will generate a stream of economic surplus in the future as indicated by the time weights (see Table 3.2). The discount rate that makes the present value, at time t, of the future flow of benefits equal to one rupee is known as the internal rate of return to one investment. It is the interest rate that would allow a bank to pay a depositor the stream of marginal product, i.e., zero in the first few years, rising to the full MP by year 8 (or 9) as the pay off from a one rupee investment in time t. These realized returns to investment are extraordinarily high. They indicate that research investment has been productive. They also indicate a high degree of under investment in research.

In concluding this chapter, we note that we have achieved an explanation for a considerable part of the TFP change in Pakistan agriculture. We note that the research system, including varietal and non-varietal and more general research, contributed to TFP growth. The estimated marginal products of investment in research are high. The estimated returns to investment are high. We will undertake further discussion of these estimates in Chapter VI after examining the question further through TFP decomposition analysis (Chapter IV) and duality analysis (Chapter V).

Chapter IV: Research and Partial Factor Productivity in Pakistan Agriculture

Although Partial Factor Productivity (PFP) indexes are simpler to measure and calculate than TFP indexes, their decomposition analysis is more complex. This is because PFP indexes contain the effects not only of technology, skills, and infrastructure (as with TFP measures), but of other input changes as well. Accordingly, decomposition specification requires that we deal with this "other inputs" problem. In addition, since PFP indexes are typically measured for specific crops (which is the best reason for utilizing them), there is an additional land quality problem that also must be dealt with. These two problems require a two-stage procedure for PFP or yield decomposition. In the first stage we must predict or analyze land use decisions. In the second stage we take these land use decisions as given and include predicted area variables in the yield decomposition equation. Both stages require that we introduce prices into the analysis in addition to the technology, skills, and infrastructure variables. Furthermore, we are constrained somewhat in the way we can define and use these variables.

Section I of this chapter discusses the methodological issues involved. Section II reports decomposition results. Section III reports estimated marginal elasticities and marginal products of research variables.

I. Methods and Variable Definition

As noted above, we have two problems in PFP decomposition that we did not have to address in the TFP decomposition analysis. One is the "other inputs" problem, which requires that we develop variables controlling for or correcting for the unobservable inputs other than land. The second is that since land is not homogenous among districts or farms, this creates a "land quality" problem. We may observe, for example, that when acreage planted to soybeans increases in a district, that the land may be of higher or lower quality than land planted to soybeans in the past.

Were it not for this second problem, the most natural way to handle the "other inputs" problem would be to utilize the "duality" between transformation and profits functions and use both output and input prices to correct for missing inputs. This in fact is what is done in Chapter V. However, this limits the interpretation that can be placed on estimated commodity research program impacts. In this chapter, we develop an approach that is intermediate in some sense between the

TFP decomposition approach (Chapter III) and the duality approach (Chapter V). We utilize prices but also attempt to take advantage of the fact that farmers do make sequential decisions regarding acreage and other inputs.

II. Modeling Acreage Decisions

Consider the farmer's decision regarding the allocation of land to alternative crops. The farmer takes expected relative prices of other crops, (P_i, P_o) as well as expected technology available for the crop in question and for other crops, (T_i, T_o)into account. He considers factor prices as well (P_j). He also takes total farm size as fixed in the short run.

(4.1) $A_i = F(P_i, P_o, T_i, T_o, P_j)$

This decision is implicitly a decision to commit other inputs to the process even though there may be a change of plans later. A large literature dealing with supply response models has emerged over the years. Early specifications of (4.1) usually included lagged A_i, i.e., A_{it-1} as an independent variable to reflect "adaptive price expectations" and/or "cost of adjustment" concerns. This older literature has been criticized for failing to consider technology choice (Mundlak 1988) and for imposing expectations that may be unrealistic ("or irrational", Eckstein 1984). The duality literature, on the other hand, (see Chapter V) does not generally recognize the acreage decision as an independent decision. It focuses instead on the supply decision. Mundlak and McQuirk (1990) have recently argued that the acreage decision is an independent decision because it is made before planting starts and cannot respond to unexpected price changes that may affect yields. They have also argued that technology should be incorporated into an acreage decision. This can be taken to be a two-stage decision. First, acreage decisions are made. Then, given these decisions, full production decisions determining yield are made. They further note that, for econometric purposes, acreage decisions are not subject to unanticipated weather effects, whereas yield decisions are.

Given acreage decisions, yields are determined by factor prices (these also affect the acreage decision) and by weather events. Ideally, we would like to have good product price variables and a reliable weather index for the analysis of yields. Prices, at least prices as measured in Pakistan, tend to vary primarily from year to year, as does weather. There are some differences

by region but these tend to be constant differentials over time. We are thus faced with a choice as to whether to utilize prices in the yield equation or to use year and region dummy variables to "dummy-out" price effects. This decision is also governed by the fact that output-input price relatives themselves reflect productivity change (see Chapter II). After consideration of these factors, we decided to utilize output price relatives and input price relatives (but not output-input price relatives) in the acreage response functions. (District dummy variables were also used). We then decided to use year and region dummies to dummy-out price effects in the yield equations. This effectively means that we do not estimate full supply elasticities in this analysis (see Chapter V for more direct estimation of these elasticities) for the technology, infrastructure and skill variables.

III. Variables and means

Table 4.1 reports variables, variable definitions and means for the PFP analysis. In the first stage, area is regressed on the input price relatives,PRFERT, PRLABOR, PRANLAB; the output price relative, PRICER, the research stocks, APPRES and OTHRES; total cropped area; FARMSIZE; district dummy variables (thus it is a "fixed effects" specification); and year and year squared terms.

In the second stage, the logarithm of the yield index (based on 1956-60 in each district) is regressed on crop research variables, ln (APPRES) and SHHYV, MKTDISTANCE, FARMSIZE, LITERACY, ROADS, POPDENSITY and the predicted acreage index for the crop (ln (Predicted Acreage) - ln (Predicted Area in 1970 in the District)). The specification also included year dummy variables and geo-climate regional dummy variables. These variables are expected to control for or "dummy-out" price effects on yields. They also reflect weather effects and some trends in productivity. We do not attempt to interpret them, however. Our interest is in the research variables.

Table 4.1 Variable and Means: PFP Analysis

RIABLES	VARIABLE DEFINITIONS	MEANS
:A	AREA PLANTED TO CROP (000 HECTARES)	BY CROP
FERT	PRICE INDEX FOR FERTILIZER/ PRICE INDEX FOR TRACTORS	..607
LABOR	PRICE INDEX FOR LABOR / PRICE INDEX FOR TRACTORS	1.184
ANLAB	PRICE FOR ANIMAL LABOR / PRICE INDEX FOR TRACTORS	.961
)PAREA	TOTAL CROPPED AREA (000 HECTARE)	376
PRES	RESEARCH STOCK FOR THE CROP	BY CROP
HYV	SHARE OF AREA PLANTED TO HYV'S	BY CROP
HRES	RESEARCH STOCK FOR COMPETING CROP	BY CROP
:CER	PRICE INDEX FOR CROP / PRICE INDEX OF COMPETING CROPS	BY CROP

:DISTANCE:]
MSIZE:]
:ERACY:] See Chapter III
DS:]
DENSITY:]

NS BY CROP

ROP	AREA	APPRES	OTHRES	PRICER
IRA	20.96	65.8	144.6	.656
AR	12.37	65.8	143.7	.574
ZE	14.07	65.8	143.9	.597
:E	44.84	21.8	163.0	1.119
:AT	160.89	183.0	109.0	.475
TON	53.89	285.0	121.0	4.858
ARCANE	18.28	71.0	159.6	1.094

IV. Estimates, Stage I Acreage Decision

Table 4.2 summarizes the acreage response estimates. We expect acreage for each crop to respond positively to its output price relative (PRICER) and to its own research flow (APPRES). We expect a negative response to the research attention directed to substitute crops.

Table 4.2 Area Coefficient Estimates: PFP Analysis.

S	R^2	PRICER	APPRES	OTHRES	PRFERT	PRLABOR	PRANLAB	CROP AREA	FARMSIZE
A	.88	1.904	.0344*	-.0582**	-.966	7.231**	-.350	.079***	-.001
R	.88	- .170	.0551**	-.0113**	-.121	.801	1.144	.002	.001
E	.96	-1.143**	-.0143**	-.0034	1.762**	.913	-1.475	.019**	.002
	.95	4.095**	-.654 **	-.0753**	-2.634	-5.382**	10.828**	.057**	-1.611
T	.95	13.757**	-.019	-.0156	.859	-.8565	-11.658**	.647**	- .011
ON	.94	-.920	-.048**	.100 **	7.62 **	.596	- 7.881*	.136**	.045*
RCANE	.90	-1.906**	-.0365**	.0197**	-.080	1.029	2.318	.026**	.001

1.7 and < 2.0.
> 2.0.

We find positive price effects only for wheat and rice. Other cereals show little response to price. We find the expected responses to research flows in the all cereals except wheat. We find effects on cotton and sugarcane acreage that are contrary to expectation. We do not wish to conclude that we have identified the acreage decision for these two crops.

The input price relatives are not expected to have particular effects. High prices of fertilizer, for example, will have negative effects on fertilizer intensive crops and positive effects on crops using little fertilizer. Similarly, higher wages will stimulate production of crops that use little labor and reduce production of labor intensive crops (such as rice). It is difficult to claim many obviously reasonable impacts for these price effects. Rather than attempt to provide strong interpretations it is perhaps best to note that we observe some price effects and that they are not implausible. Thus,

in summary, we have probably identified reasonable research effects on cereal grains acreage decisions.

V. Estimates, Stage II Yield Effects

Table 4.3 reports the yield index estimates. Predicted areas are included in these regressions. It is of interest to note that predicted area changes contribute to yield changes as expected in the cereal grains and cotton, but not for sugarcane.

Table 4.3 Yield Index (PFP) Decomposition Estimates

DEPENDENT RIABLES	COMMODITY REGRESSIONS						
	BAJRA	JOWAR	MAIZE	RICE	WHEAT	COTTON	SUGARCANE
EDICTED EA	.049**	.0672**	.0594**	.03269**	.02397	.0241	.00038
PRES	.0161	.0113	.0622**	.0243*	.0837**	-.5247**	-.0364**
YV				.4735**	1.486**	.0609	
PRES*SHHYV				-.3182*	-.20936**	.12798**	
TDISTANCE	-.00186	-.00493**	-.0053**	.0010	.0042	-.0033	-.00523*
RMSIZE	.00020	-.00095**	-.00006	-.00012	-.00031	.000067	-.00004
TERACY	.00290	.00486**	.00035	-.00021	-.0018	-.0075**	.00586*
ADS	-.0216	-.0491**	-.0137	-.0051	-.0515**	.0352**	-.0209**
PDENSITY	.07944**	.05787**	.0178*	.0078	.14893**	.054987**	.01772*
	.384	.489	.734	.754	.695	.628	.444
	10.84	18.73	46.04	45.47	43.69	24.59	13.51

' > 1.7 and < 2.0.
" > 2.0.

Of most interest are the research impacts on yields. Here we observe positive impacts for all cereal grains and cotton, but not for sugarcane. The cotton impacts appear to be closely related to varietal usage. For wheat and rice, the negative interaction between the HYV and the research variable indicates some substitutability between varieties and research. This is consistent with the fact that a considerable amount of HYV importation occurred in both rice and wheat. Thus we have strong evidence of research and HYV impacts for the three major cereals, maize, wheat and rice. For bajra and jowar there is positive support for a research impact. For cotton there is also support, but it is mixed. There is no evidence for a research impact for sugarcane.

The effects of other variables in the specification are generally mixed, although statistically significant effects are generally of the expected sign. Market distance has a negative impact on yields. Literacy generally has a positive impact. The POPDENSITY variable appears to be picking up a positive impact because it is measuring labor impacts. Since we do not wish to develop a strong interpretation for variables other than the research variables, we simply note that there may be several ways by which population density has a positive impact on crop yields. We believe that this variable is contributing to improved estimates of the research impacts.

VI. Marginal Products and Marginal Internal Rates of Return

We have two options regarding marginal product calculations. We could consider the yield index marginal products to be the primary impacts of the research variables. However, there is also reason to evaluate the impacts of research programs on acreage decision and then treat the predicted area impacts on yields as being research induced. Both calculations are reported in Table 4.4.

The procedure utilized to compute marginal products is to first compute marginal product elasticities from the estimated yield and acreage equations (Tables 4.2 and 4.3) and then to convert these to marginal products using product-investment ratios (see Chapter I, Table 1.5, for product-investment ratios by commodity). Marginal products thus are annual rupees of increased product per rupee invested after the full impact of the investment is realized (that is, after 8 years, see Chapter III, Table 3.2).

Table 4.4 reports elasticities separately for applied research and HYV impacts. It is probably most reasonable to consider the combined elasticities and marginal products as the full contributions of applied research. We have not considered general research estimates in this analysis, and it is probably reasonable to attribute some of these gains to general research. As noted earlier, sugarcane research appears not to have had a PFP impact. For wheat and cotton, the impact is entirely through the HYV variable. For rice, most of it is through the HYV variable. The HYV elasticities are converted to expenditure elasticities by assuming that all expenditures were required to produce the HYV's.

Table 4.4: Marginal Product Elasticities and Marginal Product Estimates: PFP Analysis

	Estimated Elasticities				Estimated Marginal Products		MIRRI	
PS	APPRES	HYV's	ALL	ALL (A)	ALL	ALL (A)	ALL	ALL (A)
ra	.0494		.0494	.0547	3.06	3.39	42	44
ar	.0672		.0672	.0864	4.17	5.36	48	52
ze	.0594		.0594	.0627	3.68	3.88	45	46
rse Cereals	.0571		.0571	.0663 (.0541)	3.54	4.11 (3.35)	45	47
e	.0159	.1090	.0448	.0546	22.4	27.3	84	89
at	-.005	.2446	.1088	.1087	16.53	16.52	76	76
Cereals			.0851	.0910 (.0831)	21.17	22.64 (20.87)	83	84
ar	- 0364		-.0364	-.0365	neg	neg		
ton	-.0555	.5328	.3483	.3428	43.53	43.52	102	102
Commodities			.1585	.1605 (.1580)	26.31	26.64 (26.62)	88	88

Note: The All (A) estimates include the acreage effects. Numbers in parentheses include the indirect effects of other research.

Marginal products were computed using the product-investment ratios reported in Chapter I and presuming that one rupee investment in extension and related activities is required per rupee invested in research. The actual calculations turn out to be generally consistent at the aggregate level with those reported in Chapter III. The marginal products for all commodity applied research is higher (26 versus 16), but if the applied research impacts actually include a substantial part of the returns to general research, the estimates reported in Table 4.4 are consistent with those reported in Chapter III, Table 3.4. Marginal Internal Rates of Return are computed from the marginal product using the estimated weight schemes reported in Chapter III (Table 3.2). This rate of return is the rate realized from an investment in time t that produces the marginal product indicated over the future time periods. These rates of return are all extraordinarily high (except in case for cotton). They are discussed in the context of a general investment program and in the context of estimates reported in other studies in Chapter VI. .

Chapter V. "Meta-Duality" Estimates

As noted in Chapter II, total factor productivity expressions can be derived from the duality relationship between a transformation function and minimized cost or maximized profits functions. In this chapter a "meta-profits function" approach is pursued. Meta-functions are defined to include technology, infrastructure and skill variables that are not normally included in conventional specifications. (That is, they are normally treated as part of the background or underlying conditions). The approach entails estimation of a system of product supply and factor demand functions that include technology and infrastructure variables.

Section I of this chapter discusses the methodology involved. Section II discusses the data. Section III discusses estimates. The final section discusses economic implications.

I. Methodology - Meta-Duality Estimates

In Chapter II, a transformation function relating multiple products to multiple factors of production was specified:

$$(5.1) \quad Y_1 = F(Y_2 - Y_m, X_1 - - X_n, F, t)$$

This expression relates outputs or products, $Y_1 - Y_m$, to variable inputs, $X_1 - - X_n$, fixed factors of production (F) and a general index, t. If we extend this basic specification to include variables measuring technology (T), and infrastructure (I) we can treat this as a meta-transformation function:

$$(5.2) \quad Y_1 = F(Y_2 - - Y_m, X_1, - - X_n, F, T, I,)$$

If farms maximize variable profits by choosing the optimizing mix of products, Y_i^* and variable factors, X_j^*, the maximized profits function can be written as:

$$(5.3) \quad \Pi^* = P_1 Y_1^* + P_2 Y_2^* - P_m Y_m^* - R_1 X_1^* - R_2 X_2^* - - R_n X_n^*$$

Since the profit maximizing outputs and inputs can be expressed as functions of prices, and F,T,I and S, the maximized profits function can also be written as:

$$(5.4) \quad \Pi^* = \Pi^*(P_1, P_2 - P_m, R_1 R_2 - - - R_n, F, T, I,)$$

The first partial derivatives of 5.3 or 5.4 with respect to product prices yield the product supply equations:

$$(5.5)\quad \partial\Pi^{*}/\partial P_i = Y_i^{*} = \Pi_i^{*}(P_1, P_2 \text{ -- } P_m, R_1, R_2, \text{ - } R_n, F, I, T,)$$

Similarly, the first partial derivative of 5.3 and 5.4 with respect to variable factor prices yield the variable factor demands equations:

$$(5.6)\quad \partial\Pi^{*}/\partial R_j = X_j^{*} = \Pi_j^{*}(P_1, \text{ - } P_2 \text{ -- } P_m, R_1, R_2 \text{ -- } R_n, F, T, I,$$

The system of equations described by 5.5 and 5.6 can be estimated with the data for Pakistan agriculture. Note that we do not require data on variable inputs for each product to estimate this system. By the profits function argument, crop acreage data as analyzed in Chapter IV is essentially redundant. This methodology analyzes optimal decisions on supply, and this in turn implies a particular acreage allocation. However, prices are specified to contain all relevant information for profit maximization.

If we view the Pakistan district data as reflecting average farm data, the system 5.5 - 5.6 can be estimated with output quantity and factor quantity data as dependent variables. Independent or "right hand side" variables in 5.5 - 5.6 include fixed factors (F) and the meta variables, T,I, as well as prices.

Chapter III developed the F, T, and I variables and they are relevant to the estimation of 5.5 - 5.6. Note that they are included in each equation in the system. Fixed factors can be characterized by cropped area and farm size variables.

The analysis in Chapter IV relative utilized price data for acreage decisions, but raised some questions as to the reliability of the data. In the yield equations, it was argued that year dummy variables and geo-climate region variables can effectively "dummy out" both price and weather effects, and that, given the general quality of the price data (see the Data Appendix), one probably

obtained better estimates of the parameters associated with T and I (and we are primarily interested in the T parameters) using this "dummy" procedure than using the available price information. (Of course, we then do not estimate price parameters). That argument is used in this specification as well.

There are several "flexible functional form" issues that have to be dealt with for price effects. Typically, the analyst specifies a normalized quadratic, a generalized Leontief, or a translog form for (5.4). Since we are not actually specifying the price terms we will not discuss these issues further except to note that they justify a simple linear system of regressions. The Zellner Seemingly Unrelated Regression framework is suited to estimating this system of equations. (See Evenson and Pray 1991).

II. Data and Variables

Table 5.1 summarizes the variables and means. All equations include a full set of year dummy variables as well as the 12 geo-climate region variables to control for price and weather effects. Seven product supply functions and four variable factor demand functions are estimated. In the absence of price terms no cross-equation parameter restrictions are imposed.

III. Estimated Parameters: Meta-Duality Analysis

Table 5.2 summarizes the estimated parameters of the meta-duality system of 7 crop supply and 5 factor demand equations. Note that price effects were not estimated , they were "dummied out". Thus the relevant parameters are those for the F,T, and I variables. Given the short-run variable profits model employed here, where cropped area and irrigation variables characterize fixed factor (F), it was deemed unnecessary to include population density as a variable. (The argument for its inclusion in the TFP decomposition specification in Chapter III is that that was a long-run specification allowing land and irrigated acreage to change.) Literacy was also not included. General research was included because it affects factor use.

Table 5:1: Variable Definition and Means Meta-Duality Analysis Pakistan Agriculture

Variable	Definition	Mean
Crop Supply		
QSUGAR	Sugar production in district: quantity index	65.5
QCOTTON	Cotton production in district: quantity index	16.0
QMAIZE	Maize production in district: quantity index	16.6
QBAJRA	Bajra production in district: quantity index	9.68
QJOWAR	Jowar production in district: quantity index	6.85
QWHEAT	Wheat production in district: quantity index	209.9
QRICE	Rice production in district: quantity index	60.76
Factor Demand		
FERTILIZER	Fertilizer used on all crops: quantity index	1.03
LABOR	Labor used on all crops: quantity index	1.03
TRACTORS	Tractors used on all crops: quantity index	1.32
ANIMAL POWER	Animal power used on all crops: quantity index	.95
Determining Variables - See Tables 3.1 and 4.1		
APPRES		
GENRES		
CROPAREA		
FARMSIZE		
ROADS		
MKTDISTANCE		
IRRGSH		
CANALSH		
TUBEWSH		
RAIN		

Table 5.2 Crop Supply -- Factor Demand Estimates: Duality

CROP SUPPLY	INDEPENDENT VARIABLES										
	APPRES	GENRES	APRES X GENRES	SHHYV	CROP AREA	FARMSIZE	ROADS	MKTDISTANCE	IRRGSH	CANALSH	TUBEWSH
PRODUCT SUPPLY											
SUGAR	.3276	-.0179	- .0000171	-	.311**	.108*	19.31**	-.9266**	87.11**	41.00**	-112.66**
COTTON	.0348**	-.0081	.0000116**	8.56**	.113**	.028	3.36**	1.060**	7.65	-11.45**	- 9.31*
MAIZE	.1108**	-.0124**	.0000115*	-	.062**	.014	1.659**	.1548	11.12**	5.69	-19.21**
BAJRA	-.088**	-.0048**	.0000152**	-	.028**	-.012	-2.33**	.142*	-9.058**	-12.98**	-787 **
JOWAR	.0335**	.00109	-.0000025	-	-.002	-.000	-.001	.493**	10.08**	- 2.64**	-12.25**
WHEAT	-.3771	-.00039	.0000836**	42.23**	.023**	-.029	19.94**	3.541**	86.60**	-58.03**	15.30
RICE	.3990	.0443**	-.00053**	51.31**	-.037	-.113*	-19.73**	-4.95**	-10.95	-51.95**	165.2**
FACTOR DEMAND											
FERTILIZER	.0002	-.00103**	3.892(7)**	-	.0000	.000	.053*	.012*	.515**	.642**	.986
LABOR	.0003**	-.0001**	-1.607(8)	-	.00023**	.000	-.009*	-.0052**	-.0065**	-.305**	-.248*
TRACTORS	.0018**	-.00035**	4.944(7)**	-	-.0002	.001	.105**	.012**	-.006	.492**	.748*
ANIMAL POWER	.00038**	-.00012**	3.278(8)	-	.00005*	.0001	-.005	-.0026**	.020	-.077*	.046

*"t" > 1.7 and < 2.0.
**"t" > 2.0.

The reader can interpret each column in Table 5.2 as a "vector" of impacts from one of the F,T and I variables. Because of the interaction variables for applied and general research (APPRESxGENRES) the reader should refer to Table 5.3 to interpret the research impacts. The net effects of other variables can be seen in the table.

The impact of the HYV variables was clearly to increase product supply. In this specification the SHHYV and APPRES variables refer to the crop specific research and HYV's. Accordingly, the SHHYV effects are net effects in these crops. HYV effects on other crops are largely contained in the APPRES and GENRES effects. Similarly the APPRES effects are also net of their impacts on other commodities.

Expansion of crop area tends to favor sugar and cotton production, but has less impact on cereal production. An increase in farm size also favors sugar, cotton and maize production; decreases are associated with increased rice production. Improved roads appear to stimulate sugar and wheat production and fertilizer and tractor use. Improved markets favor sugar and rice production. Irrigation expansion has differential effects on crops, but stimulates fertilizer demand. Canal and tubewell irrigation stimulates both fertilizer and tractor use and reduces the demand for labor.

Table 5.3 reports estimated elasticities showing how applied, general and all research impacts on crop supply and factor demand. These estimates show that the overall impact on all crops combined has been practically nil. At the same time these research variables have also had very little if any real impact on variable factor demand. These estimates, however are not directly suited to evaluating the productivity impact of research.

Table 5.3: Estimated Elasticities: Meta-Duality Analysis

	Estimated Elasticities			
Crop Supply	APPRES	GENRES	HYV	ALLRESEARCH
Sugar	.334	-.285		.129
Cotton	-.372	-.304	.0761	-.269
Maize	.424	-.686		.058
Bajra	-.465	-.372		-.429
Jowar	.298	.131		.242
Wheat	-.257	.070	.0491	-.097
Rice	-.042	.522	.202	.346
All crops	-.1197	-.077	.138	-.0014
Factor Demand				
Fertilizer	.0777	-.9824		-.271
Labor	.0379	-.1094		-.011
Tractors	.2321	-.2112		.083
Animal Power	.0904	-.1193		.021
All Factors	.0854	-.1792		-.0031

Chapter VI: Summing Up: The Contribution of Agricultural Research in Pakistan

This study has documented the institutional development of the agricultural research system in Pakistan and has pursued several methods to evaluate the contribution of the system. In this final chapter we summarize the conclusions and estimates of each chapter and compare them to conclusions and estimates obtained in other studies.

Chapter I documented the growth and development of the agricultural research system in Pakistan after independence. Pakistan did not inherit extensive research capacity from its colonial period. It thus faced a major institutional challenge in building research programs suited to its agricultural conditions. In Chapter I we provided quantification of the ways in which Pakistan has addressed this challenge. We noted that, even though Pakistan was without extensive research capacity after independence, it did build a set of research centers and programs that is today roughly comparable to institutions in other countries in the region.

The standard quantitative indicators for research investment show that Pakistan has achieved approximately the same ratio of annual research investments to the value of agricultural product as in other South Asian and low-income developing countries. The allocation of research programs among regions and among commodities is probably somewhat more unequal or unbalanced, however, than in other developing economies.

There are also indications that the system in recent years has been subject to budgetary stress in the sense that operational support to scientists has been too low. In addition, the system has a low level of basic research backing up its applied research programs when compared with other countries.

The responsibility for agricultural programs and support in Pakistan resides heavily in the provinces. The strongest research institutions and the strongest agricultural universities are provincial. This situation creates potential problems of research duplication and coordination. The Pakistan Agricultural Research Council (PARC) has responsibility for these concerns. The Council has been in place for a relatively short period, and it is generally too early to determine its full effectiveness.

Chapter II initiated the process of evaluating the impact of the research program. The major contribution of research programs is to make improved technology available to farms through adoptive research and screening of technology produced abroad. If this technology is adopted by farmers and used effectively it should lead to productivity gains. Did such gains actually occur in Pakistan?

Chapter II showed that Pakistan did achieve significant gains in Total Factor Productivity (TFP) and in Partial Factor Productivity (PFP) for most crops. Some part of these gains was obviously achieved as a result of the rapid adoption of improved "green revolution" high yielding varieties, particularly of wheat, as the late 1960's showed the highest rates of TFP (and PFP) gains. There were, however, significant differences in the timing and rate of TFP and PFP growth in different districts.

Chapter III sought to identify the sources of differences in TFP changes in Pakistan's districts. A TFP decomposition formulation was developed and applied to district data for the 1956-85 period. In this specification, TFP growth was statistically related to variables designed to reflect the contribution of research programs and improved infrastructure. The timing pattern between research investment and the ultimate impact that research programs have on productivity growth was also estimated.

The TFP decomposition procedure reported in Chapter III did find significant contributions to TFP change from applied, commodity-oriented research, from general non-commodity research, and from varietal improvements, part of which represented imported technology from abroad. (Of course, all research builds on prior international science and related research to some extent). The timing pattern estimates showed that applied research probably has little impact until 4 years after investment takes place and does not have its full impact on productivity until 8 years after investment. General non-commodity oriented research has a slightly longer time lag. First impacts are realized after 5 years, full impacts after 9 years.

It is possible to evaluate the "marginal product" of research investment from the estimated decomposition relationship. This is expressed in rupees of surplus (i.e., increased output due to the research program) per rupee invested, realized when the full impact is achieved. By using the

timing estimates it is thus possible to calculate the future "stream" of benefits (value of the surplus) from a one rupee investment in time t. The interest rate or discount rate at which this stream has a present value of one rupee at time t is the "internal rate of return" to the investment. Since it is calculated from a marginal product, it is appropriate to consider it a marginal internal rate of return (MIRR).

Comparable TFP Studies

Table 6.1 summarizes 45 MIRR estimates reported in 25 different studies where aggregate research programs were the object of study. The table includes 7 estimates from Chapters III and IV. It also includes the earlier study of Pakistan by Nagy and the historical study of the British Indian Punjab by Pray. Most of these studies are of the type developed in Chapters II and III. Several (noted as M) were meta production studies.

The Chapter III estimates are reported both for estimates holding HYV constant (i.e., not including HYV benefits in the conclusion) and for estimates which count the HYV benefits. The Chapter IV estimates are for the combined commodities analyzed below.

We may first observe that all of the Chapters III and IV estimates are extraordinarily "high" when considered in an investment context. Rates of return above 20 percent are relatively rare in any economy except for rapidly growing economies. If an economy such as Pakistan could actually realize returns to all public and private investment in the 40 to 60 percent range, its overall rate of economic growth would be extraordinarily high. Investment in agricultural research even where the time lags are relatively long as they are in Pakistan, is yielding very high returns and thus is providing economic growth at low cost.

It must be noted that these returns are so high that even if the MPs are substantially over-estimated, the MIRRs are still very high. For example, the MP for applied research, including HYVs, was 20.9, and this gave a MIRR of 82 percent. Supposed that the 20.9 was overestimated by a factor of 5 and was actually only 4. A MP of 4 still has a MIRR of 47%.

Table 6.1 Estimated Marginal Internal Rates Of Return To Research To Aggregate Research Investment: Pakistan And Other Countries.

STUDIES	COUNTRY	COVERAGE	TYPE	TIME PERIOD	ESTIMATED MIRR (%)
Chapter III	Pakistan	Applied (HYV Constant)	D	1956-85	57 - 63
Chapter III	Pakistan	General (HYV Constant)	D	1956-85	40
Chapter III	Pakistan	Applied (Including HYV)	D	1956-85	82
Chapter III	Pakistan	General (Including HYV)	D	1956-85	56
Chapter III	Pakistan	All Research	D	1956-85	57 - 65
Chapter IV	Pakistan	Commodity Research	D	1956-85	88
Nagy 1991	Pakistan	All Research	D	1959-1979	64
Pray 1978	Punjab (British India)	Research & Extension	M	1906-1956	34 - 44
'enson & Kinsey, 1991	India	All Research	D	1958-1983	65
hlon, Bal :xena & ıan, 1977	India	All Research	M	1960-1971	63
'enson & ıon, 1973	India	All Research	D	1953-1971	40
'enson, 1987	India	All Research	D	1959-71	100
'ay & Ahmed, 1991	Bangladesh	All Research	M	1948-1981	100
:rletta, 1970	Mexico	Crop Research	M	1943-63	45 - 93
'enson, 1982	Brazil	All Research	D	1970-1980	60
.lva, 1984	Brazil	All Research	M	1955-1983	23 - 53
'enson, 1986	Brazil	Field Crop Research	D	1970-75-80	55
" "	" "	Permanent Crop Research	D	1970-75-80	90
ıng, 1963	Japan	Research & Schooling	M	1880-1938	35
'iliches, 1964	U.S.A	Research & Extension	M	1949-59	35 - 40
:timer, 1964	U.S.A	Research & Extension	M	1949-1959	NS
'enson, 1968	U.S.A	Research & Extension	M	1949-1959	47
.ine, 1975	U.S.A	Research & Extension	M	1949-1958	39 - 47
		Research & Extension	M	1959-1968	32 - 39
		Research & Extension	M	1964-1972	28 - 35
ıvis, 1979	U.S.A	Research	M	1949-1959	66 -100
			M	1964-1979	37
'enson & :lch 1979	U.S.A	All Research	M	1964	55
ıx, 1986	U.S.A	Livestock (Applied)	M	1944-83	150
		Livestock (Basic)	M	1944-83	116
		Crop (Applied)	M	1944-83	180
		Crop (Basic)	M	1943-1977	36
ırton, 1981	U.S.A	Cash Grains	M	1974	85
		Livestock	M	1974	88
'enson et al 1979	U.S.A	All Research	D	1868-1926	65
		Applied	D	1927-1950	95
		Basic	D	1927-1950	110
		Applied	D	1948-1971	93 - 130

		Basic	D	1948-1971	45
'man & ıson, 1989	U.S.A	Crops (Applied)	D	1950-1982	45
		Livestock (Applied)	D	1950-1982	11
		Crops (Basic)	D	1950-1982	57
		Livestock (Basic)	D	1950-1982	83
		Private R & D	D	1950-1982	83

:S: NS - Not significant
D - Decomposition study
M - Meta production study

Reference to the other estimates in the table show that the Pakistan results are not unusual. High rates have been observed in a broad range of countries at different periods. There is a high degree of consistency underlying this evidence. Many studies have shown that agricultural research has a high payoff and produces low cost growth.

Comparable PFP Studies

We now turn to comparative evidence for commodity specific studies. Table 6.2 summarizes the Chapter IV estimates and compares them with other estimates on a commodity by commodity basis.

The wheat research productivity estimates indicate that wheat research has been productive in many countries and that it has been particularly productive in Pakistan. Many of the measured impacts were due to the varieties released in the mid 1960's but national programs have contributed by "adding on" to the original HYV material.

The same analysis applies to rice research. In general, return to rice research are even higher than returns to wheat research. Pakistan's rice research program, as noted is simply too small. Nonetheless, it is highly productive (note, we are not included the recent extraordinary gains in Basmati rice productivity in these calculations).

For maize research, the level of MIRR's is a little lower than for rice, but again the evidence is clear. Maize research is highly productive in Pakistan and has been highly productive elsewhere. The basic Griliches (1958) hybrid corn study is included in the table, and it reported the first estimates of this type. Hybrid corn development in the U.S was regarded to be an extraordinary success story. It is clear after many more studies that there are many success stories in virtually all commodities, but particularly in cereal grains.

Table 6.2 Estimates of Marginal Internal Rates of Return to Crop Specific Research Investments: Pakistan And Other Countries

JDIES	COUNTRY	COMMODITIES	TYPE	TIME PERIOD	ESTIMATED MIRR (%)
ıapter IV	Pakistan	Wheat	D	1956-1985	76
ıgy, 1991	Pakistan	Wheat	M	1967-1981	58
ʼenson & ıkinsey, 1990	India	Wheat	D	1959-1983	50
ırletta, 1970	Mexico	Wheat	M	1943-1963	90
ɜrtford et al,1977	Columbia	Wheat	M	1927-1976	11 - 12
ɜrnergren & ıittaker, 1977	Bolivia	Wheat	M	1966-1975	NS
ʼrazaval ıl, 1982	Chile	Wheat	M	1949-1977	21 - 28
ʼosi & ʼruz, 1984	Brazil	Wheat	M	1974-1982	59
ıapter IV	Pakistan	Rice	D	1956-1985	84 - 89
ıson & .nsey, 1991	India	Rice	D	1959-1983	155
ʼes et al, 1978	Philippines	Rice	D	1966-1975	75
" "	Asia	Rice	D	1966-1975	46 - 71
ıson & ʼes, 1978	Asia	Rice	D	1950-1965	32 - 39
" "	" "	Rice	D	1966-1975	73 - 78
" "	IRRI	Rice	D	1966-1975	74 - 108
ɜverria, ıl 1988	Uruguay	Rice	M	1965-1985	52
.a, 1981	Brazil	Rice	I	1959-1978	87 - 119
ɔie & ıda, 1978	Columbia	Rice	I	1957-1964	79 - 96
ımi & ıo, 1977	Japan	Rice	M	1915-1953	25 - 27
" "	Japan	Rice	I	1932-1961	73 - 75
ɜford et al, 1977	Columbia	Rice	I	1951-1972	60 - 82
ɔter IV	Pakistan	Maize	D	1956-1985	46
ʼ, 1990	Pakistan	Maize	D	1967-1981	19
ıson & .nsey, 1991	India	Maize	M	1959-1983	94
.etta, 1970	Mexico	Maize	I	1943-1963	35
ɜs, 1972	Peru	Maize	I	1954-1967	35 - 40
ʼrazaval, 1982	Chile	Maize	I	1940-1977	32 - 34
ɜinez & ı, 1983	Panama	Maize	I	1979-1982	47
ıson & ʼruz, 1989a	Brazil	Maize	D	1966-1988	30

ʼenson & ı Cruz, 1989b	PROCISUR	Maize	D	1979-1988	191
:iliches, 1958	USA	Maize	I	1940-1955	35 - 40
:to & ıvlicek, 1981	USA	Maize	M	1967-1979	152 - 210
ıapter IV	Pakistan	Bajra	D	1956-1985	44
ʼenson & :kinsey, 1991	India	Bajra	D	1959-1983	107
ıapter IV	Pakistan	Jowar	D	1956-1985	52
ʼenson & :kinsey, 1990	India	Jowar	D	1959-1983	107
·iliches, 1958	USA	Sorghum (Jowar)	I	1940-1957	20
ıapter IV	Pakistan	All Cereals	D	1956-19856	81 - 84
ʼenson & :kinsey, 1990	India	All Cereals	D	1959-1983	218
ʼenson, 1987	Latin America	All Cereals	M	1960-1982	44
	Africa	All Cereals	M	1960-1982	NS
	Asia	All Cereals	M	1960-1982	50
	IARC - Latin America	All Cereals	M	1960-1982	>80
	IARC - Africa	All Cereals	M	1960-1982	>80
	IARC - Asia	All Cereals	M	1960-1982	>80
:ay, 1980	Bangladesh	Wheat & Rice	I	1961-1977	30 - 35
ıapter IV	Pakistan	Cotton	D	1956-1985	102
ʼer, 1970	Brazil	Cotton	I	1924-1967	77 - 110
:rtford et al, 1977	Colombia	Cotton	I	1953-1972	NS
ıapter IV	Pakistan	Sugarcane	D	1956-1985	NS
:nazza, : al, 1984	Brazil	Sugarcane	D	1972-1982	35
ʼenson, 1969	South Africa	Sugarcane	M	1945-1962	40

)TES: NS - Not significant
D - Decomposition study
M - Meta production study

Chapter IV reported estimates or bajra and jowar as well as for all cereals. As with wheat, rice, and maize, research on bajra in Pakistan has been highly productive, although not as productive as research in India. The results for combined cereals add further to the conclusion that national research programs for cereals grains improvement have been highly productive almost everywhere. The IARC programs for cereal research have been even more productive.

Chapter IV also reported results for cotton and sugarcane research. The high returns to cotton research in Pakistan have been replicated in Brazil it seems. The absence of evidence of sugarcane research impact in Pakistan is contrary to studies in Brazil and South Africa.

A Final Summary

This study reports evidence that has strong statistical support to the effect that Pakistan's agricultural research system has been productive. It has produced high rates of return to investment. It has produced economic growth in agriculture at lower cost and that growth has been vital to Pakistan with its rapidly growing population. There is little doubt that investment in agricultural research program have been among the most productive investment in Pakistan over the past 40 years.

It does not follow, however, that the research system has been as productive as it could have been. This study has noted problems with "congruence" ie with the commodity mix (particularly series for rice). Currently there are serious problems with providers support to allow scientists to got their work done. The system appears to have weak basic research support system.

Nor does it follow that the system has solved all or even some of the major problems. Soil salinity has probably worsened. Our data show sever problem in NWFP and these will have to be addressed. It however is important to note that agricultural research programs cannot solve all problems. They are designed to develop technology enabling farms to examine their productivity and to enable the economy to get more products from the resources at hand.

And this they have done in Pakistan. It is clear that even given the flaws in the system (and these are probably not too serious) Pakistan has underinvested in agricultural research. It should have invested more. Among the alternative by which an economy can increase output -- via land expansion -- irrigation -- more fertilizer -- research has been the "bargain". Indeed for an economy like Pakistan's, the biggest bargains in the business of providing economic growth are probably the agricultural scientists. Not only they are productive, but they are low cost. This study has documented the fact that the real cost of supporting a scientist relative to the costs of irrigation equipment -- fertilizer etc are probably one tenth of their level in developed countries.

Pakistan faces challenges in the future. Its population will double in the next few years (perhaps a few as 3). It must double food production merely to maintain per capita food production. It has brought most cultivable land under cultivation now. If Pakistan is to meet this challenge, it must realize gains in productivity. to do this it must expand and strengthen its agricultural research system as well as its extension and farm education program. The evidence showing have agricultural research contributes to productivity is abundant. Numerous studies reveal the same conclusion. Agricultural research program will have to play a larger role in the future. Countries such as Pakistan cannot afford to continue to underinvest in their system and to provide inadequate support to its agricultural scientists.

The overall evidence is clear, indeed overwhelming. Research has an exceptionally high pay-off as reflected in the rate of returns measures. The average return to investment in public and private capital and infrastructure in Pakistan cannot possibly have yielded the returns reported here. Indeed, the aggregate growth of the Pakistan economy would indicate that average rates of return to investment in Pakistan are probably less than ten percent in real terms.

Research can also be seen as a means to "purchase" economic growth in agriculture. The cost of obtaining a unit of growth via research can be compared with the costs of obtaining a unit of growth via irrigation, land clearing and through input use (fertilizer). No other growth producing activities can demonstrate that they can achieve the lower costs per unit of growth demonstrated for agricultural research in this study and reinforced by international comparisons.

This study has shown that research is a "bargain" in Pakistan. It is a bargain even though the research system is severely stressed by support and skill constraints at present. These constraints should be relaxed, and they will make research even more of a bargain. Fundamentally, research is a bargain because the real costs of scientific effort in Pakistan are low relative to the costs of irrigation equipment and capital goods.

The message of this study is clear. Pakistan is underinvesting in research. It is not taking advantage of the growth bargain offered by research. It is underinvesting in both qualitative and quantitative terms. If Pakistan is to meet the massive challange that it faces regarding agricultural production in the future, it will have to investment more in its agricultural research system. It will have to provide better support to its scientists. It will have to upgrade the skill level of its scientists. It will have to expand its research system as well and develop extension and related systems to further support its research program. Only then will it be able to expand agricultural production at a rate sufficient to meet the development challenge that lies ahead.

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APPENDIX: Statistical Sources and Variables in the Data Set

This appendix describes the variables used in the data set for this study. It describes their sources, units, and any transformations that they underwent.

I. Coverage

We covered all of the districts in Sind, Punjab and the NWFP. These three provinces constitute the bulk of agricultural production in Pakistan.

As far as possible, we used the original districts as they existed within their boundaries in 1955. Any new district created after 1955 was included in the parent district. This was done to maintain consistency among the observations and to allow meaningful comparisons through time. The districts that existed in 1955 and are our observational units:

PUNJAB (1)

Attock (01)	Jhang (11)	Sahiwal (19)	Rawalpindi (02)
Mianwali (12)	Multan (20)	Jhelum (04)	Sialkot (14)
Muaffargarh (22)	Gujrat (06)	Gujanwala (15)	D. G. Khan (24)
Sargodha (07)	Sheikhupura (16)	Bahawlapur (28)	Faisalabad (09)
Bahawalnagar (29)	Lahore (17)	R. Y. Khan (30)	

SIND (2)

Khairpur (01)	Nawabshah (05)	Tharpakkar (08)	Thatta (12)
Jacobabad (02)	Larkana (06)	Dadu (09)	Sukkur (03)
Sanghar (07)	Hyderabad (10)		

NWFP (3)

Peshawar (01)	Abbottabad (05)	D. I. Khan (10)
Mardan (02)	Hazara (08)	
Kohat (03)	Bannu (09)	

The district of Karachi was excluded due to its lack of agricultural production. Rawalpindi includes the present Islamabad district. Each district was assigned a unique identification code in the data set. This is composed of a one-digit province identification code, which is the variable STATE, and a two-digit district code called DISTRICT. Thus 1 01 represents Attock while 2 01 represents Khairpur. The variable STDIST gives the three digit for each district, 101 represents Attock.

The study covers the period from the agricultural year 1955-56 to the agricultural year 1985-86, which is the last year for which we have data. The two-digit variable for year is called YEAR.

II. Outputs

The data set contains data for the quantity of output and the price of 12 major crops in Pakistan. The variable names of the crops studied are:

WHEAT	for total wheat.
RICE	for rice, regardless of type.
COTTON	for cotton, regardless of type.
SUGAR	for refined sugar.
BAJRA	
MAIZE	
JOWAR	
GRAM	
RAPEMUS	for rapeseed and mustard
TOBAC	for tobacco
BARLEY	
MUNG	

We collected additional data for a few sub-varieties and improved varieties.

MAXWHT	for High Yielding Varieties of wheat.
BASRCE	for basmati rice.
IRRIRCE	for improved (IRRI) varieties of rice.
PAKCTTN	for Pak Upland cotton.
DESCTTN	for desi or local cotton.

For quantity of output the prefix Q is attached to the variable. Thus QGRAM represents the quantity of gram produced. Output is expressed is 1000 metric tons. The data come from Agricultural Statistics of Pakistan except for 1968. For that year we were forced to estimate the quantity for approximately half of the crops because the data were missing.

Output prices are indicated by the prefix P attached to the variable. Due to the lack of consistent data we do not use farmgate prices, instead using wholesale prices from Statistical Year Books. Wholesale prices are only available for certain key markets over the time period in question. These key markets are:

SIND

Sukkur 203 Hyderabad 210 Karachi 213

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PUNJAB

Sargodha	107	Lahore	117	Multan	120
Faisalabad	109	Rawalpindi	102		

Each district was assigned to a market on the basis of distance. This market provided the output prices. The code for the market is the same as the code for the state-district (STDIST). The variable is called MARKET and it is indicated above, next to the name of the market.

The prefix Y before the name of the crop indicates the yield of the crop, that is quantity divided by area. Thus YDESCTTN is the yield of desi cotton.

The prefix YI before the name of the crop is the variable for the yield index. For example YIGRAM is the yield index for gram. The yield index is a normalized index for the yield. The average yield for the first three years of the series (in this case 1955, 1956, and 1957) is the base, set equal to 1.00000. Thus if the yield index is at 2.00000, it indicates that in the particular year the yield of the crop is twice that in the first three years of the series.

A weighted output was constructed using the price as the weights. The variable QCROPS is the weighted index of the quantity of output. PCROPS is an aggregate index of the output prices, normalized to 1.00000 for the first year.

III. <u>Inputs</u>

We considered five inputs: land, labor, tractors (mechanization), animal power, and fertilizer. For each we have a quantity and a price for each year and district in the data set.

The data on land comes from the various editions of the Agricultural Statistics of Pakistan. It is reported in 1000 hectares. The variable is denoted by the prefix A and followed by the name of the crop. Thus ARICE is the area under rice cultivation. There are virtually no data on the value or price of land, therefore we set the price of land equal to 30% of the total input costs. Although this is not the true value of land, it is, according to our evidence, a good approximation of the cost of land.

There is no direct annual source reporting the number of farm laborers on a district level. Therefore it was necessary to estimate the number of farm laborers from two sources. The variable

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QLABOR reports the number of agricultural workers presented in the 1951, 1961, and 1981 Population Censuses. Since the 1972 population census was not available, the Agricultural Censuses were used for comparison. The agricultural labor force from these censuses in 1972 and 1980 are reported in 1000s under the variable AGLABOR. Interpolation is used for the missing years. The ratio between the 1980 Agricultural Census's work force and the Population Census's was found for each district. This ratio was imposed on the 1972 Agricultural Census to create the hypothetical results for 1973 population census. We used interpolation to fill in the missing years for QLABOR.

There is little direct data on wages paid to agricultural workers. We have some geographical diversity from a cost of production study that reports the following daily wages in 1983-84:

Sargodha	20.5	Sahiwal	16.8	Sheikhupura	20.0
R.Y. Khan	22.5	Hyderabad	23.3	Sukkur	23.0

These wages were imposed throughout each of the district's division, using the division's boundaries as they existed in 1955. An index based on ILO data and industrial wages was used to adjust the wages in time. We assumed that workers worked 188 days per year.

1985	170	1975	30	1965	11	1955	8
1984	170	1974	32	1964	12		
1983	100	1973	23	1963	10		
1982	80	1972	13	1962	8		
1981	78	1971	13	1961	9		
1980	53	1970	12	1960	9		
1979	45	1969	10	1959	8		
1978	40	1968	10	1958	8		
1977	36	1967	9	1957	8		
1976	30	1966	11	1956	8		

Our data on the tractor stock came from a variety of sources. When district level data was available, we used it directly. When only provincial data existed, we estimated the share of each district from different years. When no data was available, we interpolated between years. QTRACTOR represents our estimate for tractor quantity.

The wholesale price for a 47 HP tractor from the Statistical Yearbooks was used when available. This is a "typical" tractor in Pakistan. An index using FAO data was constructed to project the price into the past. The variable PTRACTOR reports this. After we determined the

value of the tractor stock in each year, we multiplied this by .25 to approximate the annual spending on tractors.

Concise data on animal labor is only available for the few years in which there were Agricultural Censuses and Livestock Censuses. For intervening years we used straight interpolation. This variable is called QANLAB.

An estimate of the price of bullock was made in 1981, from this an index based on the price of maize was used to compute the estimated price of animal labor. This is PANLAB. As with tractors, once the value of the animal work force known, it was multiplied by .50 to get an estimate for the total amount spent on animal labor annually.

District level data on fertilizer exists back to 1978, from 1965 to 1977 there is only provincial data. The average district share was imposed on these provincial totals. The fertilizer types we used are NITRO, P2O5, and K2O. The Q prefix indicates metric tons of each nutrient. The price of fertilizer comes from official sources for the government set price. The prefix P before the fertilizer name indicates the price per nutrient metric tons, in Rupees.

Once the input quantities and prices were estimated, an aggregate input quantity and price index was constructed. QINPUT is the input index with input prices as the share weights. PINPUT is the aggregate price index for inputs. They are all normalized to 1.00000 for 1955. Cost shares have been computed under the headings SHFERT, SHLABOR, SHTRAC, SHANLAB, and SHLAND for fertilizers, labor, tractors, animal labor, and land respectively.

IV. Infrastructure

A variety of sources reported irrigation by source by district in the Punjab. There were fewer sources for Sind and the NWFP. Linear interpolation was used to fill in missing data. Road length data were reported in the Statistical Year books of Pakistan and Road Transport Statistics. Data on the average distance to market were obtained from Village and Mauza Statistics.