ECONOMIC EVALUATION OF THE COLOMBIAN AGRICULTURAL RESEARCH SYSTEM

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CHAPTER I

INTRODUCTION

Problem Statement

Agricultural research in Colombia can be traced to the establishment of an official livestock acclimatization farm in 1879 and official crop research stations in the 1920's at three key locations (Picota, Cundinamarca; Armero, Tolima; and Palmira, Valle). Agricultural research by the private sector began in 1938 with the creation of the National Center of Coffee Research (CENICAFE). This was followed by the formation of an Institute of Cotton Development (IFA) in 1947 and the initiative of the National Federation of Rice Growers (FEDEARROZ) in assigning a fee on rice sold to finance public research. In 1938 the Ministry of Agriculture took over responsibility for the Palmira station, where research was in progress on sugarcane, rice, tobacco, plantains, cassava, maize, beans, soybeans and forage crops.

Following a long period of review (1943-50), responsibility for public agricultural research was brought together within the Ministry of Agriculture in the Office of Special Investigations (OIE) which received strong support from the Rockefeller Foundation. OIE initiated soil and plant protection studies and included potatoes among the commodities under research. The OIE was upgraded to a Division of Agronomic Investigations (DIA) in 1955 and eight years later ICA (Colombian Agricultural Institute) was created as an autonomous entity dependent on the Ministry of Agriculture. It was given responsibility for all public agricultural research, extension and graduate education, in accordance with Decree 3116 of 1963. As a result of the restructuring of the public agricultural sector, in accordance with Decree 2420 of 1968, ICA[1] was assigned additional responsibilities for a number of regulatory and service functions which previously had been carried out directly by the Ministry of Agriculture.

Currently ICA is responsible for the following functions in the agricultural sector: biological, physical, economic and social research; the transference of technology to other entities; extension services for small-scale farmers; analysis and control of the quality of agricultural inputs and outputs; registration of private farm extension agents; crop and livestock health campaigns; the use of improved inputs and techniques; and, post graduate training in agriculture.

There are 27 research centers and stations distributed throughout the farming areas of the country. These are classified as four national research centers and one national veterinary laboratory; 12 regional centers and one regional veterinary laboratory; and nine research stations. In addition, ICA has 30 diagnostic centers for animal diseases, and 13 laboratories which provide services for the public as well as supporting the commodity research programs. Other complementary services provided by ICA are a livestock quarantine station at Barranquilla; a specialized agricultural library; and a program for post-graduate training in association with the National University.

For administrative purposes all centers and stations outside Bogotá are subordinate to one of the Regional Managers of ICA. On the other hand, in matters of research, the line of control runs from the Sub-manager of the

[1] More detailed information about research history, ICA's functions and administrative structure can be found in Appendix A.

Research Department to the National Program Division Chief and then through Program Coordinators responsible for each scientific discipline, commodity or research centers or experiment stations, and, finally, to the leaders of multidisciplinary groups that are formed for specific research programs or projects.

At the end of 1982, ICA had a staff of about 5,800; 1,200 (21%) of these had professional qualifications, including 50 Ph.D. and 413 MS. Only 38% (2,200) of the ICA staff was directly engaged in the work of the Research Department; 391 (18%) of them had professional qualifications; 31 Ph.D., 162 MS, and 198 BA. This level of staffing for research was considerably below that of the early 1970's, principally as a result of resignations of qualified staff in the second half of the 1970's, because of dissatisfaction with working conditions and declining public priority and financing for research.

Since its creation ICA has developed and diffused an impressive body of agricultural knowledge and technologies in crop sciences, livestock, agricultural engineering and socioeconomics, with emphasis on new varieties, new cultural practices, new methodologies and on publications. To illustrate, the National Plan for Technology Transfer (PLANTRA, ICA 1983) identified the following bibliographic references about the technology developed by ICA during 1963-1982.

ICA has generated technological information for 208 species (108 crops, 75 forages, and 25 animal species) detailed in 6,838 bibliographic references (articles, reports, thesis and manuals). Of the references on technology available, 49% were on crops, 29% on livestock, 13% on economic and general support, and 9% on pastures.

On crops, the references were devoted to cereals (23%), grass and forages (16%), legumes (15%), roots (11%), fruits (10%), vegetables (7%), oil palm (3%), multiple crops (2%) and other crops (13%). Regarding livestock the distribution was: bovines (40%), grass and forages (18%), swine (10%), sheep (6%), poultry (6%), rabbits (7%), other species (3%).

Another indicator of ICA's performance concerns the development of 227 improved varieties up to 1980, representing 33 crops. During the 1971-1981 period the total use of certified seeds in commercial crops increased at an annual rate of 7.9%, but since 1978 the rate has been declining. During the 1970's the growth of this agroindustry permitted the country to stop its imports and become an exporter of seeds (Thomas, 1985, p. 140). A similar trend is observed in other inputs such as fertilizers and pesticides (Balcazar 1986 p. 219). A kind of "index of general yields" for the Colombian agriculture[2] is found in National Department of Planning-DNP (1982, Table 15) which could serve to describe the overall technological path for 1960-1980 period. According to this, the annual growth rate in general yields was 5.1% from 1960 to 1975. After that the trend shows a slowdown in the rate of growth, to 2.3% annually for 1975-1980 period.

At the same time, it is claimed that there is underinvestment in agricultural research in Colombia since economic evaluations performed up to now on specific crops show high profitability on the government investment (i.e.: over 60% internal rate of return (IRR) on rice research expenditures). Additionally, there is a decreasing tendency and instability in the allocation of funds for research and extension in the country, as can be observed in Table I.

Even though there are several studies calculating the internal rate of return on investment in specific crops, there is a lack of economic evaluation of the whole agricultural research effort and little economic evidence to guide the

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[2]The methodology of this index is not known at the present time.

TABLE I

PUBLIC SECTOR RESEARCH AND EXTENSION EXPENDITURES
THROUGH ICA, 1960-1982, COLOMBIA
(CONSTANT PESOS 1970=100)

Year	Public Sector Expenditures
1960	84.0
1961	78.8
1962	103.0
1963	70.4
1964	103.7
1965	95.8
1966	119.9
1967	164.5
1968	182.2
1969	191.1
1970	213.5
1971	233.2
1972	245.4
1973	167.5
1974	145.6
1975	151.8
1976	172.0
1977	123.0
1978	154.2
1979	162.1
1980	148.9
1981	177.4
1982	174.3

Source: 1960-1969, Elias (1981, p. 52)
1970-1982, ICA Oficina de Planeación (1984)

[1]Deflated by the Index of Implicit Prices for the GNP.

Note: The loan 2303-CO from the World Bank by U.S. $63.4 million in 1984, could have helped to overcome the observed decreasing tendency in public research and extension expenditures, in constant terms.

Colombian government as to what level of expenditures can be justified in a given set of local circumstances and what return might justify more funds in this area of public activity.

The above contrasting situation leads to a resource allocation problem which can be stated as follows: has the lack of precise economic evidence acted as a disincentive to expand investment in agricultural research, or is the failure to invest due more to a modest performance of the agricultural research system? Is the investment in agricultural research more profitable to society than those in other alternative economic activities? Or, finally, is the national investment in publicly-funded research justified by the economic benefit it generates?

Thus, agricultural research evaluation is of fundamental importance, since it offers useful information to justify the support received by financing institutions and it also offers the basis that allows the resource allocation process to be more effective. This research is oriented to help answer the above questions.

Objectives of the Study

In general, this research has the purpose of providing a conceptual and empirical framework to evaluate economically the global performance of the Colombian publicly-supported agricultural research system during the 1960-1982 period.

The specific objectives are to:

(1) analyze the relationship between several indicators of the agriculture technological change in Colombia (i.e. trends in productivity, input use and output) and the evolution of the agricultural research system during 1960-1982;

(2) build an agricultural productivity index based on total factor productivity approach;

(3) calculate both the average and marginal internal rate of return (MIRR) for the public investment in the whole agricultural research system and to compare these with those in other sectors;

(4) estimate the assumed time lag from the time of the initial investment in research and its impact on production; and,

(5) estimate the indirect benefits due to government expenditures on research.

Working Hypotheses

The observed performance of the Colombian agricultural research system and related financial support can be analyzed by studying the following propositions.

(1) During the 1960-1982 period valuable technical progress has been made in Colombian agriculture but this process has been characterized by a phase of rapid increment in productivity up to the middle of the 1970's and stagnation from that time on.

(2) Allocation of funds to agricultural research in Colombia has been below the optimum level. In this sense, it seems to have an underinvestment in this activity in the country as indicated by the internal rate of return on such an activity in comparison with the opportunity cost of capital in Colombia. Additionally, the internal rate of return of investments in research are favorable compared with those obtained in other sectors of the economy.

Data Sources and Time Period Selected

Time series information to be used in this research has to do mainly with value of production of crops and livestock, labor employed in the crop and livestock sectors, cropped area and pasture land, fertilizer use, machinery and horsepower in agriculture, intermediate consumption in general (fertilizers, concentrates, herbicides, seeds, oil, etc.) This information is found mostly in several issues of Departamento Nacional de Planeación (DNP), Sociedad de Agricultores de Colombia (SAC), and in Norton (1985) and Elias (1985). Regarding the information about public expenditures in research and extension, this is found in Elias (1981) and ICA-Oficina de Planeación (1984). Lastly, the information concerning the input-output matrix is found in Departamento Nacional de Estadistica (DANE) (1982). Appendix B provides more details about the variables and their sources of information.

The period of time selected for this research is from 1960 to 1982. 1960 was selected as the initial year because the information about research and extension expenditures is not well known before that year; and, also to incorporate the technological situation for the years previous to the creation of ICA which was in 1963. 1982 is the ending year selected because in some series the latest figures reported refers to that year. Even so, conclusions coming from studies like the present stand for an extended period of time. Monetary values are expressed in 1970 prices to avoid the problems of the effects of price changes. At the present time, most of the real term statistics in Colombia are expressed using a 1970 base. The price deflator used was the index of implicit prices of gross national product which is the best index available for this purpose in Colombia.

Organization of the Study

The remainder of this thesis is organized as follows: Chapter II deals with the revision of the principal concepts and methodologies available in the literature over the topic in several countries including Colombia. Chapter III is devoted to the description of the methodology to be used in the study, including selection and definition of variables and factors to be considered. Chapter IV contains the principal empirical findings of this research focused on the analysis of Colombian agriculture productivity; the estimation of the productivity change model and the calculations of the internal rate of return and indirect effects are shown in Chapter V. Chapter VI presents the conclusions, recommendations for future research, policy implications, and summary.

CHAPTER II

LITERATURE REVIEW

This chapter reviews the most representative literature concerning agricultural productivity and economic evaluation of investments in agricultural research. It is focused mainly on aggregative level of approaches, models, and conceptualization. Since the literature existing in this particular field is vast, the search has been organized by subtopics to gain efficiency and comprehensibility. The material is presented in the following order: general concepts and definitions; measuring productivity and technological change; evaluation of agricultural research; and, indirect effects of agricultural research. Each sub-topic, in turn, is organized looking for the basic pattern first and then for the deviations from this basic pattern. In doing so, however, it is not always possible to keep citations in chronological order. The Colombian experience is emphasized also.

General Concepts and Definitions

The general relationship between agricultural output and input usage has long been one of the principal indicators of the agricultural performance in a particular country or region. This relationship is called "productivity" and it is a measure of the efficiency with which resources are transformed into goods and services for the society. Such an efficiency can be measured by partial factor productivity (PFP) i.e., ratio of total output to one particular input, or by total factor productivity (TFP), the ratio of total output to total inputs. Usually, when we refer to productivity change we are concerned with changes in such ratios.

The efficiency with which factor inputs are transformed into goods and services is determined, in the most part, by the "technology", that is, by the stock of knowledge available at a particular time. Through time, an increase in productivity means that it is possible to obtain more output using the same quantity of input, or it is possible to obtain the same output using fewer inputs. When society in general or any sector in particular makes progress creating new technology and this technology is incorporated into the economy (general or sectorial), a process of "technological" or "technical" change is underway.

In agriculture, technology and technological change have been identified as a major source of economic growth and progress as documented by Schultz (1953), Griliches (1963), Mellor (1966), and Hayami and Ruttan (1985). As pointed out by Arnt and Ruttan (1977), the capacity to develop technology consistent with physical and cultural endowments is the single most important variable accounting for differences in agricultural productivity among countries (p. 3).

To produce, farmers combine traditional or conventional inputs - land, labor, capital - with nonconventional inputs, mainly research, extension and education. The role of the nonconventional inputs is to modify the quality of the conventional inputs and/or create new inputs. Tweeten (1979) considers that gains in output per unit of conventional resources in U.S. agriculture are the direct result of nonconventional inputs such as new and improved machinery, fertilizers, seeds, pesticides, feeds, and management techniques. In addition, education has shaped the goals and values of farmers and made them more profit conscious and more aware of cost-reducing innovations (Tweeten, p. 138). Extension also plays an important role linking research and farms.

Research, extension and education have been identified as major sources for increasing agricultural productivity in many studies, for example, Schultz (1953), Griliches (1964), Evenson (1968), Peterson (1971), Evenson and Jha (1979), Norton, Coffey, and Frye (1984). Some other authors also include weather as an important variable, such as Powell (1974), Hasting (1981), Cline (1975), and Fox (1985). Of course, other non-conventional factors have been analyzed as being of importance in the process of increasing agricultural productivity. Mansfield (1968) mentions economies of scale and specialization, improved transportation and communication, health and nutrition, among others.

Habtu (1985) following Cline (1975), categorizes research, extension, and education as production-oriented and non-production-oriented activities. Production-oriented activities are those that improve the agricultural productivity by enhancing technology and its application. Alternatively, non-production-oriented sources improve agricultural productivity by altering the social and economic environment in which agricultural production decisions are made (marketing and nutrition research, pest control). These two groups of variables are valid for both public and private activities. Habtu hypothesized then that the observed productivity changes in U.S. agriculture can be explained by production-oriented research and extension carried out by the public and private sector, the level of educational attainment of farmers, weather, and nonproduction-oriented research and extension by both the private and public sector. Based on these sources of productivity, an index of agricultural productivity can be estimated.

According to Arndt and Ruttan (1977) the significance of any technological change is that it permits some substitution of a less expensive and more abundant resource - knowledge - for more expensive and often scarce resources - land, water, and the like. Technology releases the constraints imposed upon growth by inelastic resource supplies. The constraints imposed on agricultural development by, for example, an inelastic supply of land may be offset by advances in biological technology. The constraints imposed by an inelastic supply of labor may be offset by advances in mechanical technology.

de Janvry (1985) points out that technological change can be characterized by its bias and its rate. The bias of technological change is given by the difference in the rates of change in the marginal productivity of factors due to technology. It measures which factor of production is made relatively more productive by technology and, hence, which factor is for substitution in production. Technological change can, for example, be land-saving or labor-saving according to whether it increases most the rate of change in the productivity of land or that of labor.

Regarding underdeveloped countries, the best way to understand the key role of the technological change in agriculture is to analyze the role of the agricultural sector in the development process in such economies. The most important forms in which increased agricultural output and productivity contribute to overall economic growth can be summarized in the following prepositions (Johnston and Mellor, 1961, p. 5).

(a) Economic development is characterized by a substantial increase in the demand for agricultural products, and failure to expand food supplies to keep pace with the growth of demand can seriously impede economic growth.

(b) Expansion of exports of agricultural products may be one of the most promising means of increasing income and foreign exchange earnings, particularly in the early stages of development.

(c) The labor force for manufacturing and other expanding sectors of the economy must be drawn mainly from agriculture.

(d) Agriculture, as the dominant sector of an underdeveloped economy, can and should make a net contribution to the capital required for investment and expansion of secondary industry.

(e) Rising net cash incomes of the farm population may be important as a stimulus to industrial expansion.

It is apparent that as the development process advances, the demands on the agricultural sector increase. Given the limitation of traditional resources (land, labor) and the high cost of incorporating them in the production process, the alternative of increased factor productivity as a result of technological improvements is crucial for the development process.

Measuring Productivity and Technological Change

Every year, the agricultural sector as any other productive sector, makes use of determined quantities of productive resources of the economy such as land, labor, fertilizer, fuel, and machinery, from which results a corresponding flow of agricultural products. The simple question to be answered in this case is how much output is obtained from the resources. A productivity measure can be used to answer the question by means of a number which enables the researcher to compare times, sectors, and places. There are, however, many ways to construct ratios of outputs to inputs, since there are alternative ways to measure outputs and inputs and to aggregate output and input categories. This, in turn, raises many conceptual and empirical problems as stated by Loomis and Barton (1961), Griliches (1960), and Christensen (1975).

The Task Force on Measuring Agricultural Productivity identifies the critical points raised as being:

(1) obtaining appropriate measures of inputs used;

(2) capturing changes in quality of inputs; and,

(3) obtaining appropriate weights on input and output categories and keeping weights updated (USDA 1980).

As pointed out at the beginning of this section, two main types of commonly used productivity measures can be distinguished according to their handling of inputs: partial productivity and multifactor or total factor productivity. In what follows, a review of the several modalities or classifications concerning those measures are presented.

Partial Productivity Ratios

Partial factor productivity (PFP) ratios relate agricultural output to a single output, and because of that, many partial productivity measures can be calculated, such as labor productivity (Y/L), land productivity (Y/A), and capital productivity (Y/K) where Y stands for output and L, A and K for labor, land (acres) and capital, respectively.

For Fitzharris (1974), the basic measure of productivity is the amount of output produced by worker (labor productivity), which can be divided into two components: growth in land per worker (A/L) and growth in output per acre (Y/A) together form the output per worker (Y/L). This is the approach used previously by Hayami and Ruttan (1977). Using a multiplicative relationship it is possible to analyze the direction of innovations in the agricultural sector, as follows:

$$Y/L = A/L \cdot Y/A$$

If, for example, the technology increases the acreage a worker can utilize in the same amount of time and then increases the acreage per worker (A/L) ratio, the innovation is said to be labor-saving. The change may reflect increasing scarcity of labor as the price of labor is increasing relative to the price of land. Land-saving innovation, on the other hand, increases the amount of output per acre (Y/A); in this case the price of land has been increasing relative to the price of labor and it may reflect increasing land scarcity.

Labor productivity as a partial index of agricultural productivity can be a meaningful performance measure if labor is the dominant fraction of total input as it is in many of the underdeveloped countries. But the index does not measure the output obtained from other important agricultural inputs such as machinery, fertilizer, and other capital equipment. That is why some multifactor approach is necessary when measuring productivity. This approach comes with the modernization progress in agriculture as pointed out by Ruttan (1986):

> The beginning of modernization in agriculture is signaled by substained growth in productivity. During the initial stages of development, productivity growth is usually accounted for by improvement in a single, partial productivity ratio, such as output per unit of labor or output per unit of land. As modernization progresses there is a tendency for growth in total productivity - output per unit of total input - to be substained by a more balanced combination of improvement in partial productivity ratios (p. 334).

Total Factor Productivity

The simplest way to calculate total factor productivity is using a ratio dividing total output by an index of total input without any weight to reflect the importance of each input in the production process. The construction of an aggregate input is a major difficulty since disparate quantities such as hours of work, acres of land, pounds of fertilizer, and number of tractors need to be combined to produce a single input measure. The common method to aggregate is by using monetary value.

Because of the lack of weights, the simple ratio to express total factor productivity is not used very often. To overcome the problem, economists use two general approaches: the index number approach and the production function approach, as described below.

Index Number Approach

At least three general index number methods to measure productivity can be identified: arithmetic, geometric, and Divisia formulas. The arithmetic formula combines inputs with constant factor prices as weights. This formulation implies that the underlying production function is linear and homogeneous (Lu, 1975). Several studies on productivity change in agriculture have used this approach, for example, Loomis and Barton (1961). Kendrick (1961) also used arithmetic index to study the rate of change in total factor productivity in the American economy for the 1899-1957 period. According to Evenson and Jha (1974) the arithmetic index has been shown to be a poor measure of production function shifts when factor ratios change. The official USDA agricultural productivity index has also been computed with an arithmetic formula since the Loomis and Barton study.

The geometric formula combines inputs geometrically and relative factor shares are used as weights for aggregating inputs. In this regard the geometric index is superior to the arithmetic index. The geometric index implies a multiplicative aggregation as in the Cobb-Douglas production function. Solow (1957) used the geometric approach in a study of technical change in the United States for the 1909-1949 period, with two production factors: labor and capital. Nevel (1969) also used Solow's approach in the study of technological change in American agriculture for the 1950-1966 period. He introduced some modifications in defining capital to include three distinct categories: (a) land, buildings, livestock, and other inventories; (b) farm machinery and equipment; and, (c) intermediate purchased products such as feed, seed, fertilizer, etc.

Neither, the arithmetic approach (fixed coefficients) nor the geometric approach (Cobb-Douglas) are likely to be the correct specification with changing relative prices, so serious bias remains a concern with either of the two approaches. An approach which has received attention to overcome the problem is the Divisia index. This index is a weighted sum of growth rates, where the weights are the input component's shares in the total value of inputs used; in addition, the weights are changed often. The Divisia index allows the researcher to estimate total factor productivity growth, that is not biased by the lack of factor substitution possibilities.

This approach has been used by Evenson and Jha (1974) in a study about the contribution of the agricultural research system to agricultural production in India. Recently Habtu (1985) used the Divisia index approach to recalculate the USDA productivity index. Shoemaker and Somwaru (1986) also worked with a Divisia index to calculate the total factor productivity in the dairy sector in U.S.A.

The geometric index and the Divisia index have the important feature that they permit the researcher to analyze and determine the sources of growth in output between the growth in factor inputs and technological change. Using the relationship that growth in output should equal the weighted-average growth in inputs, it is possible to determine the sources of growth in output and its rate of change.

To conduct the above analysis and assuming an aggregate production function structure, an expression as follows may be used:

$\hat{Y} = W_K\hat{K} + W_L\hat{L} + W_M\hat{M} + \hat{A}$ (Shoemaker and Somwaru 1986, page 10); where w_i are the factor share weights of total output and the hat (^) means proportionate ratio of change. Y represents output and K, L, and M denote capital, labor and materials, respectively. The residual, or A is the portion of output growth not explicitly explained by input growth, that is, the portion attributed to productivity growth. The equation can be also expressed in percentage terms.

Production Function Approach

The main difference between the production function approach and the index number approach is that the former defines explicitly the form of the production function; also, the production function approach allows the researcher to test statistically the significance of its parameters.

In trying to analyze the role of nontraditional inputs on productivity changes over time, two methods have been employed: adjusting inputs for quality differences; and explicitly recognizing nontraditional inputs as explanatory variables. In the first case, changes in quality of conventional or traditional inputs can happen in several ways. Education, training and experience are factors likely to improve labor productivity; quality of capital inputs is also improved over time (e.g. more energy efficient).

Under the second possibility, it is assumed that research, extension, and education affect quality but their effects are estimated separately in the production function in such a way that is possible to differentiate the influence of traditional inputs from nontraditional inputs. Doing so, it is possible to infer the role of public and private efforts in research, extension and education.

Another source of difference using the production function approach concerns the restrictions imposed on the production function. Two general cases exist: a priori restrictions and no a priori restrictions. Most of the research estimating such production functions used a priori or restrictive formulations that may have biased results. Notably, the Cobb-Douglas production function, which assumes separability among inputs, has been used. The constant elasticity of substitution (CES) production function also has been used with some frequency. Recently, however, attempts to use flexible or variable elasticity of substitution (VES) has been made. See for example, Lu (1975) and Lyu, White and Lu (1984). These attempts try to overcome some of the bias by using restrictive Cobb-Douglas formulations, but at the present time these studies are not so conclusive, to abandon using the Cobb-Douglas production function.

Whatever the production function, this approach often faces serious econometric problems, mainly multicollinearity in time series estimation. Some authors assume or calculate distributed lag model on research and extension variables to reduce the number of parameters to be estimated and then deal with the multicollinearity problem as discussed by Evenson (1968), and Cline (1975).

Some other representative studies using the production function approach to measure agricultural productivity are Griliches (1964), Hayami and Ruttan (1971), and Hertford (1971).

Regarding the Colombian experience on agricultural productivity studies up to 1976, this has been summarized by Atkinson and Berry. Atkinson (1969) used partial productivity indexes to analyze the Colombian agricultural sector for the 1948-1968 period. He concluded that over the twenty year period there was a limited technological change in crop production and indicated that the restrictions on imports of some inputs like fertilizers and chemicals were a serious constraint on improving technology. In another study about agricultural productivity in Colombia, Atkinson (1970) found that total production per unit of input, increased at an annual rate of 1.6 percent during the 1950-1967 period, and total agricultural production increased at an annual rate of 3.0 percent, but this progress has been uneven, with the highest gains for crops such as cotton, rice, sugar cane, and poultry. Also, one-half of this growth was attributed to an increased land use and the remaining growth to greater yield.

Berry (1971), in his study on income distribution and efficiency of Colombian agriculture, concluded that the growth of agricultural production until 1950 was explained mainly by the growth of traditional inputs. From 1950 on, the technological change became more important.

Orozco (1977) relates the Colombian experience using the Cobb-Douglas production function, especially the studies carried out by Bostwick (1968) and Rojas (1967). He concludes that even though there have been no previous aggregate level studies in Colombia, the studies cited proved the Cobb-Douglas to be useful for production economic research in the country. The main gap in the studies undertaken in Colombia at that time were that they did not identify the sources of growth, they did not determine the contribution of inputs to growth in agriculture, and they did not measure systematically total factor productivity through time. Thus, Orozco worked to fill these gaps. Furthermore, his attempt incorporates in the analytical framework nonconventional factors such as research and extension, credit and education.

Orozco fitted production functions for the crop sector and for livestock and calculated total factor productivity for the 1950-1971 period. The relevant sources of total productivity growth in Colombia's agriculture were rural education, agricultural credit, and research and extension. He also used the factor share method to calculate evolution in productivity and he found that the underlying production function for both crop and livestock sectors has remained stable during the 1950-1971 period, meaning that the production movements have taken place mostly through movements along the same production function and not through shifts in the aggregate production function (p. 140). However, Thomas (1985) points out that during the last decade there was a positive association between rates of growth of agricultural production and the use of improved production inputs such as fertilizer, certified seeds, and machinery (p. 136).

Economic Evaluation of the Agricultural Research

A considerable range of methods and procedures are now available for evaluating the economic contribution of agricultural research and extension. Schuh (1979) classifies these methods and procedures into two groups:

(a) ex-post procedures which attempt to evaluate research efforts that have been underway for some time (after the facts sense); and,

(b) ex-ante procedures which attempt to assess the research effort before the fact.

The ex-post procedures generally attempt to evaluate the effect on agricultural output, combining quantitative evaluations of these effects with costs of bringing about the observed changes. On the other hand, the ex-ante procedures generally start with specific goals and objectives for the research, evaluating alternative research projects to the attaining of these goals and their costs.

Ex-Post Studies

According to Norton and Davis (1981) ex-post evaluations fall into two major groups:

(a) those using consumer and producer surplus directly and estimating an average rate of return to research; and,

(b) those that estimate a marginal rate of return to research (and extension) by considering research as a production function variable.

In addition to these two approaches, we consider the pioneer work by Schultz (1953) as a third approach for evaluating the contribution of the agricultural research, which is known as "input saved approach".

Input Saved Approach

Schultz (1953) performed the first attempt for quantifying the returns to investment in agricultural research looking at the United States agriculture as a whole and by calculating the value of input saved due to more efficient productive techniques compared to the investment on research and extension. However, in applying this approach, Schultz confronted an index number problem since relative factor prices change over time. To overcome the problem he used price weights from the end and from the early part of the period for calculating lower and upper limits for the resource saved.

By calculating the amount of resources that would have been needed to obtain the production level of a base period using the techniques of production of an earlier period, he was able to estimate the resources savings. Comparing these resources savings versus the resources actually used in current production gives an estimate of the resources saved.

According to this approach, the value of the resources saved represents the benefits obtained from the agricultural research and extension effort. With the benefits estimated and with the cost of carrying out research and extension, a benefit-cost ratio or the social rate of return can then be calculated.

To calculate the value of inputs saved in 1950 compared to 1910, Schultz estimated the agricultural product being 32% higher in 1950 than in 1910. To have produced the 1950 output, which employed $30 billion in resources (using 1910-1914 prices), with 1910 techniques, additional resources by $9.6 billion would have been required, attributing the difference to the improved techniques used in 1950.

He also calculated the value of inputs saved using 1946-48 price weights. The value of 1950 level of production using 1910 techniques would have been $16.2 billion in additional inputs, which were saved by productivity gains.

Schultz himself argued that the estimates could be biased since other things also contribute to raise the level of agricultural productivity, for example, education, public roads, television which are not accounted for in conventional inputs. In addition, estimates may include gains coming from the private sector and not only from public oriented research.

Peterson (1971) used a similar approach with more recent data (1950-1967), finding an even more favorable picture for agricultural research than was the case from 1910-1950. In 1907 alone, the value of the inputs saved amounts to $25.9 billion. This value compares favorably to the bill for research and extension which was $9.5 billion for the period 1950-1967. Peterson also calculated internal rates of return by periods based on this approach. The rates of return he obtained were: 81% for the period 1942-1947, 53% for 1952-1957, and 42% for 1962-1967.

Another approach for assessing the impact of the agricultural research was used by Tweeten and Hines (1965) which is similar to the input-saving approach since they deal with resources the agricultural research releases from the agricultural sector to the non-farm sector. They worked on the notion that national income growth is due to increments in agricultural productivity allowing out migration of workers to the urban areas where they have a higher marginal product and hence greater salaries. The benefits of research results from calculating how much lower the national income would be if the percentage of farmers was still the same as in 1910, and the resulting additional farmers had the income of today's farmer instead of today's nonfarmers. Combining the estimated benefit with the costs of public and private research, education, and federal programs, the calculated benefit-cost ratio was 2 to 1.

Economic Surplus Approach

This approach uses the concepts of consumer and producer surplus to measure the benefits derived from agricultural research. To review the theory and applicability of these concepts see Currie et al. (1971) and Hertford and Schmitz (1977) for their use in measuring the returns to agricultural research.

The remainder of this section will present the basic model using the economic surplus approach and the departures from it.

Basic Model. For any agricultural commodity, the technological change made possible by the research and extension is assumed to shift the supply curve for the product to the right as despicted in Figure 1 (from S to S'). This shift in the supply curve produces a change in the consumer's surplus by the area P_0ABP_1. Consumers benefit from technological change having more of the commodity available and at lower price (general case). Producers may

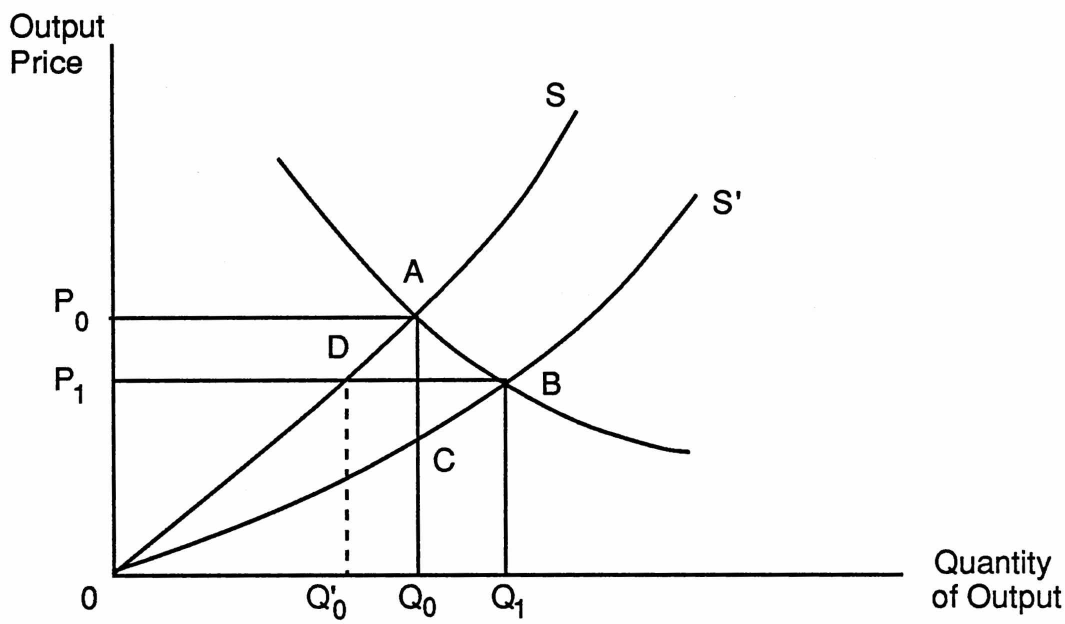


Figure 1. Basic Model for the Analysis of Agricultural Research Using Consumer and Producer Surplus

benefit from the reduction in cost of production. The same shift in supply produce a change in producers surplus by the area BDO minus the area P_0ABP_1. The total change in economic surplus (producer plus consumer surpluses) will be the area AOB which is the net social gain or benefit as a consequence of a particular technological change. Clearly, the quantity of the commodity increases from Q_0 to Q_1 and the price declines from P_0 to P_1.

This basic model can be used for analyzing several aspects of agricultural research. To estimate benefits from research knowledge is required about how much the technical change shifts the supply curve and about the parameters of supply and demand curves for the commodity. Then, the benefits are combined with the research (and extension) costs to obtain a benefit-cost ratio or an internal rate of return in the conventional way. After that, it is possible to evaluate the economic performance of one particular research program and to make a judgment about the economic efficiency in using given resources in that program. The main departures from the basic model are described below.

Distributive Aspects. The economic surplus methodology also permits analysis on how the benefits of research are divided between consumers and producers by analyzing the demand and supply curves. As is apparent from Figure 1, producers can lose from the technological change if area P_0ADP_1 is greater than the area BDO. In fact, this kind of distributional analysis has been carried out by many authors.

Some studies have permitted additional details in the analysis of the distributional impacts. For example, Scobie and Posada (1978), in a study about technical change in Colombia rice production, considered the incidence of research costs and the distribution of benefits among upland producers, irrigated producers, and consumer strata (high and low income). They concluded that while consumers obtained the larger part of benefits, small producers lost the most. Schmitz and Seckler (1970) examined the mechanical tomato harvester as an innovation that caused unemployment among farm workers. This situation represents a sacrificed return and it must be subtracted from the benefits.

On the producer side, Ayer and Schuh (1972) analyzed which group of factor owners received the benefits of the technological change in cotton production in Brazil by analyzing the characteristics of demand and supply for the individual input categories. They estimated 60% of the benefits going to producers and 40% to consumers. Also, landowners and managers received a large part of the benefits. Even though labor did not benefit in higher wages, it did benefit through greater employment.

General Equilibrium. Even though economic surplus is basically a partial equilibrium concept, Peterson (1967) has studied the way to use this concept to take account of general equilibrium effects. Agricultural technical change modifies resource productivity, which in turn induces the resource use into the progressive sector or expels the resource from it. Peterson's procedure is based on the fact that if price elasticity of demand were -1, the total value of any price-quantity combination along the curve is the same. The relation between the unit elastic demand curve and the actual demand curve provides the means for taking account of the general equilibrium aspects (Figure 2).

To see the adjustment for general equilibrium effects, assume a decline in productivity. As a consequence, social benefits decrease by areas L + J + G, made up by consumer and producer surpluses. The decrease in output, Q_0 Q_2, is due to a withdrawal of resources from the agricultural sector, which have an opportunity cost represented by areas K + I + E + D. There is also a loss in

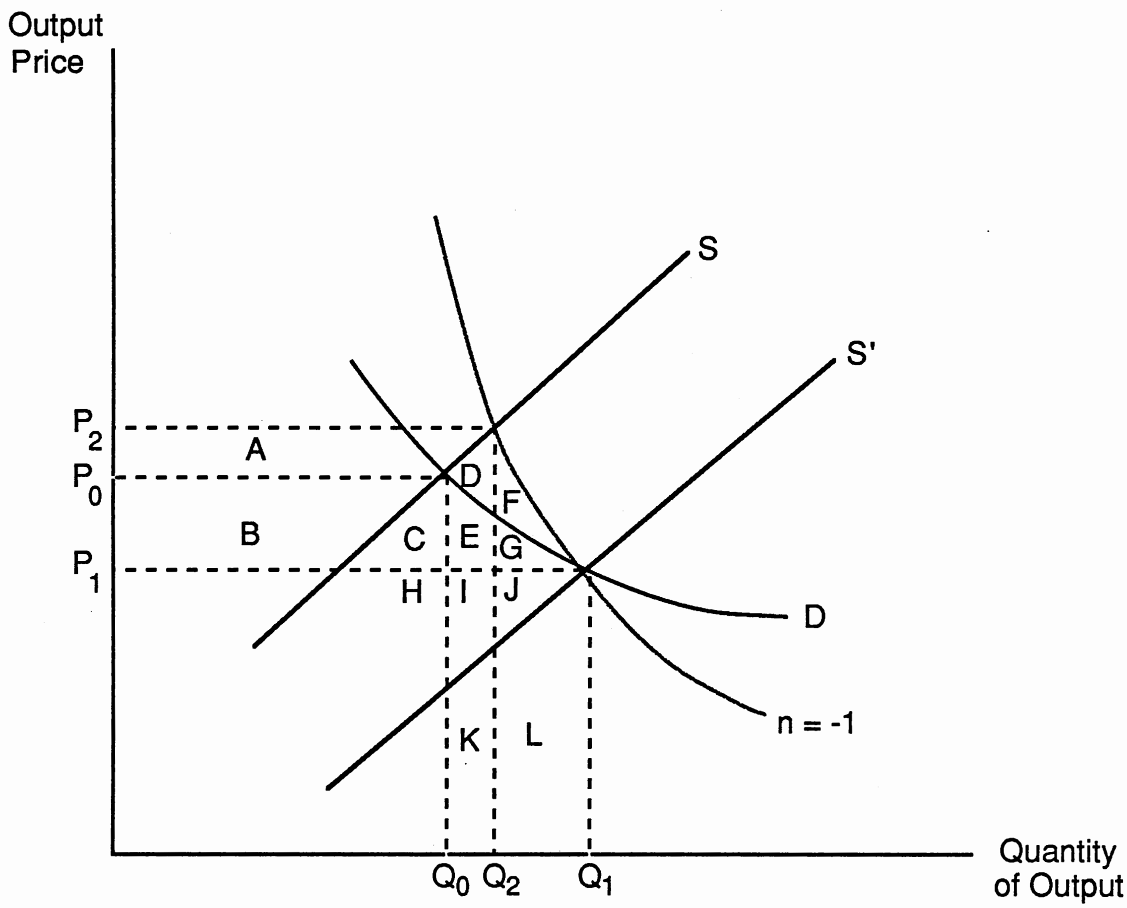


Figure 2. General Equilibrium Effects Associated with a Supply Shift

consumer surplus by K + I + E. Therfore, there is a net gain due to the "freeing" of resources represented by area D. This area needs to be subtracted from the social benefit in the partial equilibrium framework.

Open Economy and Trade. The economic surplus approach can be modified to take account of some indirect effects such as the impact on trade. If the agricultural technical change occurs for a product being exported and if the demand elasticity is high, then the benefit of the research program will accrue to producers. Economic surplus also permits the analysis of the case when the commodity is or has been imported. For example, Aquino and Hayami (1975) estimated the social benefit in Japan for rice breeding research. Assuming market equilibrium and no rice imports the change in net surplus due to research equals ABO (Figure 3). D and S represents actual demand and supply, and S' supply in absence of improved varieties. Without the increased production due to research, Japan would have to import rice at a total cost of $ACQ'nQ_o$ (foreign exchange) to keep the price at P_o.

Evenson and others (1978) also examined a similar situation in the Phillipines in which imports have been utilized to maintain a stable price for consumers, with sufficient rice imported to maintain a target price of P_1 in Figure 3. The quantity CA would have been imported with the original supply function. The movement of the supply function to S' would eliminate rice imports. The area OCA represents a gain to society and is equal to the change in the resources devoted to domestic rice production (OAQ_o - OCQ'_n) plus the value of the imports in the initial situation, Q'_nCAQ_o.

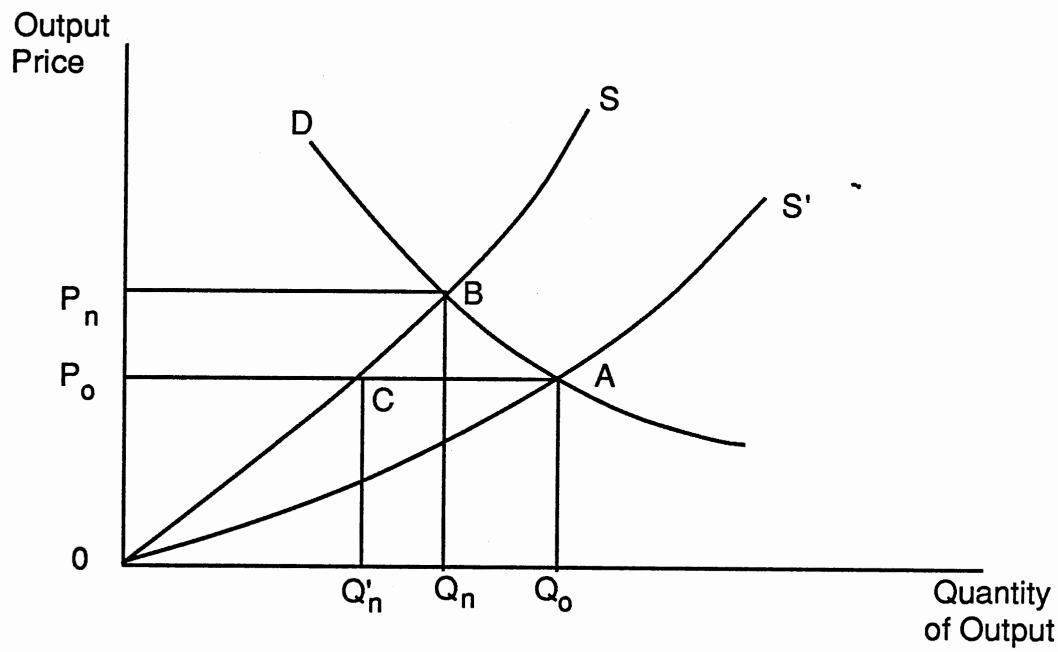


Figure 3. Rice Supply Shift Due to Breeding Research.

Special Situations. The relative flexibility of the economic surplus has permitted the study of different problem situations which are managed by assumptions and calculations about demand and supply elasticities, shifts in the supply function due to the technological change, and other relevant parameters. What it follows is a representative sample of these studies in addition to those described previously.

Griliches (1958) assumed that all benefits of agricultural research in hybrid corn were realized in the form of a consumer surplus; he calculated upper and lower limits of the benefits of this research. These two estimates of the consumer surplus were made by assuming the supply curve to be perfectly inelastic (parallel shift) or perfectly elastic (horizontal shift) (see Figures 4 and 5). He also assumed a unitary demand elasticity. These assumptions permitted him to make no estimates of demand and supply parameters, ignoring distributional, general equilibrium, and trade problems. In Figure 4 the change in consumer surplus is equal to E + F, which can be estimated by KP_1Q_1 (1 - 1/Kn) where:

$$K = \frac{\Delta P}{P_1}$$

and N is the absolute value of the demand elasticity. In Figure 5, the change in economic surplus is A + B - A + C, which equals KP_1Q_1 (1 + 1/2 K/N) where:

$$K = \frac{\Delta Q}{Q_1}$$

On the other hand, Peterson (1967) developed a formula for estimating net social surplus changes for poultry research. In Figure 2, when price and quantity move from P_1 to P_2 and from Q_1 to Q_2, respectively, Peterson's

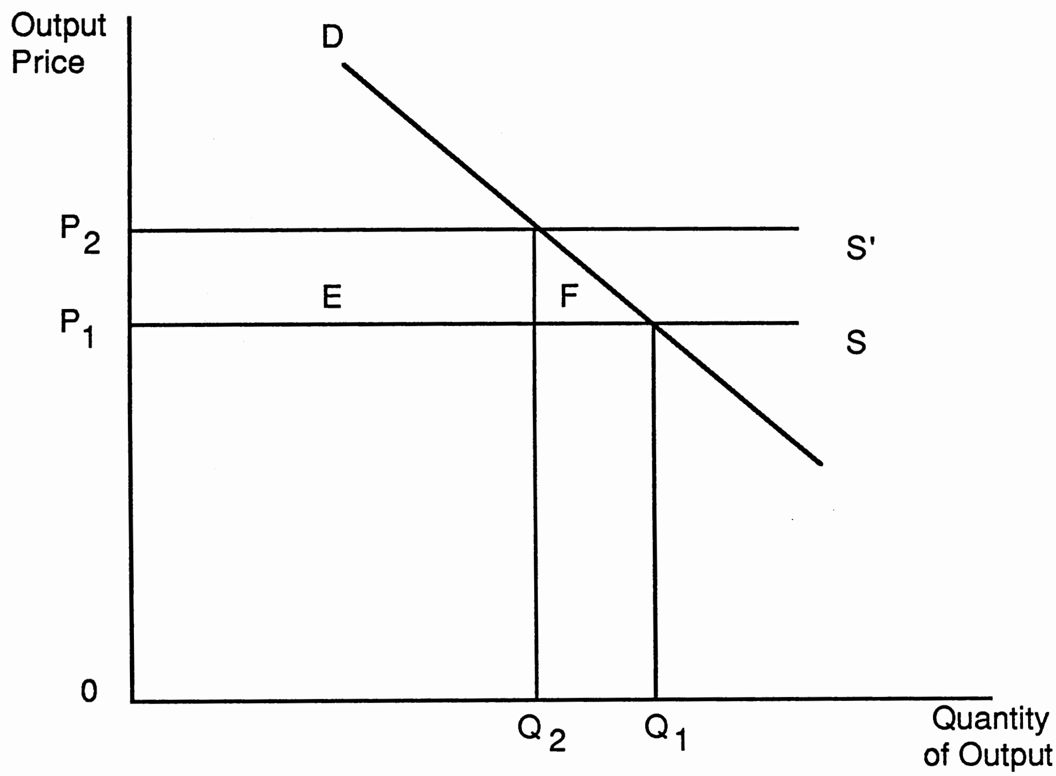


Figure 4. Hybrid Corn, Perfectly Elastic Supply

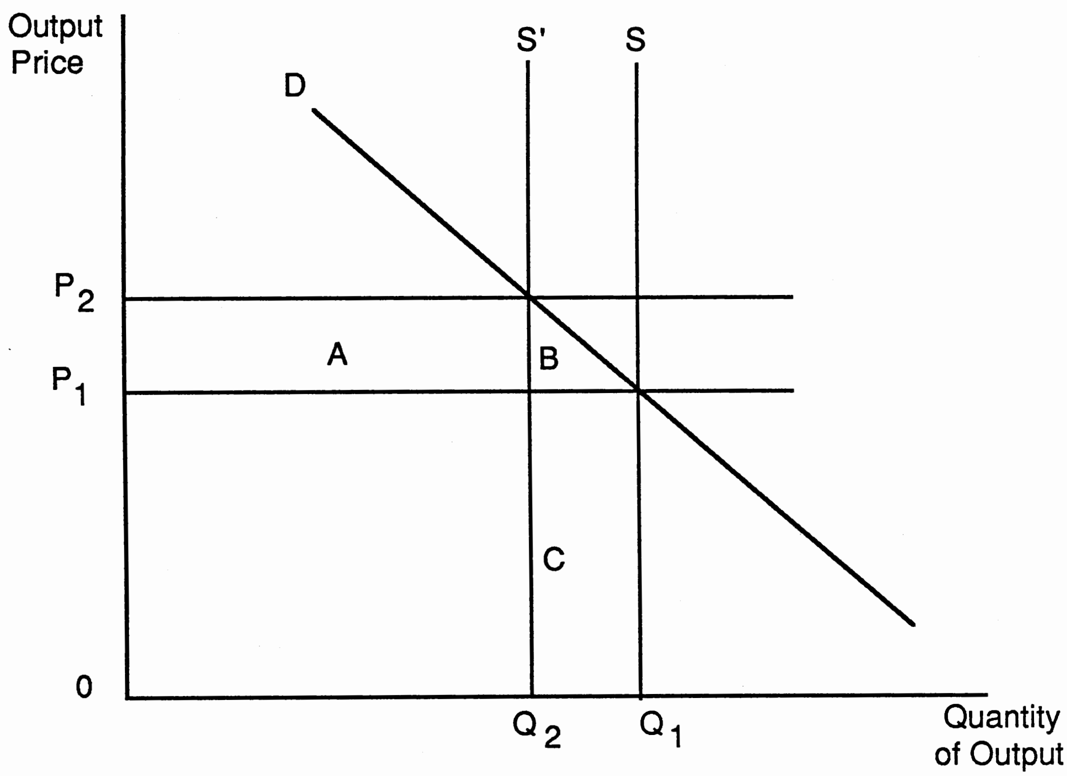


Figure 5. Hybrid Corn, Perfectly Inelastic Supply

change in economic surplus is equal to C + E + G + H + I + J or I + J + K + L + E + G - D; he provided the following expression to approximate it:

$$KQ_1 P_1 + 1/2\, K^2 P_1 Q_1 /n - 1/2\, Q_2 K^2 P_1 \left(\frac{P_1}{P_2}\right)\left(\frac{en}{n + e}\right)\left(\frac{n - 1}{n}\right)^2$$

where n = absolute value of the demand elasticity, e = the supply elasticity, and K = the percentage shift in the supply curve

$$K = \frac{Q_1 - Q_2}{Q_1}$$

The first expression reduces to:

$KQ_1P_1\ (1 + K/2n)$ if n = 1 or e = 0

These two extreme works illustrate the flexibility of the economic surplus in evaluating the agricultural research: on one side, Griliches' simple analysis, on the other side Peterson's more precise estimation. In some sense these two studies show that the principal aspects to take account for in this kind of evaluation have to do with specification of demand and supply function, elasticities of demand and supply, and the nature of supply function shift (K). The size of K is a major determinant of net benefit. In some cases K has been measured as an output effect (horizontal shift in the supply curve) and in others as a cost effect (vertical shift in the supply curve).

Duncan used the consumer-producer surplus approach in a somewhat different manner. He estimated the benefits of research that increases of a product which, in turn, is an input into the production of another commodity (derived demand). The increase in productivity moves the demand curve for the input from ID_1 to ID_2 (Figure 6). The benefits from the increment in productivity are presented by the shaded area; this benefit accrue to the producer because

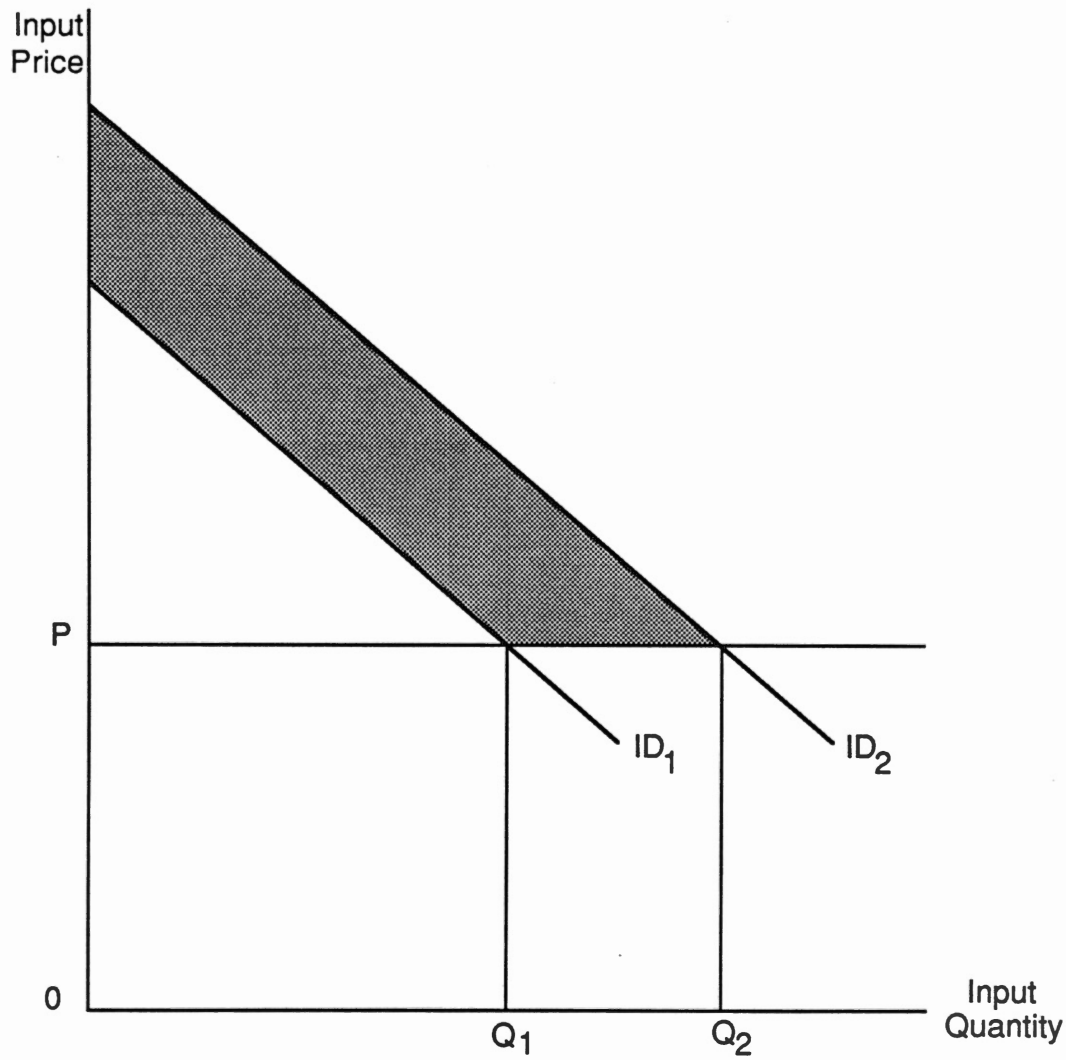


Figure 6. Increased Productivity and Demand for an Input

he assumed a perfectly elastic demand curve for the final products. Duncan uses the research leading to a new pasture technology as an example (Norton and Davis, 1981).

Rose (1980) tries to avoid some of the biases arising from specific assumptions about supply shift (parallel or pivotal) and elasticities by using a kink in the supply curve and a generalized formula:

$$\Delta NS = 1/2\ Q_0\ (KP_0 + A_0 - A_1) + 1/2\ KP_0\ (Q_1 - Q_0)$$

where ΔNS equals change in total net social surplus (Figure 7).

The above formula corresponds to the benefits of the research, that is, to the area $A_0M_0BA_1 + M_0M_1B$.

The representative studies about the Colombian experience using the economic surplus approach are: Rocha (1972), Ardila (1973), Montes (1973), and Trujillo (1974). The principal findings can be found in Hertford, Ardila, Rocha and Trujillo (1977) which summarizes results for rice, soybeans, cotton, and wheat. The estimated internal rates of return (IRR) were:

Crop	Time Period	IRR
Rice	1957-1972	60-82
Soybeans	1960-1971	79-96
Wheat	1953-1973	11-12
Cotton	1953-1972	0

The IRR for cotton was reported by the authors to be zero under the assumption that the benefit of increments in cotton productivity cannot be attributed to the national program since producers could select the varieties from U.S. sources by themselves. However, if the national research program did play an important technological role in selecting, adapting, maintaining, and managing foreign and native cotton varieties, a positive internal rate of return can be attributed to the investments in the national program. According to

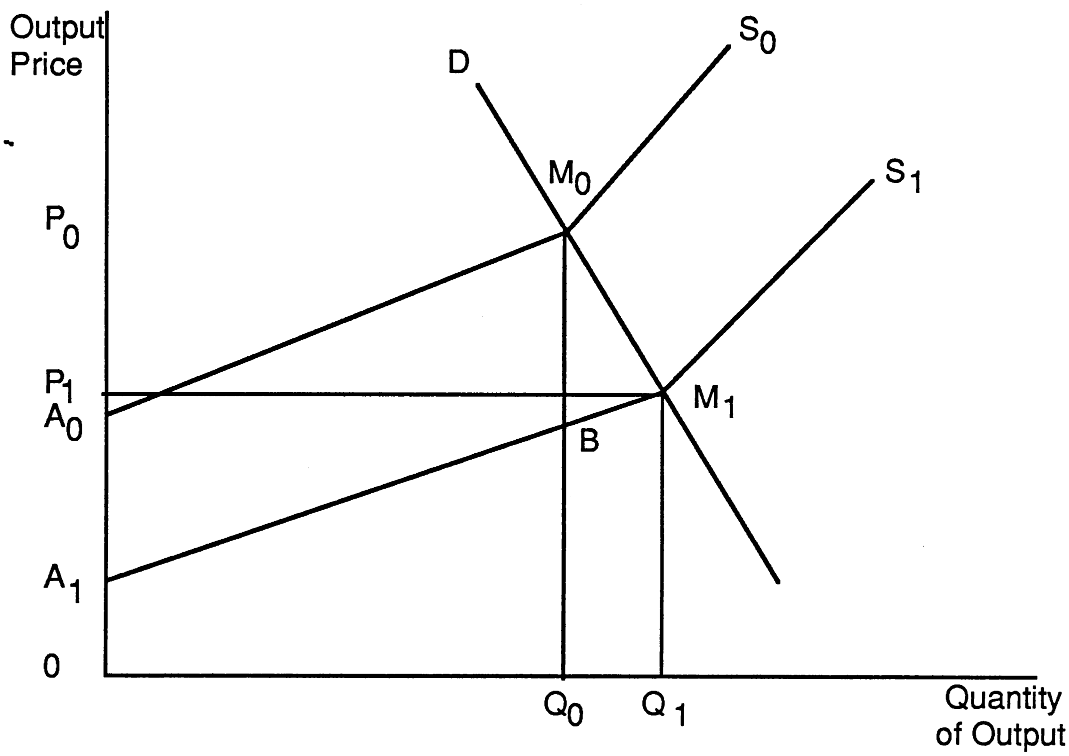


Figure 7. Rose's Generalized Case with Kinked Supply Curve

Evenson and Jha (1974) it has not been possible to effect a simple transfer of technology internationally within a country if the technology is not "new" or at least modified (p. 224).

Production Function Approach

The production function approach has been one of the most popular methods for assessing the impact of agricultural research, extension, and other variables on agricultural productivity. This is done mainly by estimation of the marginal internal rate of return (MIRR) to agricultural research and extension.

As in the case of economic surplus approach, the basic model using production function approach will be presented first then and some of the most important departures from it, or the different sources of variation when estimating the model.

Basic Model. The production function approach assumes that a change in research and extension investments is expected to produce quality changes in inputs, and this, in turn, affects the output-input relationship. The production function approach includes research and extension variables directly in the production function for measuring the impact of research and extension on agricultural output.

According to Davis (1981) the most common model used in the production function approach is given by:

$$Q = A \prod_{j=1}^{m} X_j^{B_j} \prod_{i=0}^{n} R_{t-i}^{\alpha t-i} e^{\mu}$$

where:

Q = value of agricultural output

A = a shift factor

X_t = the conventional inputs

R_{t-i} = the expenditures on research in years t to t-n

B_j = the production coefficients on the conventional inputs

α_{t-i} = the partial production coefficients of research

$$\alpha = \prod_{i=0}^{n} \alpha_{t-i}$$

μ = the random error term.

To assess the impact of any of the variables (i.e. research) a two step procedure is followed:

(a) estimation of the value of the marginal product of research, by multiplying the research production coefficient times the average product of research.

(b) estimation of the MIRR, which is the discount rate that equates the discounted flow of the benefits with the discounted research costs.

As in the case of the economic surplus approach, Griliches (1964) was also the first who used the production function approach to evaluate the contribution of research to production. The main departures form the basic model are described below.

Type of Data Used. Most of the time, the above model has been estimated using cross-section data, as did Griliches (1964) for U.S. agriculture. He used aggregate output and specified research and extension as expenditure of state and agricultural experiment station, and extension. He reported a marginal product for research and extension of about $13, that is, each dollar invested in research and extension contributed $13 in product increment. Norton (1981) also used cross-sectional data to estimate marginal internal rate of return for group of commodities (cash grains, dairy, poultry, and livestock), showing how to reallocate resources from low to high return commodities, as Bredahl and Peterson (1976) did in a previous work. Norton also used his model to test if the coefficient for the research variable for the commodities had changed from 1969 to 1974 and for studying research externalities, weather difference, and land quality differences across states.

Peterson (1967) in his poultry research, fitted cross sectional data over states, including poultry research as a separate variable in a Cobb-Douglas production function. He estimated a marginal rate of return of 33%.

Time series studies use different production function specification to avoid typical econometric problems when working with time series, especially the problem of multicollinearity. The alternative specification has become:

$$P = A\, W^{r}\, E^{e} \prod_{j=0}^{n} R_{i-j}^{\alpha t-j}\, e^{\upsilon} \quad \text{(Norton 1981)}$$

where:

P = Productivity index of agricultural output

W = Weather index

E = Education level of farm workers.

Evenson (1967) used a model like this to study the effect of research and extension on productivity. He fitted time series data for the U.S. (1938-1963) and cross section data for states, using a productivity index as dependent variable and research and extension expenditures, weather index, and an index of educational level as independent variables. He found the marginal internal rate of return for research and extension to be 57%. Taking into account private research reduces this rate to 48%.

Cline (1975) used a model of this kind for aggregate agricultural output for the years 1939-1972, and information about 10 states. He used a Cobb-Douglas production function and estimated the national internal rate of return to be 26%; ranging from 54% for states in the Pacific region to 17.5% in the Southern Plains.

Length of Time Lag. In time series studies one of the most important sources of variation has been the length and shape of the time lag that exists from the initiation of the expenditure in research and its impact on output. According to Evenson (1967) there are three different lags:

(a) the lag between research expenditure and relevant research output discoveries;

(b) the lag between these discoveries and the use of new production techniques embodying these discoveries; and,

(c) the lag which incorporates the diminishing impact on production of a new discovery due to the depreciation of these discoveries.

Two main approaches to manage this problem have been used. In earlier studies a total research production coefficient was estimated:

$$\alpha = \prod_{i=0}^{n} \alpha_{t-i} \quad \text{(Davis 1981)}$$

Griliches (1964) and Peterson (1967) used a single research and extension variable with weighted average of two or more years' expenditure levels. Bredahl and Peterson (1976) included the level of expenditure in a single year as the significant variable. Evenson (1967) have used an inverted "V" or "U" shaped distribution with a mean lag of six to seven years. This latter estimation has been assumed by most of the subsequent studies about agricultural research and productivity.

The other approach is the partial estimation of the research coefficient. This approach was followed by Cline (1975) who used an Almon distributed lag model to estimate the length of lag between investment and the beginning of returns which was also about six years. White and Havlicek (1982) confirmed Evenson's finding since they report that research and extension expenditure in year t will have their greatest contribution to agricultural productivity in the sixth and seventh year, and the impact of these expenditures in each of these years is four times as great as their impact in the first year.

Functional Form and Variable Specification. The functional form of the production function which is almost always used is the Cobb-Douglas production function, mainly because it is easier estimated. Recently, however, its use in agricultural production has been questioned due to the restrictions underlying the Cobb-Douglas function which can bias the result. These restrictions refer to homogeneity, unitary elasticity of substitution among inputs and separability.

"Flexible" functional forms for estimating production functions are thought to be adequate to overcome these restrictive assumptions. One of these functions is the transcendental logarithm (translog) which does not assume constant or unitary elasticity of substitution between inputs. Also, the separability and homogeneity properties can be tested by the translog. While the translog has this advantage, it has some serious limitations, mainly concerning the number of parameters to be estimated which are more than in the case of Cobb-Douglas function; secondly, the curvature conditions of the production function can be violated.

Lyu, White, and Lu (1984) worked with the translog and the Cobb-Douglas to compare results estimating the effect of agricultural research and extension expenditures on productivity in the United States during 1949-1981. Their results indicate that the Cobb-Douglas biases the results by which this formulation is called into question. Instead they recommend further use of the translog and other flexible functional forms in spite of the large data base needed to mitigate possible problems of multicollinearity.

Regarding variable specification, even though almost all the studies consider research and extension expenditures as a measure of research and extension activities, some differences do exist in such a specification.

Evenson (1974) used the number of scientific publications as a proxy variable for research. Evenson and Binswanger (1978) separated the research variable to measure effects of applied research and science-oriented research.

Habtu (1985) went further and separated research and extension expenditures into eight categories according to the nature of the research and extension: production-oriented public sector, production-oriented private sector, nonproduction-oriented public sector, and nonproduction-oriented private sector, each of these for research and for extension.

Spillover affect and regional impact also have been studied by using production function specification. Bredahl and Peterson (1976) for example used the national marginal product of research and the state average product to calculate marginal product at state level.

Critical Comments About the Ex-Post Methods

The above discussion indicates the diversity of problems and situations that can be analyzed using the input-saving, economic surplus, and production function approaches. Each of them, of course has its own strengths and weaknesses.

The principal features of the economic surplus, for example, have to do with the possibility of calculating the average internal rate of return, and the flexibility to account for the effects of many economic problems and special situations including effects of economic policy. It also allows the analysis of distributional issues (i.e., distribution of benefits between consumers and producers). The economic surplus technique has been used mostly for the study of particular research programs since we need to know specific parameters to apply the technique (i.e., elasticities, prices, supply shift). There is not, however, professional agreement about the use of the economic surplus as a measure of the benefit of the agricultural research or of other sort of public programs.

The production function approach can be used to measure the marginal internal rate of return on research and extension expenditures, separate out the effects of research and extension on the production while holding the other inputs constant, model the time path of response of the production to expenditures in research and extension, and to study spillover effects. Frequently this approach allows the analysis of policy questions and the reallocation of resources among research programs. The time series option of this approach has the serious problem of high correlation among the variables over time.

On the other hand, the national income and input saving approaches do not have the same level of sophistication as the economic surplus or production function approach, but they have some advantages for aggregate studies, specially when the data are scarce and in situations where computational facilities are not available. These two approaches permit the analysis of structural modifications in the agricultural sector and the results are more understandable to policy makers and research administrators.

Neither of the above methods takes into account adequately some aspects such as secondary impacts of the expenditure on research and extension, displaced resources out of the farm sector, and the importance of maintenance research.

Ex-Ante Methods

The ex-ante methods are used to rank research activities, to establish benefit-cost analysis, to calculate rates of return to research for resource allocation decisions, to simulate the future path of variables affected by decisions on research, and to select an optimal mix of research activities. Ex-ante approaches include scoring models, mathematical approaches, benefit-cost analyses, and simulation models.

Scoring Models

One of the better known models of this kind is that at Iowa State University. As described by Mahlstede (1971), to determine the most valuable research alternatives in agriculture for the Iowa Agriculture and Home Economics Experimental Station, three goals were recognized for the research: growth, security, and equity. Research projects were classified into three areas and these into nineteen subareas, and then several scientists were assigned to each of them to classify and evaluate alternatives and costs. To score these alternatives, 10 criteria were developed: the probability of a successful outcome, the anticipated resources saved, the time over which the resource saving will occur, indirect benefits to other commodities, the direct cost of doing the research, the time needed to complete the research, the time needed to make the specific package transferable to farmers, the cost of any associated research or development effort, the degree and speed of adoption, and the public extension cost. Finally, based on the above alternatives, projects were ranked by the panel and submitted to the administrative instance for resource allocation decision. Mahlstede points out that the validity of these approaches rests on the scientists predicting scientific outcomes and then on improving the selection of research alternatives.

The North Carolina Agricultural Experimental Station Model (Shumway 1977) and the National Association of State Universities and Land Grant Colleges-USDA system belong to the scoring models for ranking research projects or programs.

Ex-Ante Benefit-Cost Analysis

This approach is essentially equal to the economic surplus approach being the main difference the heavy dependance of the former on subjective judgements of research scientists, administrators, and decision-makers. Usually, the ex-ante benefit-cost approach uses the answers of scientists and administrators to estimate probabilities of research success and adoption of technology, costs, and benefits. With this information expected, benefit-cost ratios and internal rates of return on alternative projects are calculated.

Using the above approach Araji, Sim, and Gardner (1978) performed an evaluation for various commodities in western states of the United States. They estimated yields, quality, production cost changes, benefits and costs, and then benefit cost ratios and internal rates of return for each project. Productivity reduction resulting from eliminating maintenance research also was calculated.

Focusing on research priorities, Ramalho de Castro and Shuh (1977) analyzed distributional effects, factor scarcity, and effects of economic policies on benefits and costs of research. Using secondary data they projected yield increases, adoption rates, and probabilities of success for selected commodities in the Brazilian economy.

Easter and Norton (1976) also applied an ex-ante benefit-cost analysis to budget allocation of Land Grant Universities in the North Central region. Based on estimations of yields provided by the scientists and the costs of each research project as well as on the expected rates of adoption, they calculated expected benefit-cost ratios. Their model allows testing of the sensibility of benefit-cost ratios to changes in the probability of success, yield increases, length of lag between research expenditures and its effect on the agriculture and product prices. The analysis is thought to be useful for administrators and decision-makers in order to better allocate funds to research.

A rather more complicated model is the Minnesota Agricultural Research Resources Allocation Information System (MARRAIS) where the benefit-cost ratios and internal rates of return are calculated by computer. With information provided by scientists, the model estimates probability distributions of benefits and costs via a Monte-Carlo procedure. More detail about this model can be found in Fishel (1971). Norton, Ganoza, and Pomareda (1985) used an ex-ante economic surplus framework to evaluate research on corn, rice, wheat, potatoes, and beans in Peru. They introduced some improvement in the basic economic surplus model to analyze:

(a) the proportion of food consumed in the farm-household where it is produced;

(b) factors causing shift in the demand curve; and,

(c) imports of some commodities.

They also used questionnaires to obtain their projections of the most likely yield due to a particular research project, estimated probabilities of success and estimated time lags for the release of new technologies.

Simulation Models

The most representative attempts to simulate and predict the future impact of the agricultural research are summarized below. Andersen and Franklin (1977) developed a simulation model to predict the relative benefits or contributions and costs coming from alternative research projects. They start defining several working objectives stemming from national development plans. The subsequent steps in the model concern the estimation of changes in product supply, input demand, and farm consumption necessary to obtain the stated goals and then the identification of research problems and alternative technologies to solve every problem. Finally, the model estimates time, cost, probabilities of farm adoption, and the impact of each research alternative to the achievement of the development goals.

This model was expected to be useful for planning research activities in the International Center for Tropical Agriculture (CIAT) and for national research agencies, especially in Latin America. Some parts of the model have been tested in Colombia and in Guatemala.

Lu, Quance, and Liu (1978) examined the relationships between research and extension and agricultural productivity growth and then formulated a productivity simulation model including research and extension as a decision variable. They used the model to project agricultural productivity growth under alternative scenarios (low technology, baseline, and high technology). The next step was to evaluate the impact of research and extension on social benefits and estimate benefit-cost ratios and ex-ante internal rates of return to research and extension investments.

The authors fitted U.S. time series data for 1939-1972 using Almon distributed lag model and they found that one percent increase in research and extension expenditures would increase productivity with the maximum impact being after six or seven years. They also calculated the impact of emerging new technologies in the projections using probabilities of innovation and adoption. With this information they were able to project the productivity index under the three scenarios. Under the optimistic scenario, for example they estimated productivity index increases from 112 in the base year to 168 by the year 2000. A 3.3 to 1 benefit-cost ratio and an internal rate of return of 15 percent were reported.

Knutson and Tweeten (1979) made an attempt to determine a more nearly optimal rate of future investments in publicly supported agricultural production research and extension. They consider that the historic rate of return obtained in past studies are of limited use in judging appropriate future levels of research and extension. Working on Cline's production function and using several assumed scenarios they found decreasing internal rates of return over time, from 36% for the 1939-1948 period to 35% for the 1969-1972 period. They concluded that slow rates of growth in demand coupled with rapid increases in research pose potentially severe economic hardships for farmers.

In an attempt to identify optimum patterns of investment based on rate of return estimates and to foresee the consequences of failure to achieve the optimum investment, White and Havlicek (1982) used a productivity model to project changes in productivity according to investment in research and extension. To select the investment level of research and extension to reach the desired price level (target variable) the authors introduced control theory.

One of the most important conclusions of that study refers to underfunded research and extension. They concluded that if research and extension are underfunded by 10% of the optimal level during the period 1981-1990, then it will cost the government $2.56 for each dollar underfunded if the government fixed the problem in later years. If not, the cost for the consumers will be $4.39.

Finally, Habtu (1985) performed a similar analysis to investigate the impact of alternative rates of growth (3%, 5%, 7%, 9%) in research and extension production-oriented on farm prices and income. To conduct the analysis he used simulation and optimal control techniques.

Critical Comments About Ex-Ante Methods

Even though the outcomes of the agricultural research activities are highly uncertain, agricultural economists have used ex-ante approaches with profusion trying to improve the allocative resource process to research. The models used range from the simple scoring models to the more sophisticated mathematical or benefit-cost models.

One of the most important advantages of these models has to do with the process of pooling information coming from a large number of scientists and qualified experts, establishing a means of relating the research activity to a set of goals. In addition, the ex-ante methods provide optimal level of investment in research and its impact on some socioeconomic variables such as prices, employment, and income.

On the other hand, the disadvantages of the ex-ante methods are that some of them can be quite costly and time-consuming (pooling large numbers of opinions or using large computer facilities).

Secondary Impacts of Technological Change

Most of the investigations just described deal mainly with the calculation of rate of returns as a means to judge the social profitability of investment on research. Society invests in research expecting the present value of future income streams generated by technological advances will be superior to the cost of generating such improvements, which leads to the concept of efficiency of resource use and the evaluation of whether the research expenditures constitute a socially profitable use of resources (Scobie, 1979).

Besides the efficiency criterion, social researchers have performed several studies focused on distributional impacts of technological change. Studies such as relative share of research benefits accruing to producers and consumers, impacts of research on functional income shares, and regional distribution of benefits and costs of research are examples of distributional issues.

According to Schuh (1979), agricultural research can contribute to social and economic development in a number of important ways, but up to now the major emphasis has been on research that increases output directly and relatively less has been placed on indirect contributions. Efficiency and distributional studies for example, are based on the direct contribution of agricultural output increase. However, increases in real agricultural output stimulates other sectors of the national economy through the interdependence among agricultural producers, input suppliers, processors, transporters, and sellers. For example, in a normal situation an increase in agricultural output results in demand for additional fertilizer, capital, etc. which generates additional output, income and employment in other sectors. These indirect effects can be accounted for the benefits of the research.

There has been little research in this field of analysis. Studies that focus on a broad perspective of the economic impacts of agricultural research should be encouraged. Eddleman (1977) carried out a study in which he estimated the secondary impacts of expanded agricultural output for the U.S. using an input-output framework. By calculating a series of multipliers he was able to estimate net profit and net wage gains in other sectors others than the agricultural sector, due to agricultural output increases. The additional stream of benefits was added to the primary benefits and then an overall estimation of economic benefits was done until the 2000 year.

Norton and Bernat (1985) in a study about economic aspects of agricultural research and education in Virginia also estimated impact of additional appropriations for the College of Agriculture on non-agricultural output, employment and household income using the methodology of multipliers within the input-output framework.

Basically, the essence of the input-output model is the technological relationship that the purchases of any sector in the economy depends on the level of output of the purchasing sector (technological coefficients). Direct and indirect coefficients can be derived from this basic set of coefficients and a set of multipliers derived from the direct and indirect coefficients. These multipliers show the effects of a change in final demand for a given sector on output, income, employment, and value added in other sectors (Norton and Bernat, 1985).

Contributions of This Research

The present research will focus on the economy of the Colombian research system for the 1960-1982 period. To study systematically the behavior of this system in the mentioned period, two main hypotheses are stated in Chapter I having to do with the agricultural productivity evolution and with the optimal funding of research in the country. Several measures of productivity will be developed aimed to analyze the relationship between agricultural productivity and the behavior of the research system through its financial evolution. Some partial productivity indicators will be presented; however, the major expected result from this part of the study refers to the calculation of a productivity index, nonexistent in Colombia at the present time. Such an index would serve as an important indicator of the aggregate technological change in agriculture. Also, for the first time testing statistically for changes in the aggregate production function will be attempted.

To judge about the social profitability of funds spent in agricultural research and extension during the period of analysis, the calculation of average and marginal rates of return will be performed. In doing so, this research is filing an important gap since there is no such estimation currently available in Colombia for the aggregative level despite the fact of the existence of estimated rate of returns for some crops as referenced in the literature review.

The calculation of the marginal internal rate of return is estimated from a productivity change model which allows the analysis of the contribution of other factors than research and extension to the productivity. Examples are education and weather. The model also allows the projection of rate of growth in future productivity according to different assumptions in financing research. All of these results are of great importance for the government. They allow the government to compare the relative benefits of investing in research and extension in comparison with other sectors of the national economy. The future productivity level is also of some importance for decision-makers to evaluate current decision concerning the pace and timing of research. In addition, the calculation of the average internal rate of return will provide additional insights in the process of technological change in Colombian agriculture. In estimating the marginal rate of return, the time lag between the initial investment in research and extension and its impact on productivity will be calculated. Currently, this is another unknown aspect in Colombia.

Finally, this research intends to incorporate a methodological device to calculate secondary impacts resulting from expenditures in research and extension. This is important to see indirect impacts of technological change in Colombia. The policy and methodological importance of this attempt is obvious. The methodological instrument to be used is the input-output framework.

CHAPTER III

CONCEPTUAL AND EMPIRICAL FRAMEWORK

The objective of this chapter is to establish the main methodological steps to study the overall economic performance of the Colombian agricultural research system during the 1960-1982 period. The calculation of the internal rate of return (IRR) to investment in research is thought to be the quickest way to assess this performance. However, before going to this calculation, it is useful and necessary to analyze the principal indicators of the Colombian agricultural productivity evolution during the same period. Also, after the IRR calculation, some intend to project or predict some future outcomes based on current or new policies proceeds.

The remainder of this chapter is organized as follows: the first section describes the evolution of the agricultural productivity through the analysis of trend in output, land, labor, fertilizer, and simple productivity ratios and then by using more complex relations among output and production factors or inputs. Since there is an interest of seeing the influence of the Colombian agricultural research system on productivity changes, a model using production function will be determined. The section ends with a workable procedure to calculate and establish a productivity index (Total Factor Productivity) for the Colombian agriculture.

Drawing from the first section, the second section deals with the evaluation of the average and the marginal internal rates of return for investments in agricultural research and extension in Colombia during the 1960-1982 period. The model to calculate the average rate of return rests on the input-saved methodology described before in Chapter II. To estimate the marginal internal rate of return, a productivity change model is first developed in which the dependent variable is the productivity index calculated in the previous section and the independent variables are those identified in the literature as influencing productivity changes such as research and extension, among others. With this model it is possible to estimate the marginal productivity of research and extension and then the marginal internal rate of return (MIRR).

This section also discusses a procedure to project or simulate future productivity outcomes, working with several assumptions about budgeting behavior. The third section concerns the description of a suitable method to estimate secondary impacts coming from investments in agricultural research and extension. This method of estimation has to do mainly with the input-output approach.

Productivity Index and Productivity Analysis for Colombian Agriculture

Trends Analysis and Partial Productivity Ratios

To see the evolution of the Colombian agricultural sector, it is useful to perform the graphic and arithmetic analysis of tendencies over time (trend) for the agricultural output, for traditional inputs such as land and labor, and for modern inputs as machinery, fertilizer, seeds, concentrates, and others. Usually, a simple analysis is enough to appreciate the main changes using inputs over the time and to observe technological patterns.

Several productivity ratios can be defined based on the relationship between output and each one of the production factors, which means it is feasible to construct as many productivity ratios as factor of production participate in the production process. They are usually a direct sign of technological change since they permit comparing input intensity over time. The most important productivity ratios are defined below.

Labor Productivity Ratio

$$\frac{O}{L} \tag{3.1}$$

Where O stands for total agricultural output and L represents labor, expressed as the total number of man days employed in a specific year. The ratio indicates the output per man-year and its changes over the time can be considered to be the result of changes in capital per worker and the quality of labor induced by improvements in technology. This ratio has been considered as one of the basic measures of productivity and some refinements can give additional insights about the effects of technological change. For example, the use of net change in output per net change in labor measures the changes in productivity between two year.

$$\frac{O_1-O_o}{L_1-L_o}=\frac{dO}{dL} \tag{3.2}$$

Another way to see changes in productivity is by determining how many workers would have been necessary to produce the current year's output using last year's technology which is represented in this case by its output per worker ratio.

$$\frac{O_1}{\left(\frac{O_o}{L_o}\right)}=L'_1 \tag{3.3}$$

The subscript o represents last year's quantity while the subscript 1 is for today's quantity. If technical change has occured $L'_1 > L_1$. In addition, if no technical change has occurred between two years, the expression (3.1) becomes identical in the two years, that is:

$$\left(\frac{O}{L}\right)_o = \left(\frac{O}{L}\right)_1 \tag{3.4}$$

Land Productivity Ratio

$$\frac{O}{A} \tag{3.5}$$

Where A represents land on production (hectares) and O is total agricultural output. This is also a direct indicator of change in technology, since the increase in this ratio from one period to another is frequently associated with the use of biological technology such as improved seeds and other modern inputs (fertilizer, herbicides). In fact, this ratio is used in many underdeveloped countries as almost the only indicator of agricultural productivity.

Combining acreage and fertilizer used, it is possible to construct another partial productivity ratio which is proxy index for factors substituting for land:

$$\frac{F}{A} \tag{3.6}$$

Where F represents quantity of fertilizers used in the current year and the whole expression represents the amount of fertilizer per unit of land (hectares).

Likewise, combining acreage and machinery (horsepower) result in another productivity ratio, as below:

$$\frac{M}{L} \tag{3.7}$$

This ratio is considered as a proxy for factors substituting for labor. While it is feasible to define some other partial productivity ratios, those described are by far the most used for analyzing changes in agricultural productivity.

More Complex Relations

To go deeper in the analysis of the direction, magnitude and sources of technological change, still within the scope of partial productivity analysis, some more complex relations among output and production factors can be stated.

In Chapter II it was pointed out that the ratio $\frac{O}{L}$ in (3.1) can be allocated by identity, into the land-labor ratio $\frac{A}{L}$ and land productivity $\frac{O}{A}$ components:

$$\frac{O}{L} \equiv \frac{A}{L} \times \frac{O}{A} \tag{3.8}$$

From the above relationship (3.8) a judgment about the direction, in other words, the bias of technological change can be drawn. To do that, it is assumed that labor-saving technical change is associated mostly with mechanical innovations and land-saving technical change is associated with biological and chemical innovations. Thus, if land per worker increases, ceteris paribus, mechanical, labor-saving innovation has occurred. In contrast, if output per acre increases, biological or chemical, land-saving innovation has occurred.

As mentioned before, many underdeveloped countries use the evolution in land productivity (output per unit of land) or yield as an important measure of technological change in agriculture. Dalrymple (1977) states that changes in crop production are a function of changes in area and/or yield. In general, new technologies need less expansion of area than old technologies, so improvements in technology are reflected, for the most part, in increased yield.

Because of the above, in evaluating the effect of technological change on production it is of interest to analyze the relative importance of changes in area and yield. Such an analysis can be done by using the formula below which was developed by Niehaus, cited by Dalrymple (1977, pg. 187).

$$1 = \frac{\log (1 + A)}{\log (1 + O)} + \frac{\log (1 + Y)}{\log (1 + O)} \tag{3.9}$$

where A, O, and Y are the percentage change from one period to another in area, output, and yield, respectively. The formula allows the calculation of what percentage of the increment in output is attributed to land and how much to yield. It is expected that as the technological change advances, the relative participation of land in this process becomes increasingly less important.

Agricultural Productivity Index

Even though partial productivity indexes and related concepts allow many types of analyses to assess the performance of the agricultural sector as just described, they are considered of limited usefulness to evaluate the whole technological change process since technological change is associated with many improvements in the efficiency of using production factors and can be defined as a shift in the underlying production function. The total factor productivity concept was developed to incorporate these improvements together in one expression, implying an index of output per unit of total inputs which measures shifts in the production function. In other words, shifts in the production function are identified with changes in total factor productivity (Jorgenson and Griliches, 1967, pg. 249). So, to observe these changes over the time it will be useful to construct an agricultural productivity index based on total factor productivity concept.

Several problems arise when a productivity index is intended, however. First of all, the very index-number problem arises whenever a quantitative expression is used for a complex that is made up of individual measurements for which no common physical unit exists (Frisch, 1936). The problem is solved by expressing each input in monetary form and then summing them up. The second problem refers to weights, geometric, constant weights, or chain-linked variable weights (Divisia type). Arithmetic (Laspeyre or Paasche) weights have been shown to assume linear structure in the underlying production function, while geometric weights assume multiplicative structure as in Cobb-Douglas production function.

Besides, these a-priori restrictive assumptions about the production process arithmetic and geometric weights-type indexes have the problems of the weights being fixed for long terms (prices or quantities) used in the base year. The answer to this problem is the "chain-linked" or Divisia-type index; for each year the current prices are used as a base in estimating the rate of growth for the following year. The process is followed for each year in succession and the year-to-year rates of growth are linked into a chain index. It is apparent that the main advantage of a chain-linked index is in the reduction of approximation as the economy moves from one production configuration to another (Jorgenson and Griliches, 1971).

To see the relationship between the production function, the total factor productivity and the productivity index, suppose the production structure is represented by a Cobb-Douglas production function, as below:

$$Q_t = A_t L_t^{\alpha} K_t^{\beta} \qquad (3.10)$$

where:

Q = Agricultural product

L = Labor

K = Capital

A_t = multiplicative factor that measures the accumulated effect of shifts over time.

α, β = parameters to be estimated

By definition A t represents total factor productivity.

Working on (3.10) we get:

$$A_t = \frac{Q_t}{L_t^{\alpha} K_t^{\beta}} \tag{3.10.1}$$

for any period of time.

Defining A_o for the base period:

$$A_o = \frac{Q_o}{L_o^{\alpha} K_o^{\beta}} \tag{3.10.2}$$

it is possible to define the productivity index as follows:

$$P_t = \frac{A_t}{A_o} = \frac{\dfrac{Q_t}{L_t^{\alpha} K_t^{\beta}}}{\dfrac{Q_o}{L_o^{\alpha} K_o^{\beta}}} \tag{3.10.3}$$

From (3.10), using logarithms and taking derivative with respect to time results:

$$\ln Q_t = \ln A_t + \alpha \ln L_t + \beta \ln K_t \tag{3.11}$$

$$\frac{\frac{dQ_t}{d_t}}{Q_t} = \frac{\frac{dA_t}{d_t}}{A_t} + \alpha \frac{\frac{dL_t}{d_t}}{L_t} + \beta \frac{\frac{dK_t}{d_t}}{K_t} \tag{3.12}$$

(3.12) represents the rate of change on production over time. Using dots, (3.12) is expressed as:

$$\frac{\mathring{Q}_t}{Q_t} = \frac{\mathring{A}_t}{A_t} + \alpha \frac{\mathring{L}_t}{L_t} + \beta \frac{\mathring{K}_t}{K_t} \tag{3.13}$$

The above expression (3.13) allows "decomposition" analysis or sources of growth analysis since the rate of change in production is divided among the rate of change of inputs and technological change, in this case the residual.

The rate of productivity change or residual is expressed as the difference between the rate of change in production minus the rate of change of inputs. The share-weighted growth of an individual input indicates the contributions of that input to output growth. α and β are factor share weights. In the Cobb-Douglas they represent partial production elasticities.

$$\frac{\mathring{A}_t}{A_t} = \frac{\mathring{Q}_t}{Q_t} - \alpha \frac{\mathring{L}_t}{L_t} - \beta \frac{\mathring{K}_t}{K_t} \tag{3.14}$$

$\frac{\mathring{A}_t}{A_t}$ represents a "shifter" of the production function and when the physical relation between output and inputs changes over time, the value of $\frac{\mathring{A}_t}{A_t}$ changes to reflect this. This residual is the expression for technological change in agriculture. Also, the residual is considered to be a "catch-all" since it could contain such elements as effect of changing input quality, economies of scale, omitted variables and specification errors.

By setting 1960 as the base period, the index of technological change for Colombian agriculture can be computed using a Tornqvist[1] approximation to the Divisia index as follows:

[1]Tornqvist approximation is a procedure to convert a continuous index to a discrete one.

$$\ln\left(\frac{A_t}{A_o}\right) = \ln\left(\frac{Q_t}{Q_o}\right) - \frac{1}{2}\sum_i (S_{it} + S_{io}) \ln\left(\frac{X_{it}}{X_{io}}\right) \tag{3.15}$$

where:

X is total input in period t and the base period o and

S is the cost share of input X_i.

Expressions (3.11) through (3.15) will be used to calculate the productivity index for Colombia agriculture and for performing the sources of growth in production analysis, that is, the decomposition of output growth rate into the growth rate of production factors and growth rate of productivity.

Variables to be used in this analysis are defined as follows:

Qt = Gross value of crops and livestock in each year

Lt = Labor, measured as the total number of man-days employed in crop production and livestock per year.

Instead of working with an aggregate capital (Kt) variable, it will be divided into several categories, as follows:

A = Land, measured as hectares of cropped land and pasture land per year.

I = Intermediate purchased inputs used in production of crop and livestock for a single year (seed, fertilizer, pesticides, concentrates), measure in monetary value per year.

S = Stock or inventories of machinery, livestock and other physical assets.

One of the present study hypothesis has to do with the creation of an organized system to conduct the research and extension in the country in 1963 and its subsequent financing behavior. The hypothesis states that as a consequence of the creation of this system (ICA), the productivity of the Colombian agriculture increased during the 1960's decade, reached a peak in the middle 1970's and since then entered in a period of stagnation as a consequence of financial trouble in the research system.

The expression (3.15) just described would permit analysis in general of this behavior. However, to test more formally the above hypothesis, the production function approach will prove to be useful.

As mentioned before the idea of technological change comes close to a shift in the underlying production function in such a way that testing for changes in the production function parameters from one period of time to another is a mean of inferring about changes in productivity and about changes in the relative importance of each production function. The use of dummy variables makes it possible to analyze the shifts in production functions. According to Leistritz (1978, pg. 4) when zero-one variables, say dummy variables, are incorporated into a regression model, a simple covariance model is obtained. The covariance model is a mixed model, basically a combination of the regression model and the analysis of variance model, where the former involves the usual quantitative independent variables, and the latter involves the dummy variables. Dummy and covariance analysis allows the examination of changes in the intercept and in the slope of any function.

Here production functions for the 1960-1967, 1968-1975, and 1976-1982 periods will be fitted; also, the pooled production function for the three periods including a dummy variable to represent the technology will be estimated. The three periods are thought to represent three different technological eras.

The specification of the production function to be used in the analysis, in econometric framework, is as below:

$$Q_i = a_o \, x_{i_t}^{\alpha_1} \, x_{i_2}^{\alpha_2} \, x_{i_3}^{\alpha_3} \, x_{i_4}^{\alpha_4} \, \mu_i \qquad (3.16)$$

where:

Q = Value of the agricultural production including, crop and livestock production.

x_1 = Labor, measures either by value of the labor or in man-days of farm labor.

x_2 = Land measured in hectares of cropped land and pastureland.

x_3 = Intermediate purchased inputs used in crop production and livestock, measured in monetary terms or in index.

x_4 = Stock or inventories of machinery, livestock and other physical assets.

μ_i = Error term.

i = Period of time.

(3.16) is an unrestrictive Cobb-Douglas production function which, according to Orozco (1977) is suitable to represent the Colombian agricultural sector.

Taking logarithms over the expression (3.16):

$$\ln Q_i = \ln \alpha_0 + \alpha_1 \ln x_{i1} + \alpha_2 \ln x_{i2} + \alpha_3 \ln x_{i3} + \alpha_4 \ln x_{i4} + \ln u_i \qquad (3.17)$$

Equation (3.17) will be fitted for the three periods mentioned one at a time; afterward, a pooled equation for the three periods will be estimated including dummies variables to represent the technology. To do that, the model (3.17) is added with dummies as follows:

D_1 = 1 if the observation is 1960-1967 period
= 0 otherwise

D_2 = 1 if the observation is 1968-1975 period
= 0 otherwise

D_3 = 1 if the observation is 1976-1982 period
= 0 otherwise.

Alternatively, dummy variables can be included by pairs, that is, representing first and second periods and then pooled and representing second and third periods and then pooled. Also, since this study seeks the effect of research and extension on production in different periods of time, this variable could be included in each period to analyze changes in its parameter over the time.

Productivity Change Model and Internal Rate of Return

Model Specification

The main goal of this section is to develop a productivity change model capable of explaining the factor leading the observed changes in the Colombian agricultural productivity. The model should be also adequate to estimate the average and marginal internal rate of return corresponding to investment in agricultural research and extension.

Conceptually, the problem is to explain the factors behind changes in the expression (3.10.3), that is:

$P_t = \frac{At}{Ao}$ or, expressed in logarithmic form:

$$\ln Pt = \ln At - \ln Ao \qquad (3.18)$$

In other words, changes in the productivity index correspond to changes on the multiplicative factor in the production function or total factor productivity.

Agricultural research and extension, farmers' education, and weather among many factors, were documented in Chapter II as being the principal variables explaining these changes, so that the functional relationship can be established as:

$$P_t = f\,(R, Ex, Ed, W, O) \qquad (3.20)$$

where R, Ex, Ed, W, and O represent research, extension, education, weather, and other factors, respectively. Generally, it is not necessary to include the traditional factor of production of land, labor, and capital in the above formulation since qualitative and quantitative changes in those factors are directly or indirectly the effect of research and extension activities. Thus the parameters of the latter variables account for changes in the others (Bal and Kahlon, 1977).

As has been stated before, the new knowledge, product of research, facilitates quality improvements in conventional inputs and that, in turn, speeds the rate of growth in agricultural production. Through research, the productivity of existing resources is increased, and even more important, it becomes feasible to utilize an increased quantity of new and traditional resources at higher levels of productivity and profitability than previously. But to impact the agricultural production significantly, the product of the research effort such as new seeds, chemicals, improved cultural agronomic practices, technological "packages", better management practices, and the like must be adopted by the farm sector. That is why activities of extension are an important and necessary step following research results.

Although research and extension activities have different roles in the technological change process, they are highly complementary; thus it is difficult to isolate the effect of each aspect on productivity in the productivity change model. Normally, it is expected to find some degree of correlation between them.

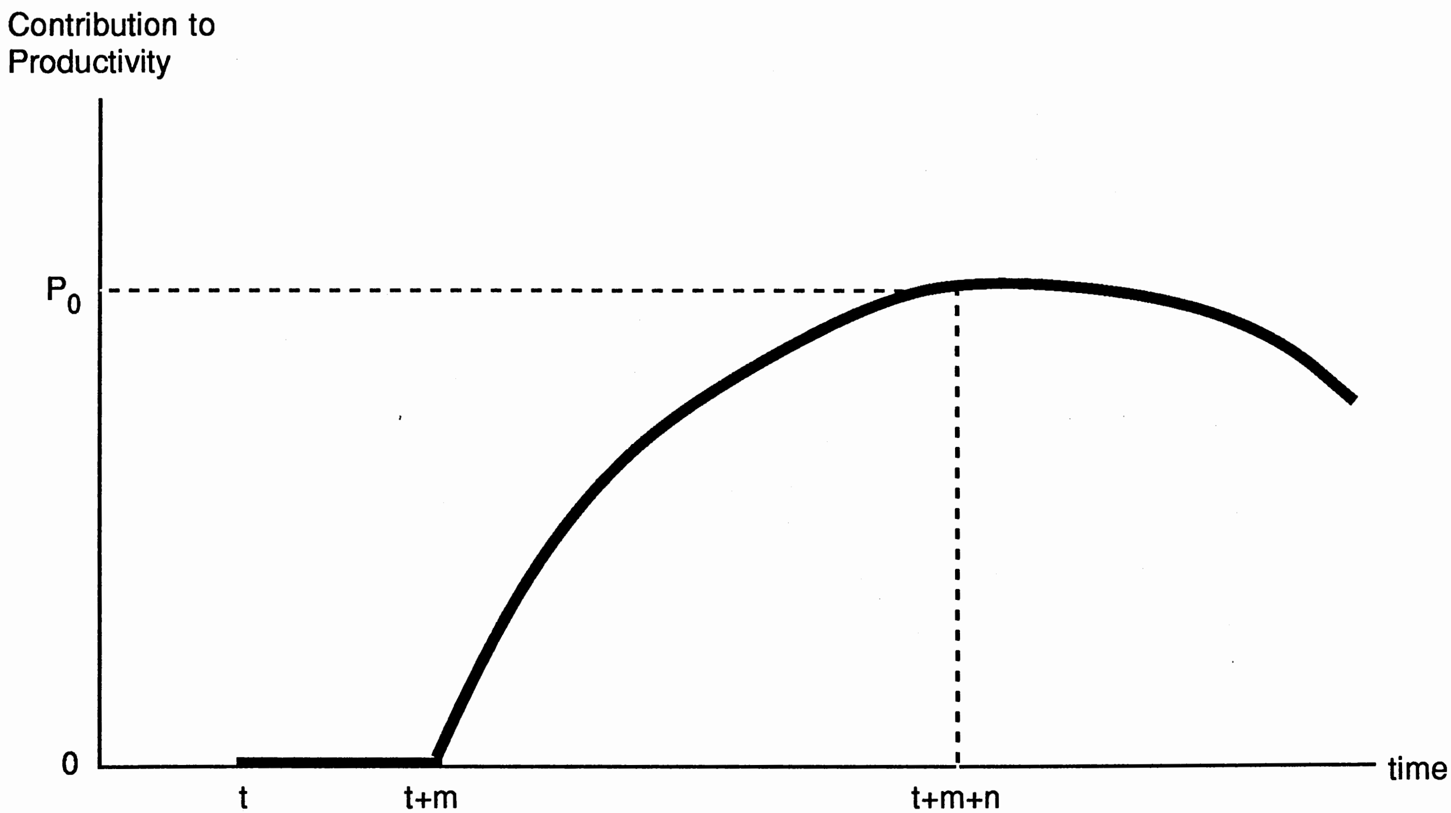
The standard procedure for including these two aspects in the model is by including the expenditure carried out by public institutions and private enterprises on research and extension (sometimes called "development" expenses at private agencies). Some authors, especially Cline (1975) and

Habtu (1985), subdivide research and extension not only by public and private, but also according to the orientation: production-oriented and non-production oriented. However, in underdeveloped countries because of the lack of information, accounting system, or weakness of private research, it is rarely possible to distinguish such categories in the expenses for research and extension.

In Colombia, for example with the exception of research on coffee, sugar cane (starting in 1977), and in some aspects rice, most of the activities about agricultural research are performed by one public institution, namely the Colombian Agriculture Institute (ICA). Concerning extension, ICA also conducts the main part of the effort but there are other public institutions undertaking extension activities tied to specific goals, especially to supervised credit. Some crop growers and input sellers also carry out some extension activities.

Here a theoretical attempt will be made to separate public research and extension from private research and extension in the model. For the public research and extension, ICA's expenditures will represent this variable in the model. For private research and extension, coffee growers association's expenditures on these activities could represent such a variable for the most part due to the heavy weight that coffee has for the Colombian economy.

Another aspect to consider about research and extension is the time evolution of the effects of them on the productivity. According to Griliches (1967), research will not immediately impact production in terms of improvements in the current productivity level; rather, the effect of research on productivity is spread over time. An illustration of the time lag between the initiation of a single research activity and its ongoing impact on productivity is presented in Figure 8.



Source: Cline (1975), page. 49.

Figure 8. The Effect of Research and Extension Activities on Productivity

As depicted by the Figure 8, research activities begins in time t and from this point to time t + m there is no technology available coming from this research. This lag between the time when funds are invested in research (t) and the time when the output of research begins to appear (t + m) is caused by administrative, operational, and reporting activities (Swallow, Norton, Brumback, and Buss, 1985, page 2). At time t + m the research is completed and its product is taken and transformed by extension activities. There is another lag between the production of research output and its adoption by farmers, depending on educational level of farmers, complexity of the invention, profitability, risk, among other factors. As the new technology is adopted by farmers, technical change occurs and the contribution of research to productivity increases, reaching a maximum as a consequence of more and more farmers adopting the new technology. This happens at point P_0 at time t + m + n. Finally, the technology will become irrelevant, or obsolete (old inputs are replaced by improved inputs), or depreciate after some point due to biological decay. Overall, there is depreciation of research output beyond the point t + m + n. For several doses of research activities, the corresponding figure is a composite of that depicted in Figure 8.

Apart from research and extension, education is another important factor to explain changes in productivity gains. Although education is not itself a sufficient condition for development of agriculture, it is a necessary condition. Almost all elements of the technological change process are based on educational improvement at all levels. For instance, through better educated labor, farmers combine other resources more efficiently; better educated farmers minimize resistance to change, speed adoption and improve the decision-making process, however education is also a condition to create new technology and disseminate it. There have been several approaches for including rural education in the productivity model. Griliches (1964) used weighted average school years of rural farm population and Hayami (1969), trying to explain the productivity gap among selected countries, used the variable "literacy ratios" and school enrollment ratio for the first and second levels of education. Here the variable education will be represented by the ratio between students who had finished rural education and enrolled student in rural education.[2] The timing of the effect of educational attainment for farmers on productivity refers to the same time, that is, the level of formal education of farmers in time t determines their ability to assimilate and utilize information in the decision-making process of period t (Cline 1975, p. 47).

As in the case of education, weather also affects productivity in the same period. This variable, as pointed out in Chapter II, is thought to be important to explain changes in productivity since it affects the physical environment in which the agricultural production takes place. Also, weather variability has an impact on the rate of adoption of new technologies since farmers associate risk in production with weather variability. Here, the variable representing the influence of weather is measured as the annual deviation of the overall average rainfall for the period 1960-1982, expressed in index form (1970 = 100).

Based on the above background, the productivity change model can be established as follows:

$$PI_t = EI_t^{\gamma} \, WI_t^{\beta} \prod_{j=0}^{n} PR_{t-j}^{\alpha_j} \prod_{i=0}^{m} PVR_{t-i}^{\varepsilon_i} \, e_t^{\mu_t} \qquad (3.21)$$

The above expression (3.21) is a time-series model set up for econometric estimation. It implies the hypothesis that productivity is a function of the current

[2]Rural education is a six year program providing school instruction and some training in farm practices.

level of educational attainment, current weather, and current and past levels of public and private research and extension.

Each time-series variable is defined as follows:

PI_t	=	Productivity index at time t.
EI_t	=	Educational attainment index at time t.
WI_t	=	Weather index at time t.
PR_{t-j}	=	Public sector research and extension expenditures in the current and past n preceding periods.
PVR_{t-i}	=	Private sector research and extension expenditures in the current and past m preceding periods.
u_t	=	Disturbance term at time t.
$\gamma, \beta, \alpha_j, \varepsilon_i$	=	Parameters to be estimated

To estimate the parameters of (3.21), a logarithmic transformation is needed:

$$\ln P_t = \gamma \ln EI_t + \beta \ln WI_t + \sum_{j=o}^{m} \alpha_j \ln PR_{t-j} + \sum_{i=o}^{m} \varepsilon_i \ln PVR_{t-i} + u_t \tag{3.22}$$

where the variables expressed in logarithmic form are defined as before.

The parameters of the model (3.22) can be estimated directly by using ordinary least squares techniques (OLS). But in the presence of lagged variables such as PR_{t-j} and PVR_{t-i} and time series format, it is presumed that some of the classical assumptions of OLS estimation do not hold, especially the assumption of independence of explanatory variables and no covariance among disturbance terms.

If the model (3.22) violates the assumption of independence among explanatory variables (multicollinearity), then estimators of these variables will show high variances, imprecision and tests of hypotheses over these parameters become invalid. In the present case, the existence of multicollinearity is almost certain since the lagged variables are regressors and EI_t tends to move in the same direction.

As stated by Johnston (p. 984, p. 353), a general strategy for dealing with this collinearity and the associated imprecision is to reduce the number of parameters to be estimated by introducing a priori restrictions. The Almon lag technique is a flexible technique for reduced parameterization, using a polynomial of suitable degree (Almon, 1965).

To illustrate, consider the variable PR and its distributed lag over time.

$$PI_t = \alpha_t PR_t + \alpha_1 PR_{t-1} + \alpha_2 PR_{t-2} + \ldots\ldots. + PR_{t-n} + e_t \qquad (3.23)$$

Where $\alpha_0 \ldots, \alpha_n$ are parameters to be estimated and e_t is the disturbance term.

To estimate the parameters of (3.23), the Almon technique assumes that the weights on the parameters α_i's can be approximated by a suitable polynomial of degree p (p<n), where p is the degree of polynomial such that:

$$\alpha_i = w_0 + w_{1i} + w_{2i} + \ldots + w_{pi}{}^p \qquad (3.24)$$

$i = 0, 1, 2, \ldots n$

Expression (3.24) reduces the number of parameters to be estimated from n to p. If the restrictions imposed on the model are true, the Almon technique gives estimators, which are unbiased, consistent, and more efficient than the least squares estimates.

Equation (3.24) is plugged back into (3.23) and (3.22) to estimate the parameters of the latter equations. This can be done following the procedure described by Johnston (1984, p. 353).

To apply the Almon polynomial distributed lag technique it is necessary to specify the lag length of the pertinent variable and also the degree of the polynomial. Concerning the lag length there are two alternatives: (1) by estimating the model by increasing the number of lags each time by one and stop when the last lags is statistically insignificant; or, by (2) estimating the model with several lags, choosing that with Theil's $\bar{R}^2$ criteria (Theil, 1961). The approach to be followed here is the latter. The degree of the polynomial to be estimated will be 2, since this describes well the behavior of Figure 8.

Finally, since PVR is also a lagged variable, the presence in the model of several lagged variables imposes more estimation difficulties, this variable is dropped from the model (3.22) to be handled later.

Concerning the other problem, and as was pointed out before, time-series analysis usually presents a problem of autocorrelated disturbances; then the assumption of a serially independent disturbance term may not hold. In such circumstances the estimated parameters may be unbiased but the variances are no longer minimum. The existence of autocorrelation can be tested by using the Durbin-Watson d statistics. To face autocorrelated disturbances the model (4.22) is transformed to an autoregressive model under the assumption that the disturbance term u_t follows a first-order autoregressive pattern.

$$\ln PI_t - \rho \ln PI_{t-1} = \gamma (\ln EI_t - \rho \ln EI_{t-1}) + \beta(\ln WI_t - \rho \ln WI_{t-1} + \sum_{j=o}^{n} \alpha_j (\ln PR_{t-j} - \rho \ln PR_{t-j-1}) + e_t \quad (3.25)$$

where:

$e_t = u_t - \rho u_{t-1}$

ρ = coefficient of autocorrelation

According to Johnston (1984), Durbin's two-stage method yields estimations of ρ that are preferable to ordinary least squares or some other methods of estimation such as Cochrane-Orcutt and Drais-Winsten. However, the method to be used will be that available in the computational package.

Marginal Internal Rate of Return (MIRR)

Another concern of this research refers to the underfunding in agricultural research in Colombia. The hypothesis here is that based on estimated internal rate of returns for some crop research programs conducted in Colombia, the aggregate internal rate of return on investments in research is greater than the opportunity cost of capital for the whole economy. That means that the MIRR for research compares favorably to those obtained in other types of agricultural investment or in other projects such as road building, education, etc. If this is the case, the country is losing the opportunity to increase the national product via investment in research. The rule for optimal investment is that, as long as the MIRR is greater than the opportunity cost of capital, it is profitable to increase the stock of knowledge by investing in research (de Janvry 1985, p. 26).

To investigate the hypothesis of underfunding, it is then necessary to calculate the MIRR corresponding to investments in research (and extension)[3] from the model (3.25). To do that, the elasticity of productivity with respect to research and the marginal productivity of research are first calculated. What it follows is a description of this procedure.

Given the specification of the model (3.75) is in logarithmic form, each individual distributed lag coefficient is a direct estimate of the elasticity[4] of agricultural productivity with respect to research and extension expenditures in the appropriate time period (short run elasticities). The sum of these coefficients

[3]Even though it is conceptually possible to separate research from extension in the econometric estimation process, it is preferable to maintain the two variables together to avoid serious problems of correlation between them.

[4]Defined as percentage change in productivity index as a consequence of a one percent increase in research and extension expenditures.

is an estimate of the total elasticity over the entire life of a unit of investment in research and extension.

Following Knutson and Tweeten (1979, p. 71), the elasticity and marginal product are calculated according to the following expressions.

From (3.25) the elasticity of the productivity index with respect to investment on public research and extension is:

$$\varepsilon_{P/R} = \frac{\partial \ln PI_t}{\partial \ln PR_{t-j}} = \frac{\partial PI_t}{\partial PR_{t-j}} \cdot \frac{PR_{t-j}}{PI_t} = \alpha_j \tag{3.26}$$

The marginal product of research and extension is:

$$MP_j = \frac{\partial Q_t}{\partial PR_{t-j}} \cong \frac{\partial PI_t}{\partial PR_{t-j}} \cdot \frac{\partial Q_t}{\partial PI_t} \tag{3.27}$$

$$\cong \frac{\partial PI_t}{\partial PR_{t-j}} \cdot \frac{PR_{t-j}}{PI_t} \frac{PI_t}{PR_{t-j}} \frac{\partial Q_t}{\partial PI_t} \tag{3.28}$$

$$MP_j \quad \cong \alpha_j \frac{PI_t}{PR_{t-j}} \frac{\partial Q_t}{\partial PI_t} \tag{3.29}$$

Where Q_t = agricultural production at time t

Marginal products from (3.29) for each year are calculated by multiplying α_j (regression research coefficients) times the ratio of average productivity to average PR_{t-j} during the period. The long-run marginal product is defined as the summation of all partial marginal products, that is:

$\sum_{j=0}^{n} MP_j$ (Norton and Scobie, 1980).

The stream of marginal products serves as a base to calculate the internal rate of return, which is defined as the rate of return that equates the net present value of all future benefits to zero. The expression to calculate the IRR is as follows:

$$\sum_{j=1}^{n} \frac{\alpha_j (\overline{TQ}/\overline{TR})}{(1 + IRR)^j} - 1 = 0 \qquad (3.30)$$

where:

α_j = Regression coefficient as defined before

$\overline{TQ}$ = Geometric mean for agricultural output for the period 1960-1982

$\overline{TR}$ = Geometric mean for research and extension expenditures for the period 1960-1982

IRR = Internal Rate of Return

Average Internal Rate of Return (AIRR)

Most of the time, the calculation of an marginal internal rate of return instead of the average internal rate of return (AIRR) is taken under the assumption that what is needed for decision-makers is information on the returns to additional investment in each time period, so that the return to investment in a long period, say 1960-1982, should not influence the decision to invest today. This information is provided by the marginal internal rate of return. The marginal rate of return is calculated from the production function approach.

On the other hand, the average internal rate of return, stemming from input-saving or economic surplus approaches, represents the rate of return to the investments in research from the time of inception to the point where the study ends, giving information about the past performance of research. Based on this and on the possibility of analyzing some other aspects of the technological change allowed by this approach (i.e. displacement of resources), the calculation of the average internal rate of return to the investments on research and extension in Colombia during the period 1960-1982 will be also performed to complement the analysis provided by the marginal rate of return. The calculation is carried out using the input-saving approach, which is, additionally, less demanding in information than the production function approach. Also, since input-saving approach do not use any econometric technique of estimation, multicollinearity and autocorrelation are not problems to face in calculating the contribution of research and extension expenditures to the productivity.

In this approach the benefit of research and extension are represented by the value of inputs-saved year by year. Taking into account the stream of annual costs of carrying out research and extension activities, the traditional cash-flow analysis can be employed to calculate the internal rate of return, as follows.

Following Kumar, Maji, and Patel (1974) and Peterson (1971), the value of input saved is estimated by the following formulas when the analysis is carried out by periods:

$$S_t = I_t \cdot P_t^* \tag{3.31}$$

$$P_t^* = (PI_t - PI_o)/PI_o \tag{3.32}$$

$$PI_t = O_t/I_t \tag{3.33}$$

Where:

S_t = Value of input saved in t th year;

I_t = Value of inputs in t th year;

P_t^* = Proportionate increase in productivity of inputs (O_t/I_t) in year t over the base year productivity (PI_o) for the period; and

PI_t = Productivity index as defined before in this research.

The value of input saved given by expression (3.31) represents the additional expenditures on inputs that would have been required to produce

O_t in t th year by using past technologies and it is the base to calculate the benefits coming from research and extension. For the calculation of benefits and costs and the average internal rate of return, a series of intermediate steps are needed to be performed as below:

(a) Present Value of Accumulated Returns

$$PVCR = \sum_{t=o}^{T} S_t \ (1+i)^{-t} \tag{3.34}$$

(b) Present Value of Research and Extension Expenditures

$$PVC = \sum_{t=o}^{T} C_t \ (1+i)^{-t} \tag{3.35}$$

(c) Average Internal Rate of Return

The internal rate of return is defined here as the rate of interest that makes the accumulated present value of the flow of costs equal to the discounted present value of the flow of returns, at a given point in time. It can be expressed as that rate which results in:

$$AIRR = \sum_{t=o}^{T} F_t/(1+i)^t = 0$$

$$= PVCR - PVC = 0 \tag{3.36}$$

Where:

S_t = Value of input saved in constant pesos (1970=100);

C_t = Research and extension expenditures in constant pesos (1970=100);

i = Discount rate; and

AIRR = Average internal rate of return, expressed as percentage annual rate from the date of investment.

Using the same information and few additional calculations, the external rate of return and the benefit-cost ratio can be also calculated.

Projecting Productivity Index

Since public decisions at the current and near time about expenditures in research and extension will affect productivity growth for many years to come, it is useful to project or simulate the productivity growth under different assumed growth rates in research and extension expenditures. The exercise has obvious policy implications because the obtained productivity growth rates are compared with those estimated to be necessary to meet future demand for food and raw material and also to foresee probable levels of inflation.

Based on the productivity change model (3.21), a simulation model can be formulated to project the productivity index under three different scenarios. The simulation model is presented below:

$$PI_t = EI_t^{\gamma} WI_t^{\beta} \prod_{j=o}^{n} PR_{t-j}^{\alpha_j} e_t^{u_t} \qquad (3.37)$$

Where:

PI_t = Productivity index at time t;

EI_t = Educational attainment index at time t;

WI_t = Weather index at time t; and,

PR_{t-j} = Public expenditures on research and extension at time t-j.

All variables are measured as before. The period of projection covers 1983-1992.

The assumptions and the scenarios are the following:

(a) low technology scenario, which assumes a zero annual growth rate in research and extension expenditures by the government;

(b) baseline scenario, which assume the historical research and expenditure annual growth rate (approximately 5%); and,

(c) high technology scenario, which supposes a high research and expenditure growth rate, say 10%, to accelerate development of new technologies and to increase extension activities.

Weather and educational indexes will be included in the scenarios following their projected tendencies.

Secondary Impacts of Agricultural Research

As stated in Chapter II, the input-output approach is a suitable methodology to study secondary effect in a national or regional economy. As described by Schreiner, Ekholm, and Chang (1977), the economic units (individuals, firms) are specialized in their contribution to the economic process and at the same time there is a tremendous interdependence of these units in the production and distribution of goods and services. Specialization and interdependence are made possible by the process of exchange, and as a result, a large number of transactions occur among interdependent economic units. One method to classify, arrange, and see the interdependence of economic units is through input-output analysis. It shows the markets and amounts sold to each market of all products produced (p. 1).

The transactions table is the basic table used in input-output analysis, and other tables are developed based on it. The total gross outlay (column total) must equal the total, gross output (row total) for each processing industry so that for the entire economy total output = total outlay. From the transactions table the direct requirements table is derived to show the proportion of inputs for each column industry needed from each row industry to produce one dollar of output.

These are obtained by dividing each column entry by the corresponding column total (Schreiner et al. p. 3):

$$a_{ij} = \frac{x_{ij}}{x_j} \qquad (3.38)$$

where:

a_{ij} = Technical coefficient or intermediate requirement from sector i per unit of output of sector j;

x_{ij} = Flow of intermediate goods from sector i to sector j; and,

x_j = Production in sector j.

The intermediate production for the whole economy plus the final demand can be expressed in matrix notation as:

$$X = AX + F \qquad (3.39)$$

or, solving for X:

$$X = (1 - A)^{-1}\ IF \qquad (3.40)$$

where:

$(I\text{-}A)^{-1}$ = "technological matrix";

I = The identity matrix;

Z = Matrix of technical coefficients;

X = Matrix of total production; and,

F = Vector of final demand.

Equation (3.40) constitutes the solution of the static input-output model. Given exogenously specified demand, the equation can be used to determine production requirements necessary to satisfy the demand. Due to some convergence propriety of (I-A) matrix, it is possible to express (3.40) as:

$$X = (I + A + A^2 + \ldots)\ F = F + AF + A_2F \qquad (3.41)$$

which illustrates the process of reaching a solution starting from a vector of exogenous final demand F, it is feasible to compute successive rounds of input requirements that arise in the attempt to satisfy the exogenous F vector. When the process converges, a general equilibrium solution has been reached (Dervis, De Melo, and Robinson 1982, p. 23).

Calculation of the inverse $(I-A)^{-1}$ in (3.40) is very useful to estimate "multipliers" that give the impact on endogenous variables of shifts in exogenous elements of final demand. In general, multipliers allow to calculate direct and indirect requirements coefficients for all the transactions in the economy. To illustrate, consider a three-industry economy, which can be written by:

$$\bar{x} = Bd \tag{3.42}$$

where:

$\bar{x}$ = solution variables

$B = (I-A)^{-1}$

d = exogenous final demand.

$$\underset{\bar{x}}{\begin{pmatrix} \bar{x}_1 \\ \bar{x}_2 \\ \bar{x}_3 \end{pmatrix}} = \underset{B}{\begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{pmatrix}} \underset{d}{\begin{pmatrix} d_1 \\ d_2 \\ d_3 \end{pmatrix}} \tag{3.43}$$

To the question what will be the rates of change of the solution values $\bar{x}_i$ with respect to the exogenous final demands d_1, d_2, d_3? The answer is:

$$\frac{\partial \bar{x}_i}{\partial d_j} = b_{ij} \quad (i,j = 1, 2, 3) \tag{3.44}$$

In the standard formulation final demand includes personal consumption, capital formation, net inventory change, export, and government purchases. The interest here is to analyze the impact of changes in government purchases represented by research and extension expenditures on the output, income and employment of the whole economy via increased agricultural output. This analysis is possible by defining and calculating output, income and employment multipliers.

Output Multiplier

According to Miller and Blair (1985) an output multiplier for sector j (agriculture) is defined as the total value of production in all sectors in the economy that is necessary to satisfy a dollar's worth of final demand for sector j's output. In this formulation the total production is the direct and indirect output effect (with households exogenous). The initial output effect on the economy is defined to be the initial dollar's worth of sector j output needed to satisfy additional final demand. The output multiplier can be defined then as the ratio of the direct and indirect effect to the initial effect above. In terms of the expression (3.41), F is the initial effect, AF is the direct effect and the remainder terms A^2F . . . are the indirect effects. In general, the simple output multiplier for sector j, O_j is given by the expression (3.45), that is:

$$O_j = \sum_{i=1}^{n} b_{ij} \tag{3.45}$$

The same expression is used in the case when the model considers household endogenous but with a superbar on b_{ij} indicates the difference. The output multiplier allow the calculation of extra output in the non-agricultural sector that is generated by increased agricultural output due to government expenditures on research and extension.

Income Multiplier

The income multiplier attempts to translate the impacts of final-demand spending changes into changes in income received by households (labor supply), rather than translating the final-demand changes into total value of sectoral output (Miller and Blair, p. 105). One way to estimate the income multiplier is adding the household sector to the matrix of technical coefficient (a_{ij}'s) to indicate income received per dollars worth of sectoral output. The new coefficients are used to weight the old ones in the matrix $(1\text{-}A)^{-1}$ or b_{ij}'s and then the total (direct plus indirect plus induced) income effects or the total income multiplier can be calculated using the formula below:

$$\overline{Y}_j = \sum_{i=1}^{n+1} \frac{a_{n+1,i}\,\overline{b}_{ij}}{a_{n+1,j}} \qquad (3.46)$$

The superbar means that the household sector was included in the inverted matrix (making it endogenous), the 1 means that the technical coefficient of households were included in the initial matrix (a_{ij}'s), and

$\overline{Y}_j$ = income multipliers for sector

$a_{n+1,j}$ = monetary labor input coefficients

$a_{n+1,i}$ = technical coefficients

<u>Employment Multiplier</u>

The employment multiplier is derived by estimating relationships between the value of output of a sector and employment in that sector (in physical terms). There is a parallel between the income multiplier and th employment multiplier, the difference being that the physical labor input coefficient are used instead of the monetary labor input coefficients. The formulation in this case is:

$$\overline{W}_j = \sum_{i=1}^{n+1} \frac{W_{n+1,i}\,\overline{b}_{ij}}{W_{n+1,j}} \qquad (3.47)$$

$$W_{n+1,i} = \frac{e_i}{x_i}$$

(3.48)

Where:

$\bar{W}_j$ = Employment multiplier for sector j;

$W_{n+1,i}$ = Physical labor input coefficient;

e_i = Number of employees in sector i; and,

x_i = Total output sector i.

The employment multiplier represents jobs created of new sectoral output, which arises because of an additional dollar's worth of final demand for the sector.

CHAPTER IV

ESTIMATED PRODUCTIVITY OF COLOMBIAN AGRICULTURE

The objectives of this chapter are: (1) to present the estimates of partial productivity ratios and the implicated characteristics of the technological process for the Colombian agriculture for the period under study; (2) to test the first hypothesis of this research concerning changes in the underlying agricultural production function during the same period of time; and (3) to present the estimated productivity index for the Colombian Agriculture for 1960-1982 period.

Output Trend

During 1960-1982 period, the value of production of crops and livestock at constant 1970 prices increased by 130 percent, which gives a 5.9 annual arithmetic growth rate.[1] Over the period, livestock grew faster than crops, since the latter increased 92.3 percent for the whole period, or 4.2 per annual growth rate and the former increased 190.3 percent in total, or 8.6% annually.

During the period livestock gained some relative importance over crops in terms of value of production, increasing from 39.4 percent in 1960 to 45.5 percent in 1982. By decades, the value of crop production grew at an annual growth rate of 2.9 percent during the 1960's, 6.1 percent in the 1970's and 0

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[1]See Table XVIII in Appendix B.

percent during 1980-1982. Concerning livestock, its annual growth rates were 4.3 percent for the 1960's, 6.1 percent for the 1970's and 12.5 percent for 1980-1982. That means that livestock had a more dynamic behavior than crops in terms of value of production, especially in the last part of the period. For the total value of production the annual figures were: 3.4 percent for the 1960's, 6.1 percent for the 1970's and 2.9 percent for 1980-1982.

Input Trends

According to SAC (1984, Table 5) the number of farms were 1,209,672 in 1960 but then decreased to 1,176,811 by 1970 and increased to 1,363,392 for 1983-1984. The area corresponding to that number of farms followed a steady increasing tendency as follows: by 1960 the area was about 27 million hectares, by 1970, over 30 million hectares, and by 1983-84 almost 35 million hectares. With respect to cropped land, (Table XX) that shows an annual growth rate of 0.7 percent during the 1960's, 2.8 percent for the 1970's and -4 percent annually during 1980-1982 period. In this respect the cropped land follows a pattern like that followed by value of the output, that is, increasing dynamic in the 1970's and tendency to stagnation in the 1980's.

Laborers, including unpaid family workers, increased from 1960-1972 at a rate of 1.8 percent annually and then they began to decrease steadily. By decades, laborers increased during the 1960's, increased and decreased during the 1970's, and continued decreasing during 1980-1982.[2] Regarding the whole period of 1960-1982, labor factor decreased at an annual growth rate of 0.5 percent.

[2]See Table XIX in Appendix B.

Fertilizer's trend shows an increasing tendency during the total period of analysis.[3] The pattern by decades runs as follows: during the 1960's, fertilizer usage grew at an impressive rate of 16.6 percent per year. The 1970's shows also a high rate of annual growth in fertilizer usage, which was 9.1 percent. The decreasing tendency noted in the cases of land and labor for the last part of the period is also observed in the case of fertilizer, since the annual rate of growth fell to -3.0 percent. Another important input in agriculture refers to power, which is a kind of capital in agriculture. Converting the number of tractors into horsepower equivalents.[4] The trend followed by this production factor is as follows: 6.7 percent annual growth rate for the 1960's, 4.0 percent for the 1970's, and 0.9 percent per year for 1980-1982 period. As before, there is a slowdown in the rate of growth for this production factor in the last part of the period of analysis.

Partial Productivity Ratios

The evolution of the labor productivity ratio (O/L) or real output per man year can be observed in Table II. According to that information, labor productivity has been increasing at an annual growth rate of 7.3 percent for the whole period of 1960-1982; by decades the behavior is as follows: for the 1960's the annual growth rate was 2.5 percent; it increased for 1970's decade when it was 8.4 percent per year and remained the same for the last part of the period (1980-1982).

At the same time, the components of labor productivity (equation 38), land per worker and output per land, were as follows: land per worker (A/L) had an

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[3]See Table XXI in Appendix B.

[4]See Table XXII in Appendix B.

TABLE II

LABOR AND LAND PRODUCTIVITY, 1960-1982, COLOMBIA

Year	Output per Worker[1] (Thousand Pesos) O/L	Land per Worker[2] (Ha.) A/L	Output per Land[3] (Thousand Pesos) O/A
1960	10.49	10.04	1.04
1961	10.48	10.18	1.03
1962	11.41	10.46	1.09
1963	11.35	10.46	1.08
1964	12.44	11.30	1.10
1965	11.07	9.90	1.12
1966	12.21	10.95	1.15
1967	11.20	9.82	1.18
1968	11.52	9.74	1.18
1969	12.88	10.90	1.15
1970	12.56	10.89	1.15
1971	12.23	10.31	1.18
1972	11.91	10.03	1.19
1973	13.84	11.40	1.21
1974	16.21	12.22	1.33
1975	18.66	14.16	1.32
1976	18.03	12.97	1.39
1977	18.64	13.32	1.40
1978	19.61	13.21	1.48
1979	22.03	14.26	1.55
1980	23.08	14.66	1.57
1981	25.30	14.74	1.72
1982	27.00	15.58	1.73

[1] Source: Tables XVIII and XIX
[2] Source: Tables XIX and XX
[3] Source: Tables XX and XVIII

erratic growth during the 1960 decade with some ups and downs; during this period this grew at a rate of 1.0 percent per year. During the same period, land productivity (output per land, O/A) increased at an annual rate of 1.2 percent. According to the theory in Chapter III, that suggests that some biological innovation such as improved varieties, new cultural practices and pest management has been adopted by farmers and the biological innovation was relatively more important than mechanical innovation as indicated by the land per worker ratio. During the next decade, 1970-1979, the land worker ratio had an annual growth rate of 3.4 percent while output per land increased 3.9 percent, and again that means that the biological innovation were more important than the mechanical innovations. Also, the 1970's appears to be more dynamic decade than the 1960's according to the comparison of the output per land ratio in the two periods; it is quite likely that work done by ICA in improved varieties contributed to this dynamic trend, which is reinforced in the rest of the period (1980-1982) where the annual growth rates were 3.1 percent for land per worker and 5.1 percent for land productivity.

Another way to see the direction (bias) of the Colombian technological development is analyzing the proxy index for factor substituting land (F/A) and the proxy index for factor substituting labor (M/A), which are presented in Table III. According to that information fertilizer per unit of land (hectares) increased at a rate of 11% annually for the entire period of time while horsepower per hectare increased at a lower rate of 4 percent per year. Such analysis implies that the substitution for land in the production process has been more intensive than for labor, indicating that the direction of the Colombian technological change in agriculture has been relatively more land-saving than labor-saving. This conclusion is in accordance with the fact the process of creating new biological technology is one of greater autonomy in comparison with

TABLE III

FERTILIZER AND MACHINERY PER LAND, 1960-1982, COLOMBIA

Year	Fertilizer Used[1] (Metric tons/Ha) F/A	Machinery Used[2] (Horsepower/Ha) M/A
1960	0.050	0.253
1961	0.055	0.295
1962	0.077	0.306
1963	0.079	0.337
1964	0.099	0.322
1965	0.089	0.319
1966	0.097	0.328
1967	0.104	0.354
1968	0.109	0.350
1969	0.114	0.380
1970	0.115	0.394
1971	0.138	0.437
1972	0.160	0.434
1973	0.170	0.399
1974	0.162	0.385
1975	0.134	0.390
1976	0.143	0.396
1977	0.157	0.403
1978	0.175	0.414
1979	0.167	0.426
1980	0.168	0.437
1981	0.153	0.455
1982	0.171	0.476

[1] Source: Tables XXI and XX
[2] Source: Tables XXII and XX

mechanical innovations. However, it should also be noted that for the final part of the period (1980-1982) there is a deceleration in F/A (0.9 percent of annual growth rate) in favor of factor substituting labor (M/A) whose growth rate was 4.5 percent in that part of the period of study.

Even though the previous analysis leads to the conclusion that the technological change in Colombian agriculture has been relatively more land-saving than labor-saving, technological change has saved labor through higher labor productivity. Output per worker ratios can be used to measure the magnitude of that gain in efficiency and also to measure the magnitude of technical change in agriculture. It was defined in Chapter III that if no technical change has occurred between two years, or two periods, the output per worker ratios would be similar, that is, $(O/L)_o = (O/L)_i$ (i = 1, 2, . . ., n). If technical change has occurred, the labor needed to produce the output of year i (O_i) with the technology of a base (o),

$$L'_i = \frac{O_i}{(O/L)_o} \tag{4.1}$$

will be greater than the actual labor force in year i (L_i). So, if technical change has occurred $L'_i > L_i$, the difference between L'_i and L_i indicates: (a) increasing or decreasing labor efficiency; and, (b) the magnitude of that change.

In 1982, 1,827,000 farm workers and unpaid family workers produced crops and livestock valued at 49,332.5 million pesos (in 1970 constant pesos). If no technical change had occurred since 1960, 4,702,800 workers would have been needed in 1982, instead of 1,827,000 that were employed.

So, 4,702,800 workers (L'_i) - 1,827,000 (L_i) = 2,875,800 labor years were saved. That figure should not be interpreted at a real displacement of labor from current employment but in the sense of additional workers needed to reach the actual production level with the technology of some base period. By decades, the analysis shows that there was increasing labor efficiency from the 1960's to the 1970's since the labor years saved moved from 492,000 in the 1960's to 1,536,000 in the 1970's; for the last part of the period 324,400 labor years were saved. The above analysis illustrates the technological pattern already found before in this research: a technological take-off period (1960's), a technological dynamic period (1970's) and the beginning of a technological deceleration period (1980-1982).

Before leaving the partial productivity ratio approach, one additional relationship can be estimated to illustrate some other characteristics of the Colombian agricultural technological change. As indicated in Chapter III, for many underdeveloped countries the evolution of land productivity is an important measure of technological change. According to Dalrymple (1977) changes in crop production are a function of changes in area and/or yield and this relationship can be investigated by the expression (3.9).

$$1 = \frac{\log(1+A)}{\log(1+O)} + \frac{\log(1+Y)}{\log(1+O)} \qquad (4.2)^{5}$$

where A, O, and Y are percentage of change from one period to another in area, output and yield, respectively. The above (4.2) formula permits the calculation of how much percentage of the increment in output is attributed to land and how much to yield. To apply the formula, the percentage of change from one period to another in area, output and yield are first calculated, as shown in Table IV. Results of applying the formula (4.2) are given in Table V.

Results (Table V) indicate that for the entire 1960-1982 period, the increase in crop yield explain 57% of production increase and 43% is explained by area expansion. This overall situation is different when it is seen by

[5]The formula works with the notion that the rate of growth of output equals the rate of growth of area plus the rate of growth of yield plus an interaction, that is, $O = A + Y + YA$.

TABLE IV

RELATIVE INCREASES IN VALUE OF CROP PRODUCTION, AREA, AND YIELD, 1960-1982, COLOMBIA

Period	Average increase (%) in:		
	Production	Area	Yield
1960-1965 to 1970-1975	37.6	26.1	9.9
1970-1975 to 1978-1982	48.4	7.9	37.6
1960-1965 to 1978-1982	105.7	36.0	51.0

TABLE V

RELATIVE IMPORTANCE OF AREA AND YIELD IN PRODUCTION EXPANSION, 1960-1982, COLOMBIA

	Percentage Production Increase Due to Expansion:	
Period	Area	Yield
1960-1965 to 1970-1975	72	28
1970-1975 to 1978-1982	19	81
1960-1965 to 1978-1982	43	57

subperiods. Production increment corresponding to 1960-1965 with respect to 1970-1975 is due to 72% of area expansion and 28% coming from increasing yield. The picture is different for the period 1970-1975 with respect to 1978-1982 when area expansion only contributed with 19% to production increase and yield explained 81 of such increase. As expected, as the technological change advances, the relative participation of land becomes less important. The above situation illustrates the importance of the research system in leading the Colombian agriculture toward greater efficiency levels since higher yields are a consequence of activities in agricultural research.

Productivity Index

By definition, a total factor productivity index is the relationship between an output index and a total input index ($PI_t = \frac{O_t}{I_t}$).[6] As explained in Chapter III there are several ways to add inputs and weight them. In the present research a Divisia-type index for outputs and for inputs is used and the approximation formula for that goal is the formula (3.15). The output index is made up by the following products: corn, rice, sorghum, barley, wheat sesame, soybeans, oil palm, sugarcane, panela cane, beans, potatoes, cassava, plantain, bananas, cocoa, coffee and livestock. Inputs entering the index are: labor, measure as wage bill, valued at wages reported by National Department of Statistics (DANE) and considering 250 work-days per year; intermediate consumption (seeds, fertilizers, pesticides, concentrates, energy) as estimated by national accounts and reported by Department of National Planning (DNP-UEA-DC,

[6]The expression "total factor" is used here in the sense of multifactor. In fact, some production factors are left out of the input index.

1982); land (cropped and pastureland) in term of its rental value;[7] capital, represented by the rental value of inventories of machinery, investment in land improvements, and livestock. The stock of machinery and land improvements was that estimated by Elias (1985, pg. 31) and then the rental value of this stock was calculated using a 10 percent rate of return to capital for Colombian economy, according to Atkinson (1970, pg. 17) and Harberger (1969). The rental value of livestock was estimated using 4.4 percent as the rate of return for investment on livestock over the stock of livestock. Both rate of return and stock were reported by Llorente (1986, pg. 346 and 358). These estimations are in Table XXIII in Appendix B.

The formula (3.15):

$$PI_t = \ln (TFP_t/TFP_o) = \ln (O_t/O_o) - 1/2 \sum_{i=0}^{n} (S_{it} + S_{io}) \ln(X_{it}/X_{io}), \qquad (4.3)$$

allows to define growth in total factor productivity (TFP) as growth in output minus the factor share-weighted growth in inputs. Because the growth rates are calculated as natural logarithms, by taking the exponential of the growth rates, it is possible to convert them to index levels, which results in the base period (1960) being equal to 1. In the above formula S represents the cost share of input X_i (labor, land, intermediate consumption and capital) every year. All the calculations are performed in real term values (1970=100).

The evolution of factor cost shares by selected year is presented in Table VI. It can be noted that labor (wage bill), in spite of some abrupt changes in 1965 and 1970, shows a natural and expected decreasing tendency. This input declined its participation 9 percent during the entire period or 0.4 percent per year, which is much less dramatic than in the case of United States where labor

[7]According to Orozco (1977, pg. 60) financial agencies allow 15% of land value as land rent.

TABLE VI

FACTOR COST SHARES 1960-1982 FOR SELECTED YEARS, COLOMBIA (FIGURES IN PERCENT)

Year	Labor (wage bill)	Modern Inputs	Land (rental value)	Capital (rental value)
1960	46	15	19	20
1965	49	15	17	18
1970	32	22	18	18
1975	38	24	17	20
1982	37	26	15	22

Source: Calculated from Table XXIII

declined about 80 percent between 1940 and 1982, or at 1.9 percent annually (Sundquist, 1984, p. 3). In contrast, intermediate consumption or modern inputs as seeds, fertilizer, concentrates, etc: increased their participation in factor cost shares from 15 percent in 1960 to 26 percent in 1982, in accordance with biological improvements product of the agricultural research system (new improved varieties and cultural practices) and input recommendation to use new technological "packages". Land and capital represented by their rental values show slight tendencies to change in the whole period.

The productivity index for the Colombian agriculture for the 1960-1982 period is presented in Table VII. In spite of several decreases in the index it shows a total gain of 33.4 percent for the whole period, which represents an annual growth rate of 1.5 percent in productivity gain. By comparison, United States had an average annual rate of change of 1.8 for the 1965-1979 period (Sundquist, 1985). This gain in productivity reflects the fact that the output index increased at a faster growth rate than input index and, as it was deducted by partial productivity ratio analysis, this gain comes mainly from modifications in biological systems, mainly through the development of new improved varieties, agronomic and animal cultural practices, animal breeds, and agricultural chemicals inherent to the new technology. Most of such developments are a direct product of the Colombian agricultural research system. So the question to ask here concerns the possibility for the Colombian agriculture to maintain this accumulated productivity gain for the years to come, under the pattern of funding research and extension pointed out at the beginning of this research and depicted in Figure 9.

Similar worry is expressed by Sundquist (1985) regarding the American agricultural productivity:

TABLE VII

AGRICULTURAL OUTPUT, INPUT, AND PRODUCTIVITY INDEXES, 1960-1982, COLOMBIA

Year	Output Index	Input Index	Productivity Index (TFP)
1960	100.0	100.0	100.0
1961	99.0	98.0	101.1
1962	107.5	100.6	106.9
1963	107.1	99.4	107.8
1964	111.6	104.6	106.6
1965	114.3	115.0	99.4
1966	114.8	110.1	104.3
1967	118.8	122.4	97.1
1968	126.7	123.5	102.6
1969	130.6	118.2	110.4
1970	134.7	121.3	111.1
1971	137.5	126.4	108.8
1972	138.7	140.2	98.9
1973	146.7	143.4	102.2
1974	163.6	142.0	115.2
1975	165.4	140.5	117.7
1976	176.9	150.9	117.3
1977	182.6	165.2	110.5
1978	199.6	179.3	111.3
1979	208.7	171.6	121.6
1980	212.6	172.8	123.0
1981	230.7	174.6	132.1
1982	230.8	173.0	133.4

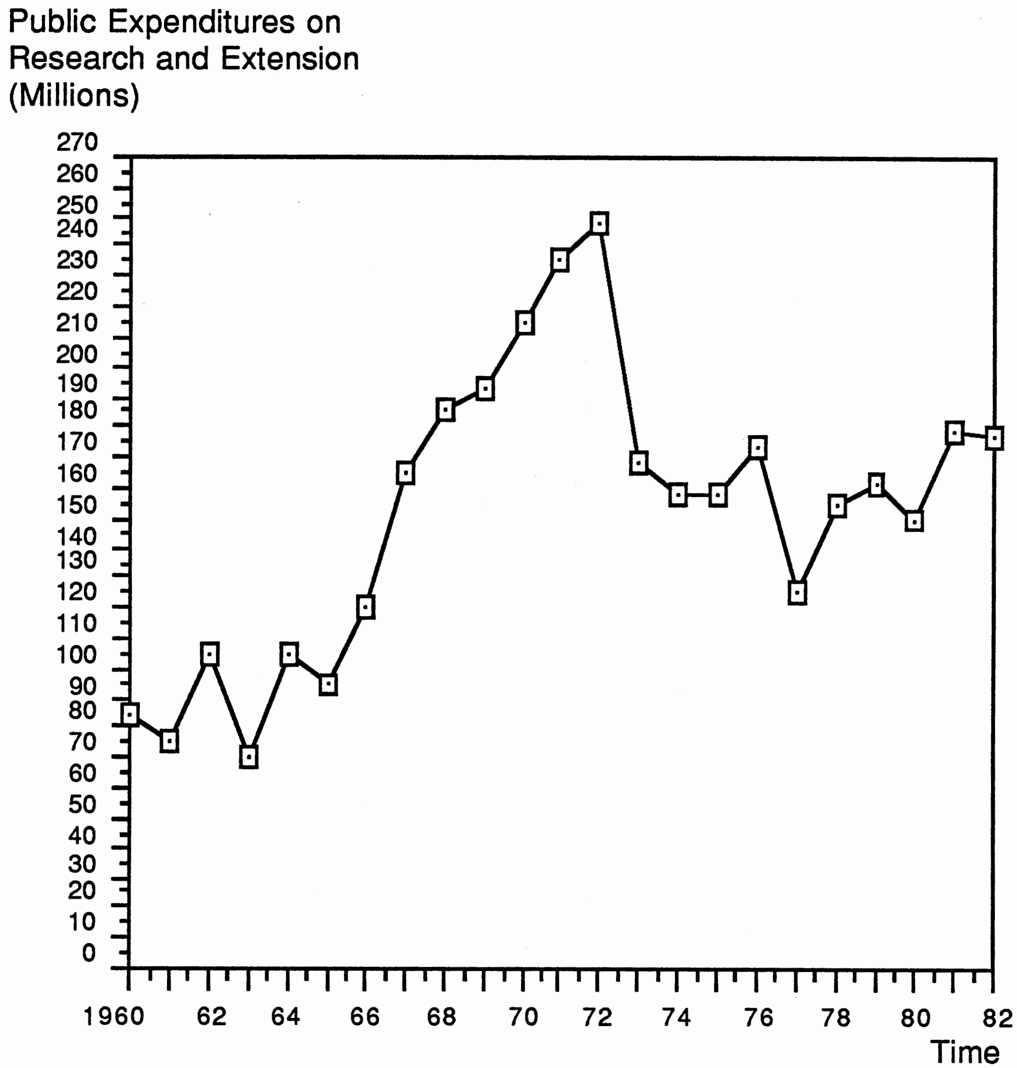

Figure 9. Public Expenditures on Agricultural Research and Extension, 1960-1982, (Real term, 1970=100), Colombia.

> There appears to be some indication of a leveling off in total farm productivity since the mid 1960's but a bigger concern is that the past sources of productivity growth have now been heavily exploited and that future growth rates may severely decline. This concern is magnified by the stagnant (and in recent years declining) real rates of investment in public research which generated much past farm sector productivity growth (p. 3).

The functional pattern for research and extension shown by Figure 9 can be divided into three different periods: 1960-1966 period, when the expenditures in research and extension grew at an annual rate of 7.1 percent; 1967-1972, when there was a "big jump" in budget for research and extension and the funds increased at an annual growth rate of 10% percent in real terms. The last part of the period (1973-1982) was very different since the annual growth rate in real term fells down to 0 percent. Assuming a mean time lag of 5 or 6 year for investment in research and extension to impact production at maximum, it can be appreciated an acceleration in both the production index and productivity index by the years 1974-1975, as a consequence of the "big jump" in research and extension real expenditures by the years 1969-1970. Similarly, the observed stagnation of the annual rate of increment for both the production and productivity index in 1981-1982 has a relationship with zero growth in research and extension expenditures, in real terms, by the years 1975-1977.

The annual output, input and productivity growth by selected period are presented in Table VIII. Several important facts can be gleaned from this table. First, there is an increasing tendency in output growth from period to period. Second, there is a decreasing tendency in input growth from period to period. Within input categories, labor tends to decrease its participation as a source of output growth; land and capital tend to maintain their participation to explain output growth and intermediate consumption increase its participation as a source of output growth from period I to period II and then declines from period II

TABLE VIII

AVERAGE ANNUAL GROWTH RATES OF OUTPUT, INPUT, AND PRODUCTIVITY, SELECTED PERIODS, 1960-1982, COLOMBIA

	Period I		Period II		Period III	
	1960-61 to 1968-69		1968-69 to 1975-76		1976-77 to 1981-82	
Annual Output Growth		3.6		4.7		5.3
Annual Input Growth		2.7		2.6		2.0
Labor	1.2		-0.1		0.6	
Land	0.1		0.5		0.1	
Intermediate Consumption	1.0		1.3		0.6	
Capital	0.4		0.9		0.7	
Residual Productivity Growth		0.9		2.1		3.3

Source: Estimations based on Table VII.

to period III. This, again, is a sign for technological recession. Third, there is an increasing tendency in productivity growth from period to period, indicating a consolidation in productivity gains for Colombian Agriculture. This phenomenon can be observed in Table IX which distributed the 100 percent in output growth between growth in inputs and growth in productivity. The picture is very clear: the contribution of inputs to the growth of output fell from 75.1 percent in the first period to 36.2 percent in the third period; in contrast, the contribution of productivity rose from 24.9 in the first period to 63.8 percent in the last period. This means that has had an important advance in productivity in the Colombian agriculture during 1960-1982 period.

The analysis performed so far based on partial productivity ratios and total factor productivity leads to the corroboration of the first hypothesis of this research, namely, that there has been an important advance in agricultural productivity in Colombia during the 1960-1982 period. However, this productivity gain has a differentiated pattern, since it grew fast up to the final part of the 1970's and then a tendency to stagnation emerges from the data analysis. In addition, it seems to be clear the relationship between the gain in productivity and the activities in research and extension, specifically between the ups and downs in funding research and extension and its effect on production and productivity years later. A final comment should be made about the overall behavior of the productivity index. Even though there are several partial sign indicating the beginning of a technological slowdown, the productivity index as a whole indicates some degree of consolidation of productivity gains in Colombian agriculture to the present as pointed out before and as a consequence of past investment on research.

TABLE IX

RELATIVE CONTRIBUTION OF INPUTS AND PRODUCTIVITY TO OUTPUT GROWTH, SELECTED PERIODS, 1960-1982, COLOMBIA

	1960-1961 to 1968-1969	1968-1969 to 1975-1976	1976-1977 to 1981-1982
Growth in Inputs	75.1	56.1	37.5
Labor	33.2	-2.1	11.2
Land	3.3	10.4	2.1
Intermediate Consumption	27.6	28.7	10.5
Capital	11.1	19.1	12.4
Growth in Productivity	24.9	43.9	63.8
Total Output Growth	100.0	100.0	100.0

Source: Estimation based on Table VII

Changes in the Aggregate Production Function

The rest of the present chapter is devoted to the statistical analysis and testing of the above hypothesis by testing changes in aggregate production function for Colombian agriculture sector in several predetermined periods. Basically, the analysis is carried out by testing changes in dummy variables representing different periods of time or eras.

The model to be used is the (3.16) model:

$$Q = a_0 \, x_1^{\alpha_1} \, x_2^{\alpha_2} \, x_3^{\alpha_3} \, x_4^{\alpha_4} \, e^{\mu} \qquad (4.4)$$

which can be expressed in log form as:

$$\log Q = \log a_0 + \alpha_1 \log x_1 + \alpha_2 \log x_2 + \alpha_3 \log x_3 + \alpha_4 \log x_4 + \mu$$

where Q and x_i (i = 1, 2, 3, 4) were defined before

μ = Disturbance term

e = Base of natural logarithms

Since equation (4.4) is linear with respect to log a_0 and the α's, it can be estimated by ordinary least squares.

However, the results in Table X on simple correlation coefficients indicate high degree of multicollinearity among some variables (x_2, x_3, x_4) which is a normal situation given the complementarity among some of the inputs. Multicollinearity increases the variances of the least squares estimators so that the estimated coefficients become imprecise. It may be a sample problem, in which case a new data set might cause the problem to disappear (Pindyck and Rubinfeld 1981, p. 88). So, a new model is specified using the standard Cobb-Douglas formulation, that is, labor and capital, as below:

$$Q = a_0 \, x_1^{\alpha_1} \, x_2^{\alpha_2} \, e^{\mu} \qquad (4.5)$$

TABLE X

MATRIX OF SIMPLE CORRELATION COEFFICIENTS AMONG VARIABLES IN THE AGGREGATE PRODUCTION FUNCTION FOR COLOMBIAN AGRICULTURE

Variable	Q	x_1	x_2	x_3	x_4
Q	1.000				
x_1 (labor)		1.000			
x_2 (land)		-0.1467	1.000		
x_3 (purchased input)		-0.0772	0.9875	1.000	
x_4 (capital)		-0.2194	0.9533	0.9609	1.000

where:

Q = Value of production in real term

a_0 = Constant term

x_1 = Labor measures as man-years

x_2 = Stock of capital, measures as the value of machinery and livestock

μ = Disturbance term

The simple correlation coefficient among x_1 and x_2 is -0.205, so multicollinearity is not a serious problem now.

Model (4.5) was run for each of the periods: 1960-1967, 1968-1975, and 1976-1982 and then pooled models were estimated, as follows: 1960-1967 and 1968-1975; 1968-1975 and 1976-1982; and also for the entire 1960-1982 period. These periods were determined to represent different technological scenarios or eras. In every pooled equation a dummy variable was included to represent shifts in the production function due to technology. The main results of this exercise are presented in Table XI.

The pooled equation for 1960-1967 and 1968-1974 shows that the dummy variable (D_2) is significantly different from zero at 0.01 level; this result and the magnitude of the dummy variable, which is 0.20, mean that there was an important shift in the production function from 1960-1967 to 1968-1975 as a consequence of technological change generated by research and extension. The dummy variable representing the first period (1960-1967) was dropped from the model to avoid singularity in X's matrix, but its effect is included in the constant term.

The pooled equation for 1968-1975 and 1976-1982 periods was run twice; the first result shows some degree of positive autoregression. To correct for autoregression a second model using first differences was tried [AR(1)]. The Durbin-Watson statistics in this case indicate that autocorrelation is no longer a

TABLE XI

ESTIMATED PRODUCTION FUNCTION FOR THE AGRICULTURAL SECTOR, SELECTED PERIODS, 1960-1982, COLOMBIA

Variables	Pooled 1960-1967 & 1968-1975	Pooled 1968-1975 & 1976-1982	Pooled 1968-1975 & 1976-1982	Pooled 1960-1982
x_1 (labor)	-0.399	-0.608	-0.071	-0.863
	(-2.157)**	(-2.627)***	(-0.403)	(-2.850)***
x_2 (capital)	0.514	0.573	0.387[1]	0.946
	(4.633)***	(3.267)***	(2.380)***	(8.252)***
D_2	0.201			
	(5.678)***			
D_3		0.127	0.056	
		(2.381)***	(1.279)	
RE (-1)[2]				0.204
				(2.572)***
AR (1)[3]			0.887[4]	
			(8.740)***	
Constant term	7.413	8.561	6.829	5.260
SE	0.049	0.054	0.034	0.080
F-Statistic	42.253	56.986	110.174	72.026
$\bar{R}^2$	0.898	0.928	0.971	0.910
DW[5]	1.590	1.432	1.935	1.648

Note: Variables are expressed in logarithms; the $\bar{R}^2$ is adjusted for degree of freedom; the number in parentheses are the t-values.

**Means significant at the 0.05 level
*** Means significant at the 0.01 level

1 Lagged one year
2 Research and extension expenditures, lagged one year
3 Autoregressive first-order process
4 Coefficient of autocorrelation (ρ)
5 Durbin-Watson statistic

problem. The dummy variable dropped in this case was D_2, and D_3 enters the model. Results indicate that D_3 is not significantly different from zero, that is, the two production functions representing two periods of time are equal or, in other words, there was no shift in the production function from 1968-1975 to 1976-1982.

Regarding the first hypothesis of this research, it has been tested statistically and the results lead to acceptance of such hypothesis in the sense that there was a significant technical change in the Colombian agriculture from 1960 to the last part of the 1970's; since then the Colombian agriculture sector has been characterized by technological stagnation. Similar results also were found in the sections devoted to partial productivity ratios and productivity index.

Finally, the pooled regression for 1960-1982 period was estimated to gain more insights about the technological process. The inclusion in the model of the variable research and extension expenditures lagged one period [RE(-1)] improved the estimation of previously estimated coefficients of labor and capital.[8] But the result to be highlighted here is the coefficient for RE which is the elasticity of production with respect to research and extension,[9] meaning that for every 1 percent of increment on research and extension, production increased by 0.20 percent.

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[8]These results are not shown in Table XI.

[9]This is inherent to the Cobb-Douglas production function (Nicholson, 1985, p. 256).

CHAPTER V

ESTIMATED MARGINAL AND AVERAGE INTERNAL RATE OF RETURN AND SECONDARY IMPACTS

One of the objectives in this chapter is to present the results derived from the estimation of the productivity model stated in (3.21), (3.22), and (3.25), namely, the elasticity of production with respect to research and extension, the marginal product of research and extension, and the marginal internal rate of return. The calculation of the average internal, external and benefit-cost ratio estimated from model (3.31) will be also presented. Additionally, the projection of the productivity index 10 years beyond 1982 under three different assumed scenarios is examined. Another goal of this chapter is to present the results concerning the attempt to estimate secondary impacts of research and extension.

Estimation of the Marginal Internal Rate of Return

The calculation of the marginal internal rate of return involves several steps: first, it is necessary to estimate the equation (3.25) to have the coefficient of research and extension estimated; second, estimation of the value of marginal product of research and extension, and then, the marginal internal rate of return is obtained using discount analysis. So, the corresponding results will be presented in that order.

A redefinition of the weather variable had to be done before the estimation of the model because of lack of information for some period of analysis. Instead, the approach used was that followed by Habtu (1986, p. 151 and Hasting (1981)). By using such approach the weather index is found by regressing the value of production against time. The residual is attributed to weather and these residuals are converted to an index whose base is 1970. So defined, the weather is a stochastic variable and as such it enters in the model (3.21) by the term e ($e^{\mu_t + w_t}$). So the model (3.25) to be estimated becomes:

$$\ln PI_t - \rho \ln PI_{t-1} = \gamma (\ln EI_t - \rho \ln EI_{t-1}) + \sum_{j=0}^{n} \alpha_j (\ln PR_{t-j} - \rho \ln PR_{t-j-1})$$

$$+ \beta (WI_t - \rho WI_{t-1}) + e_t \qquad (5.1)$$

where $e_t = u_t - \rho u_{t-1}$, ρ = coefficient of autocorrelation and the rest of variables as defined before. The difference between model (3.25) and model (5.1) being the lack of a logarithm for the weather variable in the latter.

To apply the Almon polynomial distributed lag technique for estimation of α_j three aspects need to be defined: the polynomial order, endpoint restrictions, and number of lags. As shown in Figure 8, the order of the polynomial is two, resulting in an inverted U-shape of weights over time. A zero endpoint restriction was chosen based on the fact that when no endpoint restriction was used, the polynomial distributed lag was not significant (based on two-tail significance). Concerning the number of lags, a number of different lag lengths were tried, the final choice being upon Theil's $\bar{R}$ (minimum standard error) criteria. Regarding the dependent variable, two alternative variable specifications will be used looking for better model results.

The results of fitting model (5.1) to Colombian data for the 1960-1982 period are shown in Table XII. When the productivity index was used as the dependent variable, the independent variables weather and education

TABLE XII

CONTRIBUTION OF RESEARCH AND EXTENSION EXPENDITURES TO AGGREGATE AGRICULTURAL PRODUCTION, 1960-1982, COLOMBIA

Explanatory	Regression Coefficients and Lag Length (years)		
Variables	12	14	16
$\ln EI_t - \rho \ln EI_{t-1}$	0.22639	0.21498	0.19630
	(2.38874)**	(2.19977)**	(1.84565)*
$WI_t - WI_{t-1}$	0.03039	0.02735	0.02448
	(1.96625)*	(1.71780)*	(1.42331)
$\ln PR_t - \rho \ln PR_{t-1}$	0.00622[1]	0.00497[2]	0.00398[3]
$\ln PR_{t-1} - \rho \ln PR_{t-2}$	0.01141	0.00924	0.00745
$\ln PR_{t-2} - \rho \ln PR_{t-3}$	0.01556	0.01279	0.01043
$\ln PR_{t-3} - \rho \ln PR_{t-4}$	0.01867	0.01563	0.01292
$\ln PR_{t-4} - \rho \ln PR_{t-5}$	0.02074	0.01776	0.01491
$\ln PR_{t-5} - \rho \ln PR_{t-6}$	0.02178	0.01918	0.01640
$\ln PR_{t-6} - \rho \ln PR_{t-7}$	0.02178	0.01989	0.01739
$\ln PR_{t-7} - \rho \ln PR_{t-8}$	0.02074	0.01989	0.01789
$\ln PR_{t-8} - \rho \ln PR_{t-9}$	0.01867	0.01918	0.01789
$\ln PR_{t-9} - \rho \ln PR_{t-10}$	0.01556	0.01776	0.01739
$\ln PR_{t-10} - \rho \ln PR_{t-11}$	0.01141	0.01563	0.01640
$\ln PR_{t-11} - \rho \ln PR_{t-12}$	0.00622	0.01279	0.01491
$\ln PR_{t-12} - \rho \ln PR_{t-13}$		0.00924	0.01292
$\ln PR_{t-13} - \rho \ln PR_{t-14}$		0.00497	0.01043
$\ln PR_{t-14} - \rho \ln PR_{t-15}$			0.00745
$\ln PR_{t-15} - \rho \ln PR_{t-16}$			0.00398
$\sum_{i=0}^{n} \alpha_j$ [4]	0.18877	0.19891	0.20273
	(5.2582)***	(4.54553)***	(3.66969)***
$\bar{R}^2$	0.98345	0.982347	0.97947
SEE[5]	0.03457	0.03569	0.03851
DW[6]	1.63375	1.62606	1.39548
$\hat{\rho}$[7]	0.92960	0.93169	0.94041
F	417.1964	391.0476	355.0243

[1] Coefficients are significant at 0.01 level
[2] Coefficients are significant at 0.01 level
[3] Coefficients are significant at 0.01 level
[4] Sum of research and extension coefficients
[5] Standard error of estimation
[6] Durbin-Watson statistic
[7] First-order autoregressive coefficient
Figures in parentheses are t-ratios
*** means significant at 0.01 level
** means significant at 0.05 level
* means significant at less than 0.10 and greater than 0.05 level

attainment were not significant either at the 0.05 level, or at the 0.01 level of significance. In contrast, when the production index was used as the dependent variable, the estimated coefficient for weather and education became significant at the 0.05 level of significance. Under this base and also because the model will be used later on to make projections the dependent variable is chosen to be the production index.

Three trials to select the best model in terms of lag length are presented in Table XII. The model was run using least squares alternatively with 12, 14, and 16 years-lag. According to the standard error of estimation (SEE) criterion, the model with 12 years-lag is the best since it has the minimum SEE of the three models. This means that a "dose" of research and extension expenditures injected in year t will affect agricultural production in year t and continue to affect it for the following 12 years.

The contribution of research and extension expenditures is relatively small in the early years, reaches a maximum by the sixth and seventh years and then declines thereafter. After year twelve the effect becomes negligible.[1] According to the chosen model (12 years-lag) the sum of the research and extension expenditures is 0.19 indicating that, over its lifetime, a one percent increase in research and extension expenditures increases aggregate production by 0.19 percent. The pattern of such distribution over time is shown in Figure 10. This result is equivalent to the elasticity of production with respect to research and extension expenditures.[2] The individual coefficients show the distribution of the

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[1]The sixth through seventh year maximum effect is in accordance with that found by Evenson (1967), White and Havlicek (1982), and some other authors for the United States.

[2]According to Bredahl and Peterson (1976, p. 689), the production elasticity of research is comparable to the factor "K", in the case of economic surplus approach.

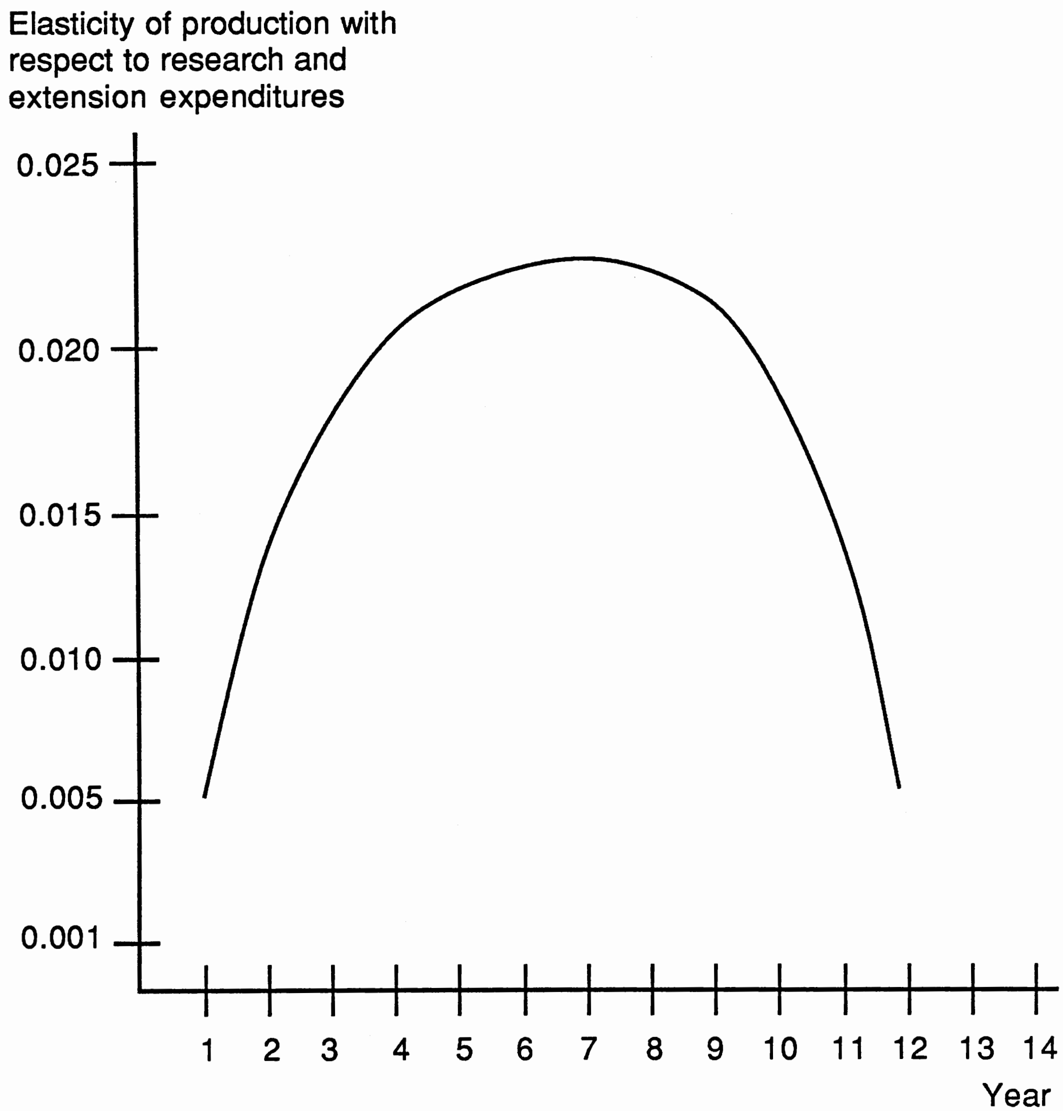

Figure 10. Time Form of the Contribution of Research and Extension to Agricultural Production, Colombia.

research and extension coefficient over time. Education is also significant in the model, whose coefficient is 0.23 meaning that one percent increase in farmer's education attainment increases aggregate production by 0.23 percent. In the case of weather which is significant for the model at 0.08 level of significance, its coefficient indicates that one percent increase in weather conditions increases aggregate production by 0.23 percent. For the 12 year-lag model the $\overline{R}$ indicates that the model does a good job explaining the variations in the agricultural production index and the Durbin-Watson statistics suggest no serial correlation in the final model. Also, an F-test of the null hypotheses that all regression coefficients R's are equal to zero is rejected at one percent level of significance.

To see the monetary effect of research and extension on production the marginal product of these variables should be calculated. Because the regression coefficients are elasticities, the marginal product of research and extension can be calculated as:

$$\sum_{j=0}^{n} MP_j = \sum_{j=0}^{n} \alpha_j \,(\overline{TQ}/\overline{TR})^{3} \qquad (5.2)$$

where:

α_j = Research coefficient

MP_j = Marginal product of research and extension expenditures in year i.

$\overline{TQ}$ = Geometric mean for agricultural output

$\overline{TR}$ = Geometric mean for research and extension expenditures

As a result, the value of marginal productivity of research and extension expenditures is $40.81. That is, one peso increase in expenditures on research

[3] Since the index is in terms of value of production, the expression (5.2) gives the Value of Marginal Product (VMP).

and extension increases the value of agricultural output by \$40.81. For example, if research and extension appropriations were increased by \$100 million pesos, farm output from this change would eventually increase, ceteris paribus, by \$4,081 million pesos. This marginal return accrues over several years, so to permit comparisons, rates of return should be expressed on an annualized basis; that is why it is so important to calculate the mean time lag for research and extension investments. Using the formula (3.30)

$$\sum_{j=0}^{n} \frac{\alpha_j (\overline{TQ}/\overline{TR})}{(1 + MIRR)^j} - 1 = 0 \qquad (5.3)$$

where:

α_j, $\overline{TQ}$, $\overline{TR}$ as defined before

MIRR = Marginal internal rate of return, the estimation of the marginal internal rate of return yields 85.55%.

The above annualized internal rate of return would tend to overestimate the contribution of public research and extension since research and extension expenditures do not include private sector research and extension. Unfortunately data about private research and extension expenditures are not well known. The theory discussed in Chapter III indicates that private research and extension contribute to productivity, but this contribution is likely to be smaller than that of the public sector contribution since much of the private research and extension pay-off will be reflected in input prices. However, some information about coffee growers' expenditures on research[4] indicates that these expenditures are approximately 20% of that of public research and extension expenditures through the ICA budget. Thus, to avoid overestimation, the research and extension coefficient is adjusted by a factor of 1.2. Performing

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[4]See Garcia and Montes (1986).

all the calculation the adjusted marginal internal rate of return turns to be 72% for public research and extension.

On the other hand, to assign the internal rate of return to research and extension separately, additional considerations are in order. Taking into account the proportion of extension expenditures on the total expenditures for research and extension, and also that returns to extension are subordinated to research and that extension activities include non-production oriented activities, the distribution of the internal rate of return is estimated to be 70% for research and 30% for extension. This being the case, the internal rate of return for research is 50% and for extension 21%.

To compare, some estimated internal rates of return for research in several countries are presented in Table XIII. According to the same source (Hayami and Ruttan, 1985), the internal rate of return for extension clusters around 15-20%. Thus, both research and extension internal rates of return for Colombia compare favorably to those obtained in other countries. In spite of the limitations of this study, the above results support the proposition that agricultural research has made a positive and substantial contribution to the growth of agricultural production. This conclusion should not be forgotten in a time of high food prices and tight governmental budgets.

So far, results are enough to accept the second hypotheses of this study, concerning the underfunding of agricultural research since the opportunity costs of the public capital in Colombia is accepted to be 10% (Harberger, 1969). Public investment in research is a good social choice, in comparison with the social profitability possible to obtain in other sectors of public activity.

TABLE XIII

SUMMARY OF ESTIMATED INTERNAL RATES OF RETURN FOR AGRICULTURAL RESEARCH (AGGREGATE)

Study	Country	Time Period	Annual IRR (%)
Peterson and Fitzharris, 1977	USA	1937-42	50
		1947-52	51
		1957-62	49
		1967-72	34
Tang, 1963	Japan	1880-38	35
Griliches, 1964	USA	1949-59	35-40
Evenson, 1967	USA	1949-59	47
Evenson and Jha, 1973	India	1953-71	40

Source: Hayami and Ruttan (1985, Table 3-A1).

Estimation of the Average Rate of Return

As explained before, the marginal internal rate of return is inherent to the production function approach while the average rate of return comes from economic surplus and input-saving approaches.[5] Here the input-saving approach was used to calculate the average rate of return for research. In this approach the benefits of research and extension are represented by the value of inputs saved year by year. Costs are those to carry out research and extension during the period of analysis. With the information about benefits and costs, cash flow analysis is applied to calculate the average rate of return. This approach has the advantage over the production function approach in that input-saving does not face any econometric problems as multicollinearity and autocorrelation and also is more simple to estimate. The basic information to calculate the inputs saved is that already estimated in Chapter IV (p. 99) concerning the value of inputs used in agriculture and the productivity index. The basic information is in Table XXIII in Appendix B. The results of using the information in the last column of Table XXIII and the productivity index (p. 103) and applying formulas (3.31) and (3.32) for the entire 1960-1982 period are presented in Table XIV. To get an idea about the productivity of research and extension, observe that the total expenditure for the whole period, $3,512.4 millions of Colombian real pesos is less than any of one single year of inputs saved from 1974 on, with the exception of 1976.

Working with the value of input saved as benefits, and with research and extension expenditures as costs, and using traditional discount procedures, some relevant financial and economic figures are obtained, as shown in

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[5]When calculated by subperiods of time, the rate of return using input-saving approach can be considered a marginal rate (Peterson, 1971).

TABLE XIV

AGRICULTURAL INPUTS SAVED BY RESEARCH AND EXTENSION, 1960-1982, COLOMBIA

Year	Value of Inputs (I_t) (Million Pesos)	Proportionate Increase in Product (P^*_t)	Value Inputs Saved ($I_tP^*_t$) (Million Pesos)
1960	19,945	0.011	215.8
1961	19,620	0.069	1,384.4
1962	20,064	0.078	1,546.0
1963	19,820	0.066	1,377.5
1964	20,871	-0.006	-137.6
1965	22,939	0.043	944.1
1966	21,956	-0.029	-708.1
1967	24,417	0.026	640.4
1968	24,631	0.104	2,452.1
1969	23,578	0.111	2,685.2
1970	24,191	0.088	2,218.5
1971	25,210	-0.011	-307.7
1972	27,972	0.022	629.6
1973	28,617	0.152	4,305.1
1974	28,323	0.177	4,961.5
1975	28,031	0.173	5,206.3
1976	30,094	0.105	3,459.9
1977	32,952	0.113	4,041.8
1978	3,5768	0.216	7,392.8
1979	34,226	0.216	7,392.8
1980	34,459	0.230	7,925.6
1981	34,815	0.321	11,175.6
1982	34,512	0.334	11,527.0
			72,935.8

Source: Value of Inputs (I_t): last column Table XXIII, p. 172.

Proportionate Increase in Product (P^*_t) $= \frac{(PI_t - PI_o)}{PI_o}$ (formula 3.32), p. 81. This formula was applied to the last column of Table VII, p. 103, (productivity index).

Value of Inputs Saved ($I_t\, P^*_t$) = S_t (formula 3.31), p. 81.

Table XV. Following Griliches (1958), the "external" rate of return is computed as follows: the flow of costs and benefits are discounted to a point in time using the opportunity cost of capital for public investment in Colombia, defined before as being ten percent. Costs and returns are accumulated to the same period in time, but then are expressed as a perpetual flow. The formula to calculate the external rate of return is:

$$ERR = \frac{A + AFR}{PVC} \qquad (5.4)$$

where:

ERR = External Rate of Return

A = Return as an Annual Flow

AFR = Average Annual Future Return

PVC = Present Value of Research and Extension Cost

As shown in Table XV, ERR is 141% meaning that there is a 10% return on investment in research and extension until the year 1982 and a 141% return in the future (After 1982). As Griliches has pointed out, this rate of return is closely related to the benefit-cost ratio. The formula for converting form ERR to B/C ratio is:

$$B/C = \frac{ERR}{100_i} \qquad (5.5)$$

Where:

B/C = Benefit-Cost Ratio

ERR = External Rate of Return

i = Rate of Discount

This ratio means that the average peso spent on agricultural research and extension returns $14.1 in social benefits (inputs saved). Both B/C and ERR are just two ways of expressing the same figure. In the present case they indicate a

TABLE XV

AVERAGE RATE OF RETURN OF RESEARCH AND EXTENSION (INTERNAL AND EXTERNAL AND B/C RATIO) DISCOUNTED FIGURES AT 10%, (MILLION PESOS), COLOMBIA

a) Accumulated past return	$15,401
b) Past return as an annual flow[1]	7,540
c) Annual future return[2]	144
d) Total annual return (b + c)	1,684
e) Accumulated past RE expenditures	1,190
f) External Rate of Return (ERR)[3]	141%
g) Benefit-Cost Ratio	14:1
h) Internal Rate of Return	+50%

[1] Defined as accumulated past returns times the opportunity cost of capital for Colombia public investment (i=0.10)

[2] Defined as value of discounted input saved in T years after the beginning of research (1960) which remains constant into perpetuity:

$1287.31/(1+i)^{23} = 1287.31/8.9543$

[3] ERR = (d/e)

high rate of average return to public investment on agricultural research and extension.

The internal rate of return has a slightly different meaning since it gives information about the return obtained annually into perpetuity from the data of the investment. In the present case the average internal rate of return is calculated to be more than 50%.[6] This means that on the average each Colombian peso invested in agricultural research and extension return over 50 percent annually from the date of investment (1960). A different way to see the value of input saved (last column, Table XIV) is considering them as resource reinvested in agriculture and mainly as resource displacement from the agriculture to urban sector for saving, consumption, or investment nationally and abroad. In that sense, such benefits are an economic surplus to help the economic development of other sectors.

Limitations of the input-saving approach are concerned mostly with the factors it leaves out to explain productivity gains such as farmer's education, public infrastructure, private research and others which may cause overestimation in the rate of return attributed to research and extension. In the opposite direction, there are some factors that cause underestimation; for example, some research and extension expenditures are not intended to increase productivity but they enter in the stream of costs because the accounting system does not allow differentiation of production-oriented from non-production-oriented activities. In addition, spillover effects in both directions are difficult to catch in the model. Finally, the validity of the results of using the input-saving approach rest upon the adequate valuation of the inputs, namely, of using the right price of labor, land, capital and intermediate inputs.

Projection of the Productivity Index

The basic model to project the future levels of agricultural production is the model (3.37), but keeping in mind that this sort of model is usually transformed into one of first-order autoregressive pattern like the one just estimated in the first section of the present chapter, that is, the model (5.1).

Based on the estimated model (5.1), projections of the production level to the year 1992 were made, assuming three different scenarios:

(a) low technology scenario, assuming zero growth rate in research and extension expenditures;

(b) baseline scenario, assuming historical rate of growth in research and extension expenditures, which is approximately equal to 5 percent annually in real terms; and,

(c) high technology scenario, which assumes a growth rate in research and extension expenditures of 10 percent per year.

Also, weather conditions were assumed to be average during the projection period. The educational index was based on maintaining the level of farmer's education reached during the last decade.

Based on the information in Table XII, the estimated equation becomes:

$$\begin{aligned} \ln PI_t - 0.9296\ PI_{t-1} = {} & 0.22639\ (\ln EI_t - 0.9296\ EI_{t-1}) \\ & + 0.03039\ (WI_t - 0.9296\ WI_{t-1}) \\ & + 0.18877\ (\ln PR_{t-j} - 0.9296\ PR_{t-j-1}) \end{aligned} \tag{5.6}$$

The results of using the above equation to project the production index 10 years beyond 1982 and under the three scenarios are presented in Table XVI. The consequences of maintaining the growth rate in real terms for the 1973-1982 subperiod, which is virtually zero percent annually, are a decay in the production index generating a negative tendency of minus 0.7 percent per year.

TABLE XVI

PROJECTIONS OF THE AGRICULTURAL PRODUCTION INDEX, 1983-1992 (1960=100), COLOMBIA

Projected Years	Low Technology Scenario 0% PR Growth Rate	Baseline Technology Scenario 5% PR Growth Rate	High Technology Scenario 10% PR Growth Rate
1983	222.1	225.4	224.9
1988	220.6	228.1	227.9
1985	219.6	231.4	231.8
1986	219.0	235.8	236.8
1987	218.5	240.5	242.4
1988	218.1	245.4	248.5
1989	217.6	250.5	255.2
1990	217.2	256.0	262.7
1991	216.6	261.3	270.3
1992	216.0	266.7	278.4
Annual Growth Rate			
1983-1992	-0.7	4.6	5.9

Equation (5.6) exhibits diminishing return for increasing research and extension expenditures. That is why growth rates of 5 and 10 percent annually produce 4.6 and 5.9 percent per year increases, respectively.

The consequences of such rates of growth in agricultural production on prices and producers and on consumers' welfare should be obvious; however, these aspects exceed the scope of this research and need to be investigated in more detail with another kind of simulation model. Even so, the results so far are enough to understand the effect of underfunding research and extension on future production levels. Policy-makers should be aware that since expenditures on research and extension affect production and productivity in later years, inadequate funding of research and extension in one period would be extremely difficult to overcome later. The results also recognize the level of effort to be done in real research and extension expenditures to reach the growth rate in production for keeping up with the internal demand for food and raw materials and also for exporting. According to Table XVI, this level has to be between 5 and 10% annually in real terms. Concerning only the internal demand, Junguito (1980) estimates that for the rest of the century the agricultural sector should be growing at annual rate of 3.5 to 4.0 percent.

Estimated Secondary Impacts of Research and Extension

So far, the economic analysis about the impact of expenditures in research and extension on the economy has been carried out on the line of direct effect over agricultural production. But it has been recognized before that the increased agricultural production affects, in turn, other sectors of the economy by demanding more input, services, transportation, etc. In addition, the household income is increased as a consequence of this greater economic activity and same employment in physical term. The objective of this section is to illustrate the other effects (secondary effects) rather than the direct effects of research and extension, using an input-output approach which has been considered suitable to estimate these sort of impacts.

The analysis is intended to be preliminary since the input-output tableaus for the Colombian economy became available only recently, and also because the lack of studies in the country and abroad using input-output approach within the specific field of secondary impacts of agricultural research and extension.[7] Some refinements and adjustments in the input-output tableau were not possible for this study. Thus, additional research is recommended in this area.

The basic information to perform the analysis was obtained from DANE (1983).[8] The data are available for the years 1970 through 1981. However, it is assumed that the relative proportions of the agricultural sector during 1970 and 1975 would remain unchanged and same for 1975 with respect to 1981, so only the 1975 input-output structure was considered to estimate the multipliers. These multipliers permit a quantitative evaluation of the impact on all other sectors' output resulting from a given change in output for the agricultural sector, and also to calculate the extra income and employment in the economy. In the present case, this evaluation is undertaken in an ex-post framework.

The basic steps to estimate the output, income and employment multipliers are:

(a) set up the transaction table for the whole economy;

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[7]According to Chapter II, only two studies have been identified in the United States.

[8]DANE is the National Department of Statistics.

(b) estimate direct and indirect coefficients ($\bar{b}_{ij}$);

(c) estimate the $(I-A)^{-1}$ matrix; and,

(d) apply formulas (3.45), (3.46), (3.47) and (3.48).

where:

A = matrix of direct and indirect coefficients

I = identity matrix

The results of such calculations are presented below. While the methodology used allows the calculation of multipliers for each sector in the tableau, only those concerning the agricultural sector are presented.[9]

<u>Output Multiplier</u>

$$\bar{O}_j = \sum_{i=1}^{n} \bar{b}_{ij} = 3.52 \qquad (5.7)$$

That means that the total output impact of a peso change in final demand (i.e. research and extension expenditures) is $3.52. It represents $1.00 of direct agricultural output and $2.52 of secondary or indirect agricultural and non-agricultural output.

<u>Income Multiplier</u>

$$\bar{Y}_j = \sum_{i=1}^{n+1} \frac{A_{n+1\ i}\,\bar{b}_{ij}}{A_{n+1\ j}} = \frac{0.7004}{0.33696} = 2.08 \qquad (5.8)$$

That figure indicates that for each additional peso of household income generated from agricultural output, a total of $2.08 in Colombia income is generated from that sector and all interdependent sectors.

Employment Multiplier

$$\bar{W}_j = \sum_{i=1}^{n+1} \frac{W_{n+1\ i}\ \bar{b}}{W_{n+1\ j}} = \frac{0.02613}{0.01835} = 1.42 \qquad (5.9)$$

This result means that each person directly engaged in the agricultural sector creates jobs for 0.42 persons in other sectors (interdependent with agricultural sector).

To multiply income and employment multipliers by the product, two "pseudo-multipliers" need to be defined. The income (employment) pseudo-multiplier is defined as the total change in income (employment) divided by the initial change in output (Johnson and Kulshreshtha, 1982). They were estimated as:

Income pseudo-multiplier: 0.70044 (5.10)

Employment pseudo-multiplier: 0.02613 (5.11)

Applying the proportions of Table IX concerning the contribution of productivity to output increase, the first column of Table XVII is estimated as direct effect of research and extension expenditures. The estimation of indirect or secondary impacts in terms of non-agricultural output, households income and employment for 1970-1982 period also are presented in Table XVII. The estimation of secondary impacts we performed as follows: column three (agricultural and non-agricultural output) results from multiplying column two (direct impact) times 2.52, which is the output multiplier less one. Column four (household income) results from multiplying column two times the income pseudo-multiplier (expression 5.10). Finally, the employment results come from multiplying column two times the employment pseudo-multiplier (expression 5.11).

TABLE XVII

DIRECT AND SECONDARY IMPACTS OF AGRICULTURAL RESEARCH AND EXTENSION 1970-1982 MILLION PESOS IN REAL TERMS (1970=100), COLOMBIA

Years	Direct Impact	Secondary Impacts		
	Value of Agricultural Output	Agricultural and Non-Agricultural Output	Household Income	Employment (man-years)[1]
1970	392.5	989.1	294.9	10,256
1971	260.0	655.2	182.1	6,794
1972	144.4	363.9	101.1	3,773
1973	752.4	1,896.0	527.0	19,660
1974	1,590.6	4,008.3	1,114.1	41,562
1975	171.2	431.4	119.9	4,473
1976	1,519.0	3,827.9	1,064.0	39,691
1977	753.3	1,898.3	527.6	19,684
1978	1,601.2	4,035.0	1,121.5	41,839
1979	1,201.6	3,028.0	841.6	31,340
1980	515.2	1,298.3	360.9	13,462
1981	2,392.6	6,029.4	1,675.9	62,518
1982	27.3	68.8	19.3	710
Total	11,321.3	28,529.6	7,949.9	295,762

[1] Man-years per $1000 of output

CHAPTER VI

SUMMARY AND CONCLUSIONS

Objectives of the Study

Agricultural research almost universally has been considered as one of the most important factors contributing to increases in the level of productivity in any country, contributing to the achievement of the most important national goals, such as self-sufficiency in food production and raw materials, improved nutrition, generation of foreign exchange, and increased employment. However, this activity is frequently funded below its optimal level and then many countries are left without the possibility of increasing their rates of socioeconomic development. The reason for this situation is generally misconception about the real role of this activity in the development process by policy-makers, lack of economic information and evaluation concerning the impact of research on the economy, or because research has actually failed to impact the current level of productivity in a generalized manner. Thus, it is important to have studies on the economic evaluation of the funds spent on research and also for determining the relationship between research and productivity, and to foresee the future consequences of today's decisions are very important. This is especially true in developing countries where the agricultural sector still has an important role.

The general purpose of this research was to provide a conceptual and empirical framework to evaluate in economic terms the global profitability of the

Colombian publicly-supported agricultural research systems during 1960-1982 period. The specific objectives were to:

(1) analyze the relationship between several indicators of the agricultural technological change in Colombia and the evolution of the agricultural research system during 1960-1982;

(2) build an agricultural productivity index based on the total factor productivity approach;

(3) calculate both the average and the marginal internal rate of return for public investment in the whole agricultural research system and to compare them with those in other sectors;

(4) estimate the assumed time lag from the time of the initial investment in research and its impact on production; and,

(5) calculate the indirect impacts due to government expenditures on research.

Methodological Framework

In Chapter III several methodological steps were developed for explaining the agricultural productivity growth and to estimate a productivity index for the Colombian Agricultural sector. Beginning with the more simple productivity ratios such as labor and land productivity and then the analysis of more complex relationships, a total factor productivity approach and a kind of chain-linked productivity index was calculated for the 1960-1982 period. In addition, technological differences between periods was tested by using dummy variables within a production function framework.

To explain the factors implicit in productivity index or the underlying production structure, a productivity change model was developed. Research, extension, farmer's education, and weather were the most important factors identified as influencing the level of agricultural productivity and production. Research included those activities carried out by the public sector institution (ICA) and the private sector, aimed at developing new and improved technical knowledge and materials to enhance the state of the art in the agricultural sector. Extension becomes an integral part of this process. It was postulated that the effect of these activities is time-delayed, or, in other words, that there are several time lags from the moment when the investment in research is performed and the moment when the effects on production disappear (obsolescence). An inverted U was hypothesized as being the time form of such effect. To avoid the econometric problem of multicollinearity, research and extension were entered in the model as a single variable represented by research and extension expenditures through ICA. Private research and extension were deleted from the theoretical model.

With the above background the productivity change model was specified explicitly as below:

$$PI_t = EI_t^{\gamma} \prod_{j=0}^{n} PR_{t-j}^{\alpha_j} \; e^{\mu_t + WI_t^{\beta}} \tag{6.1}$$

where:

PI_t	=	Alternatively productivity or production index at time t.
EI_t	=	Educational attainment index at time t.
WI_t	=	Weather index at time t.
PR_{t-j}	=	Public sector research and extension expenditures in the current and past n preceding periods.
μ_t	=	Disturbance term at time t.
γ, α_j, β	=	Parameters to be estimated.

Since the presence of autocorrelation was expected, the fitted model with a first-order autoregressive pattern was the following:

$$\ln PI_t - \rho \ln PIt\text{-}1 = r (\ln EI_t - \rho \ln EI_{t-1}) + \sum_{j=0}^{n} \alpha_j (\ln PR_{t-j} - \rho \ln PR_{t-j-1})$$

$$+ \beta (WI_t - \rho WI_{t-1}) + e_t \qquad (6.2)$$

where:

$e_t = \mu_t - \rho \mu_{t-1}$ and ρ = coefficient of autocorrelation.

To estimate the parameters of (6.2) the Cochrane-Orcut procedure was employed; in particular, the Almon polynomial distributed lag technique was used for estimating the distributed lag coefficients corresponding to PR_{t-j}. From the estimated parameters it was possible to calculate the elasticity of production with respect to research and extension, the value of marginal product, the marginal internal rate of return and the mean time lag of research and extension. To gain additional insights about the future levels of productivity as a consequence of today decisions, the model (6.2) was used to project the production index under three scenarios according to the assumptions about the growth rate in research and extension expenditures: low technology scenario (0% growth rate), baseline scenario (5% growth rate), and high technology scenario (10% growth rate).

The productivity index also was used in a different approach to calculate the benefits attributed to research. Under this approach the benefits coming from research were estimated as the value of input saved for using improved technology, as a product of research, instead of using old technologies. The approach allowed the estimation of the amount of resources saved by the technological change, as well as the estimation of several other important indicators of the social profitability of funds spent on research and extension, such as the average internal rate of return, the external rate of return and the benefit-cost ratio attributed to this investment. The basic expressions for these calculations are presented below.

$$S_t = I_t P_t^* \tag{6.3}$$

$$P_t^* = (PI_t - PI_o)/PI_o \tag{6.4}$$

where:

S_t = Value of input saved in t^{th} year

I_t = Value of input in t^{th} year

P_t^* = Proportionate increase in productivity of inputs (O_t/I_t) in year t over the base year productivity (PI_o) for the period.

PI_t = Productivity index in year t.

With the above estimation of benefits and with the information about research and extension expenditures, a cash-flow analysis was conducted for derivation of the internal (average) and external rate of return and the benefit-cost ratio.

Finally, to have a preliminary estimation of the indirect or secondary impacts of research and extension expenditures over the entire economy, an input-output approach was used. The analysis was performed by the estimation of output, income and employment multipliers, which allow to assess this sort of impact.

Results and Implications

Regarding the productivity analysis presented in Chapter IV, the results are summarized here. First of all, the overall evolution of the Colombian agricultural sector during 1960-1982 can be characterized by a period of technological take-off, which corresponds to the 1960's, then a period of dynamic growth corresponding to the 1970's and finally a technological deceleration period for the 1980-1982 period. This pattern is depicted by both the trends in the value of production and in modern inputs usage. With respect to the total value of production the growth rate per year was: 3.4 percent for the 1960's, 6.1 percent for the 1970's and 2.9 percent for the 1980-1982 period; the latter figure is due to the relatively better behavior of livestock since the growth rate for crops was zero percent per year for 1980-1982. Concerning inputs, the annual growth rates for the 1980-1982 period was: -4 percent for cropped land, -3 percent for fertilizer, -0.5 percent for labor, and 0.9 percent for horsepower. A comprehensive summary about the annual growth rates by decades is presented below:

Annual Growth Rates Corresponding to:	1960's	1970's	1980-1982
Value of Production	3.4	6.1	2.9
Cropped land	0.7	2.8	-4.0
Labor(No. of workers)	0.7	-1.3	-3.6
Fertilizer	16.6	9.1	-3.0
Horsepower	6.7	4.0	0.9

Second, the productivity index for the Colombian agriculture, calculated under a total factor productivity approach, shows an annual growth rate of 1.5 percent for the 1960-1982 period, which compares similarly to that of 1.8 percent for United States corresponding to the 1965-1979 period. Since a positive relationship between the above gains in productivity and the outcomes of the research system in general and with the appropriations for the system in particular was found, concern about the possibility of maintaining this accumulated productivity for the coming years is in order. For example, a zero growth rate per year in research and extension expenditures (real term) by the year 1975-1977 was associated with stagnation on the annual rate of increment for both the production and the productivity index.

In contrast, the acceleration in the production and productivity index by the years 1974-1975 was related with the "big jump" in research and extension expenditures. An additional analysis concerning technological differences by certain periods was also undertaken. When an aggregate production function including dummy variables to represent different technological eras was fitted, the following general result was found: the pooled equation for 1960-1967 and 1968-1975 shows that there was an important shift in the production function for that period as a consequence of technological change generated by research and extension. For the period 1968-1975 to 1976-1982 there was no shift in the production function, so technological stagnation was underway.

Third, the analysis of partial productivity ratios allows the characterization of the Colombian agriculture during the period of analysis according with the kind of dominant technology and the bias on the resource use. According to the labor productivity ratio (O/L), labor productivity (real output per man-year) increased at an annual rate of 7.3 percent for the whole period of 1960-1982. The components of this ratio, land per worker (A/L) and output per land (O/A) permit to draw some conclusions about the direction of the technological change since land per worker (A/L) increase is associated with mechanical, labor-saving innovation, and output per land (O/A) increase is associated with biological or chemical, land-saving innovation. In the present case, land per worker had annual growth rates of 1.0 percent during the 1960's, 3.4 percent during the 1970's, and 3.1 percent for the 1980-1982 period, in comparison with the following growth rates for output per land: 1.2 percent during the 1960's, 3.9 percent during the 1970's, and 5.1 percent for the 1980-1982 period.

These results mean that biological innovations were relatively more important than mechanical innovation during the entire period. This fact is in accordance with a greater degree of national autonomy for developing biological innovations (i.e. new varieties by ICA) rather than mechanical innovations. Additionally, the proxy index for factor substituting land (fertilizer per area, F/A) and the proxy index for factor substituting labor (machinery per area, M/A) also help in this analysis. The results indicate that the substitution of land in the production process was more intensive than that for labor since fertilizer per hectare grew annually at a rate of 11 percent for the whole period while horsepower per hectare grew at a rate of 4 percent per year, indicating that the bias in the Colombian technological change in agriculture has been more land-saving than labor-saving for the period of analysis.

Another set of results refers to the estimation of the productivity change model and the calculation of the input saved by the technological change. From the estimation of the model (5.1) it is known that the elasticity of production with respect to research and extension is 0.19 which is the sum of the coefficients for research and extension variables in the model. That figure means that for any increase of 1 percent in research and extension expenditures the production index increases 0.19 percent during its lifetime. This variable was significant at 0.01 level of significance. Education and weather also were significant variables to explain production index. Education had a coefficient of 0.23 which indicates that for each 1 percent increase in farmer's education attainment, the production index increases 0.23 percent. Weather had a coefficient of 0.03, that is, 1 percent increase in weather index causes an increase of 0.03 percent in production index.

To see the importance of the elasticity of production with respect to research and extension, the value of the marginal product was calculated as being $40.81. That is, a peso increase in research and extension expenditures increases the value of agricultural output by $40.81. Converting this quantity to an annualized rate, the marginal internal rate of return for research and extension during the period 1960-1982 was estimated as 85.5 percent. To avoid overestimation in the public contribution of research and extension due to the exclusion of private research and extension, the coefficient of research and extension was adjusted by a factor of 1.2. This assumes 20 percent of the total research is done by the private sector. Performing all the calculations, the marginal internal rate of return turned out to be 71 percent. According to their participation in the expenditures and to the nature of their contribution, the rate was assigned as 50 percent for research and 21 percent for extension. Both of these compare favorably with those internal rates of return for United States, Japan and India (Table XII).

The foregone analysis indicates a significant contribution by research and extension to the level of production and productivity reached by the Colombian agriculture in the past. However, it also shows an important process of underfunding research and extension activities, based on the estimated marginal internal rate of return, which is 5 times the opportunity cost for public investment in Colombia (10 percent). This means that agricultural research and extension are a good investment for the country in comparison with other public alternatives. It is apparent that the system has been productive, but it should not be concluded from the results that the system or the organization to carry out research activities has been efficient.

The underfunding process can be so serious that when the rate of annual growth in real expenditures for research and extension for the period 1973-1982, (zero percent) was used to predict the future level of the production index, the annual growth rate of such index from 1983 to 1992 was -0.7 percent (low technology scenario). To avoid a situation like this, steps should be taken for funding research and extension adequately. For example, under baseline and high technology scenarios, it is possible to obtain growth rates in production index of 4.6 and 5.9 percent per year, respectively, which are more suitable for the agricultural sector to contribute with the national goals of food self-sufficiency, generation of foreign exchange, employment, nutrition, and inflation for the rest of the decade.

Another important aspect administrators and policy-makers need to be aware of concerns the time lag for the research and extension to initially impact production. It was found in this research that the contribution of research and extension is small at the beginning of the investment period, reaches a maximum by the sixth and seventh year and then declines thereafter. From year 12 on the effect becomes negligible. So investment decisions taken concerning research and extension affect production years later.

Using the value of input saved as benefits and research and extension expenditures as costs and using discount procedures, some additional economic indicators were estimated. The input saved by technology were calculated to reach $72,936 million of real pesos (1970-100), which besides being considered as benefit of research and extension can be thought as an economic surplus for investment and consumption in other sectors and for reinvestment within the agricultural sector itself. With this stream of benefits and the stream of costs, the average external rate of return was calculated using a rate of discount of ten percent. This calculation yielded 141 percent, meaning that there is a 10 percent return on investment in research and extension until the year 1982 and 141 percent return after 1982.

The benefit-cost ratio is closely related with the external rate of return and in the present case the ratio is 14 to 1, which means that the average peso spent on agricultural research and extension returns $14 in social benefits in terms of input saved. Both figures express a high rate of average return to public investment on agricultural research and extension. Using the same basic information the average internal rate of return was also estimated. The calculation gave a rate of more than 50 percent, as the return obtained annually into perpetuity from the date of the investment. The noted limitations of this approach have to do with the fact that it does not explain factors which can cause over- and underestimation such as farmer's education, public infrastructure, private research, non-production-oriented activities included in costs of research and extension, among others.

Most of the already mentioned effects of research and extension can be considered as direct effects, but a need exists for knowing at least some indirect or secondary impacts of these activities. So, an attempt was made in that direction. The input-output approach has proved to be useful in this respect and was utilized for the calculation of three multipliers: output, income and employment multipliers (and income and employment pseudo-multipliers). The set of output multipliers and income and employment pseudo-multipliers properly used gave the estimation of secondary impacts for the period 1970-1982, as follows: $28,530 million pesos in non-agricultural output, $7,950 million pesos in households income, and 295,762 man-years. Even though these results should be considered preliminary, they do indicate the range of magnitudes about indirect impacts that can be expected from past investments on agricultural research and extension.

Limitations of this Research

Three major sources of limitations for the study have been identified. First, data availability for analysis was the major limitation. It was already mentioned that for recent years there is no information about some of the variables, but dispersion of data collection is another aspect worthwhile to be noted. For agricultural statistics there is no single source of information, so an appreciable amount of time was spent gathering, and selecting data. Second, the very aggregative level of this study imposed some restrictions and difficulties; while a high level of aggregation give a high pay-off, in terms of economy of data manipulation and interpretation, it also requires careful construction of variables and assumptions.

In the present case, it is necessary to be aware that the agricultural sector in Colombia is made up of commercial farmers and traditional small farmers, each of them with different technological structures. Also, the aggregative process combines the crop and livestock subsectors which are of very different nature and represent different technological processes and performance. It also should be recognized that there is no other way to perform a national-type research as done in this study.

The third limitation of this research concerns the risk of underestimation or overestimation of some of the results, especially the internal rate of return. These two problems could result since the variable public research and extension expenditures include only those expenditures carried out by ICA which is the main institution in these fields (overestimation). In contrast, these expenditures include those not strictly production-oriented activities (underestimation). In addition, the research failed to take into account benefits attributed to the Colombian research system but which are accruing to other countries. In contrast, benefit from some international centers and foreign institutions were only partially recognized.

Suggestions for Future Research

A great deal of time was spent in this research collecting, screening and estimating information for the construction of the productivity index since there is not any for the Colombian agriculture at the time of writing the research. For other researchers to avoid this problem and for monitoring the evolution of the indicators of productivity, it is suggested that the Government begin the construction and periodical releasing of several productivity indexes. Close observation of these indexes are supposed to help in the process of decision-taking for the agricultural sector. The results of the present research, especially those in Chapter V concerning internal rates of return, are thought to help national planners and decision-makers at the very national public investment allocative process. Additional research projects within ICA is necessary, considering several levels of disaggregation in variables such as research and extension expenditures, value of production, productivity index. Initially, the level of disaggregation could be by groups of crops and groups of animal species. This disaggregation and whatever class of cross-sectional information would be helpful in facing the multicollinearity problem. Pooling cross-sectional and time series data offers additional possibilities of analysis.

Because the results presented here about secondary impacts of research and extension are considered preliminary, additional research is suggested in that promising direction. Additionally, some other important aspects concerning impacts of research and extension which were not addressed in the present research also are encouraged for new research, especially crucial aspects such as distributional, environmental, and spillover effects. Additional research is needed in the field of simulating or projecting future events based on today's decisions on crucial variables. For example, the future level of consumers and producers prices can be predicted by simulating the effects of decisions on the level of research and extension over agricultural production.

Finally, one additional point should be addressed. One of the reasons for undertaking the present research was the lack of knowledge about the economic impacts of research. Thus, a special recommendation is in order for increasing the current level of the agricultural economics analysis inside ICA. The study of macroeconomic aspects affecting the technological process, such as the exchange rate, rate of interest, inflation, credit, and public infrastructure are of great significance in this respect. Also, microeconomic studies about the factors affecting the level of profitability of farmers, and about the limitations on marketing, storage, post-harvest losses, among others, should be emphasized.

SELECTED BIBLIOGRAPHY

Almon, Shirley. "The Distributed Lag Between Capital Appropriations and Expenditures." Econometrica. 33:1(January 1965):178-196.

Andersen, P. and D. Franklin. "A System Approach to Agricultural Research Resource Allocation in Developing Countries." Resource Allocation and Productivity in National and International Agricultural Research. ed. Arndt, T.M., D.G. Dalrymple, and V.W. Ruttan, Minneapolis: University of Minnesota Press (1977):416-435.

Aquino, M. and Y. Hayami. "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development." American Journal of Agricultural Economics. 57(1975):1-10.

Araji, A.A., R.J. Sim, and R.L. Gardner. "Returns to Agricultural Research and Extension Programs: An Ex-Ante Approach." American Journal of Agricultural Economics. 60(1978):964-8.

Ardila, Jorge. "Rentabilidad Social de los Inversiones en Investigacion de Arroz en Colombia." M.S. thesis, ICA/National University Graduate School, Bogotá, 1973.

Arndt, T.M., and V. Ruttan. "Valuing the Productivity of Agricultural Research: Problems and Issues." Resource Allocation and Productivity in National and International Agricultural Research. ed. Arndt, T.M., D.G. Dalrymple, and V. Ruttan, Minneapolis: University of Minnesota Press, 1977.

Atkinson, L. Jay. "Changes in Agricultural Production and Technology in Colombia." USDA Foreign Economic Report No. 52, Washington, D.C. (June, 1969).

Atkinson, L. Jay. "Agricultural Productivity in Colombia." USDA, Foreign Agricultural Economic Report No. 66, Washington, D.C. (October, 1970).

Ayer, H.W. and G.E. Schuh. "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton in Sao Paulo, Brazil." American Journal of Agricultural Economcis. 54(1972):557-69.

Bal, H.K. and A.S. Kahlon. "Methodological Issues on Measurement of Returns to Investment in Agricultural Research." Indian Journal of Agricultural Economics. 32:3(July-Sept. 1977):181-192.

Balcazar, Alvaro. "Cambio Tecnico en la Agricultura." Problemes Agrarios Colombianos. ed. by Absalon Machado, Bogota: Siglo Veintiuno Editores (1986): 205-214.

Berry, Albert. Land Distribution, Income Distribution and Productive Efficiency of Colombian Agriculture. Economic Growth Center, New Haven, Connecticut (March 20, 1971).

Bostwick, Don. "Agricultural Resource Allocation in the Cawca Valley of Colombia." (Unpublished Ph.D. Thesis, Montana State University, 1968).

Bredahl, M. and W. Peterson. "The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations." American Journal of Agricultural Economics. 58(1976):684-92.

Christensen, L.R. "Concepts and Measurement of Agricultural Productivity." American Journal of Agricultural Economics. 57(1975):910-915.

Cline, Phillip. "Sources of Productivity Change in U.S. Agriculture." Ph.D. thesis, Oklahoma State University, Stillwater, Oklahoma, 1975.

Currie, J.M., J.A. Murphy, and A. Schmitz. "The Concept of Economic Surplus and Its Use in Economic Analysis." Economic Journal. 18(1971):741-98.

Dalrymple, Dana G. "Evaluating the Impact of International Research on Wheat and Rice Production in the Developing Nations." Resource Allocation and Productivity in National and International Agricultural Research. ed. Arndt, Thomas, Vernon Ruttan, and Dana G. Dalrymple, Minneapolis: University of Minnesota Press (1977):171-208.

Davis, J. "A Comparison of Procedures for Estimating Returns to Research Using Production Functions." Australian Journal of Agricultural Economics. 25(1981):60-72.

de Janvry, A., and Jean-Jacques Dethier. Technological Innovation in Agriculture. The Political Economy of Its Rate and Bias. CGIAR Study Paper No. 1. The World Bank, Washington, D.C., 1985.

Departamento Nacional de Planeación, DNP. "Estadisticas del Sector Agropecuario." Documento DNP-UEA-DC-029, Bogotá, Junio 1982.

Departamento Nacional de Planeación. "Diagnóstico del Sector Agrario." Documento UEA-06. Bogotá (Enero 1983).

Dervis, Kernal, Jaime De Melo, and Sherman Robinson. General Equilibrium Models for Development Theory. Cambridge: Cambridge University Press, 1984.

Eastern, K.W. and G. Norton. "Potential Returns from Increased Research Budget for the Land Grant Universities." Agricultural Economics Research. 29(1977):127-33.

Eddleman, B.R. "Evaluation of Economic Benefit from Agricultural Production Research and Implication for Marketing." Proceedings of National Workshop on Coordination of Marketing Research. Washington, D.C. (May 1977):29-41.

Elias, Victor. "Government Expenditures on Agriculture in Latin America." Research Report No. 23, International Food Policy Research Institute, Washington, 1981.

Elias, Victor J. "Government Expenditures on Agriculture in Latin America." Research Report No. 23, International Food Policy Research Institute, Washington, 1985.

Evenson, R.E. "The Contribution of Agricultural Research to Productivity," Journal of Farm Economics. (1967):1415-25.

Evenson, R.E. "The Contribution of Agricultural Research and Extension to Agricultural Productivity." Ph.D. thesis, University of Chicago, 1968.

Evenson, R.E. "The Green Revolution in Recent Development Experience." American Journal of Agricultural Economics. 56(1974):387-93.

Evenson, R.E. and D. Jha. "The Contribution of Agricultural Research System to Agricultural Production in India." Indian Journal of Agricultural Economics. (January 1974):212-30.

Evenson, R.E., P. Flores-Moya, and Y. Hayami. "Social Return to Rice Research in the Phillipines: Domestic Benefits and Foreign Spillover." Economic Development and Cultural Change. 26(1978):591-607.

Evenson, R.E. and H.P. Binswanger. "Technology Transfer and Research Resource Allocation." Induced Innovation, Technology, Institutions, and Development. ed., H.P. Binswanger et al. Baltimore, MD: Johns Hopkins University Press, 1978.

Fishel, W. "The Minnesota Agricultural Resource Allocation Information System and Experiment." Resource Allocation in Agricultural Research. ed. Fishel, Walter, Minneapolis: University of Minnesota Press (1971):344-84.

Fox, G. "A Model of Optimal Public Investment in U.S. Agricultural Research," (Mimeograph). Department of Agriculture and Applied Economics, University of Minnesota, Minneapolis, 1985.

Frisch, Ragnor. "Annual Survey of General Economic Theory: The Problem of Index Numbers." Econometrica. 4:1 (January 1936):1-38.

Garcia, Jorge, and Gabriel Montes. "The Political Economy of Agricultural Pricing Policy: Colombia, Part II. The Effects of Price Interventions." World Bank Project N:RTO-673-64. Unpublished Semifinal Draft. Bogotá, (October, 1986).

Gittinger, J. Price. Economic Analysis of Agricultural Projects. Second Edition, Baltimore: The John's Hopkins University Press, 1982.

Griliches, Z. "Research Expenditures, Education, and Aggregate Production Functions." The American Economic Review. 54(December 1964):961-74.

Griliches, Z. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." Journal of Political Economy. 66(1958):419-31.

Griliches, Z. "Measuring Inputs in Agriculture, A Critical Survey." Journal of Farm Economics. 42(1960):1411-27.

Griliches, Z. "Estimate of the Aggregate Agricultural Production Function from Cross-Sectional Data." Journal of Farm Economics. 45:2 (May 1963):416-428.

Griliches, Z. "The Sources of Productivity Growth: U.S. Agriculture 1940-1960." Journal of Political Economy. 71(August 1963): 331-46.

Griliches, Z. "Distributed Lags: A Survey." Econometrica. 35(January 1967):16-49.

Habtu, B. "Evaluation of Past and Optimal Future Investments in Research and Extension to Increase Agricultural Productivity." Ph.D. thesis, Oklahoma State University, Stillwater, Oklahoma, 1985.

Harberger, E. "La Tasa de Rendimiento de Capital en Colombia." Revista de Planeación y Desarrolo. Bogotá, Colombia (October 1969):21-53.

Hasting, T. "The Impact of Scientific Research on Australian Rural Productivity." Australian Journal of Agricultural Economis. (1981): 48-59.

Hayami, Yujiro. "Sources of Agricultural Productivity Gap Among Selected Countries." American Journal of Agricultural Economics. 51:3(August 1969):564-575.

Hayami, Y., and V.W. Ruttan. Agricultural Development: An International Perspective., 2nd ed. Baltimore: The John's Hopkins University Press, 1985.

Hertford, R., J. Ardila, A. Rocha, and C. Trujillo. "Productivity of Agricultural Research in Colombia." Resource Allocation and Productivity in National and International Agricultural Research. ed., T.M. Arndt, D.G. Dalrymple, and V. Ruttan, University of Minnesota Press, Minneapolis.

Hertford, R. and A. Schmitz. "Measuring Economic Returns to Agricultural Research." Resource Allocation and Productivity in National and International Agricultural Research. ed., T.M. Arndt, D.G. Dalrymple, and V. Ruttan, University of Minnesota Press, Minneapolis, 1977.

Instituto Colombiano Agropecuario (ICA). Plan Nacional de Transferencia de Technología. Bogotá 1984.

Instituto Colombiano Agropecuario (ICA). Evolución del Presupuesto del ICA, 1970-1984. Oficina de Planeación, Documento ICA-DP-18-84, Bogotá, Marzo 1984.

Johnson, Thomas G., and Surendra N. Kulshreshtha. "Exogenizing Agriculture in an Input-Output Model to Estimate Relative Impacts of Different Farm Tyeps." Western Journal of Agricultural Economics. 7(1982):187-198.

Johnston, B.F. and V.W. Mellor. "The Role of Agriculture in Economic Development." American Economic Review. Vol. 41:4 (September 1961): 566-593.

Johnston, J. Econometric Methods. Third Edition, New York: McGraw-Hill Book Company, 1984.

Jorgenson, W. Dale and Zvi Griliches. "The Explanation of Productivity Change." Review Economics Studies. 34:3 (July 1967):249-283.

Jorgenson, W. Dale, and Zvi Griliches. "Divisia Index Numbers and Productivity Measurement." Review of Income and Wealth. 17(1971):227-229.

Junguito, Roberto. "El Sector Agropecuario Colombiano en la De'cada de los Años Ochenta." in Economia Colombiana en la De'cada de los Ochenta. Bogotá (February 1980).

Kendrick, J. Productivity Trends in the United States. Princeton, Princeton University Press, National Bureau of Economic Research (1961).

Knutson, M. and L. Tweeten. "Toward an Optimal Rate of Growth in Agricultural Production Research and Extension." American Journal of Agricultural Economics. 61(1979):70-76.

Kumar, P., C.C. Maji, and R.K. Patel. "Return on Investment in Research and Extension: A Study on Indo-Swiss Cattle Improvement Project, Kerala." Indian Journal of Agricultural Economics. 32:3(July-September 1977):207-216.

Llorente, Luis. "La Ganaderia Bovina en Colombia." Problemas Agrarios Colombianos. ed. by Adsalón Machado, Bogotá: Siglo Veintiuno Editores (1986):331-368.

Leistritz, Larry. "The Use of Dummy Variables in Regression Analysis." Agricultural Economic Miscellaneous Report No. 13, Department of Agricultural Economics, North Dakota State University. Fargo, North Dakota, 1975.

Loomis, Ralph, and Glen T. Barton. "Productivity of Agriculture." USDA, Washington, D.C., Technical Bulletin No. 1238, April 1961.

Lu, Yao-Chi. "Measuring Productivity Change in U.S. Agriculture." Southern Journal of Agricultural Economics. (December 1975): 69-75.

Lu, Y., L. Quance, and Ch. Lui. "Projecting Agricultural Productivity and Its Economic Impact." American Journal of Agricultural Economics. 60(1978):976-80.

Lyu, S.L., F.C. White, and Y. Lu. "Estimating Effects of Agricultural Research and Extension Expenditures on Productivity: A Translog Production Function Approach." Southern Journal of Agricultural Economics. 16(December 1984):1-8.

Mahlstede, J.P. "Long-Range Planning at the Iowa Agricultural and Home Economics Experiment Station." Resource Allocation in Agricultural Research. ed., W.L. Fishel, Minneapolis: University of Minnesota Press, 1971.

Mansfield, E. The Economics of Technological Change. New York: W.W. Norton and Company, Inc., 1968.

Mellor, J. The Economics of Agricultural Development. Ithaca: Cornell University Press, 1966.

Miller, Ronald E. and Peter D. Blair. Input-Output Analysis: Foundations and Extensions. New Jersey: Prentice-Hall, Inc., 1985.

Montes, Gabriel. "Evaluacion de un Programa de Investigacion Agricola: El Caso de la Soya." M.S. thesis, University of Andes, Bogota, 1973.

Nevel, Robert D. "Technological Change in Agriculture." Agricultural Economics Research. 21:1(January 1969):13-18.

Nicholson, Walter. Microeconomic Theory Basic Principles and Extensions. Third Edition, Chicago: The Dryden Press, 1985.

Norton, Daniel T. and Grant M. Scobie. "Optimal Investment in Research Across Commodities: A Schultzian Puzzle." (Presented to: Sumposium on Methodology for Evaluation of Agricultural Research). Minneapolis: University of Minnesota, May 1980.

Norton, George W. and G. Andrew Bernat. "Why Should a State Fund Agricultural Research and Education?" Department of Agricultural Economics, Virginia Polytechnic Institute and State University, Blackbsburg, Virginia 1985.

Norton, George W. and Jeffrey S. Davis. "Evaluating Returns to Agricultural Research: A Review." American Journal of Agricultural Economics. (November 1981): 685-699.

Norton, George W., Victor G. Ganoza, and Carlos Pomareda. Potential Benefits of Agricultural Research and Extension in Peru. Department of Agricultural Economics, Virginia Polytechnic Institute and State University, 1985.

Norton, George W. "The Productivity of Research: U.S. Agricultural Experiment Stations, Revisited." No. Central Journal of Agricultural Economics. 3(1981):1-12.

Norton, George W., J.D. Coffey, and E. Berrier Frye. "Estimating Returns to Agricultural Research, Extension, and Teaching at the State Level." Southern Journal of Agricultural Economics. (July 1984): 121-128.

Norton, Roger. "Structural Trends in Colombian Agriculture and the Role of Credit." U.S. Agency for International Development, Agricultural Policy Analysis Project, Stillwater, Oklahoma, 1985.

Peterson, Willis. "Returns to Poultry Research in the United States." Journal of Farm Economics. 49(1967):656-69.

Peterson, Willis. "The Returns to Investment in Agricultural Research in the United States." ed., Fishel, W. Resource Allocation in Agricultural Research. Minneapolis: University of Minnesota Press, 1971.

Peterson, Willis. "The Returns to Investment in Agricultural Research in the United States." Resource Allocation and Productivity in National and International Agricultural Research. ed. by T.M. Arndt, D.G. Dalrymple and V. Ruttan, University of Minnesota, Minneapolis, 1977.

Pindyck, Robert and Darrel L. Rubinfeld. Econometric Models and Economic Forecasts. Second Edition, New York: McGraw-Hill Book Company, 1981.

Powell, R.A. "Technological Change in Australian Agriculture, 1920-21 to 1969-70." Ph.D. thesis, University of New England, 1974.

Ramalho de Castro, J.P. and G.E. Schuh. "An Empirical Test of an Economic Model for Establishing Research Priorities: A Brazil Case Study." Resource Allocation and Productivity in Naitonal and International Agricultural Research. ed., Arndt, T.M., D.G. Dalrymple, and V.W. Ruttan, Minneapolis: University of Minnesota Press (1977):498-525.

Rocha, Andrés. "Evaluación Económica de la Investigación sobre variedades mejoradas de Algodón en Colombia." M.S. thesis, ICA/National University Graduate School, Bogotá, 1972.

Rojas, Gentil. Productividad de Recursos en la Agricultura del Valle del Cauca. Cali, Colombia (1967).

Ruttan, Vernon. "Technical Change and Innovation in Agriculture." The Positive Sum Strategy, Harnessing Technology for Economic Development. ed. Landaw, Ralph and Nathan Rosenberg. Washington, D.C.: National Academic Press (1986): 333-356.

Schmitz, A. and D. Seckler. "Mechanical Agriculture and Social Welfare: The Case of the Tomato Harvester." American Journal of Agricultural Economics. 52(1970):569-78.

Schreiner, Dean, Arthur Ekholm, and James Chang. "A Guide to Input-Output Analysis for the Oklahoma Economy." Department of Agricultural Economics, Oklahoma State University, 1977.

Schuh, Edward. "Costs and Benefits of Agricultural Research: The State of the Arts." World Bank Staff Working Paper No. 360. 1979.

Schultz, T.W. The Economic Organization of Agriculture. New York: McGraw-Hill, 1953.

Scobie, G.M., and R. Posada T. "The Impact of Technological Change on Income Distribution: The Case of Rice in Colombia." American Journal of Agricultural Economics. 60(1978):85-91.

Scobie, Grant. "The Demand for Agricultural Research: A Colombian Illustration." American Journal of Agricultural Economics. (August 1979):540-45.

Shoemaker, Robbin, and Agapi Somwaru. "Total Factor Productivity and Sources of Growth in the Dairy Sector." Agricultural Economics Research. 38:4 (Fall 1986): 1-13.

Shumway, R. "Models and Methods Used to Allocate Resources in Agricultural Research: A Critical Review." Resource Allocation and Productivity in National and International Agricultural Research. ed., Arndt, T., D.G. Dalrymple, and V.W. Ruttan, Minneapolis: University of Minnesota Press, (1971):436-457.

Singh, Karam. "Return to Investment on Agricultural Research in the Punjab." Indian Journal of Agricultural Economics. 32:3(July-Sept. 1977):202-207.

Sociedad de Agricultores de Colombia (SAC). Revista Nacional de Agricultura. No. 867. Bogotá, (June 1984).

Solow, Robert. "Technical Change and the Aggregate Production Function." Review of Economics and Statistics. 39:3 (August 1957): 312-20.

Sundquist, W.B. "Agriculture's Productivity and Technology Base." Department of Agricultural and Applied Economics, University of Minnesota, Minneapolis, 1984.

Sundquist, W.B. "Technology and Productivity Policies for the Future." The Farm and Food System in Transition. Cooperative Extension Service, Michigan State University, East Lansing, 1985.

Swallow, Brent, George W. Norton, Thomas B. Brumback, Jr., and Glenn R. Buss. "Agricultural Research Depreciation and the Importance of maintenance Research." Department of Agricultural Eocnomics, Virginia Polytechnic Institute and State University, Blackburg, Virginia, 1985.

Theil, H. Economic Forecasting and Policy. 2nd ed., Amsterdam: North-Holland Publishing Company 1961.

Thomas, Vinod. Linking Macroeconomic and Agricultural Policies for Adjustment with Growth. The Colombian Experience. Baltimore: The Johns Hopkins University Press (1985).

Trujillo, Carlos. "Rendimiento Ecónomico de la Investigación en Trigo en Colombia." M.S. thesis, ICA/National University Graduate School, Bogotá, 1974.

Tweeten, L., and F.K. Hines. "Contribution of Agricultural Productivity to National Economic Growth." Agricultural Science Review. 3(1965):40-45.

Tweeten, L. Foundation of Farm Policy. 2nd ed., Lincoln: University of Nebraska Press, 1970.

United States Department of Agriculture. Measurement of Agricultural Productivity: A Review of Current Statistics and Proposals for Change. Washington, D.C.: ESCS Technical Bulletin No. 1614, February 1980.

White, F.C. and J. Havlicek, Jr. "Optional Expenditures for Agricultural Research and Extension: Implications of Underfunding." American Journal of Agricultural Economics.

APPENDIXES

APPENDIX A

COLOMBIAN AGRICULTURAL INSTITUTE (ICA)

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COLOMBIAN AGRICULTURAL INSTITUTE (ICA)

History

The decade 1940 to 1950 was the initial stage of the development and organization of the agricultural experiment stations, and the application of modern techniques in agricultural research programs. Research remained principally the domain of the Ministry of Agriculture.

The success attained through the Mexico-Rockefeller Foundation Program motivated the Colombian Government to invite that Foundation to set up a similar program there. The Program began its activities under the Ministry of Agriculture in 1950, with the Bureau of Special Research. The Bureau consisted of two Rockefeller specialists and three Colombian agronomists, who began work in corn and wheat breeding. By 1955, eleven foreign specialists were working in close collaboration with nearly 40 Colombian agronomists. Research spread to the experimental centers and stations, and later included investigation in the Animal Science.

The cooperation of the Rockefeller Foundation, which in former years had provided fellowships to professional agronomists from universities and the Ministry of Agriculture, was again extended to the preparation of Colombian personnel. Young agronomists were sent to the Mexican in-service training program. Whey they returned after a year or more of training, they were reincorporated into the various research programs of the Ministry of Agriculture.

In addition, during the first five years of operation of the Colombian agricultural program, the Foundation granted fellowships for 30 professionals to several U.S. universities who went on to obtain M.S. and Ph.D. degrees.

The impact of this cooperative program on agricultural research led, in 1955, to the creation of the Division of Agricultural Research (DIA), within the Ministry of Agriculture. Greater autonomy was allowed to that Division, thus making possible a more stable, yet flexible, administration and operation of agricultural research. By agreement between the Ministry and the Foundation, the Director of the Bureau of Special Research acted also as Technical Director of the DIA during its first three years of operation.

In 1951, when the Agreement with the Rockefeller Foundation was established, land was acquired to build what is now the National Research Center of Tibaitatá, which absorbed all research functions then existing in the zone. Tibaitatá began activities in 1952, concentrating on wheat, barley, corn and potatoes. In 1955, when it was placed under the DIA, work in Animal Science began with dairy cattle, which was followed by other programs in beef cattle, poultry, sheep, animal pathology and swine.

Tibaitatá became the first CENTRO DE INVESTIGACOINES AGROPECUARIAS in Colombia. Its 550 hectares have been apportioned into approximately equal sections for Agronomy and Animal Sciences. The Center's laboratories are equipped for investigations in Soil Science, Mineral and Animal Nutrition, Plant Pathology, Entomology, Plant and Animal Physiology, Seeds, Basic Biological Sciences, Dairy Science, etc. There are installations for handling cattle, sheep, swine and poultry, as well as greenhouses. ICA has four other similarly equipped centers for investigations of crops in other bio-environments.

Recognizing the importance of maintaining complete seed collections of local crop varieties, the Bureau of Special Research began to collect native Colombian corn, bean, potato, oat, barley, sorghum, and cotton varieties.

The Corn and Wheat breeding programs, which were the first activities of the Bureau, were followed by: Beans in 1951; Entomology, Potatoes, Soils, Plant Pathology and Barley, in 1952; Farm Administration in 1954; Animal Sciences and Pastures, 1955; Dairying, Biometry, and Oats, 1957; and Rice, and Animal Pathology, in 1958. This year also marked an important phase in the cooperative program: the foreign management of the DIA was turned over to a Colombian professional who has obtained a Ph.D. degree in the United States through a Foundation fellowship. Thus, one of the original intentions, to transfer leadership of the programs to Colombian personnel, was realized.

The vigorous advance in agricultural research achieved by the Bureau of Special Research of the Rockefeller Foundation and by the DIA highlighted the lagging of higher agricultural education which was seriously in need of personnel, and physical and economic resources. This disparity indicated the necessity to broaden the influence of scientific investigation in agricultural education. In 1959, the President of the National University and the Minister of Agriculture appointed a commission of Deans of the Agronomy Colleges and technicians of DIA to visit American agricultural colleges, the USDA Experiment Station in Beltsville, and the Agricultural College of Puerto Rico. The visit was carried out under the auspices of the Rockefeller and Kellogg Foundations. The Commission proposed in its 1961 report the integration of teaching with research and agricultural extension under a single administration, and the improvement of the Agronomy Colleges. It specifically recommended the formalization of an agreement between the National University and the Ministry of Agriculture to organize bilaterally a Graduate School, utilizing the installations of the National Research Center at Tibaitatá.

The Rockefeller, Kellogg and Ford Foundations expressed interest in the establishment of this new agency, and offered their support in organizing it. Colombian authorities elaborated the project, and in June 1962, the President of the Republic officially created the INSTITUTO COLOMBIANO AGROPECUARIO (ICA), as a decentralized public institution, to "promote, coordinate and carry out agricultural research, instruction, and extension," and "to prepare technical personnel for its own service, and that of other entities, and the exercise of the professions related to the agricultural sciences."

ICA Functions

In 1968 ICA was restructured and received the following responsibilities:

A. To promote, coordinate and implement, directly or in collaboration with other entities, biological and physical investigations and socioeconomical studies, with the objectives of increasing crop and livestock production.

B. To transfer the results of agriculture research and implement studies on extension methods.

C. To train professionals and technicians within ICA.

D. To accomplish the goals of the Ministry of Agriculture in: 1) Prevention, diagnosis and control of diseases and pests, both of crops and livestock. 2) Sanitation control for export in coldstorage houses and meat processing plants. 3) Quality control in the handling, transportation and use of fertilizers, soil conditions, farm chemicals, feed supplements and drugs. 4) Seed certification. 5) Animal incubation and artificial insemination.

E. To enforce sanitary standards for agricultural exports and imports.

F. To produce certified seeds and promote their use.

G. To promote techniques of egg incubation and artificial insemination.

H. To supervise and to assist private agricultural technical assistance services.

I. To carry on research and technology transferance for the rural development programs.

J. To give seminars and short courses for the training of agricultural technicians and farmers.

Administrative Structure

The Board of Directors is composed of the heads of several governmental and private agencies. The General Manager of ICA is the legal representative of the institution and is responsible for its administration and development.

ICA activities are performed by five subdirections, those of Research, and Technology Transfer, and Development and Services. The national structure of ICA is paralleled in the nine regional offices, located in Bogota, Monterfa, Valledupar, Medellin, Cali, Ibague, Bucaramanaga, Villavicencio and Manizales.

Research

ICA does research in the following fields:

A. Agronomy: Plant pathology, soils, plant breeding, physiology and cultivation techniques for all principal crops.

B. Animal Sciences: Genetics, nutrition, physiology, grass and forages and production systems for all principal species.

C. Veterinarian Sciences: Infectious diseases, epidemiology, parasitology, entomology, pathology and toxicology.

D. Agricultural Engineering: Agricultural machinery and processing equipment, land and water development.

E. Agricultural Engineering and Rural Sociology: Regional and sectorial socioeconomic studies and socioeconomic analysis of biophysical investigation.

APPENDIX B

SELECTED COLOMBIAN INFORMATION

TABLE XVIII

VALUE OF PRODUCTION OF CROPS AND LIVESTOCK AT CONSTANT 1970 PRICES 1960-1982 (MILLIONS OF PESOS), COLOMBIA

Year	Crops	Livestock	Total
1960	12,955.2	8,412.5	21,367.7
1961	12,647.0	8,592.4	21,240.0
1962	13,895.6	9,076.4	22,972.0
1963	13,140.9	9,748.5	22,889.4
1964	13,918.8	9,920.3	23,839.1
1965	14,479.0	9,951.5	24,430.5
1966	14,562.2	9,974.9	24,537.1
1967	15,205.4	10,184.9	25,390.3
1968	16,234.8	10,833.8	27,067.6
1969	16,230.7	11,667.1	27,897.8
1970	16,567.8	12,222.6	28,790.4
1971	16,869.0	12,512.4	29,381.4
1972	17,528.3	12,113.2	29,641.5
1973	17,737.1	13,613.6	31,350.7
1974	20,242.3	14,722.7	34,965.0
1975	20,412.7	14,942.1	35,354.8
1976	21,049.5	16,756.1	37,805.6
1977	22,011.0	17,009.0	39,020.0
1978	24,672.8	17,986.9	42,659.7
1979	25,699.7	18,898.3	44,598.0
1980	25,895.8	19,533.3	45,429.1
1981	26,907.5	23,080.9	49,288.4
1982	24,907.2	24,425.3	49,332.5

Source: Crops 1960-1982: Norton (1985), Table 4
Livestock 1960-1980: Departamento Nacional de Planeacion - DNP-UEA-DC (1982)
Livestock 1981-1982: Based on Norton (1985), Table 2.

TABLE XIX

AGRICULTURAL LABOR AND WAGES 1960-1982, COLOMBIA

Year	Labor (1,000 persons)[1]	Wage (Pesos daily)	Wage Bill ($000,000)[2]
1960	2,036	5.12	2,606.1
1961	2,026	5.86	2,968.1
1962	2,013	6.59	3,316.4
1963	2,017	8.34	4,205.4
1964	1,916	10.04	4,809.4
1965	2,206	10.77	5,939.7
1966	2,009	12.52	6,288.2
1967	2,267	13.30	7,537.8
1968	2,350	14.74	8,659.8
1969	2,166	16.27	8,810.2
1970	2,292	17.21	9,861.3
1971	2,403	19.38	11,642.5
1972	2,403	19.38	15,475.4
1973	2,266	31.91	18,077.0
1974	2,157	40.90	22,055.3
1975	1,895	52.56	24,900.3
1976	2,097	63.09	33,074.9
1977	2,093	95.24	49,834.3
1978	2,175	122.04	66,359.3
1979	2,024	149.37	75,581.2
1980	1,968	191.93	94,429.6
1981	1,948	237.44	115,633.3
1982	1,827	286.76	130,977.6

Source: Labor 1960-1978: Elias (1985), Table 31
Labor 1979-1982: SAC (1984), Table 3
Wage 1960-1978: SAC #867 (Transformed to nominal terms), Table 4

[1] Includes unpaid family workers
[2] Based on 250 workdays per year

TABLE XX

COLOMBIA CROPPED LAND AND PASTURELAND 1960-1983 (THOUSAND HECTARES)

Year	Cropped Land	Pastureland	Total
1960	3,060.1	17,388.9	20,449.0
1961	2,978.2	17,647.6	20,625.8
1962	3,097.0	17,951.7	21,048.7
1963	3,014.5	18,090.4	21,104.9
1964	3,177.7	18,211.6	21,649.3
1965	3,359.0	18,471.6	21,830.6
1966	3,400.7	18,597.0	21,997.7
1967	3,279.1	18,989.3	22,268.4
1968	3,330.3	19,565.2	22,895.5
1969	3,261.8	20,336.9	23,598.2
1970	3,366.6	20,901.0	24,967.6
1971	3,372.7	21,409.7	24,782.4
1972	3,425.4	21,549.7	24,976.1
1973	3,695.9	22,126.9	25,822.8
1974	3,767.1	22,584.1	26,351.2
1975	3,884.4	22,957.4	26,841.8
1976	3,984.8	23,228.4	27,213.2
1977	4,066.3	23,815.8	27,882.1
1978	4,341.3	24,401.9	28,743.2
1979	4,223.5	24,630.9	28,854.4
1980	4,220.0	24,633.0	28,853.0
1981	4,048.0	24,661.5	28,709.5
1982	3,899.2	24,562.6	28,461.8

Source: Cropped land: Norton (1985, Table 6).
Pastureland 1960-1971: Orozco (1977, Table XXIX)
Pastureland 1972-1982: DNP-UEA (1983, Table 10)

TABLE XXI

FERTILIZER USAGE, 1960-1982 (1000 METRIC TONS), COLOMBIA

Year	Fertilizer[1]
1960	149.6
1961	159.5
1962	238.4
1963	237.4
1964	314.3
1965	300.3
1966	335.4
1967	342.0
1968	363.5
1969	373.0
1970	388.0
1971	467.0
1972	550.0
1973	630.0
1974	610.0
1975	520.0
1976	570.9
1977	636.9
1978	759.5
1979	706.2
1980	709.9
1981	618.8
1982	668.2

Source: 1960-1980: Balcazar (1985, Table 7.2)
1981-1982: SAC (1984, Table 10)

[1] Includes simple, compound and urea

TABLE XXII

TOTAL HORSEPOWER 1960-1981, COLOMBIA

Year	Thousand Horsepower
1960	774.4
1961	880.2
1962	946.9
1963	1,018.7
1964	1,023.1
1965	1,071.3
1966	1,114.7
1967	1,161.2
1968	1,164.7
1969	1,239.8
1970	1,326.7
1971	1,473.7
1972	1,485.7
1973	1,473.4
1974	1,450.5
1975	1,513.8
1976	1,579.6
1977	1,638.0
1978	1,797.6
1979	1,801.4
1980	1,842.9
1981	1,840.9
1982	1,858.0

Source: Sociedad de Agricultores de Colombia - SAC (1984, Table 11).

TABLE XXIII

BASIC INFORMATION TO ESTIMATE THE PRODUCTIVITY INDEX 1960-1982 (MILLIONS OF PESOS, 1979=100), COLOMBIA

Year	Wage Bill	Intermediate Consumption[1]	Land Rent	Capital Rent	Total Input
1960	9,208.8	2,981.1	3,681	4,074	19,944.9
1961	8,967.1	3,081.5	3,713	3,858	19,619.6
1962	9,186.7	3,275.8	3,788	3,813	20,063.5
1963	9,304.0	3,165.9	3,799	3,551	19,819.9
1964	9,814.7	3,318.5	3,897	3,841	20,871.2
1965	11,400.5	3,457.4	3,929	4,152	22,938.9
1966	9,934.0	3,648.3	3,959	4,415	21,956.3
1967	10,737.6	4,525.7	4,008	5,146	24,417.3
1968	11,246.5	4,791.7	4,121	4,472	24,631.2
1969	10,045.8	4,864.1	4,248	4,420	23,577.9
1970	9,861.3	5,382.6	4,494	4,453	24,190.9
1971	10,545.7	5,479.2	4,460	4,725	25,209.9
1972	12,360.5	5,892.0	4,495	5,224	27,971.5
1973	11,830.3	6,354.5	4,648	5,784	28,616.8
1974	11,310.4	6,428.3	4,743	5,841	28,322.7
1975	10,568.9	6,698.3	4,831	5,933	28,031.2
1976	11,342.6	7,655.1	4,898	6,198	30,093.7
1977	13,331.7	7,803.8	5,109	6,797	32,951.5
1978	15,157.4	8,348.6	5,174	7,088	35,768.0
1979	13,916.6	7,965.9	5,197	7,146	34,225.5
1980	13,667.6	8,413.0	5,193	7,185	34,458.6
1981	13,779.0	8,481.4	5,168	7,387	34,815.4
1982	12,851.0	8,792.6	5,123	7,745	34,511.6

[1] Source: DNP-UEA-DC-029, 1982, Table 4.

TABLE XXIV

EDUCATIONAL INDEX 1960-1982, COLOMBIA

Year	Ratio of Rural Education	Index 1970=100
1960	83	101.0
1961	76	98.0
1962	79	96.0
1963	73	89.0
1964	79	96.0
1965	76	93.0
1966	79	96.0
1967	79	96.0
1968	80	97.0
1969	81	99.0
1970	82	100.0
1971	83	101.0
1972	83	101.0
1973	78	95.0
1974	85	104.0
1975	75	91.0
1976	84	102.0
1977	81	99.0
1978	86	105.0
1979	81	99.0
1980	79	96.0
1981	81	99.0
1982	86	129.0

TABLE XXV

WEATHER INDEX 1960-1982, COLOMBIA

Year	Index 1970=100
1960	175.0
1961	105.0
1962	126.0
1963	58.0
1964	41.0
1965	06.0
1966	53.0
1967	75.0
1968	56.0
1969	80.0
1970	100.0
1971	135.0
1972	186.0
1973	123.0
1974	53.0
1975	98.0
1976	42.0
1977	47.0
1978	68.0
1979	98.0
1980	75.0
1981	200.0
1982	139.0

TABLE XXVI

COLOMBIA BASIC CALCULATIONS TO ESTIMATE AVERAGE INTERNAL AND EXTERNAL RATE OF RETURN AND BENEFIT-COST RATIO (DISCOUNTED FACTOR 0.10)

				Discounted		
Year	Incremental Cost	Incremental Benefit	Incremental Net Benefit	Incremental Cost	Incremental Benefit	Incremental Net Benefit
1	84	0	-84	76.36363	0	-76.36
2	78.8	215.8	137.1	65.12396	178.3471	113.22
3	103	1384.4	1281.4	77.38542	1040.120	962.73
4	70.4	1546	1475.6	48.08414	1055.938	1007.85
5	103.7	1377.5	1273.8	64.38954	855.3191	790.93
6	95.8	-137.6	-234.4	54.07660	-77.6716	-131.75
7	119.9	944.1	824.2	61.52765	484.4725	422.94
8	164.5	-708.1	-872.6	76.74046	-330.333	-407.07
9	182.2	640.4	458.2	77.27058	271.5921	194.32
10	191.1	2452.1	2261	74.83044	941.1462	866.32
11	213.5	2685.2	2471.7	74.83044	941.1462	866.32
12	283.2	2218.5	1935.3	90.23624	706.8824	616.65
13	245.4	-307.7	-553.1	71.08363	-89.1297	-160.21
14	167.5	629.6	462.1	44.10798	165.7933	121.69
15	145.6	4305.1	4159.5	34.85548	1030.606	995.75
16	151.8	4961.5	4809.7	33.03610	1079.766	1046.73
17	172	5206.3	5034.3	34.02928	1030.038	996.01
18	123.1	3459.9	3336.8	22.14061	622.2934	600.15
19	154.2	4041.8	3887.6	25.21293	660.8665	635.65
20	162.1	7392.8	7230.7	24.09513	1098.892	1074.80
21	148.9	7925.6	7776.7	20.12094	1070.990	1050.87
22	177.4	11175.6	10998.2	21.79287	1372.877	1351.08
23	174.3	11527	11352.7	19.46550	1287.314	1267.85
Total	3512.4	72935.8	69423.4	1189.646	15401.51	14211.86

2

VITA

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Candidate for the Degree of

Doctor of Philosophy

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Education: Graduated from Instituto Técnico Central High School, Bogotá, Colombia in November 1963; received the Economist degree from Universidad Nacional, Bogotá, Colombia in August 1969; received the Master of Science degree from Colegio de Postgraduados, Chapingo, Mexico in March 1975 with a major in Agricultural Economics; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in July 1987.

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