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RETURNS TO INVESTMENTS IN THE GENERATION AND TRANSFER OF AGRICULTURAL TECHNOLOGY: THE CASE OF RICE IN URUGUAY

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CONTENTS

This paper is the result of a project funded by USAID-Montevideo and carried out during November 1988 at the Department of Agricultural and Applied Economics of the University of Minnesota and at the Uruguayan Agricultural Research Institute. I thank my project counterparts Gustavo Ferreira and Martin Dabezies and to all the people in Minnesota and Uruguay that collaborated in this study, especially Vernon W. Ruttan, Willis Peterson, Phil Pardey, John Grierson and Carlos Más. The views expressed in this paper as well as any possible errors and omissions are those of the author.

SUMMARY

The objective of this paper is analyze returns to investments in the generation, transfer and adoption of rice technology in Uruguay during 1965-85. Rice is the focus of the study because of its economic importance and of its particular technological and institutional characteristics within Uruguayan agriculture. The background section of this paper briefly reviews four issues: the transfer of technology vis-a-vis the creation of it in a small-country context; the potential complementarities between public and private research; and the Uruguayan research and rice production setting. The results of testing an economic surplus model developed specifically for this case show that investments in rice research and extension had a high payoff. Methodologically, the use of this type of model relies heavily on the estimate of the supply shift. Since many assumptions were utilized in developing and testing our model the results should be considered as an approximation, and not as definite ones. Certainly it is difficult to get an exact measure of the impact of technical change independent of other factors. Some of the benefits are indirect and are difficult to measure in an appropriate manner, i.e. total benefits to society go beyond those calculated by pricing quantities generated by a shift in supply. Moreover, not all the costs attributed to the generation, transfer and adoption of rice technologies belong exclusively to these activities. This study measured the impact of a technological package based on improved seed and agronomic practices. More information on other implicit costs such as managerial ability and input costs would improve the analysis. By including two commonly omitted variables such as public extension and private research and extension this study is an attempt to obtain a more complete measure of the impact of technical change where research, transfer and adoption of technology are part of that process. It has been shown that the benefits generated by technical change are captured by producers. Private support of research is therefore economically justified. Moreover the link between public and private rice research and extension activities is a good example of complementarity and of the potential impact of it. This key agricultural research policy issue certainly deserves more attention. Finally, this study also highlighted the importance of domestic research to monitor outside the country in order to introduce and adapt external knowledge in the form of genetic materials and agronomic practices. Uruguay clearly benefitted by introducing rice varieties from abroad, this could not have happened without research capacity at the local level. The understanding of the links between technology diffusion and domestic research capacity is also an issue that deserves further analysis.

Echeverría,R.G. 1989. Returns to Investments in the Generation and Transfer of Agriculture Technology: The Case of Rice in Uruguay. ISNAR Staff Notes No.89-50. The Hague: ISNAR.

FIGURES

TABLES

1. BACKGROUND

The contributions of research and extension (R&E) to productivity growth in agriculture have been well documented since the early 1960s. The significance of technical change is that it permits substitution of knowledge for resources, or of inexpensive and abundant resources for scarce and expensive ones. In other words, it releases the constraints on growth imposed by inelastic resource supplies (Ruttan 1982). The results of many studies of the contribution of R&E to productivity growth have shown high economic returns to these investments. In Uruguay, although agricultural research efforts started early in this century, no economic analysis has been done to quantify returns to investments in R&E.

The objective of this paper is to analyze the impact of the generation, transfer and adoption of rice technology in Uruguay during 1965-85. Rice was selected because of its economic importance and particular technological and institutional characteristics within Uruguayan agriculture. It is the country's principal crop, both in terms of volume and value and it was ranked as first research priority in an ex ante study recently conducted by CIAAB and ISNAR (Ferreira 1988, pers. com.). Moreover there is high integration between production and marketing, and between public and private sector R&E.

The paper is organized in two sections. Section 1 focuses on: (1) the importance of transferring and adapting biological technology vis-a-vis the creation of it in a small country context; (2) the complementarities between public and private sector research; (3) the agricultural research setting in Uruguay; and (4) the characteristics of rice production in the country. Section 2 develops and tests an economic surplus model to analyze the impact of technical change in rice.

Transfer of Agricultural Technology

The literature analyzing the diffusion of biological and agronomic technology between countries is short. Previous studies have emphasized the environmental sensitivity of biological technology and the importance of local research capacity in the adaptation of those technologies. Evenson and Kislev (1975) related sugarcane technological discovery and diffusion to the local research effort in different regions. They also analyzed the contribution of own research and borrowed knowledge to the increase of wheat and maize yields, with the result that no borrowing took place in the absence of own research effort.

Flores-Moya, Evenson and Hayami (1978) estimated the importance of international technology transfer by calculating social benefits from rice research in the Philippines that spilled over the tropical world during 1967-75. The benefits obtained by 18 countries in Asia and 6 in Latin America from investments in rice research in the Philippines were high. The estimated returns ranged from 46% to 71%. The returns to the Philippines were in the 27-50% range.

Hayami and Ruttan (1985, pp.255-298) incorporated location specificity, and adaptive and basic research to the technology transfer concept. They distinguished three phases in the transferring process according to what is being transferred: materials, designs, and capacity. According to the induced technology transfer model developed by the authors the transfer of fertilizer-responsive HYVs of rice from Japan to Taiwan and Korea was consistent with a land saving demand from the recipient countries.

Dalrymple (1986) identified two periods in the spread of new rice varieties in Latin America: (1) before 1970 "Bluebonnet", "Bluebelle" and other varieties were introduced from the United States; (2) after 1970 CIAT and IRRI played an important role in the diffusion of semi-dwarf varieties. Dalrymple reports that 2.3 million ha were planted with HYVs in Latin America in 1981-82. This accounts for 26% of the total rice area of the region, and for 70% of all Latin America except Brazil. The pattern of adoption of semi-dwarf HYVs shows a steady increase.

In Uruguay rice technologies in the form of seed (Buebelle) and some agronomic practices have been transfered mainly from the United States. Transfer from other regions has been less important for the temperate conditions of the country. This is a good example of technological spill-ins. The existence of domestic research capacity to monitor developments in similar agroclimatic regions and to adapt materials to local conditions, has been a key factor in the spillovers of rice technology into Uruguay.

Public and Private Research

Most of the knowledge produced from research has the non-rivalness and non-excludability characteristics of a public good.[1] Provision of these type of goods by private firms would not be optimal because they are not able to capture most of the benefits generated from research. Private research has concentrated on developing mechanical and chemical technologies where patent protection is available, and less on biological and agronomic technology.

In the more developed countries, one of the basis for complementarity between public and private research is the fact that most publicly generated knowledge reaches farmers through privately developed inputs. In general, the sectors complement because private firms are more involved in applied research than public organizations are, and on developing mechanical and chemical technology. Private research in biological technology usually focuses on hybrids, where nature provides the patent. In agronomic technology, private firms usually develop new techniques that help utilize inputs in a more timely fashion, and/or more of them. Moreover, farmers--as part of the private sector--also conduct research to create or to adapt existing technologies and practices. Rice research in Uruguay is partially funded by producers. It is one of the few examples in the country where private firms fund, through a

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[1]See Echeverría (1988, pp.14-24) for a discussion of the public good nature of most agricultural research products.

formal agreement, public sector research.[2] Farmers' organizations also have technical assistance programs which focus on applied research, and extension.

Agricultural Research in Uruguay

Uruguay, a small country with three million inhabitants and an average 1984-86 GNP per capita of US$ 1,843, is endowed with a relative abundance of land well suited to agriculture and grazing. More than 90% of total land area (177,500 square km) is dedicated to agricultural uses and 90% of it is devoted to meat, wool and milk production (DIEA 1983, p.83). Rice and wheat are the principal cereal crops. In 1986 agriculture accounted for 12% of total GDP, or US$ 638.4 million. Agricultural commodities represented 60% of total merchandise exports. The record of agricultural production growth has been poor: a 1% average annual rate during 1965-80 and -0.7% in 1980-86 (World Bank 1988, p.225).

The public sector has been the main actor in the Uruguayan agricultural research scene. Its activities can be subdivided into three phases. The first one began with the creation of the National Plant Breeding and Seed Institute in 1914 ("La Estanzuela", hereafter EELE). This was primarily a wheat variety development program that became well recognized in the region by the 1920s and 1930s. By the mid to late 1950s EELE had lost its earlier recognition. At this time research was being considered an important element in an agricultural development strategy in Latin America and some countries of the region began modernizing their agricultural research systems.

The second phase started in 1962 with the government reorganization of EELE to broaden its mandate on a national basis. The "Centro de Investigaciones Agrícolas Alberto Boerger" (hereafter CIAAB) of the Ministry of Agriculture was created to focus into a variety of agricultural commodities and disciplines (soils, plant breeding, pastures, seeds, animal production, and others). In 1970, CIVET ("Centro de Investigaciones Veterinarias") was created to conduct veterinary research.[3]

With these reforms, plus a strong university research component, the agricultural research effort peaked during the 1960s. Also at this time, IICA established in EELE the agricultural sciences graduate training school for the temperate region of Latin America. During the 1960s, with support from USAID, IICA, UNDP, FAO and other agencies, CIAAB improved the number and the technical level of its staff. In the early 1970s a

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[2]Although not a very common practice there are a few examples of private funding of research through public institutes of traditional export crops in Latin America, such as the Sugar Institute in Colombia and the Coffee Institute in Costa Rica.

[3]Information on the size of the research effort conducted by other organizations such as CIVET, the Agronomy and Veterinary Faculties of the University and many private organizations, is scarce. Public research in this paper means primarily that conducted by CIAAB.

regional network of experiment stations and trials covered the principal agroeconomic regions of the country. By the mid 1970s it was recognized that the technologies developed by CIAAB were not being widely adopted. In 1975 CIAAB started research on production systems trying to integrate different research areas and improve the transfer of technology.
The third phase of public research activities, from the mid 1970s to the mid 1980s, was characterized by a decrease in the financial resources allocated to CIAAB, while the turnover of scientists increased. CIAABs total budget decreased from N$ 1.1 million in 1974-76 to N$ 0.7 million in 1982-84 (in pesos of 1973). The total number of scientists decreased from 85 (34% with post-graduate training) in 1973 to 67 in 1970, and it increased to 76 scientists (24% with post-graduate training) by 1983-85 (Grierson 1987, pers. com.). While the importance of the private sector increased during the 1970s and 1980s, mainly in the transference of technology area, agricultural research in Uruguay continued to depend heavily on public support. This support was low -- less than 0.5% of agricultural GNP -- compared with other countries in the region.

By the mid 1980s there was consensus on the importance of agricultural research on economic development. Since the mid 1980s the financial and human resource constraints had somewhat improved, while there has been a significant effort to reorganize CIAAB into a new semi-autonomous institute--publicly and privately funded. At the present time a law creating INIA ("Instituto Nacional de Investigaciones Agrícolas") is under discussion in the Uruguayan Congress.

Rice in Uruguay

The largest rice producers in Latin America are Brazil, Colombia and Peru, followed by Cuba, Mexico, Uruguay and Argentina. In 1986 Uruguay and Colombia had yields close to 5 t/ha (FAO 1987, p.72). In 1981-82, 72% of the rice area in Latin America was upland, 24% was irrigated, and the rest was rainfed lowland (Dalrymple 1986).

Rice is an irrigated crop in Uruguay. Approximately 60 days after planting the crop is inundated up to 10-15 cms over a period of 90-120 days. To reduce irrigation costs, rice production is aimed at regions with levelled topography, with soils where water will not easily permeate, and close to an abundant source of water. The "Laguna Merin" region (on the East, by the Brazilian border) fullfils the above conditions and is where most rice production is located. "Bluebelle", the variety widely planted. It has a high yield potential, a quite wide planting season (mid October to mid November), a growing season of 150-160 days, and good characteristics for the industry.

Production, Area and Yield. The evolution of production, area and yield is presented in Table 1. Commercial production began in the early 1930s. By 1935, the country achieved self-sufficiency, and by 1950 began exporting. Production increased from 10,000 tons in 1935 to 40,000 in 1950 and to 400,000 tons by the mid 1980s. This remarkable increase is mostly explained by a significant growth in area. From 3,500 ha in 1935 to 19,000 in the mid 1950s, to more than 80,000 ha in recent years. Figure 1 shows rice production, area and yield trends. Average yields have increased from 3 t/ha during most of the period to 5 t/ha in the present time. This is not a low growth record given the significant expansion in area.

Table 1. Rice production, area and yield, 1931-88

Year	Production (t)	Area (ha)	Yield (t/ha)
1931	840	390	2.15
1932	2550	670	3.81
1933	3125	1040	3.01
1934	3500	1220	2.87
1935	10500	3500	3.00
1936	14695	4735	3.10
1937	18978	4621	4.11
1938	15894	5461	2.91
1939	21426	5480	3.91
1940	17376	5358	3.24
1941	10985	4586	2.40
1942	19605	5295	3.70
1943	15499	5558	2.79
1944	17328	5265	3.29
1945	21031	6437	3.27
1946	30580	8687	3.52
1947	35170	10145	3.47
1948	37240	12576	2.96
1949	44948	14373	3.13
1950	39969	13693	2.92
1951	34402	12371	2.78
1952	47124	12818	3.68
1953	52518	15502	3.39
1954	61724	17364	3.56
1955	68398	19794	3.46
1956	63986	19399	3.30
1957	56966	19071	2.99
1958	57841	17137	3.38
1959	49327	17800	2.77
1960	53170	14453	3.68
1961	60866	17790	3.42
1962	60764	17788	3.41
1963	76992	20986	3.67
1964	47138	20557	2.29
1965	90042	27529	3.27
1966	83746	30499	2.75
1967	115617	33976	3.40
1968	104456	30747	3.40
1969	134496	34340	3.92
1970	138611	35691	3.88
1971	122158	31408	3.89
1972	127995	31146	4.11
1973	136917	34540	3.96
1974	157940	42660	3.70
1975	188535	46923	4.02
1976	216521	52327	4.14
1977	228276	56840	4.02
1978	225646	53380	3.87
1979	247973	68010	3.65
1980	287558	67350	4.27
1981	330287	62250	5.31
1982	418885	69450	6.03
1983	323166	70155	4.61
1984	344900	78906	4.37
1985	421850	84929	4.97
1986	405764	85749	4.73
1987	340153	83253	4.09
1988	388789	81237	4.79

Note: Year corresponds to year of harvest.

Source: OPP/Comisión Sectoral del Arroz. Estadisticas Básicas. Various Issues. Montevideo.

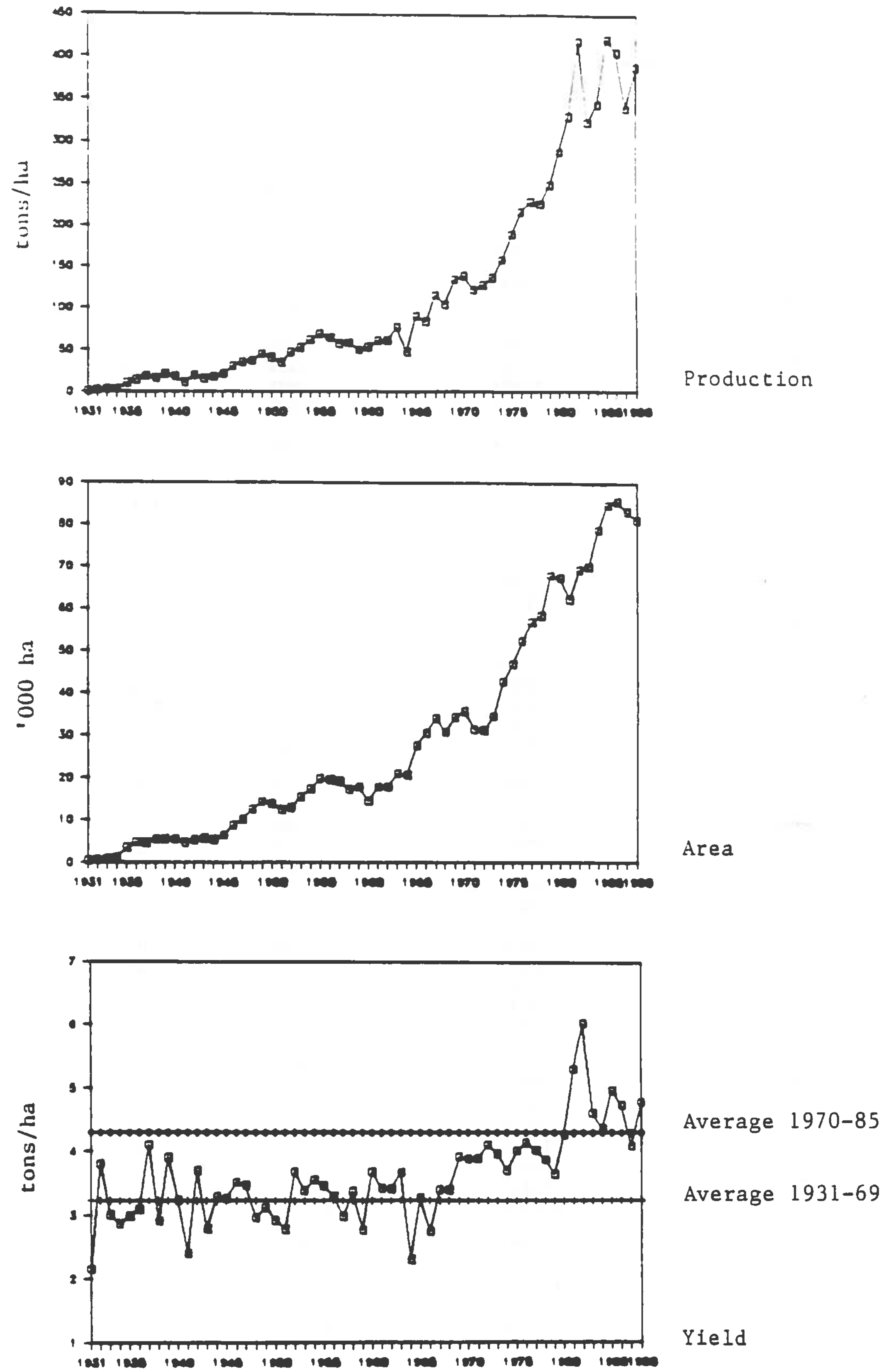

Figure 1. Rice Production, Area, and Yield Trends, 1931-88

Growth rates of production, area and yield are shown in Table 2. The period 1936-88 is subdivided in two to show that in spite of the importance of growth in area, yield growth during the 1970s and 1980s was higher than during the previous three decades.

Table 2. Growth rates of rice production, area, and yield, 1936-88

Period	Production	Area	Yield
	....	% per year	....
1936-40 to 1965-69	6.1	6.2	-0.1
1965-69 to 1984-88	6.6	5.0	1.6
1936-40 to 1984-88	6.4	5.8	0.6

Note: Growth rates are percentage cumulative compound annual rates calculated by $X_t = X_0\ [1 + (g/100)]^t$, where X_t is the final period average, X_0 the initial period average, and t the number of years between mid-points of periods.

Source: Table 1.

Those yield increments had a similar pattern of that observed in the rest of the world, especially in countries with a similar system of production such as Argentina, Colombia and USA. The evolution of yields in these 3 countries, in Uruguay and in the world are compared in Figure 2.

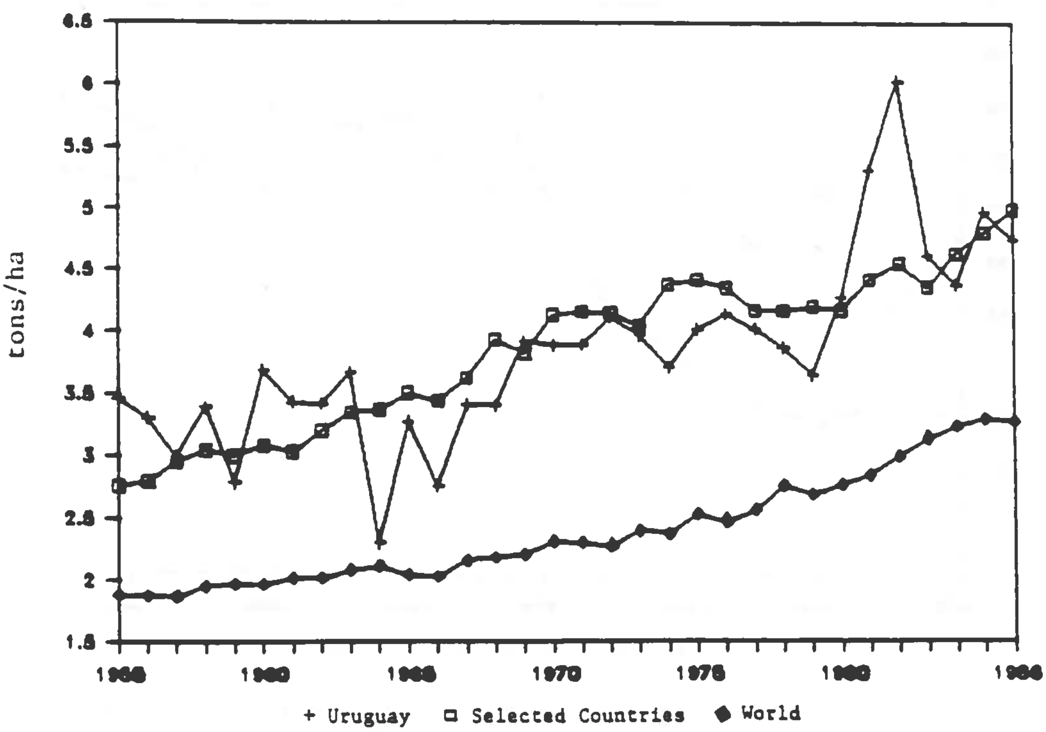

Figure 2: Evolution of Rice Yields in Uruguay, Selected Countries, and the Rest of the World, 1955-88.

Domestic consumption of rice in Uruguay is low. The increase in production was exported. These exports, which began in 1936, become significant by 1950. In recent years, almost all production is sold to a dozen different countries. The principal markets during 1981-87 are shown in Table 3.

Table 3. Principal markets for Uruguayan rice, 1981-87

Country	Annual Average Quantity Exported (000 t)
Brazil	84.6
Iran	64.7
Nigeria	27.0 (a)
The Netherlands	16.6
Portugal	15.3
South Africa	13.2 (b)
Total Average	220.2

Note: (a) 1981-84; (b) 1981-86

Source: Oficina de Planeamiento y Presupuesto/Comisión Sectorial del Arroz. 1988. Estadísticas Basicas.

By the mid 1980s approximately 90% of production was exported generating US$ 80 million. Figure 3 shows the trends of exports as a percentage of production and the income generated by those exports.

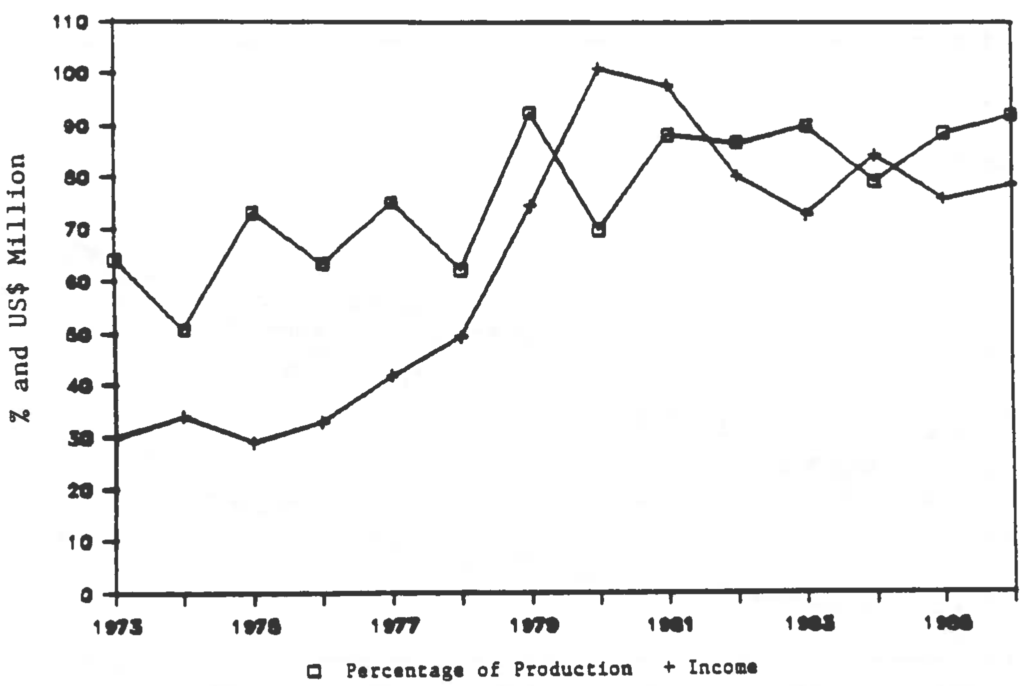

Figure 3: Rice Exports as a Percentage of Production, and Income Generated from those Exports, 1973-86.

Structure of the Industry. In 1987, 428 farmers were producing rice on an average of 200 ha each. Of the reported 55,000 ha planted with rice in 1980 (Censo 1980) almost 60% was in farms larger than 1,000 ha. Table 4 shows the number of farmers and the area planted to ricea by region. The east region accounts on average for 72% of the number of producers, and for 83% of the rice area.

Table 4. Number of farmers and area planted to rice in the two principal rice regions of Uruguay, 1981-87

Year	Number of Rice Producers East	North/Central	Total	Area Planted to Rice (1000 ha) East	North/Central	Total
1981	231	100	331	52.9	10.3	63.2
1982	221	93	314	58.0	10.6	68.6
1983	221	63	284	60.4	9.6	70.0
1984	274	100	374	66.2	12.7	78.9
1985	284	106	390	71.0	13.8	84.8
1986	307	121	428	70.9	14.8	85.7
1987	294	134	428	65.7	17.3	83.0

Note: East region is formed, for the purposes of this table, by the following departments: Rocha, Cerro Largo, Treinta y Tres and Lavalleja. North/Central region: Artigas, Rivera, Salto and Tacuarembó.

Source: OPP/CSA. 1988. Estadísticas Basicas.

The rice industry is currently formed by agro-industrial firms and farmers. Four of the eleven firms that buy, process and market rice account for more than 80% of production. These firms, in which rice farmers own shares, provide services to farmers such as technical and financial assistance, input delivery, rent of land and water, and credit for the construction of dams. They also conduct applied research in close association with the public sector. The integration within the rice sector (production and marketing) and across public and private R&E organizations has contributed to important advances in seed quality, variety improvement, crop and water management, land preparation and weed control.

Research and Extension. The introduction and development of new rice varieties began in the mid 1960s. Before that time there were no research activities more than a few variety trials carried out by private firms. In 1965 these firms introduced long-grain varieties from Texas. They adjusted well to the Uruguayan agroclimatic conditions and by the end of the 1960s their use expanded. In 1970, as part of the public research regionalization process described before, an experiment station ("Estación Experimental del Este", hereafter EEE) began activities in the region. This was the starting point of public research on rice. During its first period of activities, EEE priorities were variety selection and improvement, seed quality, and water management. With the scarcity of new soils close to sources of water, EEE began research on fertilization (rate, date of application and management), and weed control. This allowed for a more intensive use of land.

EEE has also focused on varieties other than Bluebelle given the potential risk of having the same genetic material in more than 90% of the area. In this regard there is a variety improvement program where approximately 120 cultivars (hybrids and local selections) are under evaluation. Also more than a 100 cultivars are introduced annually from CIAT, IRRI and other countries, specially the U.S. (PROCISUR 1988, p.68).

Private firms during the 1970s had their own research programs and were very active on technology transfer through their technical assistance departments. They collaborated increasingly with EEE and since 1980 by a formal agreement with EEE joint R&E plans are specified annually, including the amount of private funding. This represents almost two thirds of the total R&E budget (Table 5).

Table 5. Public and private investments in rice research and extension, 1981-85

Sector	Annual Average 1981-85	
	US$	%
Public	215,640	32
Private	467,215	68
Total	682,855	100

Note: Public sector expenses are mainly those of the EEE. Private sector includes own efforts plus funding of joint projects with public sector participation.

Source: CIAAB, 1988.

2. ANALYSIS

Evaluating the Impact of Technical Change

Schuh and Tollini (1979) classified the methods of evaluating returns to investments in research into two groups: ex post and ex ante. They grouped the procedures used to conduct ex post studies into five classes: (1) the inputs saved approach; (2) consumer and producer surplus; (3) production function; (4) impact on national income; and (5) nutritional impact.[4]

Following Schuh and Tollini classification, Norton and Davis (1981) compared the approaches used to evaluate investments in research. They identified 27 characteristics to compare evaluation procedures and discussed the major studies using the consumer and producer surplus approach: Schultz (1953), Griliches (1958), Peterson (1967), Hertford and Schmitz (1977), Ayer and Schuh (1972), Akino and Hayami (1975), Scobie and Posada (1978), and Duncan (1972). Norton and Davis also analyzed Linder and Jarret's (1978) work on the nature and size of the supply curve shift due to technical change, and of the elasticities of supply and demand.

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[4]They described the major procedures to improve ex ante decision making with respect to research resource allocation identifying the following models: (1) Scoring (Iowa, North Carolina and the NASULGC-USDA); (2) Minnesota; (3) Pinstrup-Andersen and Franklin; (4) Cartwright; (5) Castro and Schuh; (6) Easter and Norton; and (7) Atkinson-Bobis.

The economic surplus approach calculates average rate of returns based on supply and demand shifts due to technical change. The production function approach estimates a marginal rate of return, this is useful when distinguishing the effects of research from other inputs across regions. There is no one method that can be used in all different situations, hence it is important to adapt the existent methodologies for each particular case. Most studies of returns to investments in Latin America for example have utilized the economic surplus approach, probably because of the difficulty in obtaining data on the different inputs required to use a production function.

Table 6 summarizes the return to research studies conducted in Latin America since 1970. The number of studies as well as the results have been high. According to this, there has been underinvestment in research, i.e. social gains could have been higher if more resources were allocated to research in those commodities. In spite of the important contribution made by previous studies most of them ommit variables which may bias the results.

Three variables are commonly not included in the analysis of returns to research: private R&E, public extension and the costs of new inputs. By not considering these factors the results are biased upwards because not all costs are included while the total effect of all factors is usually counted as a benefit. The payoff of technical change is the product of the generation, the transfer and the adoption of a particular technology or set of technologies. Although it is difficult to get information on extension costs by commodity, and on private R&E expenses, these variables should be somewhat accounted for in the analysis since the generation of technology per se, without considering its diffusion and adoption would not have a measurable impact.

Another common measurement problem is the calculation of benefits due to variety improvement without considering the costs of the new agronomic practices and inputs related with them. The analysis presented in the next section of this paper is a crude attempt to quantify benefits and costs of technical change. By including public and private sector R&E expenditures and other factors affecting the impact of new technology it captures most of the commonly left out variables mentioned before.

Table 6. Summary of Returns to Research Studies in Latin America, 1970-88

STUDY		METHOD[a]	COUNTRY	COMMODITY[b]	PERIOD	RESULT[c] (%)
Barletta	1970	ES	Mexico	Wheat	1943 1963	90
		ES	Mexico	Maize	1943-1963	35
		PF	Mexico	Crops	1943-1963	45-93
Ayer and Schuh	1972	ES	Brazil	Cotton	1924-1985	80-107
Hines	1972	ES	Peru	Maize	1954-1967	35-40
		ES	Peru	Maize (+ Cultivation)	1954-1967	50-55
Monteiro	1975	ES	Brazil	Cocoa	1923-1974	16-18
		ES	Brazil	Cocoa	1958-1974	60-79
		ES	Brazil	Cocoa	1958-1985	61-79
		ES	Brazil	Cocoa	1923-1985	19-20
Fonseca	1976	ES	Brazil	Coffee	1933-1995	23-27
		ES	Brazil	Coffee (+E)	1933-1995	17-22
Hertford et.al.	1977	ES	Colombia	Rice	1957-1972	60-82
		ES	Colombia	Soybeans	1960-1971	79-96
		ES	Colombia	Wheat	1953-1973	11-12
		ES	Colombia	Cotton	1953-1972	none
Wennergren and Whittaker	1977	ES	Bolivia	Sheep	1966-1975	44
		ES	Bolivia	Wheat	1966-1975	48
Scobie and Posada	1978	ES	Colombia	Rice	1957-1964	79-96
Moricochi	1980	ES	Brazil (Sao Paulo)	Citrus (+E)	1933-1985	18-28
Avila	1981	ES	Brazil (R.G. Sul)	Irrigated Rice (+E)	1959-1978	83-114
		ES	Brazil (R.G. Sul)	Irrigated Rice	1959-1978	87-119
		ES	Brazil (Central)	Irrigated Rice	1959-1978	87
		ES	Brazil (N. Coast)	Irrigated Rice	1959-1978	107
		ES	Brazil (S. Coast)	Irrigated Rice	1959-1978	115
		ES	Brazil (Frontier)	Irrigated Rice	1959-1978	119
		ES	Brazil (R.G. Sul)	Irrigated Rice	1959-1978	107
		ES	Brazil (Central)	Irrigated Rice (+E)	1959-1978	83
		ES	Brazil (N. Coast)	Irrigated Rice	1959-1978	92
		ES	Brazil (S. Coast)	Irrigated Rice	1959-1978	111
		ES	Brazil (Frontier)	Irrigated Rice	1959-1978	114
		ES	Brazil (R.G. Sul)	Irrigated Rice	1959-1978	96
Franco	1981	ES	Chile	Rice (INIA)	1981-2000	87-105[d]
Cruz et.al.	1982	ES	Brazil EMBRAPA	Physical Capital	1974-1981	53
		ES	Brazil EMBRAPA	Total Investment	1974-1992	22-43
Ribeiro	1982	ES	Brazil (Minas Gerais)		1974-1994	69
		ES	Brazil (Minas Gerais)	Cotton	1974-1994	48
		ES	Brazil (Minas Gerais)	Soybeans	1974-1994	36
Yrarrazaval et.al.	1982	ES	Chile	Wheat	1949-1977	21-28
		ES	Chile	Maize	1940-1977	32-34
Evenson	1982	PF	Brazil	Aggregate	19..-1974	69
Avila et.al.	1983	ES	Brazil EMBRAPA	Human Capital	1974-1996	22-30
Cruz and Avila	1983	ES	Brazil EMBRAPA/IBRD	Total Investment	1977-1982	20
		ES	Brazil EMBRAPA		1977-1991	38
Ambrosi and Cruz	1984	ES	Brazil EMBRAPA/CNPT	Wheat	1974-1982	59
		ES	Brazil EMBRAPA/CNPT	Wheat	1974-1990	74
		ES	Brazil EMBRAPA/CNPT	Wheat (+Physical Capital)	1982	40
Avila et.al.	1984	ES	Brazil EMBRAPA/SCPA	PROCENSUL I	1977-1996	27
		ES	Brazil EMBRAPA	South Central Region	1974-1996	38

Table 6: (Continued)

STUDY		METHOD[a]	COUNTRY	COMMODITY[b]	PERIOD	RESULT[c] (%)
Pinazza et.al.	1984	ES	Brazil (Sao Paulo)	Sugarcane	1972-1982	35
Roessing	1984	ES	Brazil EMBRAPA/CNPS	Soybeans	1975-1982	45-62
Silva	1984	PF	Brazil (Sao Paulo)	Aggregate	10 years	60[e]
		PF	Brazil (Sao Paulo)	Aggregate	15 years	76
		PF	Brazil (Sao Paulo)	Aggregate	20 years	102
Ayres	1985	ES	Brazil	Soybeans	1955-1983	46
		ES	Brazil	Soybeans	1955-1983	48-49[f]
		ES	Brazil (Parana)	Soybeans	1955-1983	51
		ES	Brazil (R.G. Sul)	Soybeans	1955-1983	51-53
		ES	Brazil (S. Catarina)	Soybeans	1955-1983	29-31
		ES	Brazil (Sao Paulo)	Soybeans	1955-1983	23-24
Muchnik	1985	?	Latin America	Rice	1968-1990	89
Norton et.al.	1987	ES	Peru INIPA	Rice (+E)	1981-2000	17-44[g]
		ES	Peru INIPA	Maize (+E)	1981-2000	10-31[g]
		ES	Peru INIPA	Wheat (+E)	1981-2000	18-36[g]
		ES	Peru INIPA	Potatoes (+E)	1981-2000	22-42[g]
		ES	Peru INIPA	Beans (+E)	1981-2000	14-24[g]
		ES	Peru INIPA	Aggregate (+E)	1981-2000	17-38[g]
Luz Barbosa et.al.	1988	ES	Brazil EMBRAPA	Aggregate	1974-1997	40.5
Seré and Jarvis	1988	ES	Tropical Region	Pastures	1986-2026	15-100[h]
Echeverría et.al.	1988	ES	Uruguay	Rice (+E)	1965-1985	52

NOTES:

a. Method: ES = Economic Surplus
PF = Production Function

b. (+E) = includes extension

c. Results of conducting sensibility tests on various parameters of the models are not presented in the Table.

d. Ex ante study of improved technology, combining varieties, fertilization, and other management practices.

e. The results vary according to the different time horizons for research assumed in the study--10, 15, and 20 years.

f. Recalculation under the more realistic assumption of large country.

g. Although part of this study could be considered ex post, it is an ex ante simulation exercise, and cannot be strictly compared with the rest of the ex post studies presented in the table.

h. Ex ante estimates.

Table 6: (Continued)

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An Economic Surplus Model for the Case of Rice in Uruguay

The general concept of economic surplus produced by technical change is shown in Figure 4. The total surplus is the result of benefits accrued by consumers and producers. Consumer surplus is defined by the area below the demand curve and above the equilibrium price P_0, area daP_0. It is the difference between what consumers are prepared to pay for a product or service and what they actually pay. Producer surplus is the area above the supply curve and below P_0, area P_0a0. S_0 is the original supply curve before innovation and adoption takes place. At this point quantity Q_0 is sold at price P_0. For simplicity, we assume perfect competition, and lack of distortions between private and social prices of factors and products.

The generation and adoption of new technologies will shift the supply curve to the right, S_0 will become S_1. Price will decrease to P_1 and quantity sold will increase to Q_1. The change in consumer surplus is the area P_0abP_1. The change in producer surplus is the area cb0 minus the area P_0acP_1. Area cb0 is the gain to producers given by a unit cost reduction and by an increase in quantity sold. Area P_0acP_1 is the loss to producers due to the new (lower) equilibrium price.

Net social benefit is the sum of the changes in consumer and producer surplus, i.e. $P_0abP_1 + (cb0 - P_0acP_1) = ab0$. The size of this benefit depends on the elasticities of the demand and supply curves and on the size of the supply shift. The calculation of an economic surplus implies measuring area ab0 on a yearly basis, given changes in prices and in the size of the shift. This exercise is based on the specification of the demand and supply curves and on the nature of the supply shift.

Figure 5 shows the economic surplus model developed for the case of rice in Uruguay. The model is based on the "small country" assumption. This implies that Uruguayan rice production has no effect on world prices. This is a safe assumption since production in 1980 was only 0.08% of the world total, and exports accounted for only 1.1% of total world exports (Sisto 1982). Since almost all rice is exported, Uruguayan producers face world demand, without affecting its position. Hence the relevant part of the demand curve facing Uruguay is infinitely elastic and coincides with world price, P_w.

The change in price is given by the annual change of P_w, i.e. the price received by producers in this study. To simplify the calculation of areas we assume that the supply curve is linear, the shift is parallel, and the price elasticity of supply is zero. Annual benefits are estimated by calculating area abQ_0Q_1. The base of this rectangle is the supply shift $S'_1 - S'_0$, the height is P_w.[5]

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[5]Dabezies (1981) calculated elasticities for rice area in Uruguay very close to zero. It could be shown that area OabX is approximately equal to area abQ_1Q_0.

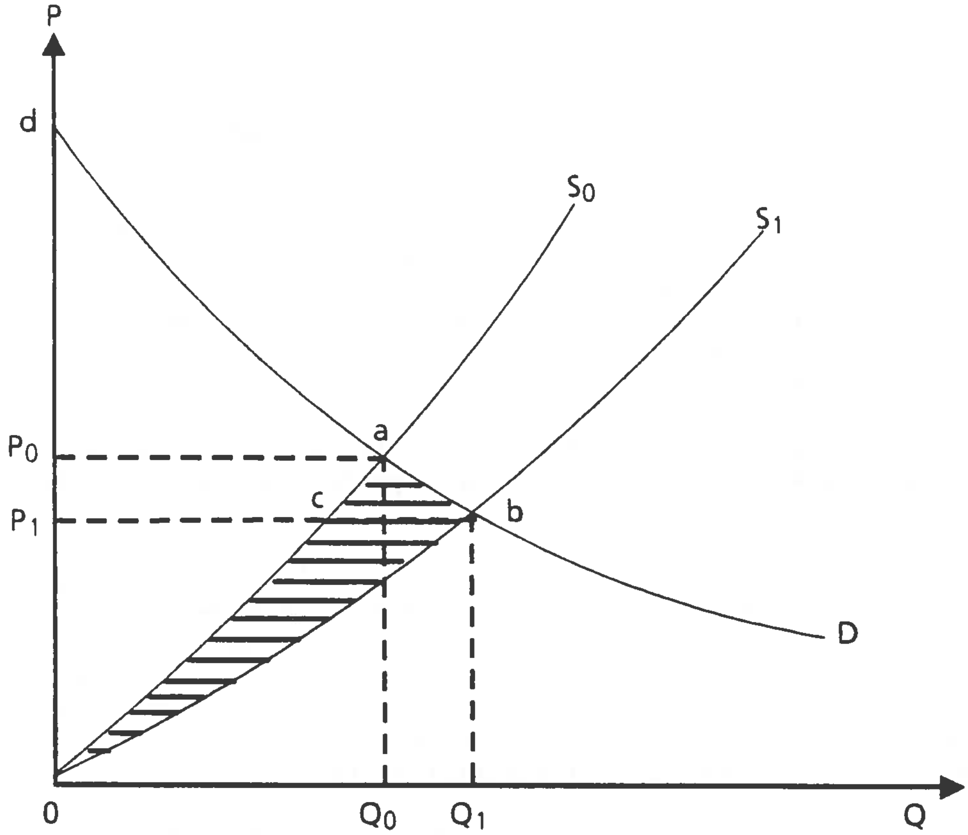

Figure 4 : Economic surplus from technical change, a general model.

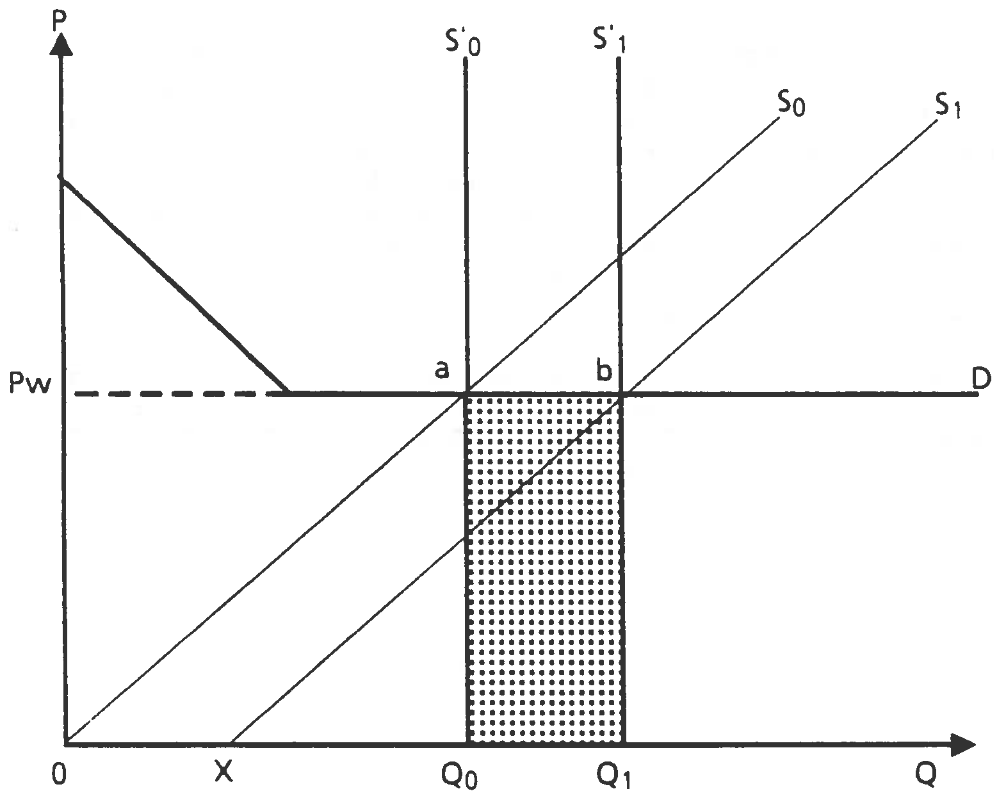

Figure 5 : An economic surplus model to estimate returns to rice research and extension in Uruguay .

Empirical Results

Supply Shift. The entire period of study is subdivided into 4 subperiods, according to the impact of new technologies on rice yields. Rice research in Uruguay began in 1965. It took approximately 5 years to introduce and adapt new varieties, and to develop adequate agronomic practices associated with them. Therefore, in the initial 5 years the impact is considered to be nil. Improved seed and new agronomic practices were the key factors explaining the improvement in rice yield. Improved seed is used here in the sense of higher genetic potential, and also quality, better germination and purity. New agronomic practices include: land preparation (levelling and drainage for a better water and crop management), planting (density and timing), irrigation, use of fertilizers, herbicides and pesticides (type, rate, timing and method of aplication).

Based on experiment station and on-farm data it was estimated how much of the yield increment was due to each of these factors. Table 7 shows the estimated evolution of the impact of new technologies on the increments of rice yields. These figures are based on information provided by rice scientists. A total impact of 28% in 1970-74 means that of the total yield increment 72% was due to factors other than seed or agronomic practices, such as the use of fertilizer, chemicals, and machinery. Since not enough data of the costs of these inputs was available, only improved seed and agronomic practices were included in the calculation. The impact of these two factors on yield increase grew from 28% to 53%, and to 63% in the final period.

Table 7. Evolution of the impact of technical change on rice yield increments, 1965-85

	1965-69	1970-74	1975-79	1980-85
	....	%	....	
Improved Seed	0	16	20	23
Agronomic Practices	0	12	33	40
Total	0	28	53	63

Source: CIAAB, EEE, personal communication

The increase in area due to the existence of a new technological package was also considered in the calculation of the supply shift. This was estimated by the percentage growth of land use on rice on the total rice area. These lands would not have been available for rice in the same time period without the new technology since the traditional cropping pattern is 2 years of rice and 6 or more years of fallow.

According to the concepts discussed above the shift of the supply curve due to technical change is defined as the increment in yield and area produced by the generation and adoption of new rice technologies. Expression (1) captures this definition.

$$J_t = \{[(Y_t - Y_{t-1})/ Y_{t-1}] K_{yt} + [(A_t - A_{t-1}) / A_{t-1}] K_{at} \} \qquad (1)$$

J_t = supply curve shift due to technical change in year t
Y_t = annual average yield in year t
K_{yt} = difference in yield due to technical change in year t
A_t = annual avrage area in year t
K_{at} = area difference due to technical change in year t

The first term on the right hand side of (1) is an index of yield growth corrected by K_{yt}, i.e. by the percentage increase in yield due to technical change. The second term in (1) is an index of area growth corrected by K_{at}, i.e. by the percentage increase in area due to technical change. K_{yt} is taken from Table 7. For simplicity we let K_{at} be equal to one and A_t be the growth index of used land instead of total area.

Estimates of Benefits. The benefits are calculated by multiplying the increase in quantity due to technical change by the price received by farmers, on an annual basis. The increase in quantity is the production in the previous year times the shift in supply due to technical change. Benefits are defined by the following expression:[6]

$$B_t = J_t \bullet Q_{t-1} \bullet P_t \qquad (2)$$

B_t = gross annual benefits due to technical change
J_t = supply shift, calculated by (1)
Q_{t-1} = rice production in previous year (tons)
P_t = price of rice paid to farmers in year t (in constant US$)

According to table 7 there were no benefits from 1965 to 1969, i.e. there is a five year lag of the impact of the R&E package. Therefore, the stream of benefits is calculated using expression (2) from 1970 to 1985, the last year where information is available. Benefits derived from past and present R&E will certainly not stop in 1985 even if all research activities did, since previous knowledge embodied in seeds an managerial ability will not dissapear. The future accumulation of past benefits will not go on forever since new pests and diseases would probably make past technologies obsolete. We assume a ten year period of future benefits (1986-95) calculated by taking the average benefits for the period 1981-85 to zero in 1996, in a linear fashion.

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[6]Note that B_t in (2) corresponds to the shaded area in Figure 5, where the base of the rectangle is $(Q_1 - Q_o)$ or $(Q_{t-1} \bullet J_t)$, and the height is P_t.

Estimates of Costs. The costs of producing and transferring the new technology are calculated, also on an annual basis, by the following expression:

$$C_t = PUBE_t + PRIVE_t + OPE_t \qquad (3)$$

C_t = costs in year t
$PUBE_t$ = public sector R&E expenses in year t
$PRIVE_t$ = private sector expenses in year t
OPE_t = other project expenses in year t

Public R&E expenses are mainly research expenses at EEE. Private R&E expenses was obtained from the technical departments of the principal firms, and was estimated by the number of technical personnel working on the others. The third term in the cost equation stands for the fraction affecting rice R&E of other projects, some of them privately funded (convenio arrocero) and others internationally funded (such as "Convenio Chino", FAO-PNUD, IICA-BID, USAID-PIATA). Table 8 summarizes the benefits and costs calculated by using (2) and (3).

Table 8. Benefits and costs of investments in rice research and extension, 1965-96

Year	Benefits	Costs
	.... 000 US$	
1965	-	272.0
1966	-	308.9
1967	-	519.6
1968	-	577.5
1969	-	618.1
1970	3278.8	563.3
1971	6.6	283.8
1972	293.3	438.9
1973	4759.6	845.4
1974	11293.7	1057.8
1975	7393.6	869.8
1976	5539.9	761.3
1977	4788.7	911.8
1978	1757.1	1075.3
1979	1188.1	980.8
1980	26261.2	800.2
1981	14886.6	901.6
1982	16521.1	865.2
1983	831.7	592.5
1984	7243.3	522.2
1985	8676.4	532.7
1986	9632.0	-
1987	8668.8	-
1988	7705.6	-
1989	6742.4	-
1990	5779.2	-
1991	4816.0	-
1992	3852.8	-
1993	2889.6	-
1994	1926.4	-
1995	963.2	-
1996	0.0	-

All values are in constant US$
(1985 = 100 CSA 1988 price index)

Calculation of Returns. To assess the efficiency of investments in rice R&E the following elementary accounting concepts are utilized:

The internal rate of return is the calculated value for the discount rate necessary for total discounted benefits to equal total discounted costs, i.e.is the rate that makes the left-hand-side of expresion (4) equal to zero.

$$\Sigma_t \; [(B_t - C_t) \bullet (1 + IRR)^{-t}] = 0 \qquad (4)$$

B_t = gross benefits in year t (in constant US$)
C_t = costs in year t
IRR= internal rate of return

The benefit/cost ratio is the total discounted benefits divided by the total discounted costs,

$$BC = B_t \,/\, C_t \qquad (5)$$

BC = benefit cost ratio
B_t = gross benefits in year t (in constant US$)
C_t = costs in year t

The net present value is the value of the benefits net of the costs, both discounted at the opportunity cost of capital. It is calculated by:

$$NPV = \Sigma_t \; [(B_t - C_t) \bullet (1 + i)^{-t}] \qquad (6)$$

NPV = net present value
B_t = gross benefits in year t (in constant US$)
C_t = costs in year t
i = rate of discount

Discounting is the adjustment of costs and benefits to their present values by choosing a discount rate and a time frame. In the above calculations a standard interest rate of 12% was used as the real rate of discount. It is clear from (4), (5) and (6) that the IRR is the rate of discount that makes NPV = 0; and also that if NPV $\geqq$ 0, then BC $\geqq$ 1.

The first row of Table 9 shows the results of applying (4), (5) and (6) to the stream of benefits and costs listed in table 8. The second and third rows of table 9 are based in supply shifts 20% smaller and 20% larger than originally calculated, respectively. The results obtained for the rate of return, benefit/cost and net present value are high. The estimates are stable when assuming a 20% variability in the supply shift. A rate of return of 52% indicates the average return on investments on rice R&E during the period 1965-96. A benefit/cost ratio of 5.5 means that US$1 invested in rice R&E have produced an average benefit of $5.5 throughout the period.

Table 9. Returns to investments in rice research and extension

	Internal Rate of Return (%)	Benefit/Cost Ratio	Net Present Value (US$ m)
	52	5.5	20.2
-20% Supply shift	46	4.4	15.1
+20% Supply shift	57	6.6	24.9

3. CONCLUSIONS

The results of this study show that investments in rice research and extension during 1965-85 had a high payoff. According to the procedures utilized to calculate benefits and costs these results are conservative. Methodologically, the use of an economic surplus model relies heavily on the estimate of the supply shift and although the information utilized was the best available, it is still somewhat subjective. Furthermore, many assumptions were utilized in developing and testing our model. Hence, the results should be considered as an approximation, and not as definite ones.

Certainly it is difficult to get an exact measure of the impact of technical change independent of other factors. Some of the benefits are indirect and are difficult to measure in an appropriate manner, i.e. total benefits to society go beyond those calculated by pricing quantities generated by a shift in supply. Moreover, not all the costs attributed to the generation, transfer and adoption of rice technologies belong exclusively to these activities.

This study measured the impact of a technological package based on improved seed and agronomic practices. More information on other implicit costs such as managerial ability and input costs would improve the analysis. By including two commonly omitted variables--public extension and private research and extension--the results are an attempt to obtain a more complete measure of the impact of technical change defined as a process which includes not only research but transfering and adoption of technology.

It has been shown that the benefits generated by technical change are captured by producers. Private support of research is therefore economically justified. Moreover the link between public and private rice research and extension activities is a good example of complementarity and of the potential impact of it. This key agricultural research policy issue certainly deserves more attention.

Finally, this study also highligthed the importance of domestic research capacity to monitor outside the country in order to introduce and adapt external knowledge in the form of genetic materials and agronomic practices. Uruguay clearly benefitted by introducing rice varieties from abroad, but this could not have happened without the necessary resources (human and financial) devoted to the task. The understanding of the link between technology diffusion and domestic research capacity is also a topic that deserves further analysis.

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