# IMPACT OF RICE RESEARCH IN LATIN AMERICA AND THE CARIBBEAN DURING THE PAST THREE DECADES



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**Abstract**

The past three decades have resulted in strong national rice improvement programs high yielding rice varieties on farmers fields and networks of germplasm improvement and related information linked via CIAT to the premier upstream research resource IRRI

The main beneficiaries of the technological innovations have been the consumers with an annualized flow of benefits (discounted at 3% per year) of US$518 million Producers have received great benefits as a group with US$340 million per year But it has been the irrigated system the one that has received the benefits of research (US$437 million per year) while the other ecosystems have been adversely affected by the rapid gains in the irrigated sector All these ecosystems had net annual losses of US$9 million in rainfed US$70 million in mechanized upland and US$5 million in manual upland With productivity gains in irrigated rice prices have decreased making upland rice less competitive and reducing the economic incentive to open new rice lands in those upland ecosystems Productivity gains in irrigated rice have played a role of release valve for the more fragile ecosystems of the forest margins and the savannas

The future of rice research holds exciting challenges and opportunities Rice research aims to make significant contributions to environmental goals and reduction of agrichemical use as well as in feeding people through devoting its efforts to the development of improved rice gene pools and integrated crop management Rice research plays and important role in the development of agropastoral protocols for the savannas adjoining the margins of the rain forest in tropical America Breeding to develop germplasm adapted to the acid soils savannas and the understanding of rice/pasture associations will lead to a more sustainable rice production in this ecosystem and a more rational use of pesticides

As a result of recent strategic changes in international donors national organizations of LAC together with CIAT and IRRI have created the Latin American Irrigated Rice Fund (FLAR) The could ensure continuity in irrigated rice research activities at the regional level This process clearly shows that Latin American rice producers are aware of the value and innovation of new technologies

## INTRODUCTION

Significant advances in rice production have been made over the past three decades in Latin America and the Caribbean (LAC) Some 275 new rice varieties have been released the majority of them (90%) targeted to flooded environments Of the new varieties 39% came from crosses made at CIAT 12% at IRRI and several of the rest has parentage from IARC s progenitors (Table 1) Modern semidwarf rice varieties now account for 93 percent of all flooded rice production itself representing more than 80 percent of total rice production in the Region (Table 2) Average yields in flooded areas have risen from 3 3 tons per hectare in the mid-1960s to 4 6 t/ha in 1995 and total rice production doubled between 1967 and 1995 to reach about 20 million tons of paddy rice (Table 3) making the Region largely self sufficient in rice With rice prices falling by about 50 percent in real terms over the period (Table 4) consumers have benefitted greatly rice is well established as a 'wage good and the crop has become the most important source of calories and proteins for that 20 percent of the Region s population with lowest incomes

Central to these accomplishments have been

- a linkage by the Region through CIAT to the world s premier source of rice germplasm (IRRI)

- the development of a strong regionally relevant rice improvement program through a productive partnership of CIAT Fedearroz and ICA in Colombia and

- close cooperation between CIAT's regional rice program and national programs and producers in major rice producing countries of LAC

While the upstream linkage to IRRI was a valuable component of this three-part improvement model high quality downstream activities at the country level frequently involving cooperation between public programs of research and extension with private producer organizations as in the case of Colombia Brazil and Venezuela were key to locally relevant adaptive efforts which accelerated and expanded the spread of improved germplasm complementary cultural practices and related institutional and policy developments Even though the investment commitments made by the private and public sectors all along the way over the past three decades were of major proportions handsome (even unprecedented) returns have been gained

Measuring past benefits and identifying the shares apportioned by main interested parties is a valuable exercise not only to gain an idea of the profitability of past research investments but also to guide future efforts The model used here measures benefits to producers and to consumers A further breakdown permits to calculate benefits by major production ecosystems irrigated rainfed lowlands mechanized upland and traditional (or manual) upland the model also calculates foregone benefits to producers resulting from imports

## RICE IN LATIN AMERICA AND THE CARIBBEAN

Throughout this century rice gradually became a staple food in the diets of consumers of tropical Latin America Per capita consumption of white rice went from 10 kilos in the 1920 s to about 30 kilos in the 1990 s Rice is the most important grain crop for human consumption across most of the tropics of Latin America and the Caribbean (LAC) It supplies more calories to these people s diet than wheat maize cassava or potatoes In the rapid process of urbanization of LAC where 70% of the population now lives in the cities rice has displaced from the diets traditional bulky and perishable staples like plantains cassava yams etc

About half of LAC s population lives below the FAO poverty line and income is lowest in the tropical parts of LAC Food purchases account for over 50% of total expenditures for the poor and rice accounts for about 15% of their total food purchases For the poorest 20% of the population it even supplies more protein to the diet than any other food source including beef milk and beans

**Evolution of Rice Production in Latin America**

Latin America produces some 20 million MT of paddy rice which represents about 3 6% of the world rice output in an area of 6 7 million has (4 5% of the world rice area) By 1995 the dominant rice environments in this continent are wetland rice (54 5% of the area) and upland rice (45 5% of the area) Wetland rice with 3 7 million has is dominated by irrigated cropping which occupies two thirds of that area the rest is almost entirely cultivated under rainfed lowland rice Upland rice (with 3 0 million has ) is predominantly mechanized (2 1 million has ) while manual rice farming covers almost 1 0 million has (Table 3) For most of this century rice has been a pioneer crop in the vast savannas and in the forest margins of Latin America Mechanized upland rice predominates in the colonization of the savannas while manual traditional rice cropping has been a key component in the forest margins

**Stages in rice production, 1966-1995**

The advent of the new rice technologies has had a sharp impact on the relative shares of the predominant rice production systems Different stages can be distinguished

*Early adoption 1966-1981* By 1966 the tall traditional varieties covered the entire rice area (5 8 million has) The 1970 s witnessed a very rapid adoption of the new semidwarf varieties for irrigated environments mainly in the tropical countries By 1981 the region produced 15 7 million MT an increase of 50% from 1966 About half of this rice came from MSVs and more than 75% of the irrigated rice area was under these new varieties With the advent of the new semidwarf rice varieties in late 1960 s the irrigated rice systems became more competitive higher yields resulted in lower unit costs and lower rice prices As a consequence upland rice confronting a lower relative price but without yield advances was also displaced by maize soybeans cassava cotton and other crops as a pioneer crop in the areas of deforestation The area under manual traditional upland rice fell from about 1 1 million has in 1966 to 0 85 million in 1981 In the savannas the story was a little different Brazil produces 90% of upland rice in the region This country made a firm commitment in the 1950 s to develop the vast acid savannas (Cerrados) the decision even embodied the removal of the nation s capital from the Coast (Rio de Janeiro) to the Cerrado (Brasilia) in the 1960 s Today the acid savannas of the Cerrados produce over 40% of the country s total agricultural supply This aggressive expansion of the Brazilian frontier had a peak during the 1970 s and was heavily based on government support Large mechanized rice exploitations were favored by several schemes based on price supports crop insurance forward contracting by the public sector etc As a consequence of the policies rice area in Brazil peaked in 1976 at 6 7 million has accompanied by a surge in upland area that reached 6 1 million has Over this period mechanized upland area went from 2 8 million has in 1966 to 4 8 million has in 1981 (Table 3)

*The lost decade 1981 1989* Throughout the 1980 s economic stagnation was the norm in the Region Promotional rice policies were phased out in the late 1970 s when the heavy foreign debt and the fiscal burden coupled with rampant inflation rates meant that promoting extensive agriculture became unviable Mechanized upland rice subsidies were virtually eliminated in Brazil by the mid-1980 s

Total rice area in LAC decreased from 8 3 million has in 1981 to 7 3 million has in 1989 but fortunately yields increased from 1 9 to 2 5 MT/ha as the adoption of new varieties continued mainly in Brazil where MSV's became widely adopted in the early 1980 s By 1989 regional paddy rice production reached 18 4 million MT MSVs accounted for two thirds of rice production and 44% of the rice area In irrigated rice 85% of the area was already under MSV's

*The 1990 s* This has been a period of economic growth open markets and reduced inflation rates in LAC By 1995 paddy rice production reached 20 6 million MT or 3 6% of the world rice output About 98% of the irrigated rice area was under MSV's Significant growth in production has ocurred in temperate South America (South Brazil Argentina and Uruguay) as the MSV's have been quickly adopted Irrigated yields for LAC have reached 5 0 MT/ha while total rice yields are at 3 1 MT/ha due to the low upland yields of 1 3 MT/ha Since the 1980 s upland rice area in Brazil has continue to decline to its current level of around 3 0 million has by 1995 (Table 3)

## THE RICE RESEARCH AGENDA FROM A CIAT PERSPECTIVE

Rice research in Latin America has emphasized growth equity and enhancement of the resource base Rice is particularly important from these standpoints Technological progress improved efficiency marked production increases and important linkages with the rest of the economy have put rice at the top of priorities for agricultural growth policies in most countries of LAC Rice is preferred by the poor because it is cheap nutritious appealing easy to prepare and easy to store and transport Rice has also been a pioneer crop in Latin America playing a protagonistic role in the expansion of the agricultural frontier of the lowlands the savannas and the forest margins

Besides outstanding technical innovation two major external reasons why rice research has had greater impact than any other area of work at CIAT are i) simplicity of seed borne technology delivery for a crop that is as simple and inexpensive to multiply as rice and ii) the well organized commercial rice sector in LAC which quickly adopts new technology These external factors will continue to give rice research a comparative advantage in achieving future impact

Research actvities at CIAT s Rice program are executed in the framework of three Projects that enable a broad commodity approach

Project 1 Improved Rice Gene Pools
Project 2 Integrated Rice Pest/Crop Management
Project 3 Strengthening public and private sector linkages

The future of rice research holds exciting challenges and opportunities Rice research can continue to make significant contributions to environmental goals such as the protection of rain forests and reduction of agrochemical use as well as in feeding people The progressive involvement of the private sector in funding national and regional rice research shows that this sector continues to be at the forefront of technology development and institutional maturity in LAC countries

**Project 1 Improved Rice Gene Pools**

New varieties represent a pooling of valuable new traits into an adapted genetic background that farmers can use to increase and stabilize yields By improving production efficiency these varieties generate cost savings to farmers much of which is passed on to consumers in the form of lower prices

***Wetland Rice*** More efficient rice varieties with higher more stable yields are the essence of what happened in the lowland rice Green Revolution" New semidwarf varieties enabled farmers to achieve a 45% yield increase across LAC s the most favored irrigated rice area from 3 5 mt/ha in 1966 to 5 0 MT/ha in 1995 stimulating an increase in production efficiency and an expansion of irrigated rice production from 4 3 million MT to 12 5 million MT over that period (Table 3)

The ongoing nature of this impact is reflected in the rather steady rate of release of new lowland varieties since the start of the Green Revolution New varietal releases are an important indicator of progress because they usually represent improvement for at least one key trait while maintaining other gains already achieved Over the past 25 years there have been an average of 10 new lowland varieties released per year across LAC (Table 1) A number of new traits are being generated in Latin America as well as globally which promise to continue the remarkable record of past impact

It has been estimated using pedigree information (Cuevas Perez et al 1992) that the relative diversity of the genetic core of LAC irrigated rice may have reached its limits in terms of yield potential Further yield enhancement may require the design of alternative genetic combinations Monitoring advances in genetic base diversification may benefit from methodologies more precise than pedigree analysis CIAT's major research in wetland rice germplasm development is typically focussing in pre breeding activities with the aid of molecular markers testing and adaptation of the new plant types commercial crosses with wild rices population improvement as well as some conventional pedigree breeding work done in collaboration with national rice programs Promising lines are made available to other NARS through the INGER network and serve as parents for further regional breeding use The objective is to develop high yielding germplasm adapted to irrigated and rainfed lowland conditions tolerant to major diseases and insect pests with good grain quality and early to intermediate growth duration To ensure good disease pressure hot spot sites are used

Market acceptable grain quality is important for LAC rice varieties Most Latin American rice consumers prefer long slender translucent grains that cook dry and loose and remain soft after cooling High percentage of head rice is required by millers The objective of this activity is to better understand the genetic control of factors affecting grain quality On the other hand demand for alternative uses of rice is increasing particularly in the U S Research on new uses of rice appears as an important window of opportunity for the next century in Latin America

Anther culture to bridge wide crosses is now a routine and useful tool in breeding in this part of the world Preliminary data as well as Chinese work suggest that anther culture can be used to overcome sterility in wide crosses It also appears to produce more intermediate types of recombinants as opposed to the parental types that seem to emerge from wide-cross populations when generations are advanced through selfing Since 1985 CIAT has incorporated anther culture (AC) as a tool to reduce generation time in rice Research on AC has increased the yield of doubled haploids making the tool more cost-efficient for breeders When compared with the traditional pedigree method AC appears to be an economically practical new tool (Sanint et al 1995) Several national programs in LAC have started to apply the AC protocol

***Upland Rice*** Much higher yielding savanna upland rice germplasm developed in the 1980 s is now reaching the farm and promises an important break trough for the savannas The new upland varieties are shorter have a more efficient use of fertilizers do not lodge so easily and have better grain quality than traditional upland varieties (Sarkarung and Zeigler 1990)

About 45% of Latin America s 6 7 million hectares of rice are in the freely-drained (aerobic soil) uplands producing almost 20% of LAC s rice crop (Table 3) About two-thirds of the total upland area is in the savannas of Brazil where large mechanized farmers predominate Upland rice is more tolerant of the acid soils of these areas than any other major food crop so it plays a strategic role in the development of sustainable systems there Traditional upland rice farming accounts for about 5% of the regional production of rice (or about 1 0 million MT) Yet over 80% of rice farmers in LAC belong to this system These farmers are rather poor and constitute important niches where rice improvements can have significant impact on their livelihood However adoption of modern varieties by those groups is relatively low (less than 30% of their area)

The new upland rices will help drive the adoption of improved pastures a leverage effect far beyond the value of the rice crop itself These agropastoral systems could provide the region with a viable alternative to clearing the Amazon forests to satisfy basic food needs Rice is also a major staple of forest margin smallholders many of whom live in extreme poverty The new upland rice germplasm promises to enhance their production and nutrition as well

Since breeding for this agro ecosystem is fairly new in most LAC countries other than Brazil much of the effort in this research area goes to developing and strengthening linkages with national as well as international groups including planning of joint projects exchange of germplasm and methodologies training and collaborative research CNPAF is a member of the Upland Rice Research Consortium coordinated by IRRI

Acid savanna soils are deficient in Nitrogen (N) Phosphorus (P) Potassium (K) Calcium (Ca) Magnesium (Mg) Silicon (Si) and toxic for Aluminum (Al) and Manganesium (Mn) These constraints are interrelated and compose acid soil syndrome

Phosphorous is one of the major constraints of acid oxic soils of the savanna The development of upland rice varieties having higher efficiency in uptake and use of phosphorous can contribute to more sustainable agriculture Study of the mechanisms of genetic differences in phosphorus uptake continues in collaboration with Japan

In South America there is an active project on agropastoral systems Colombia hosted the first workshop in 1992 Brazil held it in 1993 Venezuela in 1994 and Bolivia in 1995 Very positive results of rice-pasture systems are interchanged as well as cropping systems including other crops like soybean and corn

**Project 2 Integrated Rice Pest/crop Management**

Chemical control of rice pests (weeds fungi insects) is costly as well as hazardous both to the applicator and the environment We estimate that US$483 million are spent each year on chemical pest control in LAC rice More than half of this expenditure could probably be replaced by integrated pest management (IPM)
Pests rapidly evolve to overcome resistances and breeders have to constantly bring in new resistance sources just to maintain the same level of varietal performance as before This is called maintenance breeding' While it sounds mundane economics tells us it is in fact one of the highest payoff activities done because it prevents substantial yield losses and reversals that would otherwise have occurred

Integrated Crop Management (ICM) is a term expressing a concept similar to IPM In fact the two go together as crop management practices affect pests and vice versa ICM is a strategy which directly focuses on the yield gap to understand the reasons for the difference between researcher's yields and those of farmers ICM really deals with economic efficiency the result of technical efficiency (an agronomic concept based on optimal input-output ratios) and price efficiency (finding the most profitable combinations of inputs for the profit maximizing output) Increased efficiency makes rice farmers more competitive and eventually translates into lower prices for consumers

***Rice traits to enhance weed control*** The greatest expenditure ($218 million or 45% of the total) is on herbicides IPM strategies involving thresholds rotation better water control and seeding practices and use of varieties with weed interference properties and adapted to water seeding could probably reduce herbicide use by at least half Weeds are the number one pest of rice throughout LAC In Colombia and Venezuela unpublished panel data for 1991 to 1996 from producers show that the weed control represents an increasing share of crop production costs and has scalated from around 12% to 15% Chronic annual production losses of 11% are estimated as compared to 7% for diseases and 4% for insects

Weed scientists report that very few new herbicides are coming into the market because of the high costs of registration due to environmental concerns

While tillage and herbicides will continue to play a major role in the future there is clearly a need for complementary approaches which are cost-effective and environmentally-friendly IRRI WARDA and CIAT have recently begun research programs on traits of rice to enhance weed control in their agro-ecosystems

Some rices are much more vigorous competitors against weeds than others Allelopathy is another promising avenue for investigation Crops can inhibit weeds through chemical means i e root exudates CICA 4 and other lines identified as allelopathic in the USA have been screened for their activity against similar weeds in Colombia

The promising new upland rice-pasture system for the tropical savannas will also benefit from this research Farmers want rices that will give maximum yields without endangering pasture establishment Research to understand what traits are needed and how to select for them has been useful to breeders in the region

Besides interfering directly with weeds other traits in rice might contribute indirectly to better weed control For example the water seeding system has been widely adopted in developed countries mainly to control weeds such as red rice that can not establish under flooding Breeding can probably develop rice types that emerge through a water layer and establish more vigorously under tropical conditions

We estimate that rice traits for enhancing weed control could probably reduce weed control costs by 30% This would more than justify the research investment

***Durable Blast Resistance*** Blast is one of the most intractable fungal pest problems in cereal cultivation Crop losses cost an estimated US$200 million annually When resistance is not effective farmers use fungicide sprays This costs the region an estimated $170 million annually or 35% of total pesticide expenditures Besides being costly most are hazardous both to the applicator and the environment Durably-resistant varieties lower seeding rates more efficient use of lower amounts of applied nitrogen fertilizer the use of silicon fertilizers and fewer but better timed fungicide applications cut the need for the use of these chemicals by more than half

High levels of genetic resistance exist but they are ephemeral The fungus rapidly overcomes resistance Durable resistance is a concept receiving much theoretical attention but progress has been difficult and slow One of the world s most blast resistant varieties Oryzica Llanos 5 is a recent product of CIAT's gene pyramiding approach There are over 10 advanced lines in this region that have a similar level of resistance to Oryzica Llanos 5

A new technique called MGR DNA fingerprinting is revealing the genetic structure of blast in a way not previously possible This technique can act as an early warning system to detect the appearance of new genetic lineages of blast It might also help breeders identify resistance genes that are more durable than in the past if the lineage exclusion hypothesis is proven correct (Zeigler et al 1994)

***Diversified Tagosodes/Hoja Blanca Resistance*** The most hazardous pesticides are the insecticides which account for an estimated $95 million or 20% of the region s total pesticide bill Control of the *Tagosodes* leafhopper by pesticide application is often self-defeating because it eliminates the predators that could assist in keeping this pest in check Practical methods for monitoring the predator population as well as that of pests could give farmers the confidence to avoid unnecessary sprays

Rice hoja blanca virus (RHBV) causes severe recurrent epidemics and is exclusive of the the Andean Central American and Caribbean countries of tropical LAC It is transmitted by the planthopper insect *Tagosodes oryzicola* which can also cause serious feeding damage even when not viruliferous Colombian rice farmers were spraying up to 5-6 times to control the RHBV vector and other insect pests in the 1980 s The uncertainty of epidemics induces farmers to spray even when the problem is not apparent as 'insurance Currently we estimate that about half of the lowland rice farmers outside of Brazil apply an insecticide spray for Tagosodes each cropping season This costs the region about US$15 million annually

The RHBV-Tagosodes problem provided the original impetus for creation of the Rockefeller funded rice improvement project at ICA (Colombia) the predecessor of CIAT's Rice Program It also represents one of its most notable successes Tagosodes resistance was achieved by 1970 (CICA 4 variety) and was increased in CICA 8 (1978) based on the 'Tetep varietal source RHBV resistance based on the Colombia 1 source was added by 1989 (Oryzica Llanos 4)

There is risk however in depending on only a single resistance source for each pest for the whole region New sources have been identified but their genetic control and crossability to adapted LAC materials need to be understood and applied Transformation with viral genes is also being attempted to create an entirely novel resistance source

For Tagosodes in breeding populations screening activity tests segregating populations and advanced rice breeding lines for resistance to non-viruliferous Tagosodes (resistance to feeding damage per se) Potential parents for crossing as well as characterized lines are sent to NARS For resistance to Rice Hoja Blanca Virus (RHBV) in breeding populations the screening activity tests segregating populations and advanced rice breeding lines for RHBV behavior

**Project 3 Strengthening Private and Public Sector Linkages**

The past three decades have resulted in strong national rice improvement programs high yielding rice varieties on farmers fields and networks of germplasm improvement and related information linked via CIAT to the premier upstream research resource IRRI

***FLAR*** Building on this model and stock of capital for sustained progress while assuring its continued dedication to the tasks ahead is the challenge for the rice sector of LAC is the main purpose of the Irrigated Rice Fund for Latin America and the Caribbean (FLAR in Spanish) The Fund created in 1995 brings resources from private and public national organizations Twenty member 20 countries in LAC plus CIAT and IRRI assumed the responsibility and the control of FLAR s own rice research agenda FLAR appears to be a viable alternative by reason of several emerging constraints and opportunities

First the maturity and high level of development of national capacities for rice improvement in LAC impose a more important role and responsibility than in the past on national organizations in determining the direction and conduct of future rice improvement efforts

Second with large returns currently being enjoyed from rice improvement efforts those organizations that paid for programs of the past are logically expecting that mechanisms can be devised in the future to capture and turn some of those returns to the long-run maintenance of needed programs

Third given the process of globalization and the opening of the economies it is well known that the patterns of demand for new technologies of all kinds will change the quantities demanded of them will increase and the need to participate in economic blocks will also become more pressing Rice producers and improvement programs will be especially challenged by these changes

Fourth the rapid technological advances in the rest of the world imply that countries of LAC must find ways to keep in touch with other regions by maintaining strong linkages to foreign sources of technology The mechanism of the past has proved to be efficient in avoiding duplication of efforts using the specialization of tasks achieving economies of scale and providing a fully participatory research apparatus In this sense the new effort is being based in the principle of cooperation and efficiency in research while providing stability to the regional research system

The dissemination of technologies and information has been vital to the achievement of impact in rice The generation of more new technologies depends on knowing what has already been achieved The rice sector of LAC is dynamic and trends must be observed on a continuous basis to guide research and development planning The creation of FLAR brings stakeholders and technology generators closer together ensuring higher levels of efficiency in information and technology exchange mechanisms which are a crucial part of the international rice research and development process

***INGER-LAC*** CIAT and IRRI through the INGER LAC mechanism have convened a regional Rice Research Conference every two or three years since 1976 INGER-LAC serves as a major source of elite germplasm for most rice programs in tropical LAC Germplasm nominations for network exchange are obtained from Latin American breeding programs CIAT's rice program and from the rest of the world through the INGER Global network operating from IRRI (Table 1) Materials are pre-tested in the region before going out in the network to identify those most useful and characterize them for important traits Nurseries are custom-assembled based on the combination of traits requested by network members They are sent as unreplicated observation trials These features increase the likelihood that materials sent will meet needs of the requestor and minimizes seed dispatch and trial expenses Results are sent back to the coordination headquarters at CIAT collated analyzed and reported back to network members INGER LAC also convenes breeder training workshops every few years and maintains a germplasm information database Due to a funding crisis INGER LAC activities have been at a reduced basic level since 1993 From 1995 FLAR has been funding the activities of the network a top priority for Fund members

There are five databases related to rice germplasm research at CIAT i) INGER nursery findings over the years ii) crosses made in the LAC region and globally (NARS CIAT IRRI IITA) iii) CIAT germplasm working collection iv) CIAT rice breeding germplasm (segregating lines etc ) and v) regional scientific personnel These databases are an invaluable resource to monitor changes in the genetic origin of cultivar releases and frequency of parents used in crosses in the region identify sources of germplasm which would broaden the genetic base of LAC gene pools keep track of researchers etc We programmed the database to trace the parentage and calculate percentage contributions of different ancestors to the genetic makeup of current lines (assuming each parent contributed 50% of the genes in each cross) which lead to a publication by Cuevas-Perez et al 1992

## THE ECONOMIC BENEFITS OF PAST RICE R&D INVESTMENTS IN LATIN AMERICA AND THE CARIBBEAN

This section reports some preliminary outputs from an on-going study to develop new databases and analytical tools for generating information on the social returns to R&D investment in Latin America and the Caribbean This work is being undertaken in an IDB financed collaborative project involving IFPRI CIAT and IICA together with sub-regional institutions and NARS The main goal is to improve the capacity to undertake R&D evaluation priority setting and resource allocation in the region and one of the sub-activities is to systematize the generation of aggregate ex post assessments The ex post assessments are designed to serve two purposes to provide R&D managers and sponsors with some broad measures of the social impact of past investments and to help generate improved technical information on which to base benchmark ex ante assessments The benchmark analyses will be performed at a more spatially disaggregated level and will provide the basis for a critical review of the technical and economic data used in order to help formulate improved policy technology and trade scenarios for further ex ante evaluations

Given the scarcity of consistent historic data on rice technology generation and utilization at the national level in LAC a geographically aggregated approach is being taken to the ex post evaluation However an attempt is being made to track the evolution of the four major rice production systems of the region and to calculate separately the impacts of R&D on each *Irrigated* and *rainfed lowland* represent the anaerobic production systems while *mechanized upland* and *manual* or *traditional upland* represent the aerobic systems LAC rice production has been allocated proportionately among these systems based on an existing diverse set of regional and sub-regional studies (Scobie and Posada 1977 Valente Moraes 1977 CIAT 1979 1992 1995 Posada 1981 CIAT IRTP 1983 Muchnik de Rubinstein 1984 Dalrymple 1986) The period of analysis is 1966 to 1995 1966 being chosen to precede the widespread release and adoption of the modern semi-dwarf varieties in the region

For both ex post and ex ante assessment a multi-market economic surplus model described by Alston Norton and Pardey (1995 pp 395-410) is being used The model *Dream* is capable of analysing multiple (horizontal) markets trade in products and technology transfer between market regions technology adoption and disadoption exogenous (non R&D induced) growth in demand and supply and tax/subsidy price distortions for both producers and consumers Analyses are made using a software package based on the model (Wood Wood-Sichra Alston and Pardey 1995 1996) The approach generates a time stream of R&D benefits to producers and consumers by simulating the expected market level changes induced by the adoption and application of new technologies at the farm level The basic representation of technical change in such economic surplus models is shown in Figure 1 If we define a pre-research position at point *a* on the supply curve $S_0$, the equilibrium price and quantity are $P_0$ and $Q_0$ respectively and the associated consumer and producer surpluses are represented by the areas $FaP_0$ and $P_0aI_0$. The application of new technology can be represented as a downward shift in the supply curve up to a maximum amount determined by the effectiveness of the technology (conventionally described as the *potential unit cost reduction*) and the extent to which it is ultimately adopted This supply curve shift takes place over a period of years determined by the adoption rate In any given year the new market equilibrium position ($P_1$ $Q_1$) may be represented by point *b* on the shifted supply curve $S_1$ In this year the new consumer and producer surpluses are represented by areas $FbP_1$ and $P_1bI_1$ respectively The effects of R&D in the given year however are measured by the *changes* in economic surplus between *a* and *b* the areas $P_0abP_1$ (i e $FbP_1 - FaP_0$) and $P_1bcd$ (geometrically equivalent to $P_1bI_1 - P_0aI_0$) It can be shown that the sum of these two areas the total economic surplus is equivalent to the shaded area swept out by the movement of the supply curve ($I_0abI_1$)

Alston Norton and Pardey (1995) describe this process and its ramifications in greater detail and present the generic equations for changes in surplus that is the economic impacts of R&D For any region *j* and time *t* the producer and consumer benefits may be calculated as

$$\Delta PS_{j,t} = ( k_{j,t} + PP^R_{j,t} \quad PP_{j,t} ) [ Q_{j,t} + 0\ 5 ( Q^R_{j,t} - Q_{j,t} )]$$
$$\Delta CS_{j,t} = ( PC_{j,t} - PC^R_{j,t} ) [ C_{j,t} + 0\ 5 ( C^R_{j,t} - C_{j,t} )]$$
$$\Delta TS = \Delta PS + \Delta CS$$

where $PP_{j,t}$ $PC_{j,t}$ $Q_{j,t}$ $C_{j,t}$ are producer price consumer price quantity produced and quantity consumed in region *j* in year *t* assuming no R&D $PP^R_{j,t}$ $PC^R_{j,t}$ $Q^R_{j,t}$ $C^r_{j,t}$ are the equivalent values allowing for the effects of research and $k_{j,t}$ is the realised unit cost reduction in region *j* year *t* Alston et al set out procedures for the calculation of these prices quantities and unit price reductions using the parameters listed in Table 5 They also present procedures for calculating transfer benefits through government if producer or consumer taxes or subsidies are applied in any of the regions (although this feature is not implemented in the ex post study described)

The extension of the basic framework to the ex post case described here is shown in Figure 2 In addition to the R&D induced supply shift ($S_1$ to $S_1^R$) there are also exogenous shifts in supply ($S_0$ to $S_1$) and demand ($D_0$ to $D_1$) At the start of the ex post analysis period the equilibrium position ($P_0$ $Q_0$) is found at *a* During the analysis period the three shifts occur simultaneously resulting in a new observed equilibrium point *b* ($P_1^R$ $Q_1^R$) Without R&D (the counterfactual case) the final equilibrium position would have been *c* Thus the shaded area ($I_1cbI_1^R$) represents the economic surplus attributable to R&D It should be noted that even though the demand shift is assumed to be independent of research it generates a significant additional contribution to the total economic surplus attributable to R&D - as represented by the area *cbde*

**Market Regions and Their Interaction**

Regions can be characterized in ways that describe their capacity to generate new technologies as well as to produce and consume (Table 5) A region may have any individual property or any combination of properties Where regions are defined as countries they generally have all three properties However where important sub-groups of producers or consumers need to be represented in a modeling framework for example small traditional producers and large mechanized producers or rural and urban consumers appropriate market regions of single properties may be constructed

The analysis proceeds by a simulation through time of the release adoption and application of new technologies and the consequent changes in prices and in quantities produced and consumed As new technologies are adopted the supply-curve shifting effects of R&D in each region are transmitted between regions through prices The model assumes that in each time period price levels adjust to ensure that production equals consumption across all regions that is an aggregate market clearing condition is imposed In addition to the R&D impacts based on price effects (or price spillovers) the model is capable of simulating the R&D effects that may arise as a consequence of the transfer of technologies between regions the technology spillover effect The analysis estimates present values of the economic benefits of R&D for each region - broken down by producers and consumers (and government if any taxes or subsidies are specified) If R&D cost data are available net benefits (benefits-costs) net present benefits and internal rate of return are estimated for each market region for each group of regions and across all regions

**Model Specification and Parameter Estimation for ex Post Analysis**

The ex post rice model has been formulated at a geographical scale of LAC using six analysis regions

- Irrigated rice production system - anaerobic
- Rainfed rice production system - anaerobic
- Upland mechanized rice production system - aerobic
- Upland manual/traditional rice production system - aerobic
- Rice consumption
- Net trade

The final region was necessary to provide the required balance between LAC rice production and consumption It is effectively another (external) production region since LAC has been and is increasingly a net importer of rice Rice consumption was assumed to be equivalent to rice supply as defined in FAO s Supply Utilization Accounts i e it is more properly defined as *apparent consumption*

The modeling strategy adopted was to simulate the evolution of regionally aggregated price and quantity over the 31 year period (1966-95) while fitting the disaggregated production system trends to the limited historic data points available at this level To reflect several distinct phases of the evolution of rice production in LAC as well as to coincide with the availability of key calibration datasets at the production system level the period was split into three sub-periods The sub period 1966-81 covered the initial phase of strong growth in the adoption of semi-dwarf varieties as well as major expansion in the mechanized upland area predominantly in Brazil

The regional overview of the situation with regard to rice production technology at the end of this period was summarized by Muchnik de Rubenstein (1984) The second sub-period 1982-1989 witnessed a major reversal in the growth of the upland mechanized area A 1989 regional summary of the major rice production systems defines the end of that sub-period (CIAT 1992) The final sub-period 1989 1995 coincides with strong growth in production from the temperate irrigated areas but otherwise much instability in both production and prices

To evaluate the economic consequences of R&D it is necessary to decompose the observed production trends for each of the four rice production systems and for each sub-period This is done in two stages firstly into the relative contribution of the area and yield components of production change in each sub-period and secondly into the shares of those area and yield changes attributed to R&D and other (exogenous) sources respectively Shares have been estimated on the basis of the sources used in deriving Table 3 other econometric studies of rice technology impacts (e g Evenson and Flores 1978) and frequently expert opinion This heuristic process provides estimates of the R&D induced effect (that is the unit cost reduction as a percentage of the initial price) the exogenous supply growth rate (as an annual percentage rate) and the maximum adoption level (percentage of MSV production in total production)

For each sub-period it was assumed that technology was available to be adopted (R&D time lags were set to zero and the probability of R&D success was 100%) and that adoption was a continuous process (adoption lags were set equal to the sub-period length) Since R&D cost streams were not available that covered all sources of technology applied in LAC rice production only gross benefits have been calculated Technology spillover was not explicitly modelled in the ex post analysis but its effects are embodied in the historic data For example the 1988 national rice census of Colombia reports 24 6% of upland producers were using the CIAT/ICA-developed CICA 8 irrigated rice variety (FEDEARROZ 1990) None of the other 75 4% of varieties used in the upland manual systems were identified but a significant proportion of those are also thought to be MSV's developed for irrigated areas On this basis we made a nominal R&D contribution of 5% to the *yield gains* in all non MSV (traditional variety) areas Within the MSV areas the estimated contribution of R&D to *yield gains* ranged between 30% in the irrigated systems to 50% in the upland systems We did not attribute any *area changes* to R&D Table 6 shows the input dataset by production system (that is by market region ) and by sub-period

**Results**

The model tracked the evolution of production and prices very closely (Figure 3) Results indicate that the main beneficiaries of technological innovations have been consumers with annualized benefits (discounted at a real rate of 3% per year) of US$518 million (Table 7) As a group producers have received annualized benefits of US$340 million per year But it was the irrigated production systems that generated practically all of the positive R&D benefits (US$437 million per year) The other production systems were adversely affected by the rapid gains in the irrigated sector although those non irrigated producers who adopted new technologies (targeted to them or to the irrigated sector) were less affected In aggregate the non irrigated production sectors had net annual losses of US$9 million in rainfed US$70 million in mechanized upland and US$5 million in manual upland[1] It is probable that the large productivity gains in irrigated rice have played an important role in releasing pressure on the more fragile ecosystems of the forest margins and the savannas With productivity gains in irrigated rice prices have decreased making upland rice less competitive and reducing the economic incentive to open new rice lands in those upland ecosystems

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[1] In this context "losses" signify the reduced economic benefits of rice production in the non irrigated areas *relative to those that would have been generated without R&D* As a consequence of R&D relative changes in the cost of production favour expansion of irrigated production and contraction of other systems Rational producers in the less favoured (that is, relatively higher unit cost of production) systems may opt to switch out of rice and into their next most profitable production activity

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**Acronyms**

CIAT Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
FEDEARROZ Federación Nacional de Arroceros de Colombia
FAO Food and Agriculture Organization of the United Nations
FLAR Fondo Latinoamericano y del Caribe para Arroz de Riego (Irrigated Rice Fund for Latin America and the Caribbean)
ICA Instituto Colombiano Agropecuario
ICM Integrated Crop Management
INGER LAC International Network for Genetic Evaluation of Rice for Latin America and the Caribbean
IRRI International Rice Research Institute
IARCs International Agricultural Research Centers
IITA International Institute for Tropical Agriculture
LAC Latin America and the Caribbean
MSV Modern Semidwarf Varieties
IPM Integrated Pest Management
NARS National Agricultural Research Systems
RHBV Rice Hoja Blanca Virus
WARDA West African Rice Development Agency

Table 1 Rice varieties released in Latin America and the Caribbean by origin.

| Sub-region and Country | 1970-1980 Total | | | | | | 1981-1990 Total | | | | | | 1991-1995 Total | | | | | | TOTAL | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Released | Local | IRRI | CT/P | Others | %CT | Released | Local | IRRI | CT/P | Others | %CT | Released | Local | IRRI | CT/P | Others | %CT | Released | Local | IRRI | CT/P | Others | %CT |
| ***Caribbean*** | | | | | | | | | | | | | | | | | | | | | | | | |
| Belize | | | | | | | 1 | | | 1 | | 100% | | | | | | | 1 | | | 1 | | 100% |
| Dom Rep | 5 | 4 | 1 | | | 0% | 4 | 2 | 1 | 1 | | 25% | | | | | | | 9 | 6 | 2 | 1 | | 11% |
| French Guyana | | | | | | | | | | | | | 1 | | | 1 | | 100% | 1 | | | 1 | | 100% |
| Guyana | 2 | 1 | 1 | | | 0% | | | | | | | 1 | | 1 | | | 0% | 3 | 1 | 2 | | | 0% |
| Suriname | 11 | 11 | | | | 0% | 1 | 1 | | | | 0% | | | | | | | 12 | 12 | | | | 0% |
| Subtotal | 18 | 16 | 2 | | | 0% | 6 | 3 | 1 | 2 | 0 | 33% | 2 | 0 | 1 | 1 | | 50% | 26 | 19 | 4 | 3 | 0 | 12% |
| Cuba | 3 | 1 | 2 | | | 0% | 5 | 4 | | | 1 | 0% | 6 | 6 | | | | 0% | 14 | 11 | 2 | | 1 | 0% |
| Mexico | 22 | 14 | 8 | | | 0% | 11 | 5 | 2 | 2 | 2 | 18% | 3 | 2 | | 1 | | 33% | 36 | 21 | 10 | 3 | 2 | 8% |
| ***Central America*** | | | | | | | | | | | | | | | | | | | | | | | | |
| Costa Rica | 3 | | 1 | 2 | | 67% | 2 | | | 2 | | 100% | 4 | | | 4 | | 100% | 9 | | 1 | 8 | | 89% |
| El Salvador | | | | | | | 4 | | | 4 | | 100% | 1 | | | 1 | | | 5 | | | 5 | | 100% |
| Guatemala | 2 | | | 2 | | 100% | 5 | | | 4 | 1 | 80% | 1 | | | 1 | | | 8 | | | 7 | 1 | 88% |
| Honduras | | | | | | | 4 | | | 4 | | 100% | 1 | | | 1 | | 100% | 5 | | | 5 | | 100% |
| Nicaragua | 1 | | 1 | | | 0% | 1 | | | 1 | | 100% | 5 | 2 | | 3 | | 60% | 7 | 2 | 1 | 4 | | 57% |
| Panama | 2 | 2 | | | | 0% | 4 | 1 | | 3 | | 75% | 2 | | | 2 | | 100% | 8 | 3 | | 5 | | 63% |
| Subtotal | 8 | 2 | 2 | 4 | | 50% | 20 | 1 | | 18 | 1 | 90% | 14 | 2 | | 12 | | 86% | 42 | 5 | 2 | 34 | 1 | 81% |
| Tropical Brazil | 4 | 4 | | | | 0% | 30 | 13 | 2 | 11 | 4 | 37% | 18 | 10 | | 6 | 2 | 33% | 52 | 27 | 2 | 17 | 6 | 33% |
| Temperate Brazil | 11 | 3 | 4 | 4 | | 36% | 12 | 5 | 1 | 4 | 2 | 33% | 7 | 6 | | 1 | | 14% | 30 | 14 | 5 | 9 | 2 | 30% |
| ***Andean Countries*** | | | | | | | | | | | | | | | | | | | | | | | | |
| Bolivia | | | | | | | 2 | | 1 | 1 | | 50% | 4 | | | 3 | 1 | 75% | 6 | | 1 | 4 | 1 | 67% |
| Colombia | 8 | | 1 | 6 | 1 | 75% | 6 | | | 6 | | 100% | 6 | | | 5 | 1 | 83% | 20 | | 1 | 17 | 2 | 85% |
| Ecuador | 4 | | 2 | 2 | | 50% | 2 | | 1 | 1 | | 50% | 1 | | | 1 | | 100% | 7 | | 3 | 4 | | 57% |
| Perú | 4 | 1 | 3 | | | 0% | 9 | 5 | 1 | 3 | | 33% | 6 | 2 | | 4 | | 67% | 19 | 8 | 4 | 7 | | 37% |
| Venezuela | 1 | | | 1 | | 100% | 4 | | | 2 | 2 | 50% | 2 | | | 2 | | 100% | 7 | | | 5 | 2 | 71% |
| Subtotal | 17 | 1 | 6 | 9 | 1 | 53% | 23 | 5 | 3 | 13 | 2 | 57% | 19 | 2 | | 15 | 2 | 79% | 59 | 8 | 9 | 37 | 5 | 63% |
| ***Temperate South America*** | | | | | | | | | | | | | | | | | | | | | | | | |
| Argentina | | | | | | | 2 | 2 | | | | 0% | | | | | | | 2 | 2 | | | | 0% |
| Chile | 3 | 3 | | | | 0% | | | | | | | 1 | | | 1 | | 100% | 4 | 3 | | 1 | | 25% |
| Paraguay | 1 | | | 1 | | 100% | 3 | | | 1 | 2 | 33% | | | | | | | 4 | | | 2 | 2 | 50% |
| Uruguay | | | | | | | 4 | 4 | | | | 0% | 2 | 2 | | | | 0% | 6 | 6 | | | | 0% |
| Subtotal | 4 | 3 | 0 | 1 | 0 | 25% | 9 | 6 | | 1 | 2 | 11% | 3 | 2 | | 1 | | 33% | 16 | 11 | | 3 | 2 | 19% |
| TOTAL | 87 | 44 | 24 | 18 | 1 | 21% | 116 | 42 | 9 | 51 | 14 | 44% | 72 | 30 | 1 | 37 | 4 | 51% | 275 | 116 | 34 | 106 | 19 | 39% |

Varieties resulting from crosses made at CIAT

**Table 2 Percent of modern semidwarf varieties (MSV) in LAC rice production and area**

| | Percent in Production | | | | Percent in Area | | | |
|---|---|---|---|---|---|---|---|---|
| | 1966 | 1981 | 1989 | 1995 | 1966 | 1981 | 1989 | 1995 |
| Irrigated | 0 0 | 79 3 | 88 1 | 98 3 | 0 0 | 76 4 | 84 7 | 97 6 |
| Rainfed | 0 0 | 53 3 | 69 3 | 76 7 | 0 0 | 50 3 | 61 8 | 71 7 |
| *Subtotal Wetlands* | 0 0 | 73 5 | 84 2 | 92 8 | 0 0 | 69 7 | 79 1 | 89 5 |
| Mechanized Upland | 0 0 | 6 9 | 13 3 | 24 7 | 0 0 | 5 8 | 10 3 | 18 0 |
| Traditional Upland | 0 0 | 30 0 | 30 0 | 30 0 | 0 0 | 26 0 | 28 2 | 31 2 |
| **Total LAC** | 0 0 | 49 9 | 67 5 | 80 3 | 0 0 | 28 2 | 43 6 | 58 8 |

**Table 3 Partıcıpatıon of modern semıdwarf varietıes (MSV) in production, area and ımplıcıt yıeld, LAC, 1966 95**

| | Productıon (1 000 MT) | | | | Area (1 000 Has) | | | | Yıeld (MT/Ha) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1966 | 1981 | 1989 | 1995 | 1966 | 1981 | 1989 | 1995 | 1966 | 1981 | 1989 | 1995 |
| **Anaerobic** | 6 354 | 9 888 | 13 863 | 16 792 | 1 927 | 2 630 | 3 291 | 3 662 | 3 3 | 3 8 | 4 2 | 4 6 |
| MSV | 0 | 7 272 | 11 676 | 15 587 | 0 | 1 832 | 2 602 | 3 278 | | | | |
| Irrıgated | 4 328 | 7 710 | 11 022 | 12 518 | 1 252 | 1 952 | 2 475 | 2 519 | 3 5 | 3 9 | 4 5 | 5 0 |
| MSV | 0 | 6 110 | 9 708 | 12 310 | 0 | 1 491 | 2 097 | 2 459 | | | | |
| Raınfed | 2 026 | 2 178 | 2 840 | 4 273 | 674 | 678 | 816 | 1 144 | 3 0 | 3 2 | 3 5 | 3 7 |
| MSV | 0 | 1 162 | 1 968 | 3 277 | 0 | 341 | 505 | 820 | | | | |
| **Aerobic (Upland)** | 3 799 | 5 858 | 4 561 | 3 879 | 3 912 | 5 633 | 4 050 | 3 063 | 1 0 | 1 0 | 1 1 | 1 3 |
| MSV | 0 | 587 | 752 | 1 009 | 0 | 499 | 580 | 675 | | | | |
| Mechanızed | 2 809 | 5 070 | 3 684 | 2 920 | 2 812 | 4 786 | 3 146 | 2 123 | 1 0 | 1 1 | 1 2 | 1 4 |
| MSV | 0 | 350 | 489 | 722 | 0 | 279 | 325 | 381 | | | | |
| Manual | 990 | 788 | 877 | 959 | 1 100 | 847 | 904 | 940 | 0 9 | 0 9 | 1 0 | 1 0 |
| MSV | 0 | 236 | 263 | 288 | 0 | 220 | 255 | 293 | | | | |
| **LAC total** | 10 153 | 15 745 | 18 424 | 20 670 | 5 838 | 8 262 | 7 341 | 6 725 | 1 7 | 1 9 | 2 5 | 3 1 |
| MSV | 0 | 7 858 | 12 428 | 16 596 | 0 | 2 331 | 3 181 | 3 953 | | | | |

Source Estımated by the authors on the basis of Muchnık de Rubensteın 1984 Dalrymple 1986 Valente Moraes 1977 CIAT 1979 1992 1995 CIAT IRTP 1983 Posada 1981 Dalrymple 1986 Scobıe and Posada 1977 Avıla 1981 IRRI 1995

Table 4 International Prices of White Rice Bangkok 5% Broken 1966-95

| Year | US Wholesale Price Index 1995=100 | Nominal Price of White Rice Bangkok 5% Broken | Nominal Price of Paddy Rice (White *0 5) | Real Price of Paddy Rice US$ of 1995 |
|---|---|---|---|---|
| 1966 | 26 7 | 165 7 | 82 8 | 309 7 |
| 1967 | 26 7 | 221 0 | 110 5 | 413 1 |
| 1968 | 27 5 | 204 7 | 102 3 | 372 2 |
| 1969 | 28 5 | 185 1 | 92 5 | 324 5 |
| 1970 | 29 5 | 143 0 | 71 5 | 242 0 |
| 1971 | 30 6 | 130 3 | 65 2 | 213 2 |
| 1972 | 31 9 | 149 9 | 75 0 | 235 2 |
| 1973 | 36 1 | 296 6 | 148 3 | 411 2 |
| 1974 | 42 9 | 541 5 | 270 8 | 631 6 |
| 1975 | 46 9 | 363 2 | 181 6 | 387 4 |
| 1976 | 49 0 | 254 1 | 127 0 | 259 2 |
| 1977 | 52 0 | 272 4 | 136 2 | 261 9 |
| 1978 | 56 1 | 368 5 | 184 3 | 328 4 |
| 1979 | 63 1 | 334 3 | 167 2 | 264 9 |
| 1980 | 72 0 | 433 7 | 216 8 | 301 0 |
| 1981 | 78 6 | 482 8 | 241 4 | 307 3 |
| 1982 | 80 1 | 293 4 | 146 7 | 183 0 |
| 1983 | 81 2 | 276 8 | 138 4 | 170 5 |
| 1984 | 83 1 | 252 3 | 126 1 | 151 7 |
| 1985 | 82 7 | 217 4 | 108 7 | 131 5 |
| 1986 | 80 3 | 210 2 | 105 1 | 130 8 |
| 1987 | 82 4 | 229 8 | 114 9 | 139 4 |
| 1988 | 85 7 | 301 5 | 150 8 | 175 8 |
| 1989 | 90 0 | 320 3 | 160 2 | 177 9 |
| 1990 | 93 2 | 287 2 | 143 6 | 154 1 |
| 1991 | 93 4 | 312 6 | 156 3 | 167 4 |
| 1992 | 93 9 | 287 4 | 143 7 | 153 0 |
| 1993 | 95 3 | 267 9 | 134 0 | 140 5 |
| 1994 | 96 6 | 294 0 | 147 0 | 152 3 |
| 1995 | 100 0 | 353 0 | 176 5 | 176 5 |

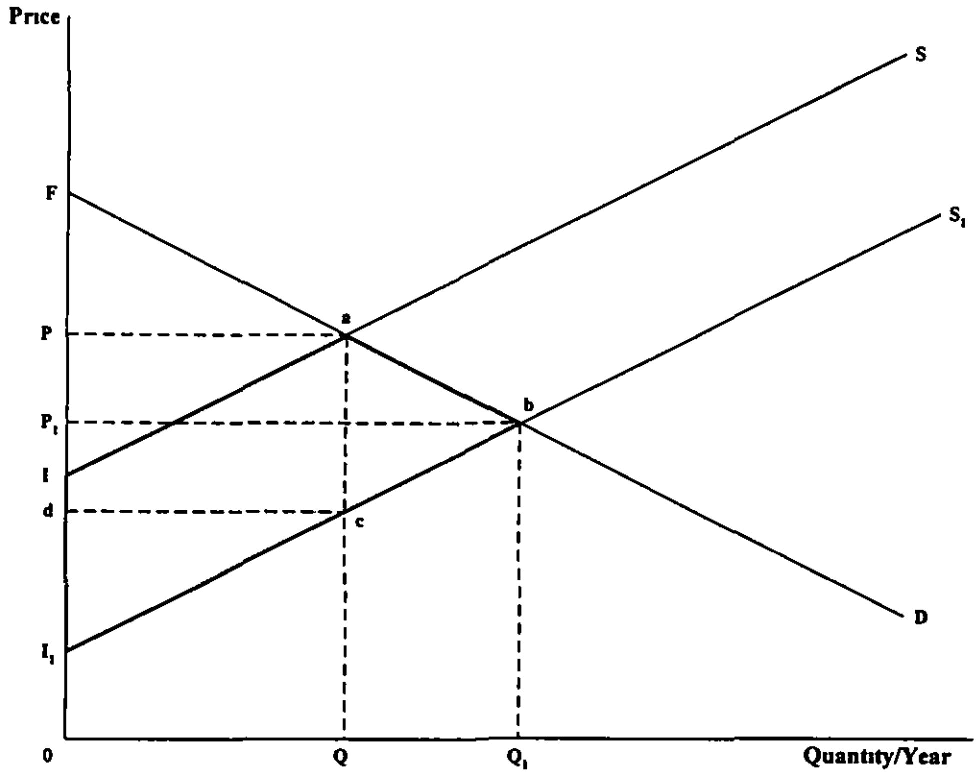


Figure 1 Representing gross annual research benefits in an economic surplus framework

**Figure 2 Ex post Representation of Gross Annual Research Benefits in an Ecomomic Surplus Framework**

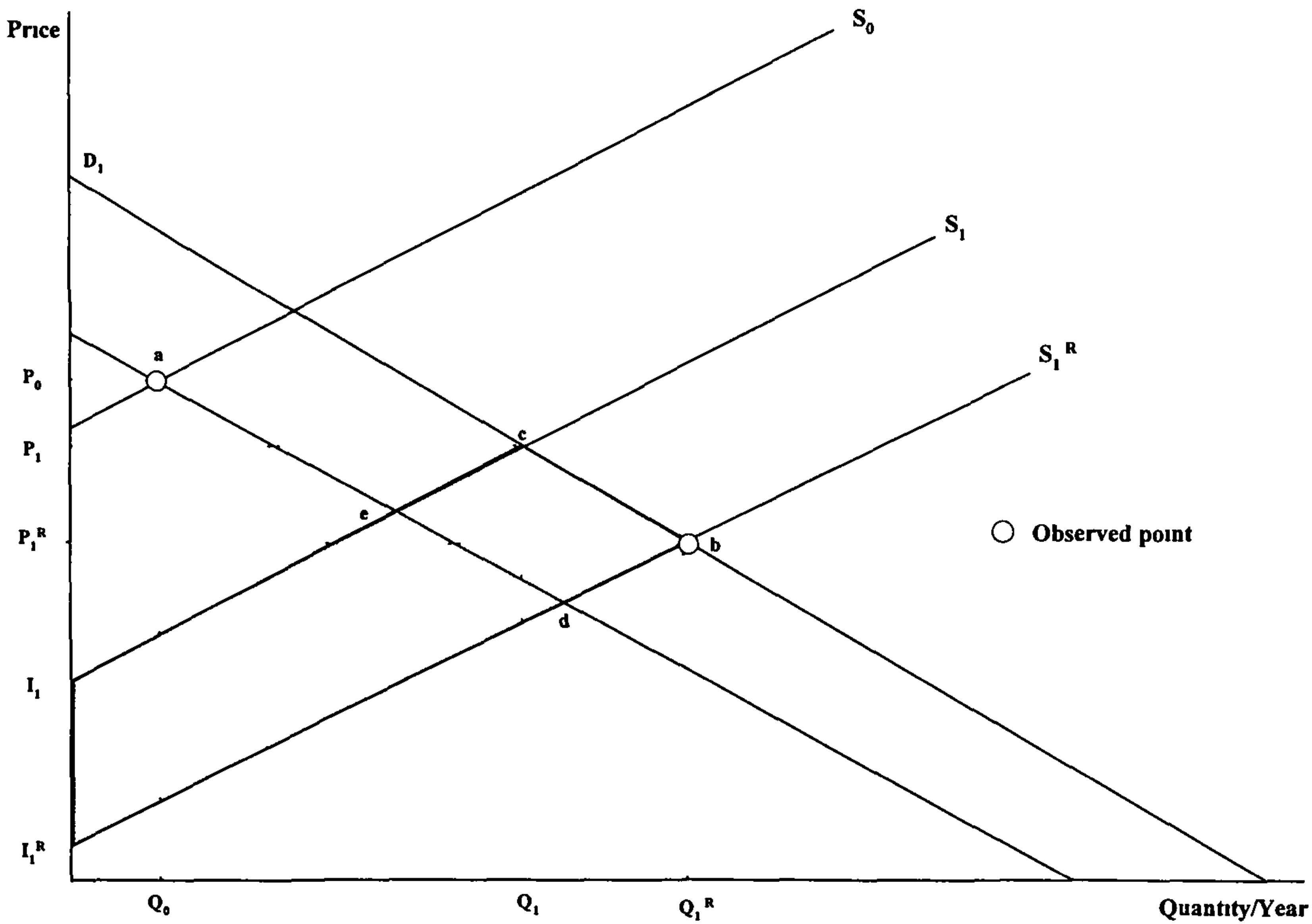

**Table 5 Properties of market regions and related model parameters**

| Major property | Parameters in the *Dream* model |
|---|---|
| Capacity to generate technology | R&D research investments<br>R&D lag times<br>Type and expected range of unit cost reductions |
| Capacity to produce | Adoption lag time<br>Maximum adoption level<br>Disadoption lag<br><br>Initial production quantity<br>Initial producer (farmgate) price<br>Price elasticity of supply<br>Exogenous (non R&D induced) growth rate in supply<br>Producer taxes/subsidies |
| Capacity to consume | Initial consumption<br>Price elasticity of demand<br>Exogenous (non R&D induced) growth rate in demand<br>Consumer taxes/subsidies |

**Table 6 Input parameters for ex post analysis**

| Period | Region | R&D Time Lag | R&D Probability of Success | R&D Shift (Kmax) | Production Adoption Lag | Production Adoption Level | Production Initial Quantity | Production Initial Price | Production Elasticity of supply | Production Exog Growth | Consumption Initial Quantity | Consumption Elasticity of demand | Consumption Exog Growth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (yrs) | (%) | ($/T) | (yrs) | (%) | (1000T) | ($/T) | | (%/yr) | (1000T) | | (%/yr) |
| | Irrigated | 0 | 100 | 59 86 | 15 | 78 5 | 4218 | 288 | 0 7 | 4 7 | | | |
| | Rainfed | 0 | 100 | 22 72 | 15 | 41 6 | 1925 | 288 | 1 | 4 | | | |
| 1966 81 | Upland mechanised | 0 | 100 | 12 87 | 15 | 8 | 3252 | 288 | 1 2 | 4 8 | | | |
| | Upland Manual | 0 | 100 | 8 65 | 15 | 8 | 760 | 288 | 1 2 | 2 7 | | | |
| | LAC Consumption | | | | | | | | | | 10214 | 0 3 | 3 2 |
| | LAC Net Trade | | | | | | 61 | 288 | 0 | 13 | | | |
| | Irrigated | 0 | 100 | 29 76 | 8 | 87 | 7676 | 208 | 0 7 | 5 3 | | | |
| | Rainfed | 0 | 100 | 4 53 | 8 | 54 | 2847 | 208 | 1 | 1 | | | |
| 1981 89 | Upland Mechanised | 0 | 100 | 1 27 | 8 | 11 | 5138 | 208 | 1 2 | 1 7 | | | |
| | Upland Manual | 0 | 100 | 0 | 8 | 11 | 854 | 208 | 1 2 | 3 | | | |
| | LAC Consumption | | | | | | | | | | 16854 | 0 25 | 1 3 |
| | LAC Net Trade | | | | | | 339 | 208 | 0 | 8 3 | | | |
| | Irrigated | 0 | 100 | 23 39 | 6 | 95 | 1123 | 180 | 0 7 | 1 4 | | | |
| | Rainfed | 0 | 100 | 4 72 | 6 | 84 | 2739 | 180 | 1 | 9 2 | | | |
| 1989 95 | Upland Mechanised | 0 | 100 | 4 43 | 6 | 19 | 3770 | 180 | 1 2 | 4 7 | | | |
| | Upland Manual | 0 | 100 | 8 07 | 6 | 19 | 904 | 180 | 1 2 | 2 | | | |
| | LAC Consumption | | | | | | | | | | 19031 | 0 2 | 2 4 |
| | LAC Net Trade | | | | | | 595 | 180 | 0 | 8 6 | | | |

NOTES
1 In the ex post setting we consider a timestream of undifferentiated technologies was adopted Since the starting point is adoption R&D lag time is set to zero and since the technology was available probability of success was set to 100%
2 Maximum unit cost (Kmax) is the product of the potentital unit cost reduction (%) probability of research success (%) the maximum adoption level (%) and the producer price
3 Adoption lags are set equal to the simulation period i e adoption is continuous in the ex post context (up to the maximum adoption level specified for each period)
4 Exogenous demand growth rates were calculated by the authors on the basis of growth in population real wages and income elasticities
5 Initial estimates of the exogenous supply growth rates were calculated as described in the text but were subsequently adjusted to fit the equilibrium quantities and price to the available data points

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**Table 6 Input parameters for ex post analysis**

| Period | Region | R&D Time Lag | R&D Probability of Success | R&D Shift (Kmax) | Production Adoption Lag | Production Adoption Level | Production Initial Quantity | Production Initial Price | Production Elasticity of supply | Production Exog Growth | Consumption Initial Quantity | Consumption Elasticity of demand | Consumption Exog Growth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (yrs) | (%) | ($/T) | (yrs) | (%) | (1000T) | ($/T) | | (%/yr) | (1000T) | | (%/yr) |
| 1966 81 | Irrigated | 0 | 100 | 59 86 | 15 | 78 5 | 4218 | 288 | 0 7 | 4 7 | | | |
| | Rainfed | 0 | 100 | 22 72 | 15 | 41 6 | 1925 | 288 | 1 | 4 | | | |
| | Upland mechanised | 0 | 100 | 12 87 | 15 | 8 | 3252 | 288 | 1 2 | 4 8 | | | |
| | Upland Manual | 0 | 100 | 8 65 | 15 | 8 | 760 | 288 | 1 2 | 2 7 | | | |
| | LAC Consumption | | | | | | | | | | 10214 | 0 3 | 3 2 |
| | LAC Net Trade | | | | | | 61 | 288 | 0 | 13 | | | |
| 1981 89 | Irrigated | 0 | 100 | 29 76 | 8 | 87 | 7676 | 208 | 0 7 | 5 3 | | | |
| | Rainfed | 0 | 100 | 4 53 | 8 | 54 | 2847 | 208 | 1 | 1 | | | |
| | Upland Mechanised | 0 | 100 | 1 27 | 8 | 11 | 5138 | 208 | 1 2 | 1 7 | | | |
| | Upland Manual | 0 | 100 | 0 | 8 | 11 | 854 | 208 | 1 2 | 3 | | | |
| | LAC Consumption | | | | | | | | | | 16854 | 0 25 | 1 3 |
| | LAC Net Trade | | | | | | 339 | 208 | 0 | 8 3 | | | |
| 1989 95 | Irrigated | 0 | 100 | 23 39 | 6 | 95 | 1123 | 180 | 0 7 | 1 4 | | | |
| | Rainfed | 0 | 100 | 4 72 | 6 | 84 | 2739 | 180 | 1 | 9 2 | | | |
| | Upland Mechanised | 0 | 100 | 4 43 | 6 | 19 | 3770 | 180 | 1 2 | 4 7 | | | |
| | Upland Manual | 0 | 100 | 8 07 | 6 | 19 | 904 | 180 | 1 2 | 2 | | | |
| | LAC Consumption | | | | | | | | | | 19031 | 0 2 | 2 4 |
| | LAC Net Trade | | | | | | 595 | 180 | 0 | 8 6 | | | |

NOTES

1 In the ex post setting we consider a timestream of undifferentiated technologies was adopted Since the starting point is adoption R&D lag time is set to zero and since the technology was available probability of success was set to 100%

2 Maximum unit cost (Kmax) is the product of the potentital unit cost reduction (%) probability of research success (%) the maximum adoption level (%) and the producer price

3 Adoption lags are set equal to the simulation period i e adoption is continuous in the ex post context (up to the maximum adoption level specified for each period)

4 Exogenous demand growth rates were calculated by the authors on the basis of growth in population real wages and income elasticities

5 Initial estimates of the exogenous supply growth rates were calculated as described in the text but were subsequently adjusted to fit the equilibrium quantities and price to the available data points

Table 7 Gross benefits in LAC of global rice R&D (period of impact 1966 96) All values in 1000 of 1995 US$

| Year | Gross Annual Research Benefits | | | | | | | Value if benefits invested at 3% | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Producer Benefits | | | | | Consumer Benefits | Total Benefits | | | |
| | Irrigated | Rainfed Lowland | Upland Mechanised | Upland Manual | Total Producers | | | Producers | Consumers | Total |
| 1967 | 10 723 | 113 | 1 941 | 667 | 8 229 | 14 887 | 23 115 | 18 826 | 34 059 | 52 886 |
| 1968 | 22 368 | 233 | 4 016 | 1 351 | 17 234 | 30 844 | 48 078 | 38 282 | 68 513 | 106 794 |
| 1969 | 31 983 | 360 | 6 231 | 2 052 | 27 061 | 47 928 | 74 988 | 58 359 | 103 360 | 161 719 |
| 1970 | 48 624 | 494 | 8 594 | 2 769 | 37 755 | 66 197 | 103 952 | 79 051 | 138 602 | 217 653 |
| 1971 | 63 346 | 635 | 11 111 | 3 503 | 49 367 | 86 715 | 135 082 | 100 353 | 174 240 | 274 593 |
| 1972 | 79 208 | 784 | 13 792 | 4 252 | 61 948 | 106 545 | 168 493 | 122 260 | 210 276 | 332 535 |
| 1973 | 96 271 | 941 | 16 643 | 5 015 | 75 553 | 128 757 | 204 310 | 144 768 | 246 712 | 391 480 |
| 1974 | 114 600 | 1 106 | 19 674 | 5 793 | 90 240 | 152 422 | 242 662 | 167 873 | 283 550 | 451 423 |
| 1975 | 134 263 | 1 280 | 22 891 | 6 584 | 106 069 | 177 616 | 283 684 | 191 672 | 320 794 | 512 366 |
| 1976 | 155 331 | 1 462 | 26 303 | 7 357 | 123 103 | 204 418 | 327 520 | 215 861 | 358 447 | 574 309 |
| 1977 | 177 877 | 1 653 | 29 920 | 8 200 | 141 409 | 232 911 | 374 320 | 240 740 | 396 515 | 637 254 |
| 1978 | 201 978 | 1 853 | 33 750 | 9 024 | 161 058 | 263 182 | 424 240 | 266 204 | 435 000 | 701 204 |
| 1979 | 227 716 | 2 062 | 37 802 | 9 855 | 182 122 | 295 325 | 477 447 | 292 252 | 473 910 | 766 162 |
| 1980 | 255 172 | 2 281 | 42 084 | 10 692 | 204 678 | 329 436 | 534 114 | 318 882 | 513 250 | 832 132 |
| 1981 | 284 436 | 2 510 | 46 606 | 11 532 | 228 808 | 365 617 | 594 424 | 346 092 | 553 028 | 899 120 |
| 1982 | 304 241 | 848 | 51 684 | 12 512 | 240 894 | 385 028 | 625 922 | 353 760 | 555 426 | 919 187 |
| 1983 | 326 065 | 813 | 56 439 | 13 522 | 255 292 | 405 062 | 660 354 | 363 985 | 577 522 | 941 507 |
| 1984 | 350 011 | 2 469 | 60 858 | 14 559 | 272 125 | 425 747 | 697 872 | 376 684 | 589 334 | 966 018 |
| 1985 | 376 186 | 4 114 | 64 929 | 15 631 | 291 513 | 447 112 | 738 625 | 391 769 | 600 881 | 992 650 |
| 1986 | 404 704 | 5 741 | 68 637 | 16 707 | 313 620 | 469 186 | 762 806 | 409 203 | 612 182 | 1021 384 |
| 1987 | 435 685 | 7 344 | 71 968 | 17 812 | 338 561 | 492 002 | 830 563 | 428 879 | 623 253 | 1052 132 |
| 1988 | 469 252 | 8 915 | 74 906 | 18 933 | 366 497 | 515 591 | 882 088 | 450 745 | 634 112 | 1084 857 |
| 1989 | 505 536 | 10 449 | 77 436 | 20 066 | 397 585 | 539 990 | 937 575 | 474 738 | 644 776 | 1119 514 |
| 1990 | 528 613 | 13 476 | 81 783 | 20 563 | 412 792 | 576 122 | 988 913 | 478 539 | 667 883 | 1146 421 |
| 1991 | 552 792 | 17 090 | 85 765 | 21 087 | 428 850 | 613 952 | 1042 802 | 482 675 | 691 008 | 1173 683 |
| 1992 | 578 022 | 21 360 | 89 384 | 21 638 | 445 641 | 653 571 | 1099 212 | 486 964 | 714 175 | 1201 138 |
| 1993 | 604 242 | 26 363 | 92 636 | 22 212 | 463 031 | 695 076 | 1158 107 | 491 230 | 737 406 | 1228 636 |
| 1994 | 631 387 | 32 185 | 95 518 | 22 808 | 480 876 | 738 569 | 1219 445 | 495 302 | 760 726 | 1256 028 |
| 1995 | 659 382 | 38 921 | 98 023 | 23 423 | 499 015 | 784 158 | 1283 172 | 499 015 | 784 158 | 1283 172 |
| **Annualized flow at 3%** | **436 651** | **8 551** | **70 396** | **5 454** | **339 551** | **518 312** | **857 863** | | | |

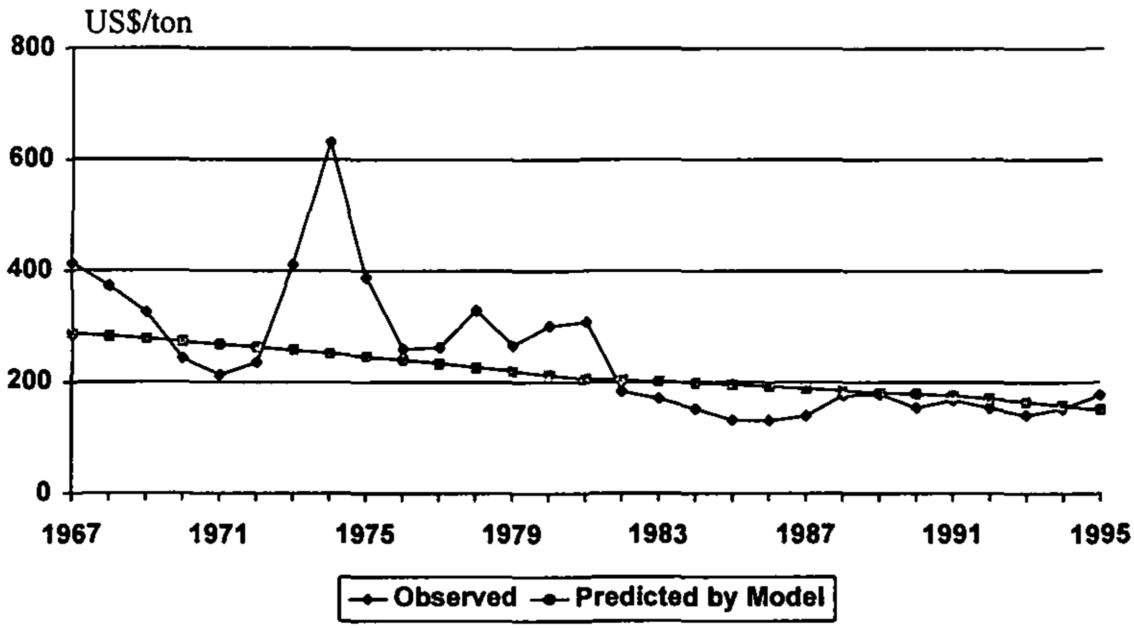


*Figure 3   Paddy Rice Prices (Bangkok 100% *0 5)*

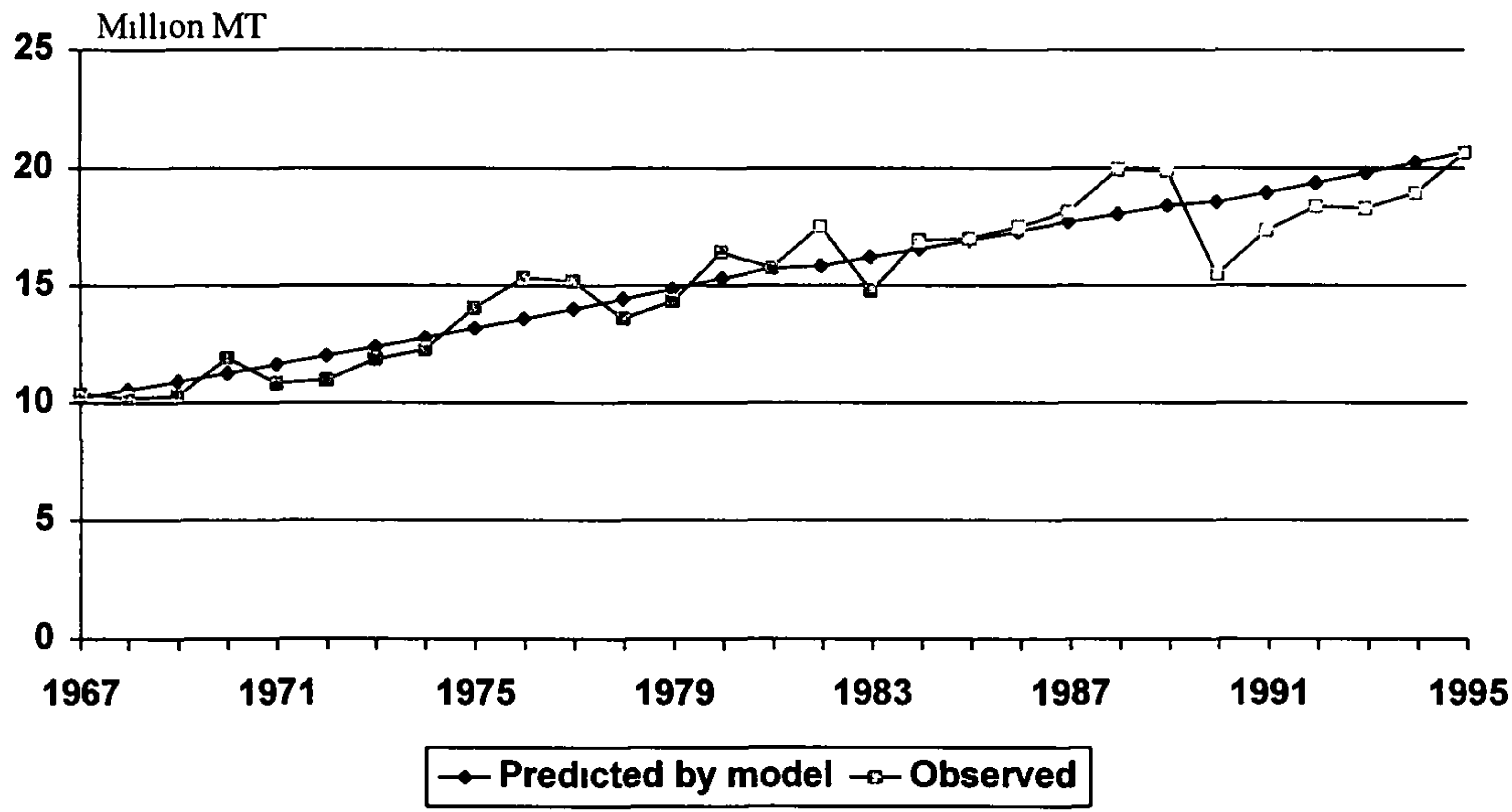


*Figure 3 Total Paddy Rice Production in LAC*