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The Impact of Technical Change on Income Distribution: The Case of Rice in Colombia

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A national rice research program adapted and developed modern rice varieties for irrigated culture. Their rapid and widespread adoption led to substantial increases in production, and a concomitant fall in the price of rice. This paper examines the incidence of both the gross benefits and the costs of the research program, by income level. As rice is a principal foodstuff, the net benefits, both absolute and relative, accrued disproportionately to the poorest households.

Key words: Colombia, income distribution, research, rice, technical change.

The contribution of technical change to agricultural productivity in developing countries has been widely recognized and increasingly documented (Arndt, Dalrymple, Ruttan). The generation of that technical change through agricultural research is now viewed as an economic activity to which scarce resources can be devoted and measurable output defined (Schultz).

In the appraisal of potential or past research strategies, two central economic issues arise: efficiency and equity. While earlier studies were concerned primarily with the efficiency goal, increasing attention has been given to the distribution of social benefits stemming from programs of agricultural research. Akino and Hayami, and Ramalho de Castro and Schuh examine the distribution of the gross social benefits between consumers and producers, while others have considered the impact on the functional distribution of income (e.g., Ayer and Schuh, Schmitz and Seckler, Wallace and Hoover).

In this paper we analyze the impact of technological change in the Colombian rice industry, giving particular attention to the consequences for the household income distribution. "It appears that relatively little theoretical and empirical work has been done on the welfare or income distributional effects of technical change. This is unfortunate, for a considerable amount of research funds is spent each year by both private and public institutions to develop new technologies for agriculture" (Bieri, de Janvry, Schmitz, p. 801). After sketching the background of the research program, we present some estimates of the social benefits: the rate of return (efficiency) and the impact on household income distribution (equity). Both costs and benefits of the research program are used in deriving the distributional consequences.

Background

In 1957 a national rice research program was formed within the Ministry of Agriculture with the cooperation of the Rockefeller Foundation (Rosero). At that time, the tall U.S. variety, Bluebonnet-50, was extensively grown; but in 1957 it was attacked by a virus disease, causing extensive losses. Imports of rice rose substantially, and the real domestic retail price was higher in 1957 than in any year since 1950 (and in fact, up to 1974). These events stimulated the formation and funding of a national rice research program whose primary objec-

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tive was the selection of varieties resistant to the virus. By this mechanism it was hoped that domestic output could be increased, partly eliminating the need for rice imports and lowering domestic prices. This strongly consumer-oriented policy contrasts with the vacillation of public policy between a consumer and a producer focus which had been characteristic of Colombian rice policy since the thirties (Leurquin).

This research effort did produce new varieties, but their impact was limited (Hertford et al.). In 1967, the newly formed rice program of the Centro Internacional de Agricultura Tropical (CIAT) joined in a collaborative effort with the Colombian program, and dwarf lines from the International Rice Research Institute in the Philippines were introduced. This was followed by the local development and release of four disease-resistant dwarf rices. The rate of adoption of these modern varieties has been spectacular. In 1966, 90% of the irrigated sector was sown to the traditional variety (Bluebonnet-50); by 1974, virtually all the irrigated rice production came from dwarf varieties.

The research program, especially since 1967, has been oriented to the irrigated sector. The modern varieties have been best suited to areas with good water control and high levels of other inputs. Thus, while widely adopted throughout the irrigated sector, they had little impact in the upland or rainfed sector. Given the possibility of rapid increases in national output through the introduction of new varieties suited to irrigated culture, this was undoubtedly a rational choice. The rate of technological progress which could have been achieved with the same research resources surely would have been less had attention been directed to the upland sector. A further explanation of the particular ecological orientation adopted lay in the close collaboration between FEDEARROZ, the National Rice Growers' Federation (founded and supported principally by the large rice growers) and the research program.

As a consequence of the emphasis on the irrigated sector together with the rapid adoption of the modern varieties, yields and production in that sector rose dramatically. In contrast, the relatively disadvantaged upland sector which experienced little or no technical change declined in importance from 50% of the national output in 1966 to 10% in 1974.

The Model

The approach taken closely follows the formulation of Ayer and Schuh.[1] A formal statement of the supply and demand framework employed is given in the appendix. A more detailed statement of the model and the estimation of the parameters is given in Scobie and Posada. The model estimates the total gross social benefits and their division between Colombian rice producers and consumers, but extends existing formulations (following Bell) by distinguishing between upland and irrigated producers. This distinction was made as a consequence of the differential impact of the research program on the two sectors. It is suggested that the proposed formulation would have general applicability in analyzing the differential impact of a new technology whose relevance is restricted for whatever reason to a subset of the producing firms.

Results

Gross Benefits

The changes in consumer and producer surpluses resulting from the introduction of modern varieties were estimated for each year from 1964 to 1974 and are summarized in table 1. Consumer benefits are positive because, in the absence of modern varieties, the volume of rice entering the domestic market would have been much lower, with a concomitant higher internal price. However, for the same reason, both upland and irrigated producers have foregone rents to factors of production whose mobility is limited in the short run. Changes in producer surplus follow as a consequence of some inelasticity in the supply of rice, imparted by rising short-run marginal cost curves. Such changes would be transitory if, in the long run, the supply elasticities of all factors to rice production approached infinity. Despite the overall reduction in short-run producer surpluses, some gains undoubtedly accrued to "early adopters" in the irrigated sector.

[1] Hertford and Schmitz provide a review of the procedures involved in estimating changes in consumer and producer surplus. A valuable survey with discussion of some of the contentious issues is given by Currie, Murphy, and Schmitz, while some apparent inconsistencies between alternative formulations are noted by Scobie.

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Table 1. Gross Benefits of New Rice Varieties in Colombia to Consumers and Producers

Gross Benefits Accruing to:	1964–69	1970–74
	------ $(Col.)m. ------	
Consumers	1,404	17,542
Producers		
Irrigated	−368	−6,468
Upland	−517	−3,878
Total	519	7,196

Note: Each entry is the sum of the annual deflated values (1964 = 100).

Had Colombia not mounted a successful research program, then upward pressure on domestic prices may well have been contained by allowing rice imports. Even in the absence of such approval, illegal imports from neighboring Venezuela and Ecuador may have had a price-depressing effect. Higher imports of rice would have reduced the amount of foreign exchange available for other imports and put upward pressure on the exchange rate. However, estimating the distributional consequences of this scenario would lead us far beyond the more modest scope of this investigation.

Net Benefits

The distribution of gross benefits between producer and consumer groups is a relatively blunt tool for analyzing the distributional impact of technological change. We attempt two extensions: first we will consider the incidence of the research costs, and so derive net benefits to producers and consumers; subsequently we examine the distribution of the gross benefits and research costs by income level within groups.

The costs of the research program were borne by three entities: (*a*) the national rice program of the Instituto Colombiano Agropecuario (ICA); (*b*) the contribution of the growers through FEDEARROZ under Law 101 of 1963, which created the *Cuota de Fomento Arrocera*. This law requires the collection of $(Col.) 0.01/kg. from all growers, and authorizes FEDEARROZ to administer the funds for support of research, regional testing, publishing technical bulletins, presenting training courses to field agronomists, and financing the Technical Division of FEDEARROZ; and (*c*) international cooperation, originally through the Rockefeller Foundation and subsequently through the rice program of the Centro Internacional de Agricultura Tropical (CIAT).

No attempt is made to include any costs incurred by the International Rice Research Institute (IRRI) in the development of IR-8 and IR-22 which occupied up to almost 60% of the area sown in Colombia. Hence, for these varieties we will overstate the net global benefits by allowing their contribution to production without discounting their full costs. However, if the measurement of net benefits is viewed from Colombia's standpoint, then it is valid to include only those costs incurred by Colombia in testing, multiplying, and releasing the IRRI materials.

The distribution of gross social benefits, research costs, and net benefits for producers and consumers is shown in table 2. The gross social benefits were totalled for the period

Table 2. Size and Distribution of Benefits and Costs of Modern Rice Varieties in Colombia: 1957–1974

Item	Producers			Consumers	Total Colombia	International Cooperation[a]
	Upland	Irrigated	Total			
	----------	----------	----------	$(Col.)m.	----------	----------
Gross benefits	−3,542	−5,293	−8,835	14,939	6,104	—
Costs of research						
FEDEARROZ	8	30	38	—	38	—
ICA[b]	1	2	2	22	25	
Total	9	32	40	22	63	19
Net benefits	−3,551	−5,325	−8,875	14,917	6,042	—

Note: All data expressed in 1970 pesos; minor discrepancies are due to rounding.
[a] From Ardila (1973), and personal communication from the Centro Internacional de Agricultura Tropical (CIAT).
[b] From Ardila (1973), and personal communication from the Instituto Colombiano Agropecuario (ICA).

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1964–74 and expressed in $(Col.)m. 1970, compounding forward the years 1964–69 and discounting 1971–74, both using an estimate of 10% for the social opportunity cost of capital in Colombia (Harberger, p. 155).

In a similar manner the costs of the research from the three sources were summed and are shown in table 2. The costs of the ICA program were assumed to come from general tax revenue and were divided between consumers and producers on the basis of urban and rural proportions of total tax revenues in 1970 (Jallade). The producer contribution was further broken down between upland and irrigated producers on the basis of the production coming from each sector in 1970. The contributions from FEDEARROZ were distributed between the upland and irrigated sectors assuming a 45% collection rate (FEDEARROZ, 1975), except that no contributions were assumed for upland producers with less than 10 hectares. Expressed in 1970 pesos, $(Col.) 82 m. were devoted to rice research between 1957 and 1974.

In order to assess the sensitivity of the net benefits to varying assumptions about the supply-demand elasticities, the results in table 3 were calculated. The demand elasticity was varied from −0.3 (a typical lower bound found in a review of numerous studies in developing countries) to −0.449 (based on Pinstrup-Andersen, de Londoño, Hoover, p. 137) to −0.754 (Cruz de Schlesinger and Ruiz). The supply elasticity of 0.235 is from Gutiérrez and Hertford, with an arbitrarily chosen upper value of 1.5.

The internal rate of return on the investment is consistently high and relatively insensitive to varying elasticities. These high returns are not uncommon in agricultural research. Ayer and Schuh (p. 581) report an internal rate of return of 89% for cotton in São Paulo, Brazil; Akino and Hayami (p. 8) report values up to 75% for rice in Japan; Peterson (p. 669) reports 20% to 30% for poultry in the United States; Barletta reports 75% for wheat in Mexico; Griliches reports 35% for corn in the United States; Ardila reports 58% to 82% for rice in Colombia up until 1971; and Montes reports 76% to 96% for soybeans in Colombia. One should resist the conclusion that all agricultural research would show such payoffs—the literature is not replete with evaluations of failures.

Table 3. Net Benefits in 1974 and Internal Rates of Return for Differing Elasticities of Supply and Demand

Elasticity of Supply (ϵ)	Elasticity of Demand (η) −0.300	−0.449	−0.754
	--------	$(Col.)m.	--------
0.235	9,052 89%	3,981 94%	2,174 89%
1.500	8,627 96%	3,556 87%	1,749 79%

Note: In each cell, the upper figure is the net benefits to Colombia of the rice research program in 1974, and the lower figure is the internal rate of return based on the period 1957–74, with the last year's costs and returns assumed to continue until 1986. The combination of $\eta = -0.449$ and $\epsilon = 0.235$ was used in calculating the results presented in tables 1 and 2.

While the net benefits in 1974 vary little with the supply elasticity they fall markedly with higher absolute demand elasticities (table 3). However, our concern here is more with the relative distribution of the net benefits within groups, rather than establishing their absolute magnitude.

Distribution of Net Benefits by Income Level

To evaluate the distributional impacts of the technological change, the gross benefits, the costs of the research program, and the consequent net benefits were distributed across income groups for consumers and upland and irrigated producers. In each case the annual average impact for 1970 was estimated by summing the gross benefits and costs (expressed in 1970 pesos), and dividing by the appropriate number of years.

Gross benefits to consumers were assumed to be directly proportional to the quantity of rice consumed, while their contributions to the research costs were distributed in proportion to tax receipts from each income stratum. The resulting net benefits to consumers by income level are shown in table 4.

Rice is now virtually the most important foodstuff in Colombia; between 1969 and 1974 total domestic consumption doubled (U.S. Department of Agriculture, p. 11), and rice is the major source of calories and the second major source of protein (after beef) in the Colombian diet (Departamento Nacional de Planeación). As rice is disproportionately consumed by the lower income groups who make limited tax contributions, the net benefits of the research program were strongly biased toward them in both absolute and relative terms. While the lower 50% of Colombian households received about 15% of household

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Table 4. Distribution of Net Benefits, Households, and Household Income

1970 Income Level	Annual Average Net Benefits	Net Benefits as a Percentage of Income[a]	Cumulative Percentage of: Net Benefits	Households[b]	Household[b] Income
$(Col.)000	$(Col.)	(%)			
0–6	385	12.8	18	19	2
6–12	642	7.1	50	39	8
12–18	530	3.5	67	52	15
18–24	333	1.6	77	64	23
24–30	348	1.3	83	71	29
30–36	353	1.2	88	76	35
36–48	342	0.8	93	82	43
48–60	200	0.4	95	86	51
60–72	128	0.2	96	89	57
72+	138	0.2	100	100	100

[a] Relative to the midpoint of the interval.
[b] From Jallade, p. 22.

income, they captured nearly 70% of the net benefits of the research program.

In the case of producers, the annual average change in producer surplus was distributed across farm sizes in proportion to estimates of the production based on census data. The research costs were also distributed by farm size assuming that tax payments were proportional to production (in the case of the ICA costs), and by the method already discussed for the research levy. The sum of the foregone income and the research costs were then expressed as a percentage of the estimated 1970 average net income by farm size for the entire rural sector (table 5). This last step is clearly less than satisfactory.

Ideally, income distribution data are required for upland and irrigated rice producers by size of farm. As no such data are known to exist, resort was made to a distribution of rural income by farm size for 1960 (Berry, p. 610), inflated to 1970 values. We have no basis for knowing whether rice producers would have higher or lower incomes than the rural average for each farm size group. However, again, our principal interest is in the relative rather than absolute distribution of benefits by income level.

The group most severely affected was the small (i.e., low-income) upland producers. For these producers, the annual average income foregone through lower rice prices (and no compensating technological change), represented a high proportion of their assumed 1970 income. To the extent that their incomes were below the rural sector average, this impact would have been even more pronounced. On the other hand, the foregone income to the irrigated producers varied more erratically depending on the size group, with the heaviest relative burden falling on the 200–500 and 500–1,000 hectare groups. However, the absolute impact may well be overstated if irrigated producers had incomes above the national average for rural income earners.

In summary, the net benefits of the techno-

Table 5. Annual Average Distributional Impact of Rice Research Program on Upland and Irrigated Producers

Farm Size	Average Income[a]	Change in Producer Surplus Plus Research Costs as a Percentage of 1970 Income: Upland Sector	Irrigated Sector
(hectares)	$(Col.)	(%)	
0–1	1,500[b]	−58	−56
1–2	3,647	−53	−39
2–3	5,330	−60	−25
3–4	6,508	−71	−38
4–5	7,406	−75	−53
5–6	10,295	−60	−43
10–20	15,652	−48	−47
20–30	18,934	−41	−48
30–40	23,394	−35	−47
40–50	28,620	−30	−45
50–100	35,904	−29	−48
100–200	66,759	−26	−53
200–500	155,398	−18	−79
500–1,000	287,513	−21	−69
1,000–2,000	532,389	−19	−49
2,000–+	1,480,199	−11	−36

[a] From Berry (1974, p. 610), adjusted to 1970.
[b] Assumed value.

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logical change accrued to consumers, with the lowest income households capturing a disproportionate share. As Hayami and Herdt note, "The decline in the price of a food staple due to technical progress in its production has the effect of equalizing income among urban consumers" (p. 249). The foregone income to producers appeared to fall most heavily on the small upland producers. Even if the average annual consumer benefits are included as benefits to upland producers, the small upland producers still appear as the most severely affected, a not surprising result, given the orientation of the research program toward the irrigated sector. However, some notion of the relative magnitudes of the different groups should be borne in mind. In 1970 (prior to the major impact of the modern varieties) there were only an estimated 12,000 upland producers with less than 5 hectares. Hence, under any plausible set of welfare weights, their losses would be more than offset by the gain to more than 1 million low-income consuming households, implying an overall gain (albeit uncompensated) in some measure of social welfare.

Caution should be exercised in generalizing from this conclusion. The urban and nonlandowning rural poor of Colombia are very much more numerous than the small farmer. In less urbanized countries with a large semisubsistence rural population, the lowest income households may benefit from technological advances specifically designed for the small farm sector (Valdés, Scobie, Dillon).

Concluding Comments

Concern is periodically voiced for the distributional implications of technological change in developing agriculture. One is often led to feel that the introduction of new technology has been only a qualified success because of its apparent failure to solve a broad spectrum of social ills. But frequently it is the well-being of only the rural poor (both the small farmer and the landless worker) that is the focus of attention. The presence of large concentrations of urban poor who are potential beneficiaries of expanded production of basic foodstuffs is sometimes neglected when castigating the "green revolution."

Throughout much of Latin America, the rural poor tend to be concentrated (for historical reasons) in the less favored ecological zones. The development of technology suited to such areas is presumably a more difficult process, which *ceteris paribus*, would divert research resources from the discovery of technologies which can result in rapid increases in total output from the more favored commercial agricultural sector.

The results presented for the case of Colombian rice exemplify this tradeoff. By focussing on the distribution between consumers and producers, and, more important, by isolating both the costs and benefits by income strata, we have endeavored to quantify some of the dimensions of this tradeoff. Concentrating the research on the upland producers would presumably have entailed foregone benefits to the numerous urban poor (without guaranteeing that small upland producers would have benefitted in the long run).

This paper has attempted some preliminary extensions of the commonly used approaches to analyzing the distributional impact of technological change: (*a*) a model which allows for differential impact of technological change on two classes of producers is introduced; (*b*) the incidence of research costs is considered in the distribution of the social benefits to different groups; and (*c*) the distributional impact (at the national level) on consumer and producer households by income strata is analyzed. These extensions have come only at a price. We have ignored the consequences for the employment of resources released from the rice sector due to the differential impact of the new technology; and the lack of data to analyze the distributional consequences for household income led us to a formidable number of assumptions, we hope not excessively cavalier.

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Appendix

Supply and Demand Relationships

The supply and demand relationships used to estimate the gross social benefits, together with the changes in consumer and producer surpluses (irrigated and upland) were:

$$\text{Demand:} \quad P_t = \alpha_t Q_{1,t} \cdot \exp(1/\eta);$$

Supply

$$\text{Irrigated:} \quad Q_{I,t} = \beta_t P_{t-1} \cdot \exp(\epsilon_I),$$
$$\text{Upland:} \quad Q_{U,t} = \gamma_t P_{t-1} \cdot \exp(\epsilon_U),$$

and

$$\text{Total:} \quad Q_{T,t} = \delta_t P_{t-1} \cdot \exp(\epsilon);$$

Identities

$$\text{Production:} \quad Q_{T,t} \equiv Q_{U,t} + Q_{I,t},$$

and

$$\text{Supply Elasticities:} \quad \epsilon \equiv \rho\epsilon_I + (1 - \rho)\epsilon_U,$$

where P_t is the deflated farm price; Q is output from the irrigated (I), upland (U) and total (T) rice sectors; η is the demand elasticity; ϵ_I, ϵ_U and ϵ the supply elasticities of irrigated, upland, and total rice respectively; and ρ is the fraction of output from the irrigated sector. In the absence of technical change, the supply curves for the irrigated and total sectors would be displaced by k percent, k reflecting the yield superiority of the modern varieties and the proportion of the area on which they were sown.

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