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RETURNS TO AGRICULTURAL RESEARCH IN COLOMBIA[1]

Reed Hertford[2]

Introduction

In a series of studies dating from 1958, economists have used some rather well-worn tools of analysis to estimate the economic returns to agricultura1 research resulting in improved varieties of seeds. In the next section of this paper, the fundamentals of the methodology are restated; and then, in the succeeding four sectîons, the methodology is applied to an analysis of four programs of varietal improvement in Colombia. The four research programs analyzed have constituted part of a larger combined program of agricultura1 research, extension, and education which has been administered since about 1950 by the Colombian Agricultura1 Institute (ICA) and its predecessor agencies, the Department of Agricultura1 Research (DIA) and the Office of Special Studies (OIE),

The underlying purpose of thís paper is to submit to this conference some tools of economics for considerarion in its deliberations about what might be íncluded in the tool chest used for planning the allocation of public research resources in Latin America. Arnon, author of the only text on the organization and management of agricultura1 research, has pointed out that "a formula, however well-planned from the mathematical point of view, but based on ingredients that cannot possibly be reliable, may give

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[1] Paper prepared for a Workshop on Methods Used to Allocate Resources in Applied Agricultura1 Research in Latin America to be held at the International *Center* for Tropical Agriculture, CIAT, November 26-29, 1974.

[2] In collaborntion with Jorge Ardila, Gabriel Montes, Andrés Rocha, and Carlos Trujillo.

an air of pseudo-objectivity to decisions on priorities but cannot serve as a reliable alternative to subjective judgment."[1] By no means are the tools offered up in this paper complex, at least by the standards of my profession; at most, they would serve to improve subjective judgment at the planning stage but certainly not substitute for it. Yet, as simple as they are, they do become sometimes deficient in the face of the data available. . These deficiencies--constituting areas where really additional research and information are needed--are highlighted in the last section of the paper along with major conclusions and implications of the analysis of the Colombian research programs.

Some Methodological Fundamentals

Consumer's Surplus

The concept of a consumer's surplus was introduced by Dupuít over a century ago, later popularized by Marshall, and ultimately extended by Hicks in the 1940's in ways which expanded and clarified its range of applicability.[2] A simple, present-day definition of the concept can be made by reference to Figure 1 and what is termed in the liternture a Hicksian compensated demand curve (HCDC) showing the maximum prices (P) a consumer would be prepared to pay for successive additional units (Q) of a commodity. If he were to pay such maximum prices all along until he had obtained (say) 100 units, he would have made a total expenditure equal in

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[1] 1. Arnon, Organisation and Administration of Agricultura1 Research (London: Elsevier Publishing Company, Ltd., 1968), p. 123.

[2] These early developments are reviewed by J. M. Currie, J. A. Murphy, and A. Schmitz, "The Concept of Economic Surplus and Its Use in Economic Analysis," Economic Journal, Vol. 81, No. 324 (December, 1971), pp. 741-800.

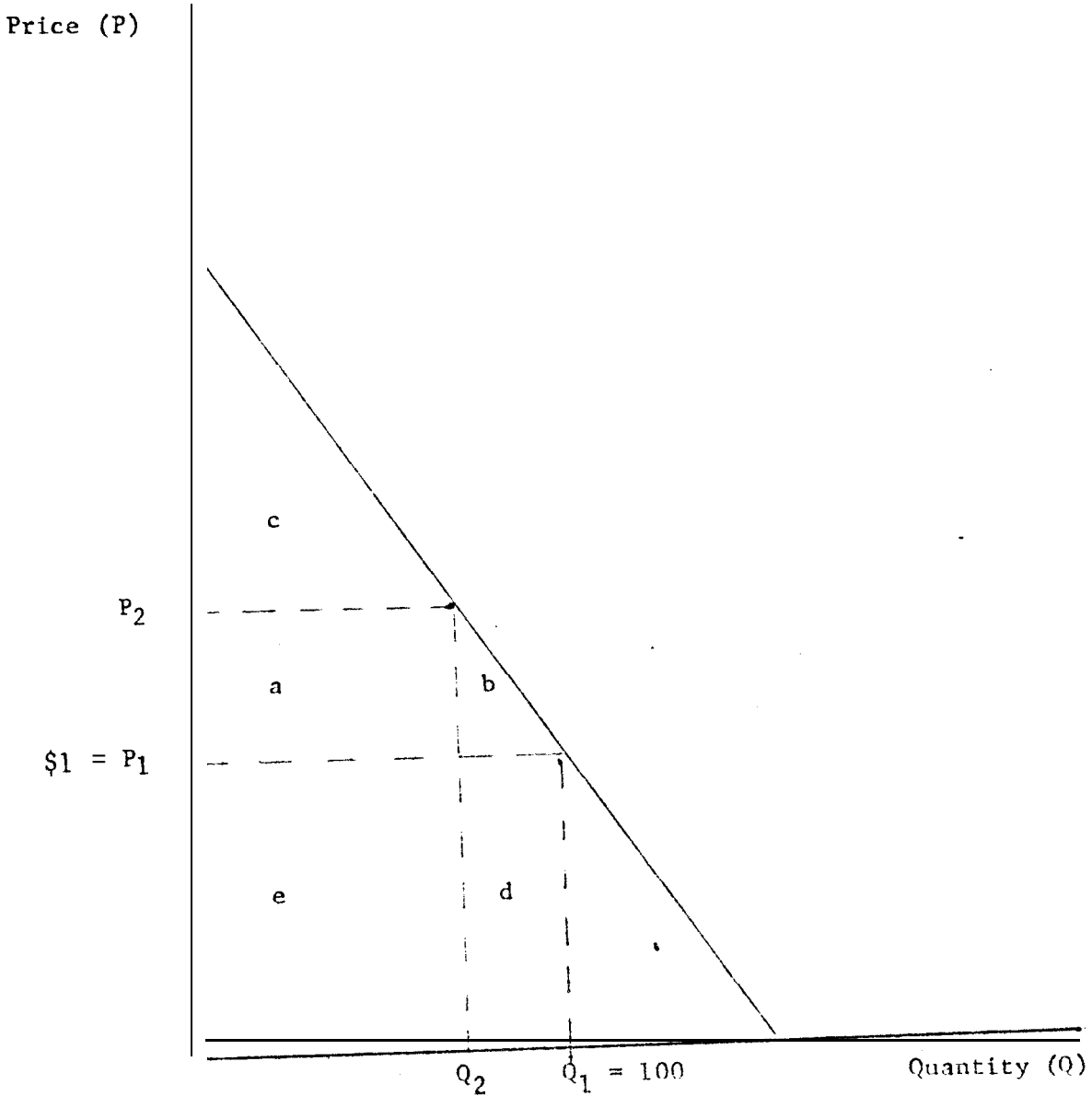

FIGURE 1. Consumers' Surplus

value to the area under the demand curve and left of Ql in Figure 1 (or the area a + b + c + d + e). If, on the other hand, he were to purchase the 100 units on the market at a single avcrage price of $1.00 per unit, he would save a value equal to the area under the demand curve above the $1.00 price line (area a + b + c). It is this saving which is termed "consumer's surplus." For a collection of consumers or a "market," the consumers' surplus is generally thc sum of individual surpluses of consumers.

Any factor which increased the market price of the good from Pl or $1.00 to (say) P_2 would reduce consumer's surplus by the area a + b in Figure 1. This area can be shown to equal

$$KP_1Q_1 \ (1 - \tfrac{1}{2}Kn) \qquad (1)$$

where K is $(P_2 - P_1)/P_1$ and n is the absolute value of the price elasticity of demand.[1] If K is associated with the change in average costs of a commodity resulting from a new yield-improving technique generated through research, then the above formula can provide a direct estimate of the value to consumers of that research in a particular year, provided estimates are also available of P_1Q_1 and n.

This rather simple and direct means of attributing a value or product to a research activity has been criticizcd in the literature on the grounds

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[1]The area a + 2b in Figure 1 equals KP_1Q_1 on this definition, and the area b equals $\tfrac{1}{2}(Q_1 - Q_2)\ (P_2 - P1) = \tfrac{1}{2}K^2P_1Q_1n$. Therefore, the difierence betwcen these two quantities is equal to (1) above and the area a + b of Figure 1.

that the value of n generally estimated is not exactly equal to thr value of the price elasticity of demand on the HCDC.[1] When the price of a commodity falls to a consumer with a given money income, he is better off in terms of total utility or welfare because his real income rises. Since the consumcr's income is adjusted downwa-rd by the amount of this real income increase following a fall in the price of the commodity in the case of the HCDC but not in the case of an "ordinary" demand curve, the price elasticity of demand as ordinarily estimated can be expected to overstate the "true" HCDC price elasticity. If, for example, the demand curve shown in Figure 1 were actually an ordinary demand curve, the HCDC would pass through the point (P_2Q_2) but evidence less slope. The implication would be that any estimate of the value of research to consumers based on equation (1) above would be biased downward.[2]

This bias has been overlooked in practice, primarily on two grounds. First, it is argued that the actual value of the bias is small. In Figure 1 the bias would equal in value only a piece of the triangle northeast of the demand curve formed by the points (P_2, Q_2), (P,, Q,), and (P_1, Q_1). The value of such a triangle is obviously small in relation ta the total area of consumer's surplus, a + b. Second, the magnitude of the bias is even

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[1] For a recent example of this criticism, see Wolfgang Bonig, "Comment," American Journal of Agricultura1 Economics, Vol. 56, No. 1 (February, 1974), p. 177.

[2] The actual direction of this bias, as well as the slope of the HCDC in relation to the ordinary demand curve, depends on the sign of the income elasticity of demand for the commodity. If the value of the income elasticity is negative, the bias referred to in the text would be in the opposite direction or upward.

smaller when the commodity in qurstion either has a small income elasticity of demand or represents a small proportion of total expcnditures on all commodities. It is argued that the kinds of agricultura1 commodities for which research returns have been quantified using the consumer's surplus concept have, in fact, low income elasticities and represent a small proportion of total consumer expenditures.[1]

Producer's Surplus

The concept of producer's surplus is analagous to that of consumer's surplus and refers, in general, to a difference betwecn what is actually received from the sale of a good and the minimum amount required to induce a seller to part with it. Consequently, producer's surplus has been equated with an area--like a in Figure 2--between the prevailing price of a good and its supply curve since the latter has been traditionally defined as a locus of minimum prices at which quantities will be sold. If the supply curve shifts to a position like that of S_1S_1' as a result of the adoption of a new production technique generated through agricultura1 research, then the benefit of that research to producers has been taken equal to area b + c.

Because there are sellers of input services like those of labor and capital, as well as sellers of final products, al1 of whom could earn

[1] A rather succinct defense of the use of the concept for purposes of estimating returns to agricultura1 research is contained in Harry W. Ayer and G. Edward Schuh, "Reply," American Journal of Agricultura1 Economics, Vol. 56, No. 1 (February, 1974), pp. 175 and 176.

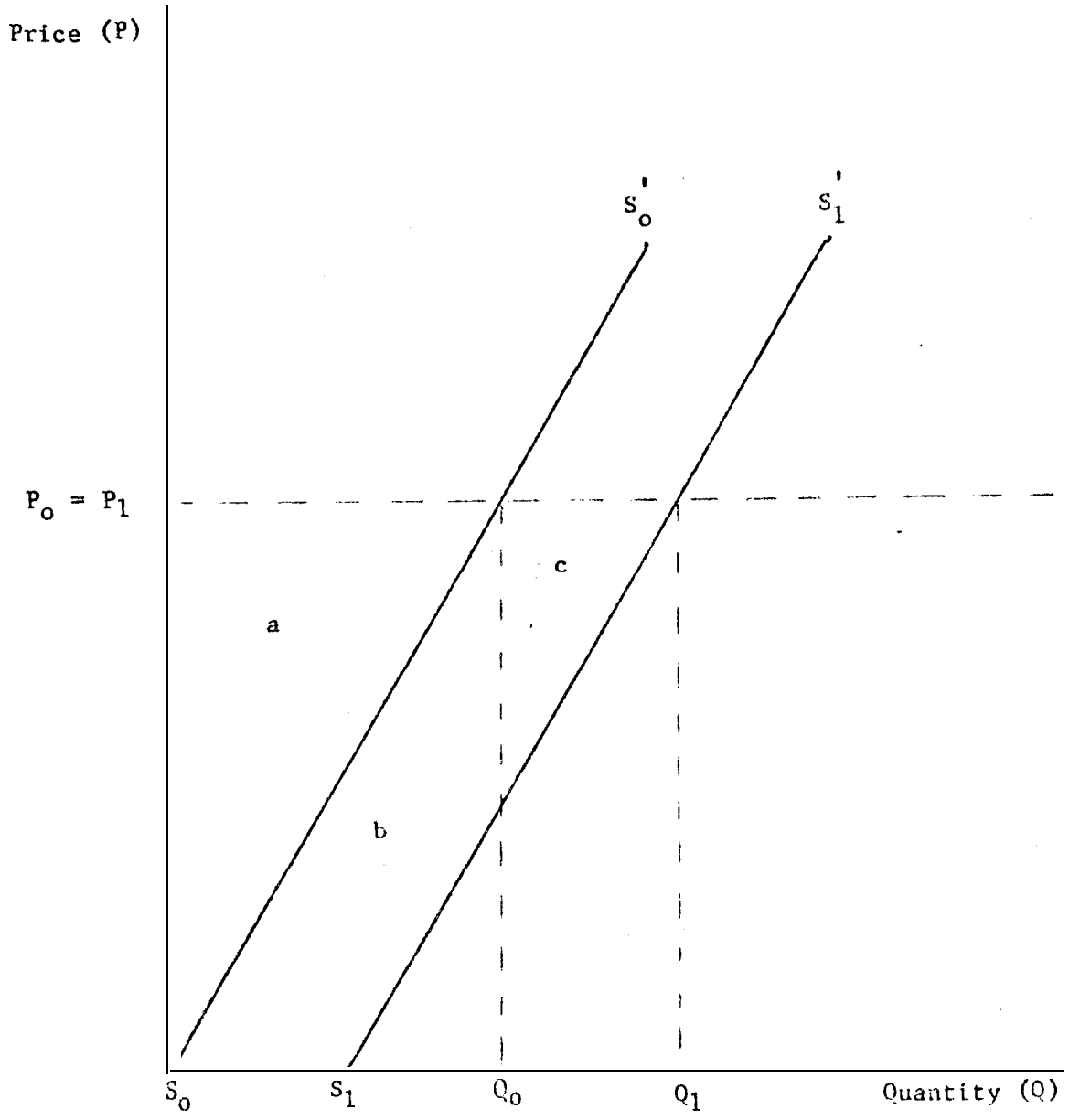

FIGURE 2. Producers' Surplus

theoretically a "surplus," some confusion has nrisen over what producer's surplus and changes in it really measure. Is only the surplus of producers included, as the term implies, or are surpluses earned by factors of production also included? Alfred Marshall, the author of the concept, was himself not clear on this point.[1] It is of crucial practical significance since any estimate of the product of agricultura1 research would be incomplete which included benefitc to consumers and producers but overlooked those accruing to factors of production.

As ít turns out, what producer's surplus includes depends on the specification of the supply curve. When variable inputs of production are available to a competitive industry at prices which are independent of its leve1 of output, it is well-known that (a) the supply curve of the industry is the lateral sum of the marginal cost (or supply) curves of individual firms, (b) the area under the industry's (firm's) supply curve represents the total costs of all variable inputs of production, and (c) the area above the industry's (firm's) supply curve bclow the prevailing price of the product is a return to all other inputs--namely, all fixed factors of production including inputs physically associated with the producer, like his labor and "entrepreneurial capacity," as well as other fixed inputs. By definition these fixed inputs are specialized to the industry or firm under consideration in the sense that they cannot produce anything elsewhere in the economy. Therefore, on a bronder view, there are no real costs associated with their employment; and any return to them would be an economic rent or surplus. Since producer's surplus

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[1]Currie, Murphy, and Schmitz, op. *cit.*, p. 754.

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has been given the same definition, we may conclude, in answer to the question posed earlier, that producer's surplus is a return to the producer, as well as other fixed factors of production, and that there is a direct correspondence between the concept at the level of the firm and the industry when prices of variable inputs are invariant with respect to changes in output.

When some variable factors of production are supplied at prices which are not constant but increase with the level of an industry's output because their supply curves slope upwards, this simple interpretation of producer's surplus disappears. Assume that the sum of the marginal cost curves of an industry, $S_oS'_o$ in Figure 2, for example, shifts down to $S_1S'_1$ at the level of output Q_o as a result of the adoption of a cost-saving, improved technique generated through research. The value of costs saved, given our definition of the supply curve, would be the area b. These savings, of course, would permit the industry to expand its output beyond Q_o. However, any output expansion achieved through increased employment of variable factors of production would now tend to bid up their prices to the industry and make their costs exceed the area under the new industry sum of marginal costs curve, $S_1S'_1$, at any level of output above Q_o since the supply curves depicted in Figure 2 assume that unit costs of variable inputs are constant. Therefore, as output expands in the industry, the sum of marginal costs curve, $S_1S'_1$, effectively begins to slip back to the position of the initial supply curve, $S_0S'_0$. Its final equilibrium position would approximate that of the initial supply curve if all variable inputs of production were subject to very inelastic supply curves. In that case the initial saving created by adoption of the new production technique

would have accrued mostly to the variable inputs of production as a surplus. Area b of Figure 2 would then almost measure the change in surplus derived by variable factors of production from the cost-saving improvement in production techniques resulting from research. The surplus of producers and other fixed factors of production would be practically unchangcd as would the leve1 of industry output (Qo).

The final position of the supply curve of the industry would normally result in an output somewhere between Q_o and Ql of Figure 2; that is, some variable inputs of production would be available at somewhat higher prices to the industry and, as output expanded, the supply curve would shift equlvalently from S_1S_1' but not return to its initial level, S_0S_0'. The area between this final positíon of the curve and the sum of marginal costs curve S_1S_1' up to the final leve1 of índustry output would then measure the increase in expenditures by firms ín the industry on variable inpüts as a result of increases in their unit prices.

Although such increased expenditures would represent very real increases in resources devoted to productíon by firms in the industry, they would not all be íncreases in real resources devoted to production from the point of view of the economy at large since a part would accrue to some of its nembers--namely, to variable inputs or variable input suppliers--in the form of a surplus above their positively sloped supply curves and below their prevailing prices. That which is a surplus should, of course, be accounted for as such and would be added to other estimated products or returns to research. To estimate such surpluscs cxactly, however, would require data on the demand and supply curves Eor variable inputs employed by the industry. Sínce they are not generally available, the most that

can be said usually is that the area between the final position of the sum of marginal costs supply curve of the industry up to the new level of output and the sum of marginal costs curve which would have prevailcd had input prices been invariant with respect to output would represent an upper-hound measure of the returns to variable inputs and their suppliers derived from the improved technique of production. The area between the initial and the final sum of marginal costs curve up to the product price line would then be a measure of the returns of the new technique captured by producers and other fixed factors of production.

If the point of intersection of the vertical line through Q_o with the supply curve S_1S_1' were connected with the point of intersection of the new equílibrium leve1 of industry output with the price line, P_1, the resulting line would define a ncw supply curve which was adjusted for the kinds of considerations discussed above. This "adjusted" industry supply curve would have a smaller slope than the "unadjusted" sum of marginal costs curve of the industry or the relevant curve when prices of all variable factors of production are invariant with respect to output.

To recapitulate: Area b + c in Figure 2 is an unambiguous measure of an increase in the surplus of all fixed factors of production, including the surplus created by the producer from his self-employment, when variable inputs of production are available to an industry at prices which do not change with output. If variable input prices change with changes in industry output, then area b becomes a reasonable measure of increases in surpluses of variable inputs when their supply curves are very inelastic. If variable input supply curves are neither very elastic nor inelastic, then the area b + c is normally an upper hound estímate of the changes

in surpluses of fixed and variable factors of production as it includes some increases in real resource costs to the economy. Finally, two industry supply curves have been identified: (1) the unadjusted sum of marginal costs curve relevant when prices of all variable inputs are invariant with respect to industry output and (2) an adjusted industry supply curve, normally more steeply sloped and more inelastic, connecting points on unadjusted supply curves after adjustments in them for input price changes. Areas above and below this adjusted supply curve are even more ambiguous than the arca b -t- c for reasons which are obvious on examination of Figure 2.

Because of possible ambiguities ín the concept of producer's surplus, 1 shall refer to areas like b + c in Figure 2 as a "production surplus." (For similar reasons Mishan has argued that the term "producer's surplus" should give way to "economic rent."[1]) To preserve euphony, I shall also refer to consumer's surplus as the consumption surplus.

Combining Surpluses

The definitions of consumption and production surpluses have been presented to this point with reference to a special set of assumptions about the slopes of the relevant demand and supply curves. In Figure 1, for example, which was used in defining what is now being called a consumption surplus, the demand curve of the commodity in question was taken to be normally sloped, while its supply curve was taken to be perfectly elastic. In Figure 2 the supply curve was normally sloped, while it was the demand curve of the product which was assumed to be perfectly elastic.

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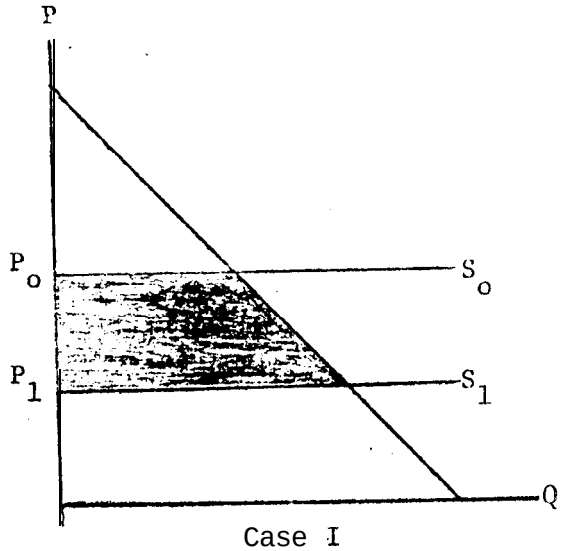
[1] E. J. Mishan, "What 1s Producer's Surplus?" American Economic Keview, Vol. 58, No. 5, Part 1 (December, 1968), pp. 1269-1283.

These assumptions were nade for purposes of exposition. Having now made the essential definitions, however, the purpose of this section is to relax those assumptions and briefly state the values for consumption and production surpluses which result when the price elasticity of demand takes values of zero, a negative numbrr, and (negative) infinity, while the price elasticity of supply ranges in value from zero to a positive number and then to infinity.

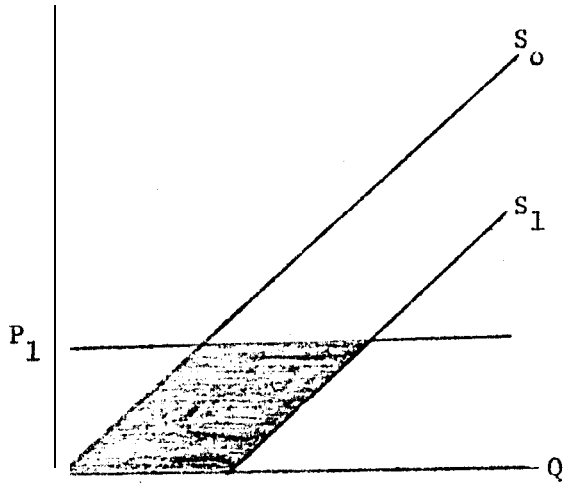
Although there are nine different possible combinations of these values of the two price elasticities, two have no meaning. This leaves a total of seven, two of which have already been discussed with reference to the definitions of consumption and production surpluses and are shown as Cases 1 and II of Figure 3; the other five combinations of the price elasticities appear as Cases III through VII. The hatched area of each figure in Figure 3 represents the sum of consumption and production surpluses following adoption of a new production tcchnique generated by research: The large K is defined as $(P_o - P_1)/P_1$; the small k is $(Q_1 - Qo)/Q_1$; S_o and S_1 are, respectively, the original supply curve and the one which prevails after adoption of a new production technique; n is the absolute value of the price elasticity of demand; and e is the corresponding value for the supply curve.

It can be seen that all cases are special cases of Case VI. From the first expression for the shnded area of Case VI, Case 1 can be derived by letting e go to infinity; Cases V and VII result from setting n equal to zero. From the second expression for the shaded area of Case VI, Cases II and IV can be obtained by letting n tend to infinity; by letting e go to zero, Case III is derived. That there are two expressions for the



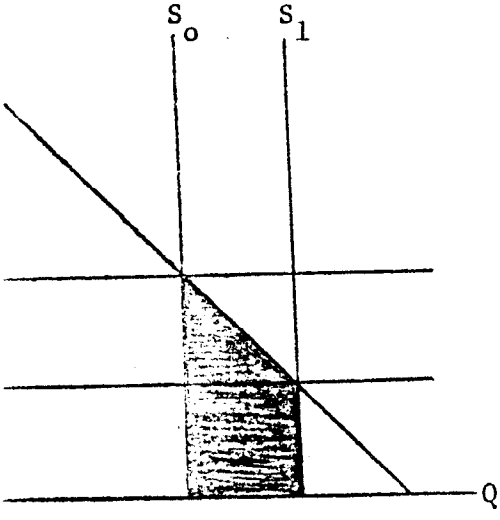
Case I

$KP_1Q_1 (1 - \frac{1}{2} K_n)$



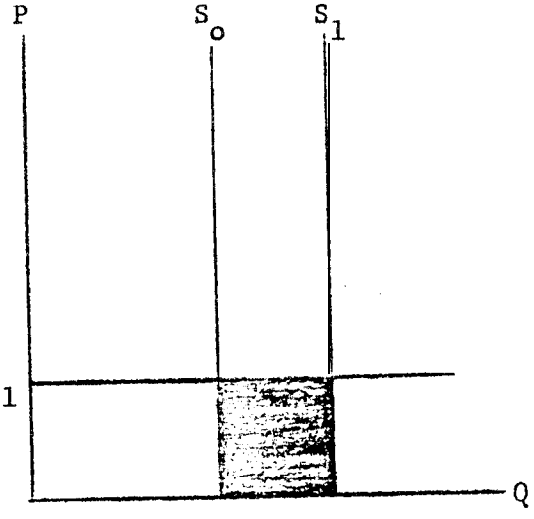
Case II

kP_1Q_1



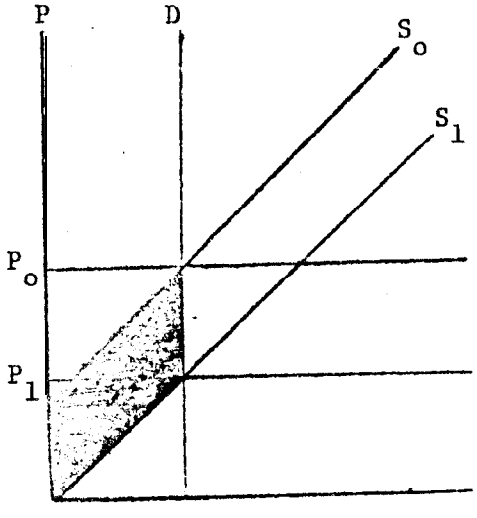
Case III

$kP_1Q_1\left(1 + \frac{1}{2}\frac{k}{n}\right)$



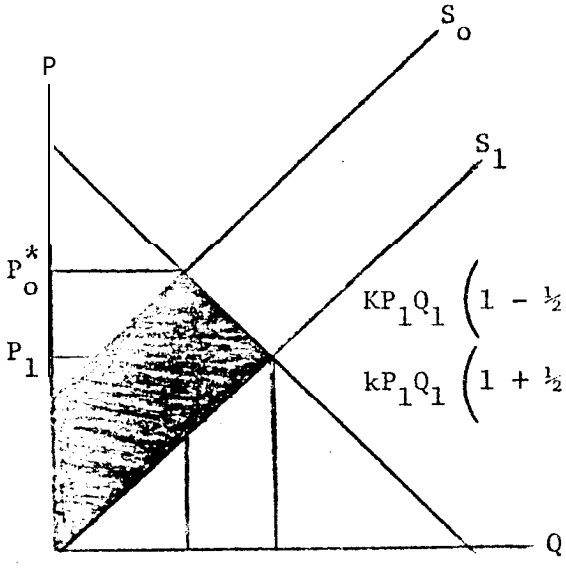
Case IV

kP_1Q_1



Case V

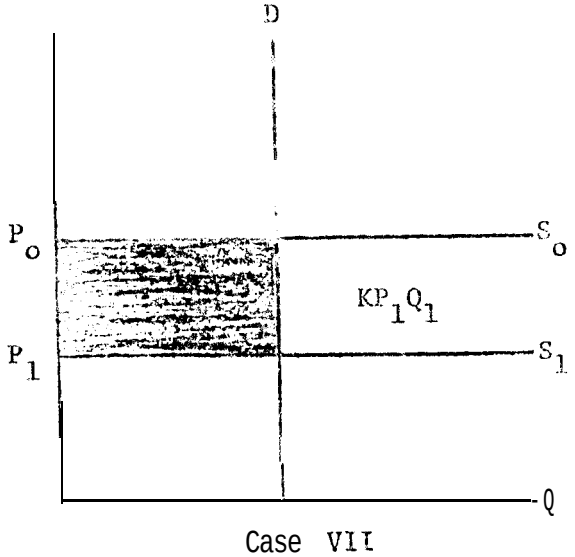
KP_1Q_1



$KP_1Q_1\left(1 - \frac{1}{2}\frac{enK}{n+e}\right)$ and

$kP_1Q_1\left(1 + \frac{1}{2}\frac{k}{n+e}\right)$

Case VI



Case VII

Case VI shaded area simply reflects the approximate nature uf all formulas.*

Reference to thc expressions given to the shaded areas of Figure 3 produces two inferences: (1) All formulas for the combined surpluses derived from the adoption of a new production technique involve only a few parameters--P_1Q_1 and a constant, which includes k or K, n, and e; and (2) total surplus would be expected to be greatest when estimated under Case III assumptions and least under assumptions of Case I, other things equal.

Additional Issues

Before turning to applications of this methodology to plant-breeding research in Colombia, a few concluding comments about what has been said thus far are in order.

1. Since the areas between the supply curves do not provide always unambiguous measures of production surpluses--and, furthermore, those surpluses cannot be disaggregated by source, e.g., "producers" and "inputs"--consideration should be given in future work to estimating production surpluses directly from the demand and supply curves of

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[1] Nicolas Ardito Barletta, "Costs and Social Benefits of Agricultura1 Research in Mexico" (unpublished Ph.D. dissertation, University of Chicago, 1971), Appendix C, has provided the following formula for the Case 6 surplus:

$$kP_1Q_1\left\{1+\frac{k}{2n}\left[1-e\,\frac{(1-n)^2}{n+e}\right]\right\}.$$

Willis Peterson, "Returns to Poultry Research in the U. S.," Journal of Farm Economics, Vol. 49, No. 3 (August, 1967), pp. 656-669, has suggested:

$$kQ_1P_1+k^2\frac{P_1Q_1}{2n}-\frac{Q_ok^2P_1}{2}\left(\frac{P_1}{P_o}\right)\left(\frac{en}{n+e}\right)\left(\frac{n-1}{n}\right)^P.$$

production inputs. In Latin America where the distribution of surpluses between factors of production assumes frequently as much importance as the aggregatc value of the surpluses themselves, this suggestion may be especially relevant.

2. If there exists ínput unemployment in agriculture and it is reduced as a result of the adoptíon of yield-improvíng new techniques generated through research, earnings of the otherwise unemployed ínputs should be added ín as a productíon surplus (benefít) of research, not as an additional resource cost.[1]

3. Combined production and consumption surpluses are commonly estimated and presented first as an aggregate and then disaggregated or divided between "producers" and "consumers" ín an attempt to show who has gained most from agricultura1 research. [2] This is not done ín the sectíons which follow. The means by whích the disaggregation is performed should be readíly apparent in the review of the methodology which has been presented to this poínt.

4. A closed economy has been assumed up until now. If the commodity affected by agricultura1 research is, howevcr,

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[1] For an interestíng applícation along these lines, see A. Schmitz and D. Seckler, "Mechanized Agrículture and Social Welfare: The Case of the Tomato Harvester," Amerícan Journal of Agricultura1 Economics, Vol. 52, No. 4 (November, 1970), pp. 569-578,

[2] Most recently, this has been done by Harry W. Ayer and G. Edward Schuh, "Social Rates of Return and Other Aspects of Agricultura1 Research: The Case of Cotton Research in São Paulo, Brazil," American Journal of Agricultural Economics, Vol. 54, No. 4 (November, 1972), pp. 557-569.

traded in foreign markets, some nominal modifications in the analysis need to be made.

Figure 4 assumes that a commodity subject to a shift in supply of Ql - Q_o is imported at a world price, Pl, which is unaffected by the leve1 of imports of the country in question. The supply shift does not change the consumption surplus; its only effect is on the side of production. The shaded area between the two supply curves up to Q_o would represent a surplus to society since it involves a saving in the costs of producing Q_o. The remaining triangular shaded area would also be included as a benefit, although it is derived from a different source, corresponding as it does to a saving resulting from producing more of the commodity locally. Figure 5 assumes that the commodity in question is exported, rather than imported, at a price Pl, likewise invariant with respect to the leve1 of exports sold by the country in question. If supply shifts from Q_o to Ql, the only "benefit" would be a production surplus equal to the shaded area of the figure. [1]

5. There is no easy, straightforward, or "most recommended" way of measuring the shift parameter k of the supply curve attributable to research. It has been estimated, for example, on the basis of essentially an educated guess

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[1]The only fully "open economy" evaluation which has come to my attention, aside from the "partially open" Ayer and Schuh study cited above, is the one done by Y. Hayami and M. Akino, "Organization and Productivity of Agricultura1 Research Systems in Japan," to be presented to a Confcrence on Resource Allocation and Productivity in Intcrnational Agricultura1 Research, January 26-29, 1975.

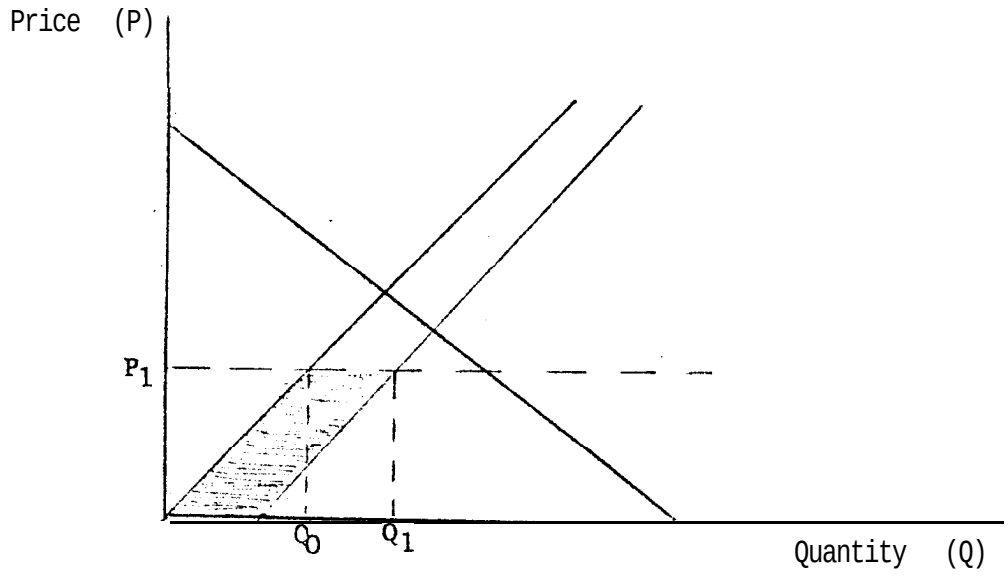

FIGURE 4. Production Surplus with Irnports

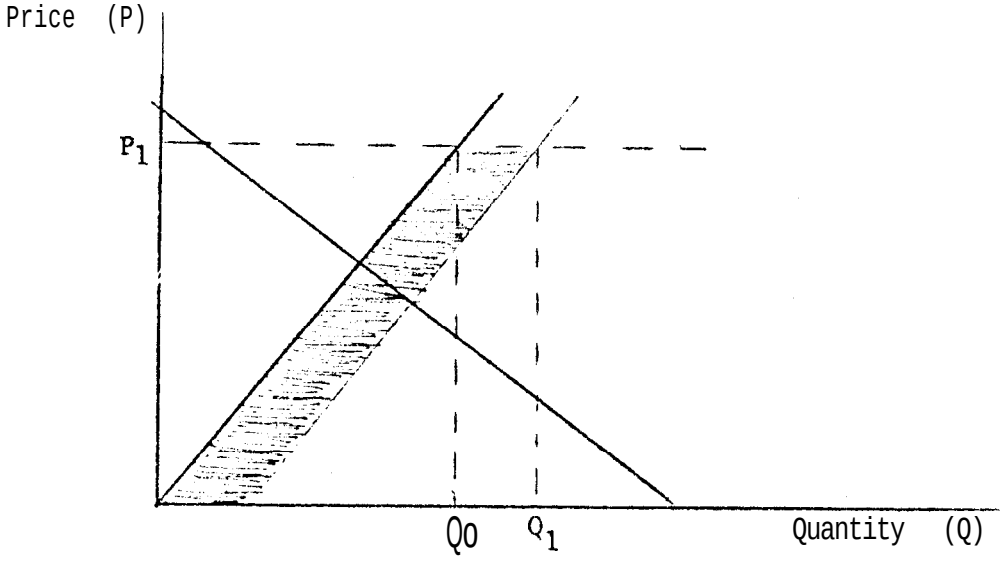

FIGURE 5. Production Surplus with Exports

by Griliches,[1] as a shift in the long-run supply curve by Peterson,[2] on the basis of estimates of farm-level production functions by Ardito,[3] and from experimental yield data by Ayer and Schuh.[4] In the research reported in the next sections of this paper, yield differences estimated from on-farm trials run by the research program itself are incorporated into estimates of the shift parameter. The tact taken in all cases, including those reported here, has been determined probably more by the availability of data than by any more superior arguments of theory and reason!

Rice[5]

Colombia's rice research program is of relatively recent origin, having been initiated in 1957 by the predecessor agency of ICA. Its establishment coincided with a sharp rise in rice imports occasioned by an outbreak

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[1]Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy, Vol. 66, No. 5 (October, 1958), pp. 419-432.

[2]Peterson, *op.* **cit.**

[3]Ardito, *op. cit.*

[4]Ayer and Schuh, *op. cit.*

[5]This section draws heavily on the work by Jorge Ardila, *"Rentabilidad Social de Zas Inversiones en Investigacion de Arroz en Colombia"* (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1973).

of the hoja blanca disease,[1] a virus of Latin America--with symptoms like the stripe dissase of Japan--which first caused substantial losses in Venezuela in 1956 and in Colombia itself in 1956 and 1957.[2] Correspondingly, the initial objectives of the research program included varietal selection and breeding for higher yields and resistance to the *hoja blanca* virus.

Rice varieties with resistance characteristics were collected throughout Colombia as a first step; in addition, *2,200* varieties were selected and imported from the U. S. Department of Agriculture's World Collection of Rice in Beltsville, Maryland. By 1959, about 400 of these varieties had shown promising resistance to thc virus.[3] Because they were *japonica* varieties in the main, previously not consumed in Colombia, the research program adopted an objective of breeding the virus-resistant characteristics of japonica into the local long-grain varieties.[4] It was estimated

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[1] Until 1957 Colombia's imports of rice were running around 2,000 metric tons annually. The 1956 crop was down about 10 percent from 1955 (from 324,000 tons in 1955 to 300,000 tons in 1956), and the 1957 crop was up less than 8 percent from 1955, in part because of a fa11 in yields. In 1957 Colombia then imported 10,200 tons of rice. In 1958 and 1959 imports returned to "normal" levels. Refer, for example, to relevant issues of the FAO Rice Report for these and related data.

[2] S. H. Ou, Rice Diseases (England: Commonwealth Mycological Institute, 1972), pp. 28-33. Apparently the attack was least severe where the Colombian red rice was grown; see Philippe Leurquin, "'Rice in Colombia: A Case Study ín Agricultura1 Development," Food Research Institute Studies, Vol. VI, No. 2 (1967), p. 231.

[3] The means by which the disease was transmitted were not identified with the insect, *Sugotodes,* until 1958.

[4] Chemica1 control of the virus provcd somewhat effective--but very expensive--among partially resistant varieties; see G. E. Galvez, "*Hoja Blanca* Disease of Rice," The Virus Diseases of the Rice Plant (Baltimore: Johns Hopkins Press, 1968), pp. 35-49.

that this objective might be satisfied in four to five years. As an interím medsure, the one superior-yielding U. S. variety which had shown some virus resistance, Gulfrose, was multiplied and released in 1961.

The first ímproved variety, Napal, to be produced by the Colombian research program was actually released in 1963 or just four years later. Napa1 had the long-grain characteristics of Bluebonnet 50, the most preferred nontraditional varíety, but was resistant to hoja *blanca*.[1] Unfortunately, Napa1 was selected out in 1965 for a heavy attack of *Bruzone* (rice blast disease) and dísappeared thereafter from commercial production. In the same year, Tapuripa, earlier imported from Surinam, was multiplied and distributed to farmers as an alternativa to Bluebonnet 50 and Gulfrose. It was long grained and flinty with some resistance to blast disease and hoja *blanca*.

In 1966 the Colombian rice research program added an objectíve whích reflected leads of the International Rice Research Institute (IRRI): to develop dwarf varietíes with a high grain-to-straw ratio and resistance to lodging. About 3,000 additional varieties were imported from IRRI, and an order went out that only those varieties already in the Colombian collection should be retained which out-yielded Bluebonnet 50 by 100 percent.

A year later ín 1967, ICA's program joined forces with the rice program of the International Center for Tropical Agriculture (CIAT). Personnel, facílities, budgetary resources, and objectives were shared under informal agreements between the two institutíons. These had the effect of reinforcing the ties of the Colombian program with IRRI as the head of CIAT's rice work had served on IRRI's staff.

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[1] Bluebonnet 50 was Eirst imported to Colombia in 1954. The history of its introduction and rapid adoption is discussed by Leurquin, **op**. *cit*., pp. 250 and 251.

In 1968, CIAT and ICA introduced IR-8. Its adoption advanced well even though the medium-type chalky grain sold generally at a 30 percent discount, and susceptibility to blast disease was evidenced. IR-8 did prove resistant to *hoja blanca.* Following strong commercial trade interest, CIAT and ICA also introduced IR-22 in 1970 and recommended it to farmers in irrigated tropical areas.

Between 1966 and 1970, ICA released independently two additional rice varieties, ICA-3 and ICA-10. These never assumed any commercial importance, however, because their yields were inferior to the IRRI varieties--while being superior and/or more certain than either Gulfrose or Napal--and their grain quality was less desirable than Tapuripa.

In 1971, CIAT and ICA released the CICA-4 variety. It was more disease resistant and had greater water and air temperature adaptability, good grain appearance and cooking qualities, and slightly superior yields. Simultaneously, CICA-4 appeared in Ecuador as INIAP-6, in the Dominican Republic as Advance 72, and in Peru under the name of Nylamp.

Yields recorded in commercial field trials of the seven major rice varieties released by the Colombian and joint CIAT-ICA programs after 1957 are shown in Table 1, together with data obtained from the same source on yields of the check variety, Bluebonnet 50. The 665 individual trials which are the basis for these yield statistics include all that are available for the 15-year period, 1957-1972. It should be mentioned that ICA's commercial trials or *pruebas regionales* are conducted on parcels of commercial farms which agree to collaborate with the Institute's programs. Farmers run the trials, but materials and instructions are provided by ICA.

TABLE 1

Colombia: Average Rice Yields From Commercial Trials by Variety
1959-1971

Year	Variety							
	Bluebonnet 50	Gulfrose	Napal	Tapuripa	ICA-10	IR-8	IR-22	CICA-4
	kilos per hectare							
1959	1,927	a/						
1960								
1961	2,893	3,071						
1962	2,967	4,065						
1963	3,875	5,391	4,420					
1964	4,336	4,138	5,166					
1965	3,462	2,739	4,343					
1966	1,590		2,436	3,645				
1967	2,890			2,690	4,707	6,098		
1968	3,208		5,356	4,600	4,789	5,890		
1969 b/								
1970	3,339			4,500	3,852	5,180	5,420	6,125
1971	3,164			3,610	4,234	4,748	5,080	4,600
Average	3,100	3,880	4,344	4,026	4,441	5,473	5,250	5,362

a/ Blanks indicate no regional trials were undertaken.

b/ Trials data were unavailable.

Source: Jorge Ardila, "*Rentabilidad Social de las Inversiones en Investigacion de Arroz en Colombia*" (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1973), Table 5.

The three rice varieties released prior to 1966 show average yields in these daca of 4.1 metric tons per hectare representing a yield advantage over Bluebonnet 50 of about 33 percent. Varieties introduced after 1966, including ICA-10, just double that yield advantage bringing it to 65 percent above Bluebonnet 50.

In view of these yield data, it is interesting to note in Table 2 that the area planted to improved rice varieties did not become a significant proportion of all riceland until the second, or post-1966, stage of the research program. Data in the table on the percentage of acreage sown to a given variety were estimated in the following way. First, available information on sales of certified seeds by variety were converted to hectare equivalents by dividing by estimates of seeding rates provided by ICA's Director of its National Rice Program. Second, it was assumed that the proportion of all acreage planted to certified seeds of any variety was equal to the proportion planted to later generation seeds of that variety produced by farmers outside the seed multiplication and certification program. Thus, the percentage of acreage sown to a variety which is shown in Table 2 equals two times the percentage sown with certified seeds. This estimating procedure has the effect of equating the percentage change in area planted to an improved variety with the percentage change in sales of its certified seeds. Since the latter rate would be expected to taper off before the rate of growth in area planted, the net effect of the procedure is to underestimate the true levels of adoption of improved rice varieties. This is doubly true in the case of the estimated percentage of riceland planted in all improved riceiarieties as data on Gulfrose seed sales could not be located.

TABLE 2

Colombia: Land Area Planted to Six Improved Varieties of Rice as a Percentage of the Total Area Planted in Rice 1964-1973

Year	Variety						All improved varieties
	Napal	Tapuripa	ICA-10	IR-8	IR-22	CICA-4	
	percent						
1964	2.5	a/					2.5
1965	2.1						2.1
1966		0.1					0.1
1967		3.2	0.1				3.3
1968		21.2	0.6	0.3			22.1
1969		18.0	0.5	3.7			22.2
1970		12.4	0.2	18.2			30.8
1971		6.9		26.1	3.1	5.0	41.1
1972				18.9	10.1	18.3	47.3
1973				20.1	24.3	12.6	57.0

a/ Blanks indicate less than 0.1 percent.

Sourccs: Jorge krdila, "*Rentabilidad* **Social de Zas Inversiones en** *Investigacion* **de** *Arroz* en *Colombia*" (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1973), Table ll for the years 1964-1971; also, after 1971, ICA, Director of the National Rice Program.

In order to estimate the shift parameter of each new variety--its yield advantage over Bluebonnet 50--production functions were fit to the *pruebas regionales* data using standard least-squares procedures. In the final round of estimation, reported yields were taken as a function of 20 variables: size of the trial plot, seeding rate, 7 seed variety variables, 2 variables to distinguish different time periods, 4 variables relating to irrigation and its interactions with seed variety, and 5 variables to differentiate locations and their interactions with variety. Only the first two of these variables entered as continuous arguments. Other continuous variables (relating particularly to "cultural practices") were either discarded or respecified in noncontinuous form in the final results presented in Table 3.

Since the estimated coefficients on the variety variables are to be interpreted as their "yield disadvantage" in kilos per hectare compared with CICA-4, it is evident that Colombian rice research has produced through time continuous and substantial improvements in yields. Again, the superiority of the post-1966 releases is evidenced.

The large and significant coefficient on the variable adjusting for some of the 48 locations used for the *pruebas regionales* indicates that yields of all varieties are increased by about 1.2 tons in those areas and that this effect is somewhat larger for the Napal, Gulfrose, and IR-8 varieties, the location-variety interaction variables for which are positive.[1]

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[1]The location variable assumed a value of one when a trial fell into areas which could be classified as tropical dry forest, subtropical humid forest, or very dry tropical forest and zero otherwise. These classifications were suggested by the Director of ICA's National Rice Program.

TABLE.3

Colombia: Production Function Estimates for Rice
Based on Commercial Trial Data, 1957-1972

Independent variable	Estimated coefficient	Estimated t statistics
1. Size of trial plot	0.15	-2.30
2. Seeding rate	2.46	1.58
3. Bluebonnet 50	-1,609.66	-3.45
4. Gulfrose	-1,486.56	-1.31
5. Napa1	-1,742.79	-1.83
6. Tapuripa	- 884.31	-1.80
7. ICA-10	- 536.93	-1.13
8. IR-8	- 798.97	-1.54
9. IR-22	- 589.97	-0.72
10. Irrigation	1,220.20	5.84
11. Irrigation * IR-8 interaction	1,278.09	3.21
12. Irrigation * IR-22 interaction	700.44	0.89
13. Irrigation * CICA-4 interaction	1,061.87	2.11
14. Location	1,185.26	7.12
15. Location * Gulfrose interaction	991.98	0.94
16. Location * Napa1 interaction	940.33	1.06
17. Location * IR-8 interaction	428.22	1.24
18. Location * CICA-4 interaction	-1,340.16	-1.14
19. Time 1	1,228.03	6.74
20. Time II	- 509.78	-2.20
Intercspt	2,028.30	3.64
	R^2 = 0.67	n = 665

Source: Jorge Ardila, *"Rentabilidad Social de Zas Inversiones en Investigacion* de Arroz en *Colombia"* (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1973), Table 13.

The Eact that the corresponding interaction term is negative and about equal to 1.2 tons in the case of CICA-4 leads to a conclusion thnt it is the only variety which is less location specific.

Results suggest, however, that yields of CICA-4, as well as those of IR-8 and IR-22, are very positively influenced by irrigation. The coefficient on the irrigation variable indicates that yields of al1 varieties are increased by about 1.2 tons with average irrigation practices. Roughly another ton is added on top of this when irrigation is applied to IR-8, IR-22, or CICA-4 as indicated by the coefficients on the variables of interaction of those varieties with irrigation. This evidence from the production functions, coupled with data which show that dryland rice yields increased 7 percent during the 1961-1972 period while those of irrigated rice increased 133 percent,[1] leads to an inference that the newer varieties have benefitted mainly the irrigated rice areas. The other side of the same coin, of course, is that adoption of improved varieties was assisted by the existence of irrigated cropland.[2]

Most of ICA's research has been focused on the irrigated rice areas. Its largest programs have been located at the Palmira and Espinal experiment stations. Wbile about 75 percent of all riceland is irrigated today (1974) in Colombia, almost 100 percent has been traditionally irrigated within the areas served by Palmira and Espinal.[3] Underscoring this point

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[1] FEDEARROZ, *Informe* de *Gerencia al XIII Congreso Nacional*, Bogota, Colombia, 1971, p. 32.

[2] In 1948 Raul Varela Martinez, *Industria y comercio de Arroz en Colombia* (Bogota: *Ministerio de Agricultura y Ganaderai*, 1949), p. 15, estimated that 18 percent of al1 riceland was irrigated and 16 percent was partly irrigated. By 1974, it is estimated that the perccnt of riceland irrigated had increased to about 75 percent.

[3] See, for example, Leurquin, op. *cit.*, Tables 5 and 11.

is the fact that 84 percent of the *pruebas regionales* were performed with irrigation. Also, among the 48 locntions used for experimentation, upland rice trials were the only type performed in 14 locations while 30 were used only for trials with irrigation. This emphasis on the irrigated are-as may have been induced by expectations of the sort of variety-irrigation interactions found in the regression results. More plausible is the commonsensical explanation that ICA's creditability would have been seriously questioned had it not produced varieties which yielded well in the irrigated areas of Colombia since the controlling interests of the rice growers and commercial trade are found there.[1]

Regression results were used to produce two estimates of the overa11 shift parameter--the percentage change in rice supply attributable to the yield advantage of all the improved varieties over Bluebonnet 50. One was taken to include only "varietal effects" on yields and estimated as a weighted sum--divided by average commercial yields--of the regression coefficient of each improved variety minus the coefficient corrcsponding to Bluebonnet 50, with weights equalling the percentage of all riceland planted which was sown in each variety.[2] A second estimate of the shift parameter derived from the regression results was taken to include other variety-specific interaction effects in addition to the direct varietal effects of the first estimate. This estimate is shown in coïumn 3 of Table 4,

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[1] *Ibid.*, p. 259. It was reported that half of the value of all dues collected by the National Federation of Rice Growers has come from Tolima.

[2] The exception to this procedure was taken in estimating CICA-4's yield advantage since, given the specification of the regreusion, the yield advantage of CICA-4 rquals simply the negative value of the coefficient on Bluebonnet 50.

TABLE 4

Colombia: Altrrnative Values of the Supply Shift Parameter for Rice Attributable to Improved Varieties, 1964-1971

Year	Estimate [1]		
	Simple	Varietal effects	Varietal plus interaction effects
	1	2	3
	nercent		
1964	1.05	-0.17	2.18
1965	1.01	-0.15	1.90
1966	0.13	0.05	0.17
1967	- 0.17	0.38	1.65
1968	10.99	5.64	13.37
1969	12.81	4.91	14.85
1970	14.89	2.85	21.48
1971	15.96	8.16	32.12

Source: Based on Jorge Ardila, *"Rentabilidad Social. de las Inversiones en Investigacion de Arroz* en *Colombia"* (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1973), Tables 5, ll, 12, 13, 17, and 20.

along with the "direct varietal effects" estimate presented in column 2,[1] and a "simple" estimate of the yield advantage of the improvecl varieties (shown in column 1 of the table) which is based on the average annual yield data for each variety obtained in the *pruebas regionales* and already presented in Table 1.

The fact that the simple estimates of the shift parameter exceed the estimates which include just varietal effects from the regression is consistent with the finding that only the improved varieties of rice interacted with other variables of the production function. Since those interactions were on balance positive and are included ín the simple estimate but not ín the varietal-effects estimate, the simple estímate overstates the shift parameter by as much as 12 percentage points. Simílarly, the estimates based on the regression whích include varietal effects plus the variety interactíons exceed the varíetal-effects estimates because-variety interactíons were posítive valued, yet less widespread than available data indicated.[2]

The simple and varietal-effects estimates were combined with assumed values of the price elasticities of supply and demand to provide upper and lower bound estimates of gross social benefits of the new seed varieties

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[1]The estimates in these two columns evidence lower values for the shift parameters than the source (Ardila, *op. cit.*, Tables 17 and 20) by reason principally of the omission here of adjustments for "time." Ardila originally added to the yield differentials estimated from the production functions appropriate values of the coefficients on the time variables in each year. Since those coefficients are on net strongly positive for the 1964-1971 period, the effect was to increase estimated values of the shift parameters.

[2]The only data availnble related to the amount of riceland irrigated in each location.

for the period 1964-1971.[1] Values considered for the price elassicities of supply were zero, 0.2347, and infinity, the intermediate value being derived from the only supply study available for Colombian rice;[2] values considered for the price elasticity of demand were -0.5, -1.372, and -2.0, the intermediate value again having been estimated in another study.[3] Maximum gross benefits resulted from using the simple estimatcs of the shift parameter and pricc elasticities of demand and supply, respectively, of -0.5 and zero; minimum benefits corresponded to price elasticities of demand and supply of -2.0 and infinity and the varietal-effects estimate of the supply shift parameter. Both these estimates are shown in Table 5 for the 1964-1971 period.

Costs of the research program for the same period, also shown in Table 5, include direct costs, indirect costs, and complementary costs, definitions given these terms being those earlier used by Ardito.[4] Direct costs of the rice program were available only after 1964. For this reason available cost data were regressed on the number of employees assigned to the rice progrnm and ICA's total expenses for all research programs; the resulting regression coefficients and available data on the two independent variables of the

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[1]Calculations based on the varietal effects plus interaction effects shift pararneters are not included here but can be inspected in Ardila, *op. cit.*, Table 27.

[2]Nestor Gutierrez and Reed Hertford, *Una Evaluacion de la intervencion del Gobierno en el mercado de arroz en Colombia*, Folleto Tecnico No. 4 (Colombia: *Centro Internacional de Agricultura Tropical*, 1974), Table 3.

[3]*Ibid.*, Table 4.

[4]Ardito, op. *cit.*

TXBLE 5

Colombia: Estimated Renefits and Costs of the Rice Research Program, 1957-1980

Year	Estimated benefits		Estimated costs
	Maximum	Minimum	
	1	2	3
	1,000 (1958) pesos		
1957	a/		15
1958			193
1959			235
1960			286
1961			429
1962			441
1963			252
1964	3,733	599	445
1965	4,750	699	538
1966	553	213	519
1967	827	1,849	867
1968	61,659	26,887	937
1969	60,872	19,673	2,074
1970	69,444	1.1.,243	2,779
1971	107,470	43,488	4,165
1972-1980	107,543	43,517	4,202b/

a/ Blanks indicate no benzfits.

b/ This figure was assumed for 1972 and figures for subsequent years were estirnated by assuming 4,202 grew 10 percent annually.

Yources:

Cols. 1 and 2: Based on preced ng tnhles.

Col. 3: Jorge Ardila, *"Rentabilidad Social de las Inversiones en Investigacion de Arroz en Colombia"* (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1973), Tables 44 and 46.

regression were then used to estimate the direct cost data for the missing years, 1957-1965. Complementary costs associated with the new program--those it incurred with other collaborating programs--were estimated for this study by the Director of the National Rice Program. Included were costs associated with the entomology, plant physiology, plant pathology, soils, and extension programs. Indirect costs were taken to include staff training costs,[1] opportunity costs of the services of fixed capital and land, management costs, and the costs of "international cooperation" including a prorated share of personnel costs of Rockefeller Foundation staff stationed in Colombia from 1958 through 1968 and, most importantly, the total costs of the CIAT rice program from 1969 to 1972 cstimated by the head of that program. This latter item was the major cost. The simple sum of total costs for the 1957-1971 period equalled 14.2 million 1958 pesos, and the costs of international cooperation were calculated at 5.0 million or 35 percent of the total.[2]

Recognizing that the current stock of new varieties will continue to produce into the future, costs and benefits of the Colombian rice program were projectcd forward for nine years to 1980 using assumptions, when necessnry, which would bias downwards the estimate of interna1 rates of rcturn. It was assumed on the cost side, for example, that the real value of the cooperativeCIAT-ICA rice progrnm would increase at a rate of about

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[1]One staff member of the rice program was trained through the Ph.D., and four othcrs were trained through the M. S. costs oftrainingpersonnel of the National Federation of Rice Growers at the National University/ICA Graduate School were also included.

[2]Costs of international cooperation are still probably understated since benefits derived from the IRRI "capital stock" have not been charged to the Colombian program.

10 percent per year, primarily on the grounds that programs which are relatively new and reputedly successful tend to grow![1] On the side of the projection of gross benefits, it was assumed that thc value of production during the 1972-1980 período will average 581,000,000 pesos, a sum which equals the value of the rnther good 1971 crop (in 1958 pesos); that the rate of adoption of the new rice varieties after 1973 will stabilize at the estimated 1973 leve1 of 57.0 percent;[2] that the percent of riceland planted to IR-8 will trend downward linearly to zero by 1980; that the percentages of all riceland sown to IR-22 and CICA-4 w-I.11 be equal after 1973; and that the increase in the shift parameter these assumptions would imply will about equal increases in commercial yields over the period 1971-1980.[3]

The resulting interna1 rate of return corresponding to the stream of maximum gross benefits was found to be 82.3 percent; the rate estimated

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[1]Since this assumption was made, ICA's budget has been severely cut and CIAT's rice program has been phased down. Nonetheless, we hold to the initinl assumption in order not to ovcrstate the final estimate of the internal rate of return.

[2]This is a more moderate assumption than that used by Ardila, *op. cit.*, Table 35, who assumed that the percentage of area sown in improved rice would fall between 72 percent and 84 percent by 1980. The data of the LJ. s. Department of Agriculture, Economic Research Servicc, Development and Spread of High-Yie Lding Varieties of Wheat and Rice in che Les:;--Developed Nations, FAER No. 95, 1974, Table 38, indicating that adoption rates in the Philippines, Malaysia, and India are topping out at rates well undcr 60 percent, plus the analysis by Robert Evenson, "The 'Creen Kevolution' in Recent Development Experience," American Journal of Agr i-cultural Economics, Vol. 56, No. 2 (May, 1974), pp. 387-394, suggest that the use of improved variet ies may never reach 70 percent in Colombia and that an assumption of 57 percent is more conservative and probab le.

[3]The increases in yields would be 14 and 11 percent , respectively, for the maximum and mínimum values of the shift parameters.

on the basis of the minimum gross benefits stream was 58.0 percent.[1] 130th are well in excess of the social opportunity cost of capital of about 10 percent which has been calculated by Harberger for Colombia.[2] Costs in each year could have been 6.1 times larger than estimated, and the maximum gross benefits would still have provided a 10 percent return on investments in research; a 10 percent return would have been obtained on the stream of minimum gross benefits had costs been increased in each year by two times.

Cotton[3]

Cotton has turned in a striking growth performance in Colombia. Since the mid-1930's, yields have about quadrupled--in fact, their pattern of change has been broadly similar to that of the United States. Currently, Colombian cotton yields are comparable to U. S. yields and roughly twice as high as average yields for all South America (Table 6). In an earlier comparative analysis of changes in cotton yields, it was concluded that Colombia ranked fourth in terms of yield increases in the

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[1] Ardila, *op. cit.*, placed a range on the internal rate of return of 53.0 to 53.4 percent. The minimum (and the maximum) reported here would have been lower and lower than Ardila's estimates had the additional costs of the new varieties to farmers been netted out of "gross benefits." Data on those costs were simply judged to be too weak to include, however.

[2] A. C. Harberger, "*La tasa de rendimiento del capital en Colombia*, *Revista de Planeacion y Desarrollo*," Vol. I, No. 3 (October, 1969).

[3] This section is based largely on the work by Andrés Roche, "*Evaluacion Economica de la Investigacion sobre Variedades Mejoradas de Algodon en Colombia*" (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1972).

TABLE 6

Comparative Cotton Yield Stacistics
1934-35/1938-39 to 1973-74

Year	Colombia		United States	South America 1
	All crops 1	Cotton		
	1	2	3	4
	index	pounds per acre		
1934-35 to 1938-39	a/	133	212	181
1947-48	100	152	267	163
1950-51	115	167	269	175
1951-52	102	150	269	203
1952-53	109	227	280	197
1953-54	119	317	324	212
1956-57	143	319	409	178
1959-60	152	377	462	207
1962-63	176	398	457	231
1965-66	158	352	526	244
1966-67	164	470	480	232
1967-68	176	516	447	267
1970-71		463	437	222
1973-74 b/		470	519	249

a/ Blanks indicate no data available.

b/ Preliminary.

Sources:

Col. 1: U. S. Department of Agriculture, Economic Research Service, Changes in Agricultural Production and Technology in Colombia, FAER No. 52, 1969, Table 30.

Cols. 2-4: Secretariate, International Cotton Advisory Committee, Cotton-World Statistics (Washington, D. C.), various issues.

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1950-1960 period among those 24 countries of the world which produced 97 percent of all cotton in 1960.[1] Production after the mid-1930's increased at least 15 times or from about 30,000 bales in 1937-38 to over 500,000 bales in the early 1970's.[2]

Yields and production advanced most rapidly in two different but not widely separated periods of time: 1951-1954 and 1957-1959. Yields about doubled in the first period. Although khey did increase in the second, production evidenced a much larger inrrease of 167 percent, Dcvelopments in both periods appear to have been the direct result of changes in government policies.

The first period of rapid development followed the reopening of the Colombian Ministry of Agriculture in 1948 and new policy pronouncements emphasizing the need tu substitute imports of food and fibers with local production. In the case of cotton, rhis involved some protection--notably a requirement that the textile industry consume stated allotments of national cotton--which resulted in an 82 percent increase in the farm price between 1948 and 1951.[3] When the local textile industry was faced with the prospect of consuming larger quantities of national cotton, it promoted

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[1] Leurquin, "Cotton Growing in Colombia: Achievements and Uncertainties," Food Research Institute Studies, Vol. VI, No. 2 (1966), p. 145.

[2] These and other production and trade data cited in this section were obtained from the relevant number of Cotton-World Statistics published by the Secretariate of the International Cotton Advisory Committee, Washington, D. C.

[3] U. S. Department of Agriculture, Economic Research Service, Changes in Agricultural Production and Technology in Colombia, FAER No. 52, 1969, p. 76. In the same source it is shown that the price of rice rose 41 percent, and the price of sugarcane rose 49 percent.
Rice and sugarcane compete with cotton for the same farmlands in many areas of Colombia.

the establishment in 1948 of the Cotton Development Institute (IFA) for purposes of improving the quality and uniformity of local cotton through research and the control of ginning.[1] IFA, eventually a government institute with its own budget, also assumed responsibilies for cotton extension, seed distribution, and credit.

The second surge in production, occurring at the end of the 1950's, paralleled changes in exchange policies. The official exchange rate in Colombia was 2.5 pesos per U. S. dollar from 1951 through May, 1957. The free rate was 3.0 to 3.5 pesos through 1954 and then edged up to 6.9 pesos by mid-1957. On June 18, 1957, the official rate was increased to 7.6 pesos. Through the 1951-1957 period, the Colombian textile industry was permitted to import raw cotton and capital items at the official exchange rate. As a result, imports steadily built up to a leve1 of 77,000 bales in 1957; production stood at 95,000 bales in that same year. In 1958, following reforms, production jumped to 220,000 bales and, in 1959, reached 256,000 bales. Imports fell to 36,000 bales in 1958 and to slightly less than 2,000 bales in 1959, at which time Colombia also showed its first exportable surplus of cotton in severa1 decades. During the early 1960's, exports averaged about 100,000 bales and by 1968 had reached a leve1 of almost 300,000 bales.

As producers of cotton attained national prominence and power for satisfying domestic consumption and exporting a growing surplus, the National Federation of Cotton Growers (FNA) began to absorb IFA's functions. In 1968, IFA was dissolved completely; and its research and extension

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[1] Leurquin, "Cotton Growing in Colombia . . .," pp. 158 and 159.

activities were passed on to the ICA. Others of its activities were absorbed by the Ministry of Agriculture.

IFA's inheritance was meager when it assumed responsibilities for organized cotton research in 1948. On the advice of an English mission, some cotton research was begun in the Cauca Valley in 1928 but was later suspended when attention there turned to the prospects for sugarcane research by a visiting mission from Puerto Rico. Some research was established later (1934) in Armero, State of Tolima, to introduce and test U. S. Uplands and some Peruvian varieties. Most progress, however, up until 1948 had been made in improving the perennial tree cotton. A station on the outskirts of Barranquilla on the north coast is reported to have obtained yields of 350-400 kilos per hectare or at least twice the then prevailing average yield.[1] Nonetheless, one of the first things IFA did was to close that station as the quality of the tree cotton was considered inferior to imported cotton and tree cotton had become infested with diseases which threatened the introduction of annual varieties.

From the beginning, the Institute's sole research objective was the introduction, testing, and multiplication of improved U. S. cotton varieties. No attempt was made to produce a national variety until 1961, and that effort appears to have languished until IFA's research was absorbed by ICA in 1968.

ICA stated the first objective of its cotton research program to coincide identically with IFA's but added a second objective--the development of a national cotton variety through selection and hybridization. ICA also improved the design of research, expanded experimentation beyond

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[1] *Ibid.*, p. 154.

the three locations used by IFA (at Buga, Espinal, and Codazzi), and undertook more trials on a commercial scale as *pruebas regionales*.

Actually the first U. S. cotton variety was introduced into Colombia well before the establishment of IFA. Deltapine 12 was imported by cotton producers in 1941 and carne into general use in Tolima State during the 1940's. The year before, a Brazilian variety had been introduced, *Expresso do Brazil*; and it likewise gained acceptance in Tolima during the 1940's. In the late 1940's and the 1950's, Deltapine 15, Earlystaple, Coker 124, and Deltapine Smoothleaf were introduced. These so-called "T" type cottons carne to account for about 93 percent of all cotton production by 1959; Deltapine was by all odds the most important among them. Another 6 percent of production, mostly in the Cauca Valley, was a longer, finer "V" type cotton. The balance was "L" type tree cotton from the north coast and a short, staple length "S" type cotton (Lengupa) from Peru.[1] For 1961-62, IFA reported data showing that 92 percent of all production was from the Deltapine 15 variety; 5 percent from Coker 124; and the balance from Deltapine Smoothleaf, Deltapine 16, tree cotton, Lengupa, Delfos, Plains, and unspecified varieties.[2] By 1971, Deltapine 15 was no longer in use but Deltapine 16 accounted for 42 percent of all cotton acreage and Deltapine Smoothleaf for 38 percent, Acala 1517 BR-Z for 8 percent, and Stoneville 213 for 8 percent, with the remaining 4 percent being accounted for by Deltapine 45 and Coker 201.[3]

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[1] U. S. Department of Agriculture, Foreign Agricultura1 Service, The Cotton Industry of Colombia, FAS M-113, 1961, p. 8.

[2] *Instituto de Fomento Algodonero, Colombia: Su Desarrollo Agricola* (Bogota: Editorial Andes, 1962), pp. 51 and 52.

[3] U. S. Department of Agriculture, Foreign Agricultura1 Service, Cotton in Colombia, FAS-M 239, 1971, p. 11.

Because of the different nature of the catton research program--namely, its emphasis on the selection and multiplication of promising U. S. varieties rather than on the development of improved national varieties--contributions of research to yield increases and the specification of the shift parameter were envisaged differently than in the case of the Colombian rice program. Specifically, the shift parameter was seen to include three different factors.

First, if the cotton program successfully encountered and released U. S. varieties which out-yielded the Deltapine 12 and *Expresso do Brazil* varieties in general use when IFA was established, there would have occurred an increase in yield--analagous to the shift parameter defined for rice--and equal in a given year to

$$\sum^{n} \left(\frac{R_{di} - R_a}{R_t} \right) P_{1i}, \qquad (2)$$

where

R_{di} = yield of the ith improved variety

P_{1i} = percentage of cotton land planted to the ith variety

R_a = average yield for Deltapine 12 and Expresso varieties

and

R_t = average commercial yield of all cotton.

A second element to consider would be the change in yields which would have prevailed had new varieties been introduced and diffused by farmers in the absence of an organized research establishment, i.e.,

$$\sum^{n} \left(\frac{R_{di} - R_a}{R_t} \right) P_{2i}, \qquad (3)$$

where P_{2i} is the percent which would have been planted in the ith cotton variety. ihis expression would be subtracted from (2) in calculating the net shift parameter attributable in a given year to the cotton research program. It was hypothesized that (3) would be positive valued ín view of certain characteristics of the Colombian cotton industry. For example, there is the fact that the demand curve facing producers has been highly elastic because of the existence of an export market. Also, Colombian cotton production appears to have been concentrated in the hands of a small group of farmers. As of 1958, 422 fanners accounted for 61 percent of total production;[1] in 1967, 363 producers were reported to have accounted for 40 percent of all output.[2] The elastic demand curve would have served as insurance to individual innovators that prices and profits would not be eroded from increased production brought about by the diffusion of their innovations, and the fact that the industry was one of a few large farmers makes it more probable that a single individual or small group could have anticipated large enough rewards from search and research efforts to justify undertaking them.

A third and final factor to be considered in the specification of the shift parameter is the yield change which might have been brought about

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[1] *Idem,* The Cotton Industry of Colombia, p. 9.

[2] U. S. Department of Agriculture, Economic Research Service, Agricultural Production and Trade of Colombia, ERS-Foreign 343, 1973, p. 31. It is interesting to note that, at prevailing average yields, this would have implied that each large cotton producer was harvesting about 550 acres, given total production for Colombia of 465,000 bales in 1967. The data for 1958 imply that each of the 422 farmers was harvesting in that year only about 200 acres of cotton, suggesting that large cotton producers were major contributors to the increase in production which occurred between 1958 and 1967.

through less organized and independent research efforts which resulted in the introduction and use of cotton varieties in any year which were different from those actually observed to have been in use. This yield change can be expressed as

$$\sum_{n+1}^{m} \left(\frac{R_{di} - R_a}{R_t} \right) P_{3i}, \tag{4}$$

where P_{3i} denotes the adoption rate of the ith improved variety not currently in use; all other variables are defined as above. This factor, like (3), would be subtracted from (2) in the complete specification of the shift parameter (k) in any given year, i.e.,

$$k = \sum_{1}^{n} \left(\frac{R_{di} - R_a}{R_t} \right) (P_{1i} - P_{2i}) - \sum_{n+1}^{m} \left(\frac{R_{di} - R_a}{R_t} \right) P_{3i}. \tag{5}$$

It was assumed that the last element considered or (4) would be so small that it could be neglected. This was equivalent to an assumption that the organized research efforts of IFA and ICA left no stones unturned that would have been by the less organiaed, independent efforts of individual farmers.

Note that what is left in (5), namely,

$$k = \sum^{n} \left(\frac{Rdi - R_a}{R_t} \right) (P_{1i} - P_{2i}) \tag{5'}$$

could be zero valued in either of two circumstances: (1) if $(R_{di} - R_a)$ were negatively correlated with $(P_{1i} - P_{2i})$ or (2) if Rdi were equal for all varieties (although greater than R_a) since Sum $(P_{Li} - P_{2i}) = 0$ by definition.

The first of these two possibilities requires that farmers undertaking research independently would Lave been more effective in securing the adoption of the higher yielding, improved varieties than IFA and ICA. That, in turn, would require that farmers would have been more effective at identifying new varieties, importing them into the country, testing them, multiplying the most promising types, and releasing them to fellow farmers. Both organizations of research might have been equally fast testers of new imported varieties. But it has already been assumed that IFA and ICA were as efficient at identifying new varieties as individual farmers would have been. Further, because of their "official" status, the two institutes probably were able to import new varieties more easily and rapidly into Colombia; likewise, they had absolute control over the distribution of improved seeds.[1] Thus, it seems unlikely that a farmer-based research effort would have outperformed IFA and ICA and that the shift parameter in (5') would have been zero valued in any year as a result of a nrgative correlation between $(R_{di} - R_a)$ and $(P_{1i} - P_{2i})$.[2]

That the shift parameter in (5') might also be zero valued if yields of improved varieties were equal can be understood intuitively in the following terms. IFA's and ICA's programs were founded on a premise that yield differences existed among improved U. S. cotton varieties when cultivated in Colombia. A claim was made that it would be worthwhile to identify

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[1] IFA controlled al1 cotton gins.

[2] Note, however, that one of the implications is that it was the special privilegrs and franchises IFA and ICA possessed as official government agencies--not "pure differences" in the organization of research--which lead to this conclusion.

the value of these differences and key programs of seed multiplication and distribution on them in order to increase the positive correlation between $(R_{di} - R_a)$ and $(P_{1i} - P_{2i})$ in (5'). If, on the other hand, yields of all U. S. varieties harvested in Colombia were equal, then there would be no payoff to a program of varietal selection and distribution. Any farmer individually could import a variety of U. S. cotton selected at random and hope to obtain as good results as he would have obtained through an organized program of research like IFA's and ICA's.[1]

In order to explore this possibility more carefully, all available data were obtained on the IFA and ICA commercial trials which were comparable in design to those earlier reported for rice. The trials covered the period 1953-1972 and included 523 individual experiments. They are summarized in Table 7 which presents mean values of yields obtained for each of 10 cotton varieties. Additional trial data were destroyed when IFA's research was absorbed by ICA. Presumably they àncluded information on the two check varieties, Deltapine 12 and *Expresso do Brazil*.

It is evident from the data of Table 7 that gross differences in yields are not appreciable and that it would be difficult to reject the hypothesis that they were all, in fact, equal. For this reason a more refined test was made by estimating production functions from the trial data. In the final round of estimates, 23 variables entercd the regression; their estimated coefficients and related statistics are shown in Table 8. The first variable measures the quantity of nitrngcn applied

[1] There is another instance in which the IPA and ICA type of program would not pay, namely, when the distribution of yields by variety is the same in the United States and Colombia.

TABLE 7

Colombia: Average Yields of Seed Cotton by Variety Obtained from Commercial Trials Conducted in the 1953-1972 Period

Variety	Number of observations	Yield
		kilos per hectare
Deltapine 15	193	2,312
Deltapine Smoothleaf	71	2,369
Stardel	18	2,296
Stonville 213	39	2,375
Coker 124 B	12	2,634
Acala BR-2	48	2,287
Deltapine 45	9	2,693
Deltapine 45 A	40	2,575
Deltapine 16	42	2,457
Coker 201	27	2,568
Total/average[a/]	523	2,366

a/ Excludes 24 trials on other varieties.

Source: Andrés Rocha, *"Evaluacion Economica de Za Inves tigacion sobre Variedades Mejoradas de Algondon en Colombia"* (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1972), Table 10.

TABLE 8

Colombia: Production Function Estimates fox Cotton Based on Commercial Trial Data, 1953-1972

Independent variable	Estimated coefficient	Estimated standard error of coefficient
1. Nitrogen	2.58	0.53
2. .Irrigation	606.56	48.71
3. Parcel type	- 471.41	61.41
4. Rain deficiency	-1,150.22	47.60
5. Stardel	- 241.43	89.09
6. Coker 124 B	- 214.75	109.08
7. Acala BR-2	- 331.64	59.23
8. Location 1	381.53	88.86
9. Location 2	189.13	80.78
10. Location 3	600.73	94.34
ll. Location 4	1,094.14	149.39
12. Location 5	349.18	91.05-
13. Location 6	- 649.88	116.68
14. Location 7	- 408.99	181.04
15. Location 8	991.48	71.77
16. Location 9	408.49	62.74
17. Location 10	1,167.86	77.85
18. 1953	- 218.53	106.79
19. 1954	- 268.37	81.12
20. 1967	- 428.55	156.78
21. 1970	363.15	61.72
22. 1971	366.96	70.66
23. 1972	452.88	75.20
Intercept	2,081.20	a/
	R^2 = 0.82	n = 523

a/ Unavailable.

Source: Andrés Rocha, *"Evaluacion Economica de Za Investigacion sobre Variedades Mejoradas de Algondon en Colombia"* (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1972), Table 3.

per hectare, the second indicates simply whether or not irrigation was applied, the third adjusts for the fact that some of the trials were undertaken on plots which were "small" by *pruebas regionales* standards, the fourth is an index used by attending agronomists for the lack of rainfall, variables 9 through 17 adjust for the location of the experiments, and 18 through 23 adjust results for abnormal years.

Regression results indicated thst the only varieties out of the 10 tested with yields significantly different from Deltapine 15 were 3--Stadel, Cocker 124B, and Acala BR-2; in each case their adjusted yields were lower than those for Deltapine 15 and lower by rather similar amounts. On the basis of these results, it is concluded that no significant, positive benefits were derived from the Colombian cotton research programs.[1]

Wheat[2]

In an earlier study of production trends of Colombia's major crops, it was claimed that "the wheat situation in Colombia contains a number of paradoxes. Despite good experimental development and government programs to expand production, both acreage and output have declined sharply in

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[1]This is not to deny the role of fmproved U. S. varieties in increasing Colombian cotton yields. There are several references to their importance in the available literature. One of the strongest is International Bank for Reconstruction and Development, The Agricultural Development of Colombia (Washington, D, C., 1956), p. 86: ". . . it is the policy and program of the Cotton Institute to provide the full seed requirements for the entire cotton crop annually. Largely as i3 result thereof, the average yield per hectare of the cotton crop has doubled in four years."

[2]This section is based on the research of Carlos Trujillo, *"Rendimiento Economico de la Investigacion en* Trigo" (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1974).

to a shift in the regional distribution of wheat production from the higher-than-average-yield State of Boyaca to the State of Nariño in the south of the country where yields obtained on wheat have traditionally stood below the national average. (The impression is that production possibilities are limited in Nariño. In the *Espiga de Oro* maximum wheat yield trials, for example, sponsored by the Agricultura1 Credit Bank in 1967, the average yields reported by the 10 best wheat farmers in Boyaca and Cundinamarca were about 10 percent higher than yields obtained by the best farmers in Nariño.[1]) Another explanation for the unimpressive gains in wheat yields over the past 20 years is that experimental development has not been as successful as generally assumed. It will be shown in this section that the Colombian wheat research program has produced rather modest gains in yields.

The wheat improvement program is one of Colombia's oldest, dating from 1926 with the establishment of the La *Picota* experiment station in the central region of the country (State of Cundinamarca) for the purposes of improving yields and other characteristlcs of wheat, barley, oats, and rye. Through 1948, at least half of the total costs of the activities of La *Picota* were absorbed by wheat. In 1947, "cold climate" wheat research expanded out from La *Picota* to two additional locations: one at Bonza in Cundinamarca and another at Isla in Boyaca. A few years later, additional locations for tesearch were acquired at Tibaitata (Cundinamarca) and Obonuco (Nariño). Following the addition of the Surbatá Station in Boyaca ín 1959 for cold climate wheat research, activities were consolidated there, in Tibaitata, and in Obonuco--in just three locations.

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[1]Trujillo, op. *cit.*, Table C.5.

recent years."[1] Other more refined data now available--developed, in part, on the premise that the answers to some of the paradoxes might be the result of data errors--continue to show that both acreage and production have declined over the past 20 years. The area cultivated in wheat fell steadily from a level of 175,000 hectares in 1953 to about 70,000 hectares in 1973; over the same period production was halved. Yields increased by about 25 percent in the 1953-1958 period but stabilized at just above 1,000 kilos per hectare until 1972. In the most recent two years (1972 and 1973) for which information is available, yields may have again increased aad by about 20 percent.[2] Still, the average yield increase over the whole 20-yrar period has been rather unimpressive.

The best explanation currently available for the fall in acreage planted is that increasing P. L. 480 sales have served to dampen incentives of Colombian farmers to either maintain or increase farmland devoted to wheat production.[3] The quantity of wheat imported has increased over the 1953-1973 period from a third to almost three times the quantity of total wheat production.[4] The modest rise in yields, on the other hand, is in part attributable

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[1] U. S. Department of Agriculture, Changes in Agricultura1 Production . . ., p. 12.

[2] Data on production, land area planted, and yields of wheat prior to 1971 are from Roger Sandilands, *"Algunos problemas en Za seleccion de datos estadisticos* para trigo, cebada *y papa,"* **Informe** *Tecnico* No. 14, ICA (Bogota, 1974). Data for 1971-1973 are from the National Department of Statistics, DANE, Bogota.

[3] Many of the important issues involved are discussed by Leonard Dudley and Roger J. Sandilands; "The Side-Effects of Foreign Aid: The Case of P. L. 480 Wheat in Colombia," National Department of Planning (Bogota, 1972, mimeo.).

[4] The wheat import data are from the Food and Agriculture Organization of the United Nations, Trade Yearbook, various issues.

Colombia's wheat research has received important assistance from a number of different foreign and national organizations. In 1948, personnel of the program were sent to Mexico to study methods of wheat breeding with staff of the OIE in Mexico City, then supported by the Rockefeller Foundation. Later, in 1950, Rockefeller personnel were assigned to collaborate with the Colombian research program; the Foundation's assistance continued until the mid-1960's. In 1953, wheat seed distribution and multiplication programs received a lift from the Colombian Agricultural Credit Bank which ultimately assumed responsibility for them. In 1955 the National Federation of Rice Growers provided some support for research on the potential for wheat production in the warmer tropical areas traditionally destined to rice production; similar support was received in the same year (1955) from INA, the National Marketing Institute. PROCEBADA, a federation of barley producers, contributed to the budget of the wheat program in the 1959-1961 period for purposes of supporting an expansion of the *pruebas regionales* effort; support was received from the same purpose from FENALCO, a federation of Colombian cereal producers. In the 1967-1971 period, the wheat program benefited from inputs 'provided by personnel of the University of Nebraska Mission, financed by a consortium of international assistance agencies, including USAID and major U. S. foundations.

Data compiled on the costs of the wheat improvement program reflect these injections uf complementary support *from* outside and provide a profile of the development of the program. Table 9 presents data on the direct, complementary, and indirect costs of the program--comparable in all respects with the cost data earlier shown for the rice improvement program--plus data on the additional costs to farmers of the improved wheat seeds which were

TABLE 9

Colombia: Cost of the Wheat Research Program by Major Category 1927-1973

Year	Costs				Total costs
	Direct[a]	Complementary[b]	Indirect[c]	Added costs of new seeds[d]	
	1,000 (1972) pesos				
1927	184	e/	9		193
1928	236		9		245
1929	287		11		298
1930	338		12		350
1931	389		15		404
1932	441		17		458
1933	492		48		540
1934	543		52		595
1935	598		58		656
1936	653		63		716
1937	708		69		777
1938	709		78		787
1939	709		108		817
1940	710		120		830
1941	711		135		846
1942	670		143		813
1943	630		156		786
1944	589		170		759
1945	548		189		737
1946	508		207		715
1947	467		239		706
1948	416		255		671
1949	365		279		644
1950	315		351		666
1951	403		394		797
1952	492	88	440		1,020
1953	580	117	315	655	1,667
1954	669	74	349	2,638	3,730

(Continued on next page.)

TABLE 9--continued.

Year	Costs				Total costs
	Direct[a/]	Complementary[b/]	Indirect[c/]	Added costs of new seeds[d/]	
	1,000 (1972) pesos				
1955	758	93	385	242	1,478
1956	1,169	238	511	1,680	3,598
1957	1,117	232	562	282	2,193
1958	996	271	584	1,058	2,909
1959	841	265	483	1,170	2,759
1960	1,202	319	500	2,182	4,203
1961	914	388	510	3,002	4,814
1962	828	277	396	2,599	4,100
1963	615	280	280	2,717	3,892
1964	1,229	487	1,146	2,628	5,490
1965	1,889	658	585	5,548	8,680
1966	2,427	592	957	4,129	8,105
1967	2,150	993	2,307	8,731	14,181
1968	2,919	915	1,261	7,050	12,145
1969	3,045	1,314	2,768	5,623	12,750
1970	2,352	1,446	3,106	3,343	10,247
1971	2,020	1,603	3,260	2,901	9,784
1972	1,501	1,467	2,407	1,507	6,882
1973	1,570	1,385	2,354	1,626	6,935

a/ Salaries, supplies, and office materials directly related to the wheat varietal improvement program.

b/ Represents costs of the plant pathology, soils, entomology, biometrics, extension, and plant physiology programs incurred on behalf of the wheat improvement program.

c/ Includes costs associated with the use of experiment station facilities, agricultura1 machinery, and land as well as costs of administration and training of program staff.

d/ Equals the difference between the average price of certified wheat seeds and the price received by farmers times the quantity sold of certified seeds; for the period 1927-1949, improved varieties relevant to this study were not planted.

e/ Blanks indicate no data available.

Source: Carlos Trujillo, *"Rendimiento Economico de la Investigacion en Trigo"* (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1974), Tables 4.1, 4.2, 4.3, 4.4, and 4.5.

adopted after 1952. It is seen that, beginning in 1927, total costs built up slowly to a level by 1935 which was subsequently maintained for about 15 years. Following establishment of the joint Colombian-Rockefeller Foundation program, direct, complementary, and indirect costs again built up to a level of about 2,000,000 (1973) pesos which was maintained until 1964 with the exception of three years--1959, 1963, and 1964--the latter two being years of reorganization of the research agency. Investments began to drift upwards after 1964 and then increased sharply during the period of the University of Nebraska Mission, falling off after the Mission began to leave Colombia in 1971.

Research of the wheat improvement program can be classified into four broad categories: (1) cold climate wheats, (2) warm climate wheats, (3) *Triticales*, and (4) Durums. By all odds, the most important of these has been the first both in terms of its duration and the resources that have been devoted to it.

When the research program began in 1927, some promising cold climate wheats were introduced from the United States and tested over a six-year period, resulting in the release of 15 to farmers from the *La Picota* experiment station in 1933. By the early 1940's, the number of promising varieties available to farmers was 24. The best seven of these included Klein, General San Martin, Klein 40, Marzuolo, Pental, Florence, Barcino Barbados, and Bola Picota. As the latter two were "standard" improved varieties by the mid-1930's, they are considered in this analysis to be the check varieties. The first references to their yields indicated that between 850 kilos and 1.5 tons per hectare could be expected from them, while the other five of the best seven available varieties could be

reasonably expected to produce 1.8 to 2.8 tons per hectare under experimental conditions.[1]

The vast majority of promising wheats were obtained by crossing local *criolla* varieties. This led to a conclusion in the early 1940's that available foreign varieties were inferior to local Colombian wheats and resulted in the program's turning inwards until the arrival of foreign personnel in the early 1950's. When, with Rockefeller Foundation support, the OIE was established in Colombia, 11,000 varieties were immediately imported from the Rockefeller Mexican program. Selections were made from these imports on the basis primarily of their resistance to the yellow, black stem, and leaf rusts. These rusts had become the major preoccupation of the Colombian wheat improvementteamas a result of data produced in 1949 which showed that wheat yields were being cut 6 percent by leaf and stem rusts and by 14 to 41 percent as a result of yellow rust.[2]

The first commercial release of a new wheat variety after the establishment of the joint Colombian-Rockefeller Foundation program was of Menkemen 52. Distributed in 1953, it was the product of a cross of varieties from the Mexican collection, including Mentana and Kenya. It reduced time to maturity by 35 days, wos somewhat resistant to the major rusts, had strong stems, and outyielded Bola Picota by 30 percent. Two years later a second variety, Bonza 55, was released. It was the product of Roxamex varieties and the Yaqui and Kentana wheats. Because it was especially

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[1] *Estación Agrícola Experimental La Picota, In orme de labores de la sección experimental e industrial realizadas en 1935* (Bogota, 1937); also, *ibid.*, 1941 (Bogota, 1942).

[2] *Estación Francisco Jose de Caldas, "Influencia de Zas royas sobre el rendimiento del trigo," Proyecto I-SF-1949* (Bogota, 1951).

resistant to yellow rust of Nariño State, it was most widely distributed there. A third variety was released in 1959, Nariño 59; agnin, it was particularly well adapted to the State of Nariño, being resistant to its variety of yellow rust. Three years later (1962), a large batch of new varieties produced by the joint Colombian-Rockefeller program was released, including Maramar 63, Bonza 63, Crespo 63, Napo 63, Tiba 63, and Tota 63. At the time this release was made, the industry was advised that the research program would attempt to make "'batch releases" (i.e., releases of more than one variety) in the future in order to reduce susceptibility to new wheat rusts. Millers are reported to have reacted adversely to this announcement on the grounds that a single mill could not handls more than two varieties of wheat and appealed to the research team to revise its strategy. As ít turns out, the wheat program for cold climates made only one more additional release anyway, at which time (1968) Sugamuxi 68, Zipa 68, and Samaca 68 were distributed simultaneously.

The Colombian wheat plant began to change as the result of the introduction of dwarf varieties from Mexico in 1958. The effort to incorporate the smaller plant type characteristics did not, however, gain force and importance until about 1964. By 1970, 60 percent of allmaterials in the Colombian wheat research program included dwarf wheats. Of the 13 improved varieties released to farmers after establishment of the joint Colombian-Rockefeller program, small plant characteristico were incorporated in 9: Bonza 63; Miramar 63 and 64, Napo 63, Tiba 63, Tota 63, and the 3 varieties released in 1968. In this regard it is important to mcntion that practically none of Colombia's wheat is írrigated and that rafes of fertilizer use are low.

In 1971, ICA published the data shown in Table 10 comparing yields obtained under experimental conditions on small plots of land for 12 improved varieties and Bola Picota. The reported yield advantage relative to the Bola Picota variety was in excess of 500 percent for the highest yielding wheats but not less than 250 percent for any improved variety. By international standards, these yields of the Colombian varieties also appear to be quite good. Referring to Table ll and data published on the results of the International Wheat Trials of 1968, two of Colombia's most recently released wheats outyielded the best of the Mexican wheats, Azteca 67. The average leve1 of these yields, however, is extremely high even by experiment station standards in Colombia (e.g., those reflected in Table 10).

With reference to the second category of wheat research, namely, that undertaken on "warm climate" varieties, it is worth mentioning that large areas of wheat had existed in the *clima cálido* or warmer climates since the Colonial Period. However, these wheat areas were practically eliminated in the mid-1930's as a result of attacks by stem rust. Thus, in 1955 when the first rust-resistant varieties were available, the Federation of Rice Growers persuaded the research agency to experiment with Bonza and Menkemen in the Cauca Valley and Tolima State. Although the rust resistance of the new wheats was confirmed in these early experiments, they werc not continued because of the unpromising levels of wheat yields obtained. It was felt at the time that, in order for wheat to compete with rice, 2,500 to 3,000 kilos of wheat per hectare would be required. Commercial yields averaged 1,500 kilos,and maximum experimental yields did not exceed 2,750 kilos per hectare.[1]

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[1]Mario Zapata, *"Informe General del Programa de Trigo en Clima Calido,"* (Bogota, 1969, mimeo.).

TABLE 10

Colombia: Comparative Wheat Yields for 13 Varieties Obtained Under Experimental Conditions, 1970

Variety	Area planted	Reported yields	Reported yields compared with Bola Picota yield
	hectares	kilos per hectare	percent
Menkemen 52	0.095	2,820	427
Bonza 55	0.123	2,360	358
Nariño 59	0.106	1,700	258
Bonza 63	0.153	2,220	336
Miramar 64	0.101	2,535	384
Crespo 63	0.163	1,570	238
Napo 63	0.274	2,770	420
Tiba 63	3.740	3,017	457
Tota 63	0.200	2,680	406
Zipa 68	0.134	3,000	455
Samacá 68	0.050	3,700	561
Sugamuxi 68	0.223	2,300	348
Bola Picota	0.132	660	100

Source: Colombian Agricultura1 Institute (ICA), Informe del Programa Nacional de Trigo (Bogota, 1970), Appendix 4.

TABLE ll

Colombia: Comparative Wheat Yields Obtained for Colombian and Mexican Varieties in the International Nursery Trials, 1968

Variety	Country of origin	Reported yields
		kilos per hectare
Sugamuxi 68	Colombia	6,232
Crespo 63	Colombia	6,215
Samacá	Colombia	6,217
Azteca 67	Mexico	6,110
Tota 63	Colombia	6,954
Napo 63	Colombia	6,044
Tiba 63	Colombia	5,894
Penjamo 62	Mexico	5,833
Centrifén	Chile	5,755
Norteño	Mexico	5,538
Lerma Roja 64 x Sonora 64	Mexico	5,349
Sonora 64 x TZ.PP Nai. 60(B)	Mexico	5,249
Bonza 63	Colombia	5,233
Jaral	Mexico	5,166
Zipa 68	Colombia	5,116

Source: Colombian Agricultura1 Institute (ICA), Informe del Programa Nacional de Trigo (Bogota, 1968), p. 13.

The wheat program first experimented with rye as a rust-resistant, high-protein, water-saving alternative to wheat in 1937; and experiments with *triticales* were initiated in *La* Picota in 1946. Interest in *triticales* appears to have languished until very recently (1970). The wheat program has also evidenced interest through time in the Durum wheats. Work actually began on Durum in 1952 and was stepped up somewhat in che mid-1960's. However, successes have not been reported prfmarily because of the high humidity which prevails in Colombia's wheat areas, the short day length, and the sometimes heavy rainfalls which occur when the grains are maturing.

Again, as in the cases of rice and cotton, available data on the *pruebas* regionales were collected in an attempt to quantify the shift parameter and gross social benefits attríbutable to the Colombian wheat research program. The collection of these data was much more difficult in the case of wheat, however, because the information had been scattered by changes in the affíliatíon of the research program with other outside agencies. In the final analysis, only 1,016 individual trials werc obtained for the 1953-1973 períod; many more were undertaken on the major improved varieties.

Most of the trials obtained (about 80 percent) related to six varieties: Bonza 63, Crespo 63, Menkemen 52, Napo 63, Narino 59, and Tota 63. By region, most of the available commercíal trials were done in Cundinamarca and Nariño. Only about 5 percent were in areas of the State ot Boyaca. The Director of the National Wheat Program has stated that this does not reflect any slightlíng of the Boyaca wheat regions because there are many in Cundinamarca and Nariño which are fully representative of the areas in Boyaca. Given that wheat production in Boyaca has declined most sharply,

the facts here are important, although difficult to establish and qualify. Finally, it should be noted that most of the *pruebas regionales* data obtained (70 percent) were for five years including 1963, 1964, 1968, 1971, and 1972.

Table 12 summarizes the data collected for 13 improved wheat varieties and 2 check varieties, Bola Picota and "150." Mean yields in kilos Per hectare are reported by variety, together with the estimated standard error of yields and the range of trial yields corresponding to a 5 percent leve1 of probability, as well as the coefficient of variation of yields. It can be seen that these data assign different relative yíeld ranks to specific varíeties compared with those ranks implied by Table 10. For example, in Table 12 the yield of Menkemen 52 puts it ín 12th place among the improved varieties, while its yield in Table 10 ranks it in third place. Also, the average leve1 of yields reported ín Table 12 is lower than the avérages of Tables 10 and 11; and the yield advantage of the improved varietíes is noticeably less than indicated by ICA on the basis of its data for a single year, previously shown in Table ll.

The range in yields of most improved varieties ín Table 12 is such as to include the upper bound yields reported for Bola Picota and "150." The only exceptions to this are the Samaca 68 and Bonza 63 improved varieties, lower bound yields for which are well above the upper bound yields of tha two check varieties indicating that these two improved varieties have a significant yield advantage. The yield advantages of Samaca 68 and Bonza 63, as a percentage of the average yields of "150" and Bola picota, are 83 and 75 percent, respectively; the corresponding value for all improved varieties shown in Table 12 is 50 percent.

TABLE 12

Colombia: Comparative Wheat Yields for 15 Varieties Obtained in Commercial Trials 1953-1973

Variety	Number of observations	Output per hectare				Coefficient of variation of yields
		Mean	Standard error	Range at 5 percent probability		
				Lower bound	Upper bound	
		kilos				percent
"150"	8	1,624	1,022	771	2,476	62.9
Bola Picota	8	1,194	895	448	1,941	74.9
Samacá 68	47	2,584	1,592	2,117	3,051	61.6
Bonza 63	106	2,460	1,197	2,230	2,690	48.7
Miramar 63	29	2,348	1,218	1,885	2,812	51.9
Zipa 68	31	2,190	1,382	1,684	2,697	63.1
Bonza 55	77	2,172	1,504	1,831	2,513	69.2
Crespo 63	129	2,115	1,369	1,876	2,353	64.7
Tiba 63	51	2,110	1,265	1,754	2,466	59.9
Nariño 59	119	2,106	1,351	1,861	2,352	64.1
Napo 63	136	2,097	1,340	1,869	2,324	63.9
Sugamuxi 68	12	1,973	1,157	1,238	2,708	58.7
Tota 63	104	1,893	1,283	1,643	2,142	67.8
Menkemen 52	138	1,836	1,237	1,627	2,044	67.4
Miramar 64	21	1,643	1,496	960	2,326	91.1
All varieties	1,016	2,099	1,340	2,027	2,175	66.1

Source: Carlos Trujillo, *"Rendimiento Economico de la Investigacion en* Trigo" (unpublished M. S. thesis, ICA/National University Graduate School, Bogota, 1974), Table 5.7.

In order to adjust these estimates of the gross yield advantage of the improved wheat varieties for the effects of other determinants of yields, production functions were estimated from the commercial trials data. The final version of the production function is shown in Table 13. Thirty-nine variables entered: 12 of these represented zero-one adjustment variables for the location of the trials; 14 adjusted for the effects of variety; 4, measured as indices above a certain threshold leve1 and zero otherwise, accounted for major diseases reported (*vaneamiento*, foot and root rot, stem rust, and dwarfing virus); 1 adjusted for seeding rates of 80 kilos per hectare (only two rates were actually reported--80 and 110 kilos per hectare); 2 each were used to adjust for soil type nnd reported weather; and 1 variable each adjusted for how well the soil had been worked prior to planting, for weed growth, and for the application of lime. Coefficients on the noneontinuous variables shown in Table 13 need to be read with some care. Since fhe regression package reparameterized all variables by imposing a restriction that the sum of the regression coefficients equal zero, an estimate of the corrected mean yield associated with a given noncontinuous variable should be calculated by adding its estimated coefficient to the overa11 mean value of yields, which was 2,099 kilos per hectare.

The statistical significance of the variety variables entering the regression was surprisingly low. Only the estimated coefficients on the Bonza 63 and Crespo 63 varieties were very positive and significant. In an independent estimate made of the partial contribution of the variety variables as a group to the explanation of the variance of yields, the significance of the variety variables was found to be less than that of

TABLE 13

Colombia: Production Function Estimates for Wheat Based on Commercial Trials 1953-1973

Independent variable	Estimated coefficient	Estimated t statistic
1. Vaneamieato	13.8	- 6.98
2. Foot Rot	11.1	- 5.75
3. Stem Rust	8.6	- 3.18
4. Dwarfing Virus'	15.8	- 3.73
5. Plot size	48.5	- 5.88
6. Seeding rate	- 225.0	- 3.69
7. Good soils	482.7	8.10
8. Poor soils	- 340.2	- 4.31
9. Poor prior soil preparation	- 157.1	- 2.68
10. Heavy weed growth	- 300.6	- 6.79
ll. Unfavorable weather	-1,333.9	-10.20
12. Favorable weather	895.4	8.43
13. Lime applicd	154.1	2.35
14. Location 1	- 732.0	- 3.21
15. Location 2	3,672.8	16.40
16. Location 3	692.4	7.37
17. Location 4	1,604.9	9.24
la. Location 5	- 466.9	- 2.29
19. Location 6	-1,084.6	- 4.44.
20. Location 8	- 349.1	- 3.12
21. Location 9	- 644.9	- 5.38

(Continued on next page.)

TABLE 13--continued.

Independent variable	Estimated coefficient	Estimated t statistic
22. Location 10	- 831.1	- 6.60
23. Location 11	- 812.2	- 1.94
24. Location 12	- 856.6	- 3.05
25. Location 13	49.1	0.56
26. Menkemen 62	- 113.2	- 1.20
27. Bonza 55	98.8	0.89
28. Nariño 59	163.8	1.70
29. Miramar 63	- 375.5	- 2.17
30. Bonza 63	340.5	3.27
31. Miramar 64	- 300.3	- 1.46
32. Crespo 63	210.9	2.12
33. Napo 63	131.7	1.44
34. Tiba 63	- 169.2	- 1.28
35. Tota 63	80.7	- 0.77
36. Zipa 68	- 152.8	- 0.92
37. Samacá 68	196.9	1.22
38. Sugamuxi 68	210.3	0.80
39. Bota Picota	- 303.5	- 0.91
Intercept	2,460.8	15.73
	R^2 = 0.53	n = 1.016

Source: Carlos Trujillo, *"Rendimiento Economico de Za Investigacion en Trigo"* (unpublished M. S. thesis, ICA/National University Gradunte School, Bogota, 1974), Table 5.14.

any other single variable or group of variables (e.g., the variables adjusting for location).

Also, the value of the estimated yield advantage of most of the improved varieties is lower on the basis of the regression of Table 13 than on the basis of the unadjusted estimates of mean yields earlier presented in Table 12. The largest and most significant yield advantage of any improved variety in the regression--that of Bonza 63--is only 36 percent more than the adjusted yield of Bola Picota or roughly half the value implied by the unadjusted yield estimates of Table 12.

Table 14 presents summary statistics on the use of the improved varieties of wheat. Underlying these summaries are data for each improved variety used in weighting shift parameters taken from the estimated production function to arrive at an average annual estimate of the percentage yield increase over average commercial yields attributable to improved wheats. Two estimates of these weights were considered, and their implications for overa11 rates of adoption are reflected in Table 14 in the "upper bound value" and the "most probable value" of the percent of wheatland planted to improved varieties. The first simply assumes--as in the case of rice--that the total use of an improved variety equalled in any year two times its reported sales of certified seeds and that the average' seeding rate is 120 kilos per hectare for all varieties. As can be seen in the table, this assumption results ín levels of adoption in che late 1960's which are high by known standards for unirrigated wheat. The second estimate--and the one used in this study--maintained thc assumption that the total seed useof any variety would equal two times its certified sales but set the germination rate of certified seeds at 86 percent and the

TABLE 14

Colombia: Selected Data on Employment of Improved Wheat Varieties, 1953-1973

Year	Total certified seed sales	Wheat land in improved varieties	
		Upper bound value	Most probable value
	tons	percent	
1953	147	1.4	0.9
1954	1,039	8.9	5.6
1955	113	0.1	a/
1956	639	5.2	3.3
1957	599	5.5	3.4
1958	1,610	22.0	13.7
1959	3,050	43.4	27.1
1960	2,149	28.7	17.9
1961	2,830	33.7	21.1
1962	2,470	31.7	19.8
1963	2,100	31.8	19.9
1964	1,864	27.0	16.9
1965	2,782	38.6	24.1
1966	3,102	45.0	28.1
1967	3,795	66.6	41.6
1968	4,494	83.2	52.0
1969	2,811	72.1	45.1
1970	1,694	56.5	40.9
1971	1,621	56.3	35.2
1972	1,527	40.4	25.3
1973	1,429	33.2	20.7

a/ Negligible.

Source: Carlos Trujillo, *"Rendimiento Economico de la Inves tigacion en Trigo"* (unpublished M. S. thesis, ICA/National University Craduate School, Bogota, 1974), Tables B.3, 5.17, and 2.10.

corresponding rate for seeds retnined and planted by fnrmers from prior harvests at 39 percent.[1] The same estimate of seeding rates was used. Since the sum of the two germination rates is 125, the effect of this procedure is to assume that the real, post-germination rate of employment of an improved variety was 1.25 times the quantity of it sold in certified form.

Estimates of the yield advantage of each improved variety taken from the regression, divided by average commercial yields in each year and weighted by the appropriate adoption rate, produced two strearns of gross benefits for the 1953-1973 period of the Colombian wheat improvement program. In each case it was assumed that the c.i.f. import price of wheat was the relevant "price" at which to value the crop.[2] However, in one of the estimates, it was assumed that the price elasticity of supply of wheat equalled 0.55 and that the price elasticity of demand was -0.04. These values of the price elasticity parameters were derived from estimates of two independent studies.[3] For the second estimate of gross benefits, it was recognized that wheat was imported throughout the 1953-1973 period and that the value of gross benefits should be modified for reasons discussed earlier with reference to Figure 4.

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[1] Trujillo, op. *cit.*, Table 2.10.

[2] Because of the overvaluation of the Colombian peso, this assumption results in an underestimate of the gross henefits of research. It was found, however, that the estimated interna1 rate of return to the wheat improvement program would increase by only 4 percent if instead the (higher) price received for wheat by farmers was used.

[3] The price elasticity of demand estimate is from ICA, *"Un metodo de proyectar Za produccion y demanda para productos apicolas en Colombia,"* *Boletin de Investigacion* No. 15 (Bogota, 1971); the price elasticity of supply estimate is from LJ. S. Department of Agriculture, Economic Rcsearch Service, Measures of the Degree and Cost of Economic Protection of Agriculture in Selected Countries, Technical Bulletin No. 1384, 1.967.

Thc two estimates of gross benefits, as well as total costs earlier shown in Table 9, were then projected through 1976 on assumptions similar to those used in the case of rice. Thc interna1 rate of return estimated for the "closed economy" case corresponding to the stream of net program benefits (gross benefits minus costs) for the 1927-1976 period was ll.9 percent. When allowance was made for the fact that wheat was imported, the estimated interna1 rate of return increased to 9.0 percent.

Soybeans[1]

Soybean production in Colombia has experienced very rapid growth in recent years. The total area cultivated was only 16,000 hectares in 1962; production stood at 25,000 tons, and yields were 1,500 kilos per hectare in the same year. By 1972, or just 10 years later, the area harvested had increased to 58,000 hectares, production was 116,000 tons, and yields had risen by a third to 2,000 kilos.[2] This rapid development is attributed to the fact that soybeans are excellent in rotation with severa1 major crops (cotton, in particular) and that the demand for soybeans has been strengthened by a fast-growing poultry industry, The crop is cultivated ín Colombia only in the Cauca Valley, and its location there has been attributed to the nearness of the feed industry. An equally important explanation, however, is that available high-yielding, disease-resistant soybean varieties produced by the ICA experiment station at Palmira have been adapted to conditions of the Cauca Valley.

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[1] Based on the research by Gabriel Montes, *"Evaluación de un Programa de Investigación Agrícola: El Case de Za Soya"* (unpublished M. S. thesis, Faculty of Economics, University of the Andes, Bogota, 1973).

[2] *Ibid.*, Table 4.

ICA d-id not initiate activities in soybean research until 1960, and then work was restricted to the Palmira station. In about seven years, however, the research effort succeeded in producing three new varietics with superior yield potential and resistance to major diseases, the principal one being *cercóspora*, a fungus which attacks and destroys almost all parts of the soybean plant. Table 15 summarizes experimental data relating to yields of four soybean varieties obtained for this study of returns to soybean research. Unfortunately, data gencrated from commercial fields or *pruebas regionales* were unavailable; thus, the information used in Table 15 and elsewhere in this section relates to small experimental plots of the Palmira station.[1] The ICA Pelican, Lili, and Taroa varieties were successivc releases of the experiment station. The Mandarin variety was imported earlier from the United States and by 1967 had come to occupy about four-fifths of all soybean acreage. In terms of the data previously shown for cotton, rice, and wheat, the yield superiority of the improved varieties in Table 15 is not particularly outstanding.

Nonetheless, adoption of the new varieties has been nothing short of spectacular. Table 16 presents the percentages of soybean acreage planted to each of the four main varieties grown in the 1967-1971 period. These data were estimated using a procedure analagous to the one followed for other crops included ín this paper; i.e., total acreage planted to a variety in a given year was taken equal to two times certified seed sales

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[1]The use of experimental data is somewhat less troublesome in the case of soybeans because of the high leve1 of technology and improved practices used by farmers in the Cauca Valley.

TABLE 15

Colombia: Average Soybean Yields From Experimental Trials by Variety 1967-1971

Year	Unimproved variety, Mandarin	Improved varieties		
		ICA-Pelican	ICA-Lili	ICA-Taroa
	kilos			
1967	2,068	2,406	a/	2,490
1968	2,329	2,373	2,700	2,650
1969	1,756	2,138	2,525	2,400
1970	1,751	2,373	2,300	2,500
1971	1,828	2,578	2,410	3,034
Average	1,946	2,455	2,483	2,622

a/ No experiment reported.

Source: Gabriel Montes, *"Evaluación de un* ***Programa*** *de Investigación Agrícola: El* ***Case*** *de Za Soya"* (unpublished M. S. thesis, Faculty of Economics, University of the Andes, Bogota, 1973), Table 3.

TABLE 16

Colombia: Land Area Planted to Improved Varieties of Soybeans as a Percentage of the Total hrea Planted in Soybeans, 1967-1971[a/]

Year	Variety					Total
	Mandarin	ICA-Pelican	ICA-Lili	ICA-Taroa	Other	
	percent					
1967[b/]	89	1	[c/]		10	100
1968	77	13			10	100
1969	71	18	5		6	100
1970	35	29	24		12	100
1971	2	43	41	2	12	100

a/ Estimates derived from data on certified seed sales, assuming that the total use of a variety of seeds equaled two times its sales in certified form.

b/ Only data on ICA-Pelican use were available. The Mandarin estímate was derived on the assumption that "other" varieties occupied 10 percent of all acreage planted In 1967 as they did in 1968.

c/ Blanks indicate less than 0.5 percent.

Source: Gabriel. Montes, *"Evaluación de un Programa de Investigación Agrícola: El Case de la Soya"* (unpublished M. S. thesis, Faculty of Economics, University of the Andes, Bogcta, 1973), Table 6.

of that variety divided by an estimate of the seeding rate. The important point to note about the data of Table 16 is that roughly three-quarters of the area planted in soybeans was in the Mandarin variety in 1968 and 1969, while by 1971--just two years later--Mandarin had practically disappeared, and the ICA Pelican and Lili varieties had come to be used on 84 percent of all acreage.

The major reasons for the rapid and high levels of adoption of the improved varieties are two. First, there was a severe outbreak of the *cercóspora* fungus on the Mandarin variety in 1969. ICA found itself in 1970 in the enviable position of having two high-yielding, fungus-resistant varieties available for distribution and plenty of seed. Second, it was easy for this news to get around; the only Colombian farmers interested in soybean production are located in a relatively small geographic area with some of the best communication and infrastructure facilities that exist in the country.

As in the cases of cotton, rice, and wheat, an attempt was made to generate more refined estimates of the yield superiority of the new soybean varieties by means of the identification of a relation between yields and their major determinants, including seed variety. Final results of this effort are shown in Table 17 reporting on a rcgression of experimental yields on three independent variables for the major improved seed varieties (observations on the check variety, Mandarin, were included in the regression, of course), the number of times the experiment was weeded, kilos per hectare of active herbicide and insecticide ingredients applied, millimeters of rainfall, the presence of the *cercóspora* fungus neasured as an index with a range of 0 to 5, and an index (likewise with a 0 to 5

TXBLE 17

Production Function Estimates for Soybeans
Based on Experimental Data
1967-1971

Independent variable	Estimated coefficient	Estimated t statistic
1. ICA-Pelican	268.44	3.06
2. ICA-Lili	418.31	3.93
3. ICA-Taroa	436.95	4.37
4. Number of weedings	86.93	2.43
5. Herbicide use	78.45	2.35
6. Rainfall	113.11	1.75
7. Cercóspora	-107.30	-3.68
8. Plant density/Seeding rate	200.80	4.58
Intercept	692.08	a/
	R^2 = 0.70	n = 68

a/ Unavailable.

Source: Gabriel Montes, *"Evaluación de un Programa de Investigación Agrícola: El* Case *de la Soya"* (unpublished M. S. thesis, Faculty of Economics, University of the Andes, Bogota, 1973), Table 8.

range) which reflected essentially the ratio betwecn the observed plant density and the seeding rate. Signs of all estímated coefficient-s are those which were hypothesized at the outset, and the significance of most coefficients is seen to be hígh. The low statístical significance of the estimated coefficient for rainfall reflects the fact that rainfall variability was limited because most experiments were undertaken in a small geographic area. The statístical strength of the plant densíty/seeding rate variable is attributable to the fact that it is capturing the effects of severa1 unspecified cultural practices used in the experiments.[1] The fact that the coefficients on the improved varietíes increase in value from Pelican (the fírst released) through Lílí to Taroa (most recently released) indicates substantial progressíon in ICA's research program. A test of the null hypothesis that the estimated coefficient on the Pelican varíety equalled that of the Lili variety was rejected at the 99 percent leve1 of significance. Similarly, the hypothesis'that the coefficients estimated for the Lili and Taroa varieties are equal was rejected at the 95 percent level.

The yield advantage of the improved varíetíes taken from the production function, divided by commercial yields and weíghted by the percentages of the land area planted ín each variety, led to a "varietal effect" estimate of the shift parameter. The yield advantage of the improved varíeties estimated directly from the data of Table 15, likcwise divided by commercial yields and weighted by che percentages of the land area

[1] Thís variable may thereby have adjusted to some extent estímated coefficients on the ímproved varieties for the experimental nature of the data--the hígh levels of technology and intensive use of improved cultural practíces.

planted in each variety, led to a "simple" estimate of the shift parameter associated with the soybean research program. These two estimates of the shift parameter were combined with plausible values for the price elasticities of demand and supply--respectively, -0.77[1] and infinity--to yield a range of gross benefits in each year for the 1967-1971 period. These two streams of gross benefits are shown in Table 18 along with estimates of the costs of the soybean research program which include the same categories of expenses included in the cases of the other three commodities considered in this paper. Costs and benefits were projected nine years beyond 1971 on the assumption that in real terms they would both remain about constant. The resulting internal rate of return for the smaller benefit stream was 79 percent, while the rate corresponding to the larger benefit stream was 96 percent. These rates did not change appreciably when program costs were assumed to increase 10 percent per year after 1971.

Conclusions and Possible Explanations for the Different Levels of Returns to Research

The studies of the Colombian varietal improvement programs were undertaken with an expectation that their economic returns had been uniformly higher than those of the order of 50 percent estimated for similar agricultural research programs in the United States. The expectation of high returns reflected an assumption that Colombia had been able to reduce gestation periods and total costs of its programs, while achieving impressive increases in yields, by being a late comer to the research game and thus

[1]The price elasticity of demand estimate was suggested by the results of James P. Houck, "A Statistical Model of Demand for Soybeans," The Journal of Farm Economics, Vol. 46, No. 2 (May, 1964), pp. 371 and 372.

range) which reflected essentially the ratio between the observed plant density and the seeding r-ate. Sígns of al1 estimated coefficicnts are those whích were hypothesized at the outset, and the significance of most coefficients is seen to be high. The low statistical significance of the estimated coefficient for raínfall reflects the fact that rainfall variability was límited because most experiments were undertaken in a small geographíc area. The statístícal strength of the plant density/seeding rate variable ís attributable to the fact that it is capturing the effects of severa1 unspecifíed cultural practices used in the experiments.[1] The fact that the coefficients on the improved varíeties increase in value from Pelican (the first released) through Lili to Taroa (most recently released) indicates substantíal progression in ICA's research program. A test of the null hypothesis that the estimated coefficient on the Pelican variety equalled that of the Lili variety was rejected at the 99 percent leve1 of significance. Símílarly, the hypothesís that the coefficients estimated for the Líli and Taroa varieties are equal was rejected at the 95 percent level.

The yíeld advantage of the improved varieties taken from the production function, divided by commercial yields and weighted by the percentages of the land area planted in each varíety, led to a "varietal effect" estímate of the shift parameter. The yield advantage of the improved varieties estimated directly from the data of Table 15, likewise dívidcd by commercial yields and weighted by the percentages of the land area

[1] This variable may thereby have adjusted to some extent estimated coefficients on the improved varieties f *or* the experimental nature of the data--the high levels of technology and inttnsive use of improved cultural practices.

TABLE 18

Colombia: Estimated Benefits and Costs of the Soybean Research Program, 1960-1980

Year	Gross benefits		Total costs
	Based on "varietal effect" shift parameters	Based on "simple" shift parameters	
	1,000 (1958) pesos		
1960	a/		40
1961			41
1962			37
1963			39
1964			33
1965			37
1966			40
1967	49	62	57
1968	1,288	2,230	98
1969	3,102	6,187	179
1970	7,847	16,300	463
1971	10,217	28,643	267
1972-1980	10,217	28,643	267

a/ Blanks indicate no benefits during this period.

Source: Gabriel Montes, *"Evaluación de un Programa de Investigación Agrícota: El Case de* Za *Soya"* (unpublished M. S. thesis, Faculty of Economics, University of the Andes, Bogota, 1973), Tables 14 and 21.

having available to it a larger accumulated stock of knowledge about plant breeding techniques and more extensive international collections of plant materials.

Results, however, did not confirm the expectation of uniformly high returns. Calculated rates for rice and soybeans exceeded the 10 percent social opportunity cost of capital by a rather handsome margin; estimated internal rates of return for wheat research, on the other hand, were about equal to 10 percent, and returns to cotton research were either nil or negative valued.

Even more interesting, perhaps, than the average level of returns are the differences in returns evidenced between programs and the explanations for them that can be inferred from the preceding analysis. Among those listed below, the first three are rather more general while the others are largely the result of the data and methodology which have been used. Both groups of explanations for the variance in rates of return logically constitute areas where I believe additional analysis and data should be brought to bear in future studies which either attempt to evaluate past programs or assess prospects for new proposals for varietal improvement.

Concentration of the Industry

It has been seen that the organization of the industry for a commodity can be a crucial factor in inducing research, in defining major research objectives, and in affecting the adoption and distribution of research results, especially where that organization involves some concentration of producers. Colombian farmers and related industry interests in the cases of rice and cotton took a particularly activist role in the establishment and development of research programs on those two commodities. Their

actions--real and hypothesized--explain a part of the high return to rice research and most of the low return to cotton research.

Increased Availability of Key Complementary Inputs

Research objectives, as well as the distribution, adoption, and benefits of research, are affected Uy the availability of key complementary inputs like irrigation water. An important case in point was the interaction of irrigation and varietal research on rice. Major industry interests were in the irrigated rice areas, most research was undertaken there, and the resulting improved varieties benefited primarily irrigated rice farmers.

Other Factors Inducing Shifts in the Demand and Supply of Research

Other externa1 forces, necessarily articulated by farmers or related industry groups, dete-rmined to a certain extent when the cotton, rice, and wheat programs were established, what their content would be and, for these reasons, their estimated returns. Special reference is madc to the outbreaks of major crops diseases, policies which increased the costs of food and fiber imports, and forcign technical assistance. It was seen, for example, that an outbreak of *hoja blanca* disease was associated with tne launching of rice research, that prospects of increasing costs of imported cotton launched cotton research, and that foreign technical assistance was associated with very productive periods in the histories of the Colombian rice and wheat research programs.

Lack of Comparable Program Data

The relations between yields and their determinnnts estimated for each of the four programs for purposes of isolating the yield effects of

the improved varieties were not strictly comparable. The number and definitions of variables included varied between programs, and this may account for some of the differences in estimated rates of return. The absence of comparable research data between programs--to say nothing of the lack of comparable data on programs as between different points in time--may pose a major obstacle to more refined evaluation and planning of the use of research resources in Colombia and perhaps Latin America.

Missing Information About Adopting Patterns

Because of the absence of information on the determinants of the adoption of improved varieties, as well as even data bearing on adoption experiences in other countries, benefits of the four Colombian varietal improvement programs were projected into the future on assumptions common in practice but admittedly crude. This implies that differences in benefits and rates of return are related to the age of the research program since errors of projection should be largest where the remaining life of improved varieties is greatest.

Effects of Disease

At low levels of adoption of improved disease-resistant varieties, on-farm yields will be reduced by outbreaks of disease; and that reduction will be translated into an increase in the shift parameter attributable to the new varieties, given methodology used in this paper. However, when adoption of disease-resistant varieties has progressed to higher levels, on-farm yields fail to reflect what would have happened were the resistant varieties not planted. Correspondingly, the shift parameter and program benefits may be understated unless interactions between disease and varieties

can be identified and incorporated into rates of return estimates. They were not, however, in the studies reported in this paper and have not been fully incorporated into evaluations of the economic returns to agricultural research undertaken by other authors. The reason is simply that the disease-variety interactions are extremely difficult to simulate; much better data and analysis on them are needed.

Germination Rates

One of the side benefits of a research program in developing countries is the establishment of seed certification and distribution programs which, based just on the data presented for wheat in Colombia, may sharply increase yields for given seeding rates. More needs to be known about this, but it would appear that some part of the variance in returns to research in Colombia--a part of the lower returns, for example, to wheat research--is explained by changes in the rates of seed germination associated with seed certification programs.

Missing Information on National Program Costs

Cost-accounting practices followed by ICA and predecessor agencies over the period studied here made difficult the estimation of total costs associated with the varietal improvement programs. The ways in which these difficulties were overcome may account for some of the variation in returns between individual Colombian programs. If practices followed in Colombia have been used elsewhere in research agencies in Latin America, some additional attention should be given cost data as a prior step to either making estimates of economic returns to research or assessing returns to future programs.

Missing Data on International Research Programs

Not unrelated is the issue of costing appropriately the contributions of international centers and international seed collections to national programs of research. In the calculations of the preceding sections, costs of international programs directly associated with the Colombian pi-ograms were included when data were available and the role of the international program was unambiguous. What is really needed, however, is an estimate, not of the costs but of the benefits of international programs to Colombia. Because such information was unavailable--a surprising fact, in my judgment--some part of the economic returns attributable to at least the rice and wheat programs may be explained by benefits they received from international programs which were not appropriately included in costs or otherwise subtracted from benefits. Estimates of the returns to the international programs of research and outreach are urgently needed if accurate assessments of national research strategies are to be made in the future.

Farmers' Search and Research

The analysis of the Colombian cotton research program highlighted costs which have not been taken into account in other assessments of economic returns to research--namely, varietal improvements which would have been accomplished by farmers on an individual, informal, and perhaps ad hoc basis in the absence of an organized program of research. To the extent that such improvements would have been important in the cases of rice, soybeans, and wheat, but were not included in the calculations of interna1 rates of return, some of the differences between rates may be attributable to them. More generally, perhaps, it should be recognized that farmers must engage in

some independent search and research prior to adopting improved seed varieties generated through organized research. These costs--involving primarily the labor time of farmers--were not included in the estimates reported here and have not been taken into account in other evaluationu of returns to research. Their omission obviously gives rise to another possible source of differences between estimated rates of return to organized research.

Possible Mismeasurement of Surpluses

The second section of this paper, which reviewed some fundamentals of the methodology used in succeeding sections, pointed out that the cconomic surpluses which are equated with the benefits of research are not unambiguous concepts and that their measurement is subject to errors--which errors, of course, may constitute another explanation for differcnces in estimated rates of returns to the Colombian research programs. The methodology continues in use, nonetheless, on the grounds that the errors it produces are probably small and that alternative means of assessing past, present, and future returns to research are lacking.

Earlier in this paper an alternative was proposed: to attempt to assess production surpluses on an input-by-input basis rather than on the basis of an area between two (ambiguously defined) supply curves. The importance of this proposal is, perhaps, less in the improvement it promises to make in estimates of the total value of production surpluses than the potential it offers for identifying which inputs and input owners expropriate how the surpluses generated by research. Knowing who gains how much is important information by itself; however, it is also important for a fuller understanding of how research is induced, why it takes the directions it does, and when it will or will not be an effective tool of development broadly.

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