OBSERVATIONS ON BRAZILIAN AGRICULTURAL RESEARCH AND PRODUCTIVITY[1]

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ABSTRACT - Prior to 1970 Brazil's agricultural research program was concentrated in the state of São Paulo and directed toward the improvement of a limited number of commodities. At that time much less was invested in agricultural research than in comparable countries in Latin America and Asia. With the expansion brought about by EMBRAPA, agricultural research in Brazil now has more balance regionally and across commodities. It has also become more applied in its focus. Brazil now has one of the strongest research systems for countries of its size and level of development. An analysis of the economic impact of the pre-EMBRAPA research program showed that it had large economic impacts in the state of São Paulo and in the South. These impacts were realized only in commodities where a significant research program had been in place for a considerable period. The north and northeast realized very little in the way of benefits from pre-EMBRAPA research programs. Nonetheless the pre-EMBRAPA research programs were highly productive and a high rate of return was realized on this investment. The prospects for high economic benefits from EMBRAPA's supported research are very good.

Index terms: Brazil, agricultural research.

OBSERVAÇÕES SOBRE PESQUISA E PRODUTIVIDADE NA AGRICULTURA BRASILEIRA

RESUMO - Até 1970, o programa de pesquisa agrícola esteve concentrado no Estado de São Paulo e visava a melhoria de um número muito limitado de produtos. Naquela época, investia-se em pesquisa agrícola muito menos que em países semelhantes da América Latina e da Ásia. Com a política adotada pela EMBRAPA, a pesquisa agrícola brasileira goza, hoje, de maior equilíbrio, tanto em matéria de regiões quanto em matéria de produtos, uma vez que se tem voltado mais para o seu foco. O Brasil possui, hoje, um dos mais poderosos sistemas de pesquisa para um país do seu tamanho e nível de desenvolvimento. Uma análise do impacto econômico do programa de pesquisa pré-EMBRAPA mostrou que este produziu impactos econômicos muito grandes no Estado de São Paulo e no Sul. Esses impactos se verificaram somente em produtos para os quais foram elaborados programas de pesquisa importantes e por um período consideravelmente longo. O Norte e Nordeste realizaram muito pouco em matéria de benefícios pelo sistema de pesquisa que antecedeu à EMBRAPA. Todavia, os programas de pesquisa ante-

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riores à EMBRAPA têm sido altamente produtivos, e têm-se verificado altas taxas de retorno dos investimentos. São excelentes as previsões de benefícios econômicos que podem advir das pesquisas realizadas pela EMBRAPA.

Termos para indexação: Brasil, pesquisa agropecuária.

INTRODUCTION

In the early 1970s Brazil initiated a major expansion and reorganization of its agricultural research system. EMBRAPA, the administrative and organizational vehicle for this expansion, has now been in place nine years. EMBRAPA has invested heavily in the training of agricultural scientists, perhaps the largest such investment to be made in a single program by any nation ever. As these new research programs have spread geographically, EMBRAPA has also made large investments in land, buildings, and equipment. It is too early to evaluate the full economic consequences that these large investments will produce. It is possible, however, to estimate the economic consequences of those parts of the agricultural research program that were in place prior to the EMBRAPA expansion. It may also be possible to discern some of the early consequences of the EMBRAPA program in recent data.

In this paper I proceed first to quantify investment in agricultural research, for both the pre-EMBRAPA and the EMBRAPA periods, and draw some comparisons with investment programs in other countries. The second and third parts of the paper examine partial productivity data for Brazil, chiefly crop yield data, to explore whether Brazil's past research investment pattern is correlated with yield performance. The fourth section of the paper reports statistical estimates of research consequences in a system of output supply and input demand equations. In a final section I discuss policy issues.

INVESTMENT IN AGRICULTURAL RESEARCH: HOW DOES BRAZIL COMPARE?

At present, no single compilation of research spending or investment, in consistent economic units by commodity and by region, is available for Brazil. In this paper I have constructed such a series from available data and have attempted to achieve consistency over time and across regions. The Appendix to the paper provides a detailed discussion of the construction of the series, and also includes tables showing research units by commodity for each major region in Brazil.

Table 1 reports the basic data for Brazil by commodity for several pre-EMBRAPA periods; one period, 1970-77, with partial EMBRAPA support; and one period, 1978-80, showing the EMBRAPA investment pattern. The salient features of these data are (see the Appendix for details):

1. Data are expressed in annual average numbers of "research units" for the relevant time period and commodity. Data on scientific publications reported by Silva et al. (1980) were crucial to this measurement.

2. A combination of expenditure data and publications data was used to construct the series up to the 1978-80 period. Only expenditure data were used for the 1978-80 period. An attempt was made to include all sources of research funding for all periods. In the 1978-80 period this included EMBRAPA plus other major research institutions.

3. The research unit is defined to be a constant real value unit over time. For the state of São Paulo I was able to obtain a close matching of agricultural publications by commodity, and spending by commodity, for the 1960-76 period. I first computed average spending (in 1960 cruzeiros) per publication by commodity over this period. My research unit was chosen to be an average publication in the general commodity fields (biological research, soils, climate, mechanization and other general research). All publications in other commodities were then converted to these research units. Using expenditure/publication ratios.

4. An analysis of expenditure data showed rather clearly that, after the 1960s, the general price deflator (FGV2) is not an appropriate deflator. The cost of producing a research units was 6900 cruzeiros (1960 cruzeiros) in the 1940s, 6930 in the 1950s, 7700 in the 1960s and 13120 in the 1970-77 period. We know that real scientist salaries have also risen sharply during the 1970s relative to the general price deflator. I assumed that this rising real price of a research unit continued until 1978, bringing the price of a research unit in 1960 cruzeiros to 15288 in 1978, or Cr$ 3.944.304 in 1978 cruzeiros.

5. For the 1978-80 period EMBRAPA budget data were converted to research units as were data on spending at IAC and other state institutes, the cacao and coffee research institutes, and state universities. Allocation by commodity and region was based on a commodity analysis of 1977-78 EMBRAPA funding, Institute data and the 1970-77 pattern of research.

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TABLE 1. Brazilian Agricultural Research Investment by Commodity: All Brazil Annual Research Units.

Commodities	1927/29	1930/39	1940/49	1950/59	1960/69	1970/77	1978/80
EXPORT CROPS							
Coffee (.47)	3.60	1.79	3.34	6.21	7.66	26.84	32.6
Cotton (.37)	1.48	1.85	1.41	1.77	4.26	2.92	18.9
Citrus (.45)	0.30	1.58	2.88	1.80	2.70	3.38	13.4
Sugarcane (.44)	1.61	3.08	1.98	3.26	4.23	6.27	82.4
Groundnut (.27)	-	0.05	0.14	0.43	0.99	1.42	2.9
Soybean (.69)	0.23	0.35	0.28	0.83	1.73	16.30	35.3
Castor oil (.50)	0.17	0.20	0.45	0.50	0.40	0.56	0.6
Cocoa (.50)	-	-	-	0.15	0.45	5.06	50.6
Rubber (.50)	-	-	-	-	-	-	17.8
DOMESTIC CROPS							
Potatoes	0.43	0.39	1.33	1.32	2.08	0.98	3.7
Corn (.32)	0.11	0.77	1.05	1.70	2.65	5.08	33.4
Beans (.40)	-	-	0.72	0.24	3.28	7.15	19.9
Tomatoes (.47)	0.31	0.14	1.27	1.18	1.88	3.34	4.6
Rice (.50)	0.18	0.22	0.97	3.19	4.81	8.91	38.6
Manioc (.27)	0.18	0.14	0.76	0.43	0.41	0.67	10.7
Wheat (.50)	1.25	0.05	0.76	0.81	0.92	13.97	16.2
Banana (.50)	-	0.45	0.35	0.30	0.60	1.63	2.0
Onion (.47)	0.15	-	0.52	0.47	0.61	1.46	4.6
Horticulture (.31)	-	0.06	1.02	0.68	2.17	3.56	5.2
Fruits/temp. (.50)	0.16	1.10	1.25	1.05	2.55	4.38	5.5
Fruits/trop. (.50)	-	0.65	1.00	1.50	2.00	3.31	4.9
Other crops (.50)	2.00	1.40	4.80	3.90	6.95	11.98	15.5
Mechanization (1)	1.33	0.60	2.70	1.40	0.05	2.15	9.5
Soils (1)	2.66	3.20	5.70	6.70	17.00	29.75	92.6
Climate (1)	1.33	0.10	0.50	1.30	1.90	3.87	
Biological (1)	6.00	5.40	14.70	12.90	14.90	24.87	115.6
Other general Crop research (1)	13.66	9.60	19.40	20.60	21.10	15.20	

Sources: Appendix

Table 1 provides an historical perspective on Brazilian research investment by commodity. It shows quite different patterns of investment among commodities. In general, prior to the 1940s, only coffee, cotton, sugarcane and, to a lesser extent, citrus fruits were receiving anything more than token attention. During the 1940s the situation changed little; research on potatoes and vegetables increased. In the 1950s, research on rice began, and corn also received some attention. Even at the end of the 1960s, however, Brazil's research system did not exhibit evidence of wise planning for economic growth via investment in new technology. Important crops, notably groundnuts, manioc many vegetables and even wheat were given only token research. Cocao, rubber and bananas, also important crops, likewise received little attention.

This began to change in the 1970-77 period and by 1978-80 significant changes were apparent. Research on groundnuts was initiated, and rubber received major attention for the first time. Research on manioc became significant only in the 1978-80 period.

Table 2 reports a comparison of investment intensities measured as the ratio of the annual research expenditures to the value of the commodity for several commodities for the pre-EMBRAPA (1960-69) and EMBRAPA (1978-80) period. Table 2 also presents comparative data for all Asian and Latin American developing and semi-industrialized countries for 1971.

TABLE 2. Brazilian Agricultural Research Intensities by Commodity.

Commodity	Value in Brazil in Cr$ 1.000.000 (1978 Cr$)	Brazil 1960-69	Brazil 1978-80	Research Intensity in All Developing Countries in 1971
Coffee	40.330	.00159	.00319	.00610
Soybeans	31.598	.00520	.00440	na
Sugarcane	28.501	.00122	.01154	.0050
Citrus Fruits	15.000	.00321	.00352	na
Cotton	12.135	.00144	.00614	.0350
Cacao	12.000	.00650	.01578	na
Tobacco	5.876	.0002	.0002	na
Groundnuts	1.640	.00143	.00698	.0013
Coconuts	1.200	-		.0006
Mamona	1.200	.00220	.00212	na
All Export Crops	150.000	.00152	.00623	
Corn	26.680	.00070	.00495	.0075
Rice	23.879	.00127	.00637	.0026
Manioc	17.330	.00022	.00244	.0007
Beans	11.300	.00168	.00695	.0025
Wheat	10.700	.00136	.00598	.0065
Potatoes (Sweet & English)	7.300	.00263	.00202	.0009 (S) .0068 (E)
Vegetables (Onion & Tomato)	7.200	.00356	.00506	na
Tropical Fruits (Bananas etc.)	15.000	.00166	.00200	na
Domestic Crops	121.000	.00197	.00539	
Cattle	42.994	.00265	.00313	.0088
Swine	7.372	.00311	.00714	na
Other Animals	12.721	.00589	.00513	na
Animal Products	53.347	.00304	.00373	na

The table shows that the research intensity for all export crops increased by a factor of 4.88 from the pre-EMBRAPA to the EMBRAPA period. The comparable increase for domestic crops was 2.74 times. As a consequence, export crops, notably sugarcane and cacao, are now more research-intensive than domestic crops. Crops with especially low research intensities in 1978-80 are manioc, potatoes and tropical fruits (bananas, coconuts, etc.) Cattle and tobacco also have relatively low research intensities. In general, however, Brasil's agricultural research system has become much more balanced.

The comparison with data from all developing and semi-industrialized countries shows that, in 1960-69, Brazil was less research intense in all commodities than other developing countries were in 1971. By 1978--80, it was more research intense in most commodities than the reference countries were in 1971 (but not necessarily in 1979). In general, those commodities with low research intensities in Brazil also have low research intensities in other countries.

Table 3 reports a general comparison of Brazil's research and extension spending relative to other Latin American countries and developed countries. These data indicate that in 1959 Brazil was investing much less than Chile and Argentina, and was roughly on a par with other Latin American regions. By the early 1970s other Latin American countries were investing two or three or more times as much as Brazil, according to this measure. The EMBRAPA initiative has now partially restored this balance, but even now Brazil does not rank highly as an investor in public-sector agricultural research.

TABLE 3. International Comparisons: Agricultural Research and Extension Intensities.

	Expenditures on Research/Value of Product				
	1959	**1965**	**1971**	**1974**	**1978-80**
Brazil	.0030	.0034	.0041	.0031	.0087
Argentina - Chile - Paraguay - Uruguay	.0071	.0090	.0172	.0129	na
Brazil - Colombia - Ecuador - Peru - Venezuela	.0027	.0052	.0076	.0103	na
Mexico - Costa Rica	.0023	.0026	.0042	.0071	na
Canada - U.S.A.	.0085	.0102	.0128	.0127	na
Northern Europe	.0062	.0084	0123	.0132	na
	Expenditures on Extension/Value of Agricultural Product				
Brazil	.0057	.0077	.0083	.0066	.0113
Argentina - Chile - Paraguay - Uruguay	.0014	.0055	.0091	.0056	na
Brazil - Colombia - Ecuador - Peru - Venezuela	.0036	.0049	.0090	.0115	na
Mexico - Costa Rica	.0015	.0023	.0034	.0050	na
Canada - U.S.A.	.0043	.0044	.0054	.0055	na
Northern Europe	.0074	.0084	.0095	.0086	na

Sources: Boyce, J.K. and R.E. Evenson. **National and International Agricultural Research and Extension Programs**, Agricultural Development Council, Inc., New York, 1975.

Gabriel L.S.P. da Silva et al. "Investimento na geração e difusão de Tecnologia Agrícola no Brasil", **Revista de Economia Rural**, vol. 18, No. 2, Junho 1980.

The data on extension investment show that in 1959 Brazil was more extension intensive than other Latin American countries and that this was remained so. Until recently, Brazil exhibits a pattern of relative emphasis on extension as opposed to research, a pattern that characterizes many developing and semi-industrialized countries. This is not to suggest that Brazil has overinvested in extension; it probably has not. The emphasis on extension, however, is consistent with the neglect of research programs, ostensibly on the grounds that extension can facilitate technology transfer from other countries.

Table 4 provides an overall summary of Brazil's agricultural research system. The first panel shows the pattern of growth in research units according to research orientation: export crops, domestic crops, animals, soil/climate and engineering, and general and biological research. The second panel shows how the distribution of research units has changed. Four points bear mention:

1. Relative emphasis on export commodities has increased significantly in the EMBRAPA period.

2. Relative emphasis on animal research rose in the 1960s but has fallen since then.

3. Relative emphasis on biological (and general) research has declined steadily over time, its share falling from more than 40 percent prior to the 60s to less than 20 percent today.

4. The general pattern of growth shows that Brazil failed to expand its agricultural research system in the 1950s, thus falling behind other comparable countries. Its performance in the 1960s was somewhat better but as of 1970 Brazil's system was poor by any international comparison.

This picture is also readily apparent in the two panels showing regional investment. These data show that Sao Paulo, and more specifically IAC, dominated Brazilian research until the 1970s. In fact, Sao Paulo's share of total research investment actually rose from 63 percent in the 1950s to 77 percent in the 1960s, showing a serious neglect of research in other states, and a lack of national concern for improving agricultural technology.[1]

[1] Agricultural historians in Brazil will no doubt be puzzled over the phenomenon of serious attention to building a top-flight research program in Sao Paulo while failing to develop a national program. I will not attempt to analyze the phenomenon here - it is related to political factors at the state level and to national policies that have been short sighted.

TABLE 4. Summary Table over Brazilian Agricultural Research.

	1927/29	1930/39	1940/49	1950/59	1960/69	1970/77	1978/80[1]
1. ANNUAL RESEARCH UNITS (TOTAL)	41.01	36.79	74.69	80.87	149.98	256.90	725.6[1]
Export Crops	7.39	8.90	10.48	14.95	22.42	62.75	254.5
Domestic Crops	4.77	5.27	15.80	16.77	30.91	66.31	165.4
Animals	3.87	3.02	5.41	6.05	41.25	52.00	86.1
Soils, Climate	5.32	3.90	8.90	9.60	19.40	35.77	104.0
General & Biological	19.66	15.00	34.10	33.50	36.00	40.67	115.6
2. ALL BRAZIL, PERCENTAGE DISTRIBUTION							
Export Crops	0.18	0.24	0.14	0.19	0.15	0.24	0.35
Domestic Crops	0.12	0.05	0.21	0.21	0.21	0.26	0.23
Animals	0.09	0.10	0.07	0.07	0.27	0.20	0.12
Soils, Climate	0.13	0.11	0.12	0.12	0.13	0.14	0.14
General & Biological	0.48	0.41	0.46	0.41	0.24	0.16	0.16
3. CROP RESEARCH UNITS BY REGION							
North		-	0.10	0.15	0.49	3.63	35.70
Northeast	-	0.26	0.53	1.93	2.82	18.63	84.40
South East (excluding São Paulo)	-	0.44	8.63	2.39	4.51	34.35	74.40
South	-	-	0.83	4.63	4.47	31.83	103.60
Center West	-	-	-	-	-	1.74	67.60
São Paulo	12.16	12.58	16.62	23.05	41.66	40.75	54.00
4. TOTAL RESEARCH BY REGION							
North	-	-	1.80	5.65	1.99	9.13	52.40
							0.906[2]
Northeast	-	0.26	0.53	4.33	7.52	30.00	114.30
							0.771[2]
Southeast (excluding São Paulo)	-	1.46	19.43	7.59	9.11	51.22	138.90
							0.636[2]
South	-	-	0.84	6.23	5.67	43.71	159.30
							0.617[2]
Center West	-	-	-	-	-	2.08	116.30
							0.936[2]
São Paulo	33.41	29.53	45.60	50.94	115.56	120.58	144.00
							0.047[2]

Sources: Appendix

[1] Plus 162,5 research units for central administration.

[2] EMBRAPA's share.

One cannot help making another observation regarding the EMBRAPA expansion. This expansion certainly has brought research investment closer to optimal levels and has provided a truly national research program. It appears, however, that Sao Paulo's exemplary program has not been the centerpiece of this expansion. Indeed, the IAC budget has expanded little since the early 70s, and there are reports that it has lost some staff members. As the next sections show, few experiment stations in the world have produced more benefits per unit of investment than IAC.

PRICES, PRODUCTIVITY AND RESEARCH INTENSITIES

I now wish to turn to price and yield data by commodity and by region to see whether there is evidence that Brazil's past research investment has had important economic consequences. While this analysis is partial in nature, it is important in any study of technical change to investigate crop-by-crop or commodity-by-commodity performance.

I will turn first to price data, in part because these data have clear policy implications. If research investment lowers prices we can infer that research is shifting supply curves and causing consumer surpluses to increase. Conversely, the failure to undertake research will lead to rising prices. The assumption behind looking at price data is that over a reasonably long period of time average costs of production and prices are roughly equalized. A relative fall in a commodity price thus gives an index of a fall in the costs of production.[2]

Table 5 reports estimates of the geometric rate of change of the ratio of the prices received to prices paid by farmers for a number of products and inputs, for the period 1966-80. These were estimated by the following regression:

$$\text{Ln (Pi)} - \text{Ln (FGV2)} = a + b_i \,.\, \text{YR} + \text{dummy variables for states.}$$

All estimates of b_i reported in Table 5 are highly statistically significant and the state dummy variables correct for significant "noise" in most regressions.

[2] This does not hold for internationally traded crops where price may be determined in an international market and modified by trade policy. It will also be affected by domestic price policy.

TABLE 5. Price and Yield Changes and Research Intensity in Brazilian Agriculture.

Crops	Estimated Rate of Real Price Change 1966-80	Crop Yield Ratio 1978-80/1961-4 1978-80/1961-4	Research Investment 1950-77	Research Intensity 1950-77
Rice	.01905	1.043	13.72	101.6
Coffee	.1373	1.175	34.50	269.5
Soybeans	-.0000192 (NS)	1.451	18.03	146.6
Corn	.02924	1.254	7.73	65.0
Manioc	.07150	.966	1.08	11.8
Sugarcane	.03012	1.212	10.50	131.3
Beans	.08469	.704	10.43	175.6
Cotton	.04654	1.350	7.18	152.8
Wheat	-.01678	1.140	14.89	489.8
Oranges	.01618	2.741	6.08	262.0
Cacao	.08585	2.008	5.51	237.5
Banana	.05576	.909	2.23	110.4
Tomatoes	-.02059	2.532	5.22	341.2
Potatoes	.02121	1.874	3.06	144.3
Tobacco	.04781	1.428	2.00	136.1
Groundnut	.03245	1.383	2.41	280.2
Animal Products				
Steers - Heifers	.04397			
Fat Cattle	.04128			
Swine	.03492			
Chicken	.00796			
Milk	.03589			
Eggs	-.00198			
Inputs				
Burros	.059107			
Tractors - micro	-.00855			
Tractors - 36-45 HP	-.08158			
Tractors - 45+ HP	.00626			
Fertilizer - Potassium	.00587			
Fertilizer - Super Phosphate	-.02044			
Fertilizer - Nitrogenous	.01383			
Gasoline	.08983			
Graxa	.01917			
Diesel	.04173			
Lubricants	.05113			
Worker - Administrator	.05559			
Worker - Tractor Drivers	.04135			
Worker - Monthly Workers	.04724			
Worker - Daily Workers	.06493			
Land Rents - Cultivated Land	.11978			
Land Rents - Campos	.12876			
Land Rents - Pastures	.11164			
Land Rents - Matas	.10461			

Sources: Appendix

Almost all of the estimated price trends are positive, meaning that most agricultural prices rose faster than the general (FGV2) deflator. This is consistent with Brazilian economic experience during the period. The non-agricultural economy realized extraordinarily high productivity gains during the 1966-79 period, certainly much higher than those realized in agriculture. The only agricultural commodities that appear to have matched or bettered the non-agricultural sector in terms of productivity performance are tomatoes, eggs, soybeans, chickens and wheat, although in the case of wheat the decline may be due primarily to price policy action by the government. Oranges, potatoes and rice have done reasonably well. Manioc, beans, cacao, bananas, tobacco and cotton have done quite poorly by this measure. The very poor price performance by manioc and beans has serious implications for the welfare of millions of the poorest Brazilians who have traditionally consumed these as staple foods.[3]

Table 5 also reports price trends for agricultural inputs. These prices have also varied greatly. Tractor and fertilizer prices have generally fallen or at least not risen relative to the general deflator (this measure does not consider the effect of credit subsidies). Gasoline prices have risen at a high rate as have other petroleum-based inputs. Wages of workers have risen relative to the deflator by significant amounts. It is encouraging to note that the wages of daily workers have risen most rapidly over the period. These wage increases have been determined in large part by employment opportunities outside the sector.

Land rents have clearly risen rapidly over the period and land owners have almost certainly realized huge capital gains. Part of this price rise may be due to goverment policy that has "tied" many subsidies to land cultivation. Farmers may bid up land rents and prices simply because land gives "access" to credit subsidies.

We can make a rough calculation of total factor productivity for the sector. This can be measured as:

$$\hat{TP} = \sum_i S_i \hat{P}_i - \sum_j C_j \hat{W}_j .$$

where the S_i are output shares and C_j cost shares. $\hat{P}_i$ and $\hat{W}_j$ are rates of changes in output and input prices respectively. The data in Table 5 shows that the share weighted rate of change in output prices (relative

3 Indeed the price rises for manioc and beans are comparable to the rises in energy prices, and have had a much more severe impact on Brazil's poor than have energy price increases.

to the deflator) was 4.4 percent per year over the 1966-80 period. The share weighted rate of change in the price of inputs was 7.5 percent per year. (This measure depends partly on the land rent calculations, which are somewhat dubious). It suggests that, while agricultural productivity grew more slowly than productivity in the rest of the economy (by roughly 4.4 percent per year), productivity growth, on the order of three percent, might have been realized in the agricultural sector.

Total factor productivity growth of three percent per year is a relatively high rate for an economy investing as little in technology production as Brazil invested in this period. Brazil has, however, been able to "borrow" technology from one major source (US soybean technology) and has no doubt realized a number of organizational and infrastructural gains in this period. If the full amount of this productivity gain were realized, in terms of increased output per acre, the crop yield rations reported in Table 5 would average roughly 1.6. In fact, the average yield ratio was only 1.2. This indicates that Brazil realized significant productivity growth from efficiency gains associated with input savings.[4]

To pursue the issue more systematically I wish to look at yield ratios in more detail. Table 6 reports yield ratios for three periods, 1961-64/1951-54, 1971-74/1961-64, 1978-80/1971-74. These yield ratios were calculated from state yield data. Two adjustments were made to the data. The most important was a procedure designed to eliminate as much of the random weather variation in the data as possible. This entailed selecting the two highest yields in each four-year period over which an average was calculated.[5] This procedure was quite effective in providing consistent yield ratios. Virtually all unreasonable yields were eliminated and the average of the two highest yields appeared to be a good estimate of the yield in normal weather. The second adjustment eliminated all inter-state yield level differences from the calculations. Rates of change were first computed at the state level and then aggregated. This eliminated the spurious yield changes which are due to shifts in the relative importance of different states in production.[6]

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[4] The data on research intensity and price changes in Table 5 show a strong correlation. A regression line fitted to the data indicates that a ten percent increase in the research intensity is associated with a .01 reduction in the rate price of change. This implies a large and productive research impact.

[5] The average of these two yields was considered to be the yield level for the state for the period.

[6] Yield changes could still be due to shifts in areas within states. This problem would not seem to be too serious except in the new settled states.

The salient features of the table are:

1. Substantial variation in commodity yield ratios exists. For the entire period, tomatoes are clearly the top yield performer with coffee second. Potatoes, onions, cotton and soybeans have also performed extemely well and yields are approximately double their level in the early 1950s.

2. The yields of several commodities have deteriorated seriously. These include beans, bananas and coconuts for the entire period. However, during the 1970s the yield of coffee, manioc, rice, wheat, sweet potatoes and castor beans deteriorated as well. It is difficult to determine the cause of this decline. The data do suggest that research work can be productive in a number of commodities by simply arresting yield deterioration.

3. In general, those commodities which have been neglected by the research system have done poorly on yields, while those with serious research attention have done well.

4. By a large margin, the São Paulo region shows the best yield performance of all the regions. It has the highest yield performance in each period, including the 70s, when many commodities suffered yield declines. This performance is hardly coincidental. It is clearly related to São Paulo's investment in agricultural research, and its related investment in extension and other agricultural infrastructure. Overall, São Paulo's agricultural performance rates among the best in the world for the period.

5. Other regions have not done well. The North and Center-West are small and have high rates of land expansion. This may explain why yields have not increased. The Northeast is particularly disappointing as yields overall have risen by only 7.5 percent in the past 28 years or so. Part of this can be attributed to a high proportion of problem commodities, but, on the whole, this performance reflects the failure to invest in the region. The Center South and the South have done somewhat better, but there is reason to conclude that some of their performance is due to "spill-in" of technology from São Paulo.

6. Area ratios are not highly correlated with yield ratios.

7. Price ratios are related negatively to both yield ratios and area ratios. A simple regression of price changes on yield ratios ($DP = .1121 - .0616YR$; $R^2 = .20$) implied that had yield ratios been higher by ten

percent, prices would have risen less rapidly by .6 percent per year.

8. Yield ratios are positively related to research intensities (YR = .9594 + 99.1RI; R^2 = .34). This implies that a ten percent increase in research intensities is associated with a 2.5 percent increase in yield ratios, implying added growth in yields of .178 percent per year.

TECHNOLOGY TRANSFER IN BRAZILIAN AGRICULTURE AND YIELD-RESEARCH RELATIONSHIPS

If we are to understand the relationship between investments in research and related activities and actual changes in technology used by farmers we must be able to associate geographically these investments with the changing technology A. for example, suppose research conducted in São Paulo state produces improved technology that, when adopted, reduces the cost of production for producers in Bahia by the same amount as it reduces costs for producers in São Paulo. Then we would describe that technology as fully transferable from its origin (São Paulo) to its destination (Bahia). We could not in this case simply associate productivity growth in Bahia with research investment in Bahia. Some (possibly all) of the productivity growth in Bahia would in fact be due to the research investment in São Paulo (See also Evenson & Binswanger 1978).

The case just described becomes more complicated if the producers in Bahia do not fully adopt the technology originating in São Paulo. The failure to adopt the technology might be due to the characteristics of the farmers, the markets and the communities in Bahia. It is also possible that the technology originating in São Paulo does not lower costs by the same amount in Bahia as in Sao Paulo. Indeed, we know from many studies of agricultural technology that full transferability of technology from one location to another occurs only when the two locations have closely similar soil/climate and economic environments. Even small differences in environments deter transferability. For certain types of technology these differences need not be very large to block transferability completely (Evenson 1981).

Experience suggests that most research planners and administrators consistently over-estimate the degree of transferability of agricultural technology. This is for two reasons. First, researchers and technologists are biased toward the belief that "their" technology is highly valuable and transferable. Second, planners are biased toward the belief that factors determining adoption are highly important in explaining why technology is not more fully adopted. Thus, many agricultural planners have high hopes that technology produced elsewhere will "spill-in" to their region, eliminating the need to invest in complex research programs specific to their own region (See Rose-Ackerman & Evenson 1982). In practice, few regions, especially in Brazil, have been so favored.

I address the question of transferability empirically in a very crude way. I first assume that because of the historical pattern of heavy investment in agricultural research in the state of São Paulo most actual transfer will be outward from São Paulo. This dominance in research was shown in Table 4. In the 1950s and 1960s São Paulo accounted for 75 percent of Brazil's agricultural research investment. I then regress yield ratios computed for the crops and periods listed in Table 6 for the regions other than São Paulo on the same yield ratios for São Paulo.

TABLE 6. Brazilian Commodity Comparisons 1951-4 to 1978-80.

Commodity	1975 Share	Yield Ratios				Area Ratio 1978-80/ 1951-4	Price Ratio 1978-80/ 1951-4
		1961-4/ 1951-4	1971-4/ 1961-4	1978-80/ 1971-4	1978-80/ 1951-4		
Rice	.1349	1.043	.975	1.060	1.024	3.02	1294
Coffee	.1276	2.197	1.515	.775	2.620	.66	951
Soybeans	.1228	1.294	1.280	1.134	1.914	102.8	2839
Corn	.1188	1.040	1.118	1.122	1.243	2.25	1223
Manioc	.0911	1.087	1.073	.900	1.039	1.91	2397
Sugarcane	.0800	1.082	1.074	1.128	1.311	2.39	1625
Beans	.0594	1.041	.969	.726	.709	1.08	2111
Cotton	.0472	1.430	1.160	1.164	2.018	1.45	1249
Wheat	.0304	1.074	1.334	.830	1.162	3.69	1362
Oranges	.0292	.972	1.369	1.095	1.224	5.68	1761
Cacao	.0232	.774	1.600	1.255	1.540	1.33	4946
Banana	.0202	1.058	1.177	.772	.940	2.49	1792
Tomatoes	.0153	1.388	1.899	1.333	3.384	2.59	1299
Eng. Potatoes	.0150	1.240	1.472	1.273	2.154	1.23	1376
Tobacco	.0147	1.051	1.366	1.046	1.501	2.04	1562
Sweet Potato	.0086	1.130	1.192	.863	1.181	1.39	2063
Groundnut	.0083	1.183	1.343	1.030	1.605	1.75	1845
Grapes	.0065	1.024	1.289	1.236	1.631	1.45	1165
Coconut	.0051	1.254	1.019	.530	.685	2.89	1592
Onions	.0043	.957	1.361	1.462	2.084	2.07	1992
Castor Beans	.0043	.995	1.160	.897	1.052	1.86	1403
All Crop Commodities							
North	.010	1.096	1.030	1.094	1.198		
North East	.231	1.088	1.112	.890	1.075		
Center South (Except São Paulo)	.135	1.089	1.177	1.080	1.444		
Center West	.063	1.016	1.020	.932	.969		
South	.391	1.383	1.158	.991	1.516		
São Paulo	.170	1.500	1.490	1.105	2.429		

Sources: Appendix

The basic idea underlying this regression procedure is that if the technology that affected São Paulo yield ratios is fully transferable to other regions, the cofficient b in the regression

$$YR_{it} = a + bYR_{SPt} + cT_1 + dT_2 + U_{it}$$

should be equal to 1. (The T_1 and T_2 variables are time period dummies). If the transferability is partial, b will be less than one and if no transfer occurs it will be approximately zero. (Many other factors can affect these yields, particularly fertilizer use; I have not been able to account for this. I am assuming these errors to be part of the conventional error structure of the model)[7].

The results are summarized in Table 7. The North region shows a somewhat anomalous negative b, which is probably due to acreage expansion effects. The other regressions show no transferability between São Paulo and the northeast, and very low transferability between São Paulo and the center-west and southeast regions. Transferability from São Paulo to the South is high (but less than one, of course) and significant.

TABLE 7. Technology Transfer Analysis.

Region	Regression of Yield Ratios on São Paulo Yield Ratios					
	Intercept (a)	São Paulo Yield Ratios (b)	Period (1) (c)	Period (2) (d)	R^2	F
North	1.259 (.235)	-.634 (.171)	.053 (.183)	.002 (.183)	.22	4.6
Nort East	.962 (.225)	.005 (.164)	.134 (.174)	-.067 (.174)	.03	.5
Center West	.721 (.294)	.283 (.214)	-.302 (.229)	-.315 (.229)	.08	1.4
South East	.739 (.167)	.232 (.121)	.168 (.129)	.104 (.129)	.10	1.9
South	.492 (.136)	.560 (.099)	.065 (.106)	-.165 (.106)	.44	13.1

Sources: Appendix

These results should be interpreted with some caution since acreage, fertilizer and other effects have not been accounted for. They do reinforce the general proposition that virtually no technology is transferred from the southern regions of Brazil to the northern regions.

I now proceed to test whether research investment over a prior period is related to yield improvement. Table 8 reports yield ratio regressions of the form:

$$Y R_{it} = a + bRES_{it} + cT_1 + dT_2$$

where RES_{it} is the cumulated research units over the past 20 years in the region plus .283, .232 and .560 times the São Paulo research variable for the center-west, south-east and south regions respectively. This assumes that research has an impact on yields up to 20 years after investment. It also assumes that Sao Paulo research has produced technology transferable to the regions according to the estimates obtained in Table 7.

It should be noted here that we are relying on yield ratio data - not

[7] Actually, b will be biased toward a value of one because of common weather patterns and price effects between regions.

yield level data - to identify research effects. Further, we have very few observations for each commodity (3 periods, 6 regions). Still, the results reported in Table 8 can be taken to show that past research programs in most commodities in Brazil have produced results. Of the 18 commodities, 10 have "t" ratios of 1.5 or more. Of the remaining 8 only manioc and sweet potatoes show significant yield ratio variation. Except for these two commodities we can say that if yields have been rising, research investments appear to explain some part of their variation.

Sugar is the only commodity where a significant research program appears not to be related to yield changes. Research on beans, manioc and rice (upland), three important food crops, also appears not to have produced significant results. This appears to be due to the relative immaturity of the research programs and the lack of international pools of technology from which to draw. These crops represent very difficult problems as EMBRAPA generally recognizes.

When we pool all of the commodity data we obtain a highly significant relationship between past research and yields. The coefficient on the research stock variable implies the following. A 10 percent increase in the research stock (.7 units at the mean of the data set) would cause yield ratios to increase by .7 x .045 = .0315. Since these are calculated over 10 year periods this translates into an average growth rate effect of .315 percent per year. This may be compared to the earlier estimate of .178 percent based on the simple aggregate relationship between research intensities and yield ratios across commodities. Accounting for regional and commodity effects actually results in an increase in the estimated research effect on yields. (See the following section for a more definitive estimate that corrects for variable input use).

The final two regressions reported in Table 8 attempt to assess whether the basic research orientation of the research unit is important. An interaction variable in which the commodity research variable is multiplied by the ratio of basic research to total research in the regions is entered. The results provide moderate support for the proposition that basic research is important and productive. The positive coefficient obtained indicates that commodity research is more productive in the research units stressing basic research. Table 4 showed that the ratio of basic (general and biological) research to total research has fallen from around 40 percent in the 1950s to under 20 percent today. The result in Table 8 indicates that this decline should be a source of concern for EMBRAPA.

TABELA 8. Commodity yield ratio analysis. Regression of yield ratios on research Stocks "t" ratios in parenthesis.

Commodity	Intercept	Research Stocks	Period 2	Period 3	RBS	R^2	F
Banana	.996 (15.1)	.181 (1.60)	.125 (1.41)	-.349 (3.34)		.64	8.3
Beans	.957 (16.4)	-.010 (.32)	.036 (.32)	-.094 (.76)		.32	1.3
Castor	.702 (2.9)	.018 (.52)	.082 (.24)	-.128 (.36)		.03	.2
Cocoa	.547 (1.9)	.323 (1.26)	.097 (.23)	-.101 (.22)		.11	.6
Coffee	1.525 (4.6)	.065 (1.86)	-.648 (1.4)	-1.27 (2.6)		.37	2.7
Corn	.994 (23.4)	.041 (2.49)	-.068 (1.17)	-.086 (1.2)		.39	3.0
Cotton	.890 (4.2)	.206 (2.71)	-.303 (1.05)	-.448 (1.41)		.35	2.5
Groundnut	.868 (4.4)	.492 (1.88)	-.167 (.58)	-.250 (1.81)		.20	1.2
Manioc	1.132 (23.9)	-.087 (1.72)	-.051 (.84)	-.119 (1.88)		.43	3.6
Onions	.537 (1.7)	.743 (1.73)	.092 (.21)	-.065 (.13)		.21	1.2
Orange	.819 (17.8)	.042 (2.35)	.209 (3.9)	.161 (2.9)		.63	7.8
Potato (Eng.)	.484 (1.8)	.436 (2.57)	-.022 (.06)	-.04 (.14)		.33	2.3
Rice	1.023 (14.0)	-.005 (.37)	-.010 (.12)	.066 (.58)		.04	.2
Soybeans	.532 (0.4)	.073 (1.80)	.034 (.09)	-.302 (.76)		.19	1.1
Sugar	1.103 (11.0)	-.043 (1.43)	.091 (.17)	.478 (2.2)		.27	1.7
Potato (Sweet)	1.196 (10.4)	-.068 (.88)	.096 (.66)	-.255 (1.78)		.33	2.4
Tomato	1.131 (2.7)	.192 (.79)	.361 (.70)	-.325 (.60)		.13	.7
Wheat	.870 (8.4)	.051 (.72)	-.289 (.56)	-.574 (1.04)		.08	.4
All Commodities	.936 (17.9)	.049 (4.27)	.009 (.12)	-.184 (2.4)		.06	6.9
All Commodities including commodities Dummies	.976 (7.4)	.045 (3.57)	.011 (.15)	-.176 (2.3)		.18	3.2
All Commodities including Res Stock x $\frac{\text{Basic Res}}{\text{Total Res}}$ = RBS	.935 (17.7)	.0004 (.02)	.008 (.12)	-.185 (2.4)	.119 (1.7)	.07	6.0
All Commodities including RBS and Commodities Dummies	.985 (7.5)	.008 (.18)	.010 (4.4)	-.177 (2.4)	.090 (1.3)	.18	3.2

RESEARCH, OUTPUT SUPPLY AND FACTOR DEMAND IN BRAZILIAN AGRICULTURE (1970-75)

I now turn to estimates of the impact of Brazilian agricultural research directly on the supply functions of commodities (not simply on yields), and on demand functions for variable factors of production. I am basing these estimates on farm level data as reported for 16 states and 9 size classes of farms in the 1970 and 1975 Censuses of Agriculture.

The yield analysis just reported was based on the very simple concept of a partial productivity indicator. It is partial because other factors of production such as labor, fertilizer and tractors were not taken into account. A number of studies have gone beyond this to utilize either an aggregate production function or its equivalent, the total factor productivity index (see Landau & Evenson 1974; also Evenson 1980). It is possible to pursue these directions with Brazilian data but I will not do so here. Instead I will employ a much richer methodology that has not, to my knowledge, actually been used before to measure the impact of agricultural research investment.

The methodology recognizes that farms are multiple product firms and thus do not have a single production function (although they may be regarded as having an **aggregate** production function) (see Binswanger 1974; Berndt & Khaled 1979; Binswanger & Ruttan 1978; Weaver 1982; Hall 1973). It utilizes profit maximization "duality" theory to derive a **system of product supply** and **variable factor demand** functions. Each of these functions relates quantities of products supplied of factors demanded by farms to the prices of products and factors, to the "fixed" factors of production on the farm, and to public goods variables such as the provision of new technology by research stations. It is then possible to define a research variable (or variables) to be included in each equation, and to identify the shift in each equation due to research. Accordingly, this is a much richer specification than an aggregate production function, which estimates only the added product, holding all factors constant (see also Binswanger & Quizon 1980).

The methodology makes the following assumptions:

First, the farm is technically efficient (subject to its skill mix, etc.), and converts a vector of variable factors of production, X, into a vector of multiple products, Y, in the presence of fixed factors, F, and public good factors, Z, according to a well-behaved transformation function:

$$F(Y, X, F, Z) = 0 \qquad (1)$$

Second, the farm maximizes variable profits, which are defined as

$$\Pi = PY - WX \tag{2}$$

where P is a vector of output prices, W of factor prices.

Third, the first order conditions for the profit maximization problem substitute for Y and X in the profit definition (2) to establish the **profits function** (3) which is "dual" to (1).

$$\Pi^* = \Pi \ (P, W, F, Z) \tag{3}$$

Note that (3) shows **maximized** profits as a function of output and factor prices and fixed and public factors, none of which is a choice variable for the individual farm.

Fourth, recent advances in economic theory have established the restrictions on (3) that must hold in order for (1) to be "well-behaved". In addition, several "flexible" functional forms for the profits function have been shown to meet these restrictions without imposing other restrictions on elasticities of substitution (Lau & Yotopoulos 1972).

Fifth, instead of simply estimating equation (3) we can take advantage of an important property of (3). Shephard showed that the respective first derivatives of (3) with respect to each output and factor price form a system of output supply and factor demand equations:

$$\begin{aligned} \partial\Pi^*/\partial P_1 &= Y_1 = Y_1 \ (P, W, F, Z) \\ \partial\Pi^*/\partial P_n &= Y_n = Y_n \ (P, W, F, Z) \\ \partial\Pi^*/\partial W_1 &= X_1 = X_1 \ (P, W, F, Z) \\ \partial\Pi^*/\partial W_k &= X_k = X_k \ (P, W, F, Z) \end{aligned} \tag{4}$$

Equation system (4) can be estimated with data on output quantities and prices, variable factor quantities and prices, and fixed and public factor quantities. An important property of the flexible forms suited to (3) is that their first derivative functions can be linear functions in (4). All parameters in (3) are estimated in (4), so that in estimating (4), one can recover (3) as well. One can also recover characteristics of (1), such as the partial elasticities of substitution.

I have estimated system (4) utilizing the normalized quadratic functional form for (3).

Its derivatives are of the form:

$$Y_i = \sum_{j=1}^{n-1} b_{ij} P_j/P_n + \sum_k b_{ik} F_k + \sum_m C_{im} Z_m \tag{5}$$

This theory requires that cross-equation symmetry hold:

$$\partial Y_i/\partial P_j = \partial Y_j/\partial P_i \tag{6}$$

Table 9 reports results for a system of one aggregated output and five variable input factors. Fisher price indexes and the related quantities were used to aggregate these commodities. The five variable factors of production are: fertilizer (in nitrogen units), machinery (tractors plus implements converted into service flow units), labor (family plus hired), animal power (days of work animals) and energy (fuel). For each output and input a price index was created using FGV prices, with the rational mean being the base. Thus, we have price variations from state and over time. This is critical for the identification of price effects.

TABLE 9. Compensated Elasticities Estimated for Brazilian Agriculture 1970-1975.

Elasticities with respect to:	Equations					
	Output Supply	Labor Demand	Animal Power Demand	Machinery Demand	Energy Demand	Fertilizer Demand
Output prices	.176	.394	- .510	- .978	1.482 **	- .563
Labor prices	- 1.141 **	- .612 **	.242 **	1.508 **	001 **	. 001 **
Animal prices	- .298	2.246 **	- .814 *	1.344 *	- .004 *	- 008 **
Machinery prices	- 1.181 **	.971 **	- .085 *	.295	.175	. 001 *
Energy prices	.215	1.563 **	.504 *	.139	1.873 **	460
Fertilizer prices	.074	2.52 **	- 1.463 **	1.716 *	.512 *	- 081
Agricultural research	.2113 **	.1480 **	- 1.216 **	1.898 **	.2388 **	.1606 **
Other fixed (not in elasticity form)						
Farm size	573.34 **	102.4 *	.861 *	99.71 **	.0334 **	.0511 **
Irrigation intensity	- 2860 **	3566 **	183 **	6888 **	3.37 **	. 610 **
Farm capital	- 3.87 **	2.96 **	- .002	5.89	.0026 **	- .0029
Subsidized credit	- 38.93 **	- 7.286 **	.205	- 2.28	- .0005	- .009
Characteristic Roots of Hessian at mean						
	83342	1368	55.65	-- 1.29	-82025	

Sources: Appendix
*: "t" statistic > 1.5
**: "t" statistic > 2

The F and Z variables are labelled in the tables. F variables are fixed factors at the farm level. I am treating land, irrigation intensity (irrigated acreage/total acreage), and farm capital as fixed factors. All quantity variables are expressed in per farm units throughout the analysis. Farm capital is the value in constant national prices (FGV) of machines and breeding animal stocks. I am also treating the size structure of farms as fixed by including dummy variables for farm size groups. A dummy variable is also included to pick up constant effects related to the time periods. Among other things, this variable picks up the effects of general inflation.

I have included two public goods, or "program" - type, variables. The first is rationed credit per farm. The second is research input per farm. The justification for treating credit as a public variable rather than as a "choice" variable is that it is rationed. The credit in question is made available to farmers on terms so favorable that virtually all farmers demand more credit at the generally negative interest rates offered than suppliers are willing to supply. Suppliers then ration the credit according to various rules. If these rules are based on fixed and public factors then we are justified in treating credit as a public good. Note that I am treating total "custeio" credit as public - not its specific component. I am treating the research investment as public goods that inform producer choices. For each state, the research variables are defined as the region's cumulated research units over the past 30 years devoted to the commodities in question, expressed on a per farm basis. For the states in the center-west, south-east, and south, the proportion of Sao Paulo's research indicated by the analysis in Table 7 was added to the state's research.

The estimates in Table 9 can be said to be quite reasonable. The basic theory of production predicts that all own price elasticities of demand for inputs will be negative and that the output supply elasticity will be positive. This prediction is borne out by the estimates in Table 9. (Only the machine demand elasticity is of the wrong sign and it is not significantly different from zero).

We also expect input prices to be negatively related to output supply and output prices positively related in input demand. This is true for all elasticities that differ significantly from zero.

The Z variables included in the regressions, farm size, irrigation intensity, and farm capital stock, also generally have the expected effects. The subsidized credit program variable appears to be showing that both output per farm and labor employment are reduced by the program.

Our major concern here is with the impact of the research variable. As the table shows, this variable has highly significant coefficients in each equation. It shows that a ten percent expansion in the research stock variable causes aggregate output to increase by 2.113 percent. It also causes the employment of labor per farm to increase by 1.48 percent, the use of machinery to increase by 2.388 percent, the use of fertilizer to increase by 1.606 percent and the use of animal power to decrease by 1.216 percent. These effects are all estimated holding prices and other Z and f quantities constant. The research effects can be thought of as shifters. The weighted effect of research on all input use is to increase input use by 1.606 percent. (This is the weighted average of the individual effects). Thus we have an estimate that a research investment program sufficient to increase the research stock variable by ten percent will cause an increase in output of 2.113 percent and in inputs of 1.606 percent, leaving a net output per unit input or total factor productivity gain of .507 percent.

This productivity elasticity can now be converted into a marginal product of research expenditure. The marginal product of a research expenditure of 1000 cruzeiros in 1965 is 1000 x .507 x 0/r x r/R x α, where .507 is the estimated productivity elasticity 0/r = 200 is the ratio of output value to annual research and expenditures r/R = .0641 is the ratio of annual research expenditures in 1965 to the value of the cumulated research stock in 1965.

α = 1.51 is a correction factor for "double counting" in the research stock because of the allocation of Sao Paulo research to other states.

We thus have an estimate that an added increment to research expenditure in 1965 of 100 cruzeiros would produce an increment to agricultural product of 9750 cruzeros in 1970. (The same calculation would hold for an expenditure in 1970 producing an increment to output in 1975). The increment to output will continue indefinitely so that we can view the expenditure of 1000 cruzeiros as an investment yielding an income stream of 9750 cruzeiros beginning in the 5th year after spending and continuing into perpetuity. The internal rate of return on this investment is 69 percent.

This estimated marginal product may be roughly compared to that obtained from the yield regressions reported in section III of the paper.

Those estimates showed that an increase in spending of 10 percent in the research stock produced an increase in the yield ratio of approximately .315 percent per year or a total of 3.15 percent over a decade. Thus the comparable marginal product to that calculated above is 1000 x .315 x .507 x 70 x 1.51 = 16,180 (note that the 0/r ratio is lower because of the shorter cumulated research stock). This is higher than the 9750 calculated but given the nature of the calculation may be considered to be roughly comparable.

Perspectives on research productivity in the EMBRAPA period

This analysis of the contribution of agricultural research to productivity growth in the pre-EMBRAPA period, while incomplete in some respects, has showed that:

1. The economic impact of pre-EMBRAPA research has been large and the implicit real rate of return to this research has been well above alternative returns on other public sector investment.

2. The impact of the pre-EMBRAPA research programs was generally comparable to the impacts measured for research programs in several other developing countries.

3. The research impact varied considerably by commodity. In some commodities, the pre-EMBRAPA research program was too small to have an impact. In several others, research programs of significant size appear to have had little impact. In most commodities, however, when a significant research program was pursued for a reasonable period an impact on yields was observed.

4. The technical change generated by the pre-EMBRAPA research program was strongly biased against animal power and in favor of mechanization. It was also biased against labor (i.e., it was labor saving).

These results, it should be noted, were produced by a research program severely biased regionally as well as being unbalanced with respect to commodity emphasis. The fact that the bulk of the pre--EMBRAPA research was concentrated in the state of São Paulo, on the one hand meant that the technology gains were highly regional with the North and Northeast regions receiving little or no benefits from the research. Nonetheless enough benefits did spill in to other states, particularly in the South, to produce total gains that were quite large. It should be further noted that technology also spilled in from abroad during this period, chiefly in the form of soybean technology from the United States.

What are the prospects for the next two decades or so when EMBRAPA research programs will be the dominant factor in technical change? On the whole they look very promising. Brazil's past experience as well as the experience of many other countries indicates that a substantial degree of continuity over time in the research-productivity relationship exists.

As the ratio of research spending to the value of output rises we would expect some diminishing returns to set in, but it should be noted that in the past even if research spending had been double actual expenditures, rates of return on investiment would still have been very high. The fact that the EMBRAPA expansion has produced a more balanced research program with respect to regions will not necessarily cause a higher rate of return to be realized. On the one hand the scope for extending technological gains already realized in some regions to other regions is considerable. On the other, the degree of spill-in or spill-out of technology will be reduced.

A more balanced program commodity-wise, on the other hand, should produce higher returns in the future. Many neglected commodities may require a long research gestation period (ten or twenty years) before yielding to science. Brazil has a number of commodity research programs presently in this long gestation process. Some will yield high returns in the next decade. Others may require two decades, but the fact that Brazil is making these investments now augurs well for future growth.

Most administrators and planners have a poor understanding of the economics of agricultural growth. One often sees plans or projections calling for two or more percent per year in productivity growth. Little real understanding of how such growth is produced is in evidence. Research programs are often considered risky and unwise investments unless they yield very high returns. Yet at a ten percent real discount rate and with an average lag between research and expenditure and economic outcome of 6 years a growth rate increment of .18 percent will justify spending a full one percent of the value of agricultural product on research. Even if an unreasonably high real rate of 20 percent is expected a growth increment of .6 percent per year will support a full one percent research share of product.

The evidence from Brazil's past history and from numerous other countries is overwhelmingly clear. Brazil has underinvested in agricultural research in the past! Even with the exemplary achievements of EMBRAPA to date it continues to underinvest.

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Appendix 1. Construction of Research Units Data

The construction of the research series involved three basic steps.

1. For the state of São Paulo data are available for publications in agricultural science and technology journals and expenditures by commodity for the 1960-76 period. Using these data a **research unit** was defined. Publications were converted to research units for São Paulo.

2. For regions outside São Paulo and for São Paulo prior to 1960 we have only publications data. These data were converted to research units using the conversion procedure developed for São Paulo.

3. For the period after 1977 we have only expenditures data. Reasonably complete data on expenditures by state (both EMBRAPA and others) and expenditures by commodity, but not by region by commodity, were available. These data were first converted to research units defined to be as consistent as possible with pre-1978 research units. A commodity by region breakdown was made utilizing data on location of EMBRAPA national centers, data on the location of other research centers (coffee, cacao, rubber, IRGA, Proalcool) and 1970--77 patterns of research emphasis maintaining consitency with total spending by commodity and region.

The result of these calculations is reported in Appendix Tables A1-A6 where research units by commodity by region for the periods 1927-30, 1930-39, 1940--49, 1950-59, 1960-69, 1970-77 and 1978-80 are reported.

The key element in these data is the consistent definition of the research unit both as a quantity and as a value unit. This required two steps. The first step required a consistent weighting of publications into a standard publication. This was accomplished by first determining average spending in 1960 cruzeiros per publication for each commodity over the 1960-77 period in São Paulo. Publications data for each region, by commodity, for all periods except 1978-80 are from Gabriel L.S.P. da Silva, et al., "Pesquisa e produção agrícola no Brasil", **Agricultura em São Paulo,** 1979. Expenditure data for IAC, IB, IZ and PLANALSUCAR by commodity for the 1960-76 period are from Asignación de Recursos para investigación Agrícola en America Latina, Projeto "ARIAL", Brazil: Estudio de Caso, June, 1979, International Development Research Center, Latin American Regional Office.

Having determined average spending for the 1960-76 period we defined the weights reported in Table 1 in the text as the ratio of spending per publication for the commodity to the spending per publication for a general category including research in soils and climate, mechanization, crop biological research (including the crop pathology and parisitology work at IB, and genetics, phytopathology, entomology, physiology, virology and botanic research at IAC) and animal research at IZ and IB. This allows a standardization of all research into a general research unit.

The second step required that this research unit be related to financial data. We have reasonably consistent research expenditure data for São Paulo expressed in terms of 1960 cruzeiros (deflated by the general FGV deflator) for the periods 1940-49, 1950-59, 1960-69 and 1970-77. Expenditures per research unit were:

1940-49	6900	Cr$/RU
1950-59	6930	Cr$/RU
1960-69	7700	Cr$/RU
1970-74	13120	Cr$/RU

It is clear that research expenditures defined in 1960 cruzeiros rose substantially in the 1970's. Is this reasonable? If we are to believe that our research unit remained of constant quality and was reflecting an average research output, then we must conclude that the costs of doing research have risen faster than the general price level. I believe that such a conclusion is reasonable. It is much more costly to do research in Brazil these days than in the 50's and 60's primarily because the price of scarce high quality scientific time has been bid up greatly. The salaries of top level scientists have probably risen in a parallel fashion with expenditures per research unit.

Given this conclusion, I must further presume that the "real" cost of doing research in Brazil continued to rise after the midpoint of the 1970-76 period. Somewhat arbitrarily I assumed that these costs did rise for four years at the rate (542 Cr$/year) prevailing between 1960-69 and 1970-77. This brings the price (in 1960 Cr$) in 1978-80 to Cr$ 15.288.

The reader muy thus view these research units in terms of current cruzeiros (at 1978 costs) as units costing

Cr$ 3.944.304 in 1978
6.069.336 in 1979
12.149.592 in 1980.

The units themselves are expressed in terms of real research output and because of cost factors they cost less in earlier years.

The conversion of publications to RU's for other regions and other periods was based on the weights in Table 1. No attempt was made to adjust for different costs by region.

The 1978-80 data presented several problems. These data were entirely in expenditure terms and included the following:

1. Data for IAC, IB and IZ in São Paulo showing that these budgets changed little from 1977-79 (the IB budget did rise somewhat).

2. Data on EMBRAPA expenditure by state, by center funded by year 1974-80.

3. Data on spending by other research units and by states (these included coffee research outside São Paulo), IAA, IRGA, IAPAR and state universities.

4. A commodity breadkdown provided for 1977-78 by EMBRAPA based, I presume, on an analysis on EMBRAPA's projects.

Items 1, 2 and 3 enabled pretty good estimates of total research expenditures by region for 1978, 1979, and 1980. These were converted to research units at the 1978 costs indicated above and expressed as averages for the three years. A breakdown between EMBRAPA and other funding was straightforward. The allocation to commodities was not entirely straighforward. The São Paulo data were relatively straightforward because EMBRAPA funding is a very minor part of the total. I extrapolated the 1976 spending pattern with some variation due to relative budget changes between IB, IZ and IAC and the expansion of the São Paulo share of the IAA work.

For other regions I first established the budgets of the main research centers (EMBRAPA's national centers, the coffee, sugar, cacao centers and IRGA). I then indulged in a kind of linear programming exercise allocating remaining funds to achieve consistancy with regional expenditure totals, and the commodity allocation of average 1977-78 EMBRAPA funds and other data providing commodity totals. The result is reasonable, but should not be regarded as adequately data based. (It would be useful for EMBRAPA to undertake a survey of non--EMBRAPA research and to undertake more publication tabulation to provide a more adequate data base on a state basis in the near future).

TABLE A1. Agricultural research in São Paulo.

Comodities	1927/29	1930/39	1940/49	1950/59	1960/69	1970/77	1978/80
Coffee	3.60	1.79	3.15	5.88	7.57	7.64	7.71
Cotton	1.48	1.85	0.89	1.78	3.85	2.22	2.68
Citrus	0.30	1.58	2.21	1.62	2.34	1.18	1.48
Sugarcane	1.61	2.38	0.71	1.63	2.64	4.40	11.52
Groundnuts	-	0.05	0.10	0.40	1.00	0.99	0.78
Soybean	0.23	0.35	0.07	0.69	0.90	1.90	4.40
Castor oil bean	0.16	0.20	0.40	0.45	0.40	0.31	0.30
Exportables, total	7.38	8.20	7.53	12.45	18.70	18.64	31.50
Potatoes	0.43	0.39	0.68	1.04	2.00	0.52	0.66
Corn	0.11	0.77	0.54	1.28	1.95	1.20	1.21
Beans	-	-	0.32	0.12	2.56	1.70	1.70
Tomatoes	0.31	0.14	0.56	1.03	1.69	1.47	1.41
Rice	0.18	0.22	0.49	0.49	1.67	2.09	2.29
Manioc	0.18	0.14	0.67	0.35	0.38	0.10	0.08
Wheat	1.25	0.05	0.16	0.21	0.59	2.02	2.12
Banana	-	0.45	0.10	0.30	0.50	1.06	1.04
Onion	0.16	-	0.19	0.33	0.52	0.53	0.50
Horticultural crops	-	0.06	0.43	0.40	2.05	2.17	2.17
Fruits/temperate	0.16	0.11	0.95	0.90	2.30	2.31	2.26
Fruits/tropical	-	0.65	0.60	1.40	1.75	1.44	1.41
Other crops	2.00	1.40	3.40	2.75	5.00	5.50	5.50
Domestic crops	4.78	4.38	9.09	10.60	22.96	22.11	22.35
Mechanization	1.33	0.60	2.10	1.40	0.30	0.25	0.75
Soils	2.66	3.20	4.20	3.70	12.30	9.88	9.88
Climate	1.33	0.10	0.20	0.80	1.50	0.80	0.80
Biological R.	6.00	5.30	12.40	10.60	18.10	17.37	22.33
Other general	6.83	4.85	5.75	6.55	8.70	9.43	9.43
Animal Research	3.10	2.90	4.33	4.84	33.00	41.60	46.99

TABLE A2. Agricultural research units in Minas Gerais, Rio de Janeiro and Espírito Santo.

Commodities	1930/39	1940/49	1950/59	1960/69	1970/77	1978/80
Coffee	-	0.19	0.33	0.09	15.10	15.9
Cotton	-	0.26	-	-	0.19	2.3
Citrus	-	0.63	0.09	0.18	0.68	5.0
Sugarcane	0.44	0.79	0.31	0.66	0.39	17.0
Groundut	-	0.03	-	-	0.10	0.5
Soybeans	-	0.21	-	0.83	3.54	2.0
Castor oil beans	-	0.05	0.05	-	-	0.1
Cocoa	-	-	-	-	-	9.0
Exportables, total	0.44	2.16	0.78	1.76	20.0	49.7
Potatoes	-	0.65	0.08	0.03	0.10	0.5
Corn	-	0.51	0.19	0.42	1.92	8.7
Beans	-	0.36	0.12	0.81	3.25	5.0
Tomatoes	-	1.31	0.26	0.17	1.47	1.0
Rice	-	0.16	-	0.22	1.22	1.0
Manioc	-	0.24	0.16	-	0.71	3.6
Wheat	-	0.32	-	-	0.47	-
Banana	-	0.10	-	-	0.44	0.5
Onions	-	0.33	0.09	0.09	0.18	0.7
Horticultural	-	0.59	0.16	0.03	0.97	1.0
Fruits/temperate	-	0.30	-	-	0.67	1.2
Fruits/tropical	-	0.40	0.05	0.15	1.07	0.5
Other crops	-	1.20	0.50	0.75	1.93	1.0
Domestic crops, total	-	6.47	1.61	2.75	14.35	24.7
Mechanization	-	0.50	-	0.10	1.13	3.2
Soils & Climate	-	1.80	0.80	0.70	6.87	25.6
Biological	-	2.00	1.60	2.80	8.87	22.1
General (animal)	-	6.50	2.80	0.90	-	13.6
Total	0.44	19.43	7.59	9.11	51.22	138.9

TABLE A3. Agricultural research units in the northeast (Bahia, Sergipe, Alagoas, Pernambuco, Ceará, Piauí and Maranhão).

Commodities	1930/39	1940/49	1950/59	1960/69	1970/77	1978/80
Coffee	-	-	-	-	0.76	1.0
Cotton	-	-	-	0.41	0.46	5.0
Citrus	-	-	-	0.14	1.18	2.9
Sugarcane	0.26	0.48	1.28	0.92	1.49	12.0
Groundnut	-	-	0.03	-	0.20	0.5
Soybean	-	-	-	-	0.77	1.0
Rubber	-	-	-	-	0.20	2.8
Castor oil	-	-	0.16	0.47	5.26	39.6
Cocoa						
Exportables, total	0.26	0.48	1.47	1.94	10.32	69.9
Potatoes	-	-	-	-	0.16	1.5
Corn	-	-	0.06	0.16	1.00	1.0
Beans	-	-	-	0.16	1.05	3.7
Tomatoes	-	-	-	0.05	0.88	0.2
Rice	-	-	-	0.16	0.74	2.9
Manioc	-	-	-	-	0.07	1.0
Wheat	-	-	-	-	0.47	-
Banana	-	-	-	0.05	0.06	0.5
Onion	-	-	-	-	0.53	0.2
Horticultural	-	-	-	-	0.31	-
Fruits/temperate	-	-	-	-	0.31	-
Fruits/tropical	-	-	0.05	0.05	0.43	1.5
Other crops	-	0.05	0.35	0.25	2.50	1.0
Domestic crops, total	-	0.05	0.46	0.88	8.31	14.5
Mechanization	-	-	-	0.10	1.25	3.5
Soils & climate	-	-	1.50	2.70	8.15	16.0
Biological	-	-	0.80	0.10	1.87	4.5
General (animal)	-	-	1.10	1.80	-	(5.9)
Total	0.26	0.53	4.33	7.52	30.00	114.3

TABLE A4. Agricultural research units in the south (Rio Grande do Sul, Santa Catarina and Paraná).

Commodities	1940/49	1950/59	1960/69	1970/77	1978/80
Coffee	-	-	-	3.05	5.0
Cotton	-	-	-	-	2.0
Citrus	-	0.05	0.05	0.10	4.0
Sugarcane	-	0.04	-	0.04	17.9
Groundnut	-	-	-	0.03	0.5
Soybeans	-	0.14	-	9.83	25.9
Castor oil beans					
Exportables, total	-	0.23	0.05	13.05	55.3
Potatoes	-	0.21	0.05	0.13	0.5
Corn	-	0.16	0.15	0.68	7.0
Beans	0.04	-	0.04	0.90	2.0
Tomatoes	-	-	-	-	1.0
Rice	0.32	2.70	2.75	4.05	19.7
Manioc	-	0.03	-	-	-
Wheat	0.27	0.60	0.33	11.00	14.1
Banana	0.20	-	-	-	-
Onions	-	0.05	-	0.80	2.0
Horticultural	-	0.70	0.10	0.31	-
Fruits/temperature	-	0.15	0.25	1.00	1.0
Fruits/Tropical	-	-	0.05	-	-
Other crops	0.10	0.20	0.70	0.63	1.0
Domestic crops, Total	0.83	4.30	4.42	18.78	48.3
Mechanization	0.01	-	-	1.25	00.4
Soils & climate	-	1.20	0.90	5.00	20.6
Biological	-	0.50	0.30	6.75	25.6
General (animal)	-	-	-	-	(9.1)
Total	0.84	6.23	5.67	43.71	159.3

TABLE A5. Agricultural research in the North (Pará and Amazonas).

Commodities	1940/49	1950/59	1960/69	1970/77	1978/80
Coffee	-	-	-	0.06	1.0
Cotton	-	-	-	-	1.3
Citrus	-	0,05	-	0.12	1.0
Sugarcane	-	-	-	-	10.0
Groundnut	-	-	-	0.17	-
Soybean	-	-	-	-	-
Rubber	-	-	-	-	15.0
Castor oil beans	-	-	-	-	0.1
Cocoa	-	-	-	-	2.0
Exportables, Total	-	0.05	-	0.35	30.3
Potatoes	-	-	-	-	0.5
Corn	-	-	0.03	0.16	0.5
Beans	-	-	0.08	0.20	0.5
Tomatoes	-	-	0.05	0.06	-
Rice	-	-	0.05	0.47	1.2
Manoic	-	-	0.03	0.27	1.0
Wheat	-	-	-	-	-
Banana	0.05	-	0.05	0.06	-
Onion	-	-	-	-	0.2
Horticultural	-	-	0.05	-	-
Fruits/temperature	-	-	-	-	-
Fruits/tropical	-	-	-	0.75	1.5
Other crops	0.05	0.10	0.15	1.31	-
Domestic crops, Total	0.10	0.10	0.49	3.28	5.4
Mechanization	-	-	-	-	0.2
Soils & climate	-	0.20	0.80	2.12	8.6
Biological	0.40	1.10	0.10	0.75	6.9
General (animal)	1.30	4.20	0.60	1.63	(1.0)
Total	1.80	5.65	1.99	9.13	52.4

TABLE A6. Agricultural research in the Center-West (Mato Grosso and Goiás).

Commodities	1970/77	1978/80
Coffee	0.24	2.0
Cotton	0.05	5.6
Citrus	-	1.0
Sugarne	-	7.0
Groundnut	-	-
Soybeans	0.26	2.0
Castor oil beans	-	-
Exportables, Total	0.55	17.6
Potatoes	0.07	-
Corn	0.12	15.0
Beans	0.05	7.0
Tomatoes	0.18	1.0
Rice	0.34	12.0
Manioc	-	5.0
Wheat	-	-
Banana	-	-
Onions	0.12	1.0
Horticultural	0.25	1.0
Fruits/temperate	0.06	1.0
Fruits/tropical	-	
Other crops	-	7.0
Domestic crops, Total	1.19	50.0
Mechanization	-	1.5
Soils & climate	0.50	13.0
Biological	0.13	24.7
General (animal)	-	(9.5)
Total	2.08	116.3