Total factor productivity growth in Brazilian agriculture and the role of agricultural research

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RESUMO

Este trabalho apresenta estimativas da eficácia do Sistema Nacional de Pesquisa em Agricultura (SNPA) e empresas de extensão rural (EMATERs) no Brasil. O estudo está baseado em análise das variações na Produtividade Total dos Fatores (PTF) entre os anos censitários de 1970, 1975, 1980 e 1985, com estimativas individuais para agricultura e pecuária. Foram incorporados "spillovers" regionais (por exemplo, a região dos Cerrados) e geográficos de dois tipos: (1) de pesquisas do setor industrial privado sobre a agricultura e (2) da região onde ocorreu a pesquisa para outras regiões. Um exercício de contabilidade do crescimento indicou que as principais contribuições ao crescimento tiveram origem nas pesquisas da EMBRAPA, respondendo em média por 9% do crescimento; P&D industriais apresentam contribuição similar; pesquisas desenvolvidas em instituições estaduais contribuíram com 5% do crescimento.

Palavras-chave: produtividade de fatores, agricultura brasileira, pesquisa & desenvolvimento.

ABSTRACT

This paper reports statistical estimates of the effectiveness of the National System for agricultural research (SNPA) and rural extension enterprises (EMATERs) in Brazil. The study is based on an analysis of Total Factor Productivity (TFP) changes over the agricultural census years 1970, 1975, 1980 and 1985, with separate estimates for both crop and livestock sectors. In the analysis of the effectiveness of the research and extension programs, regional (e. g. the cerrados region) and geographic spillovers of two types are incorporated: (1) spillovers from private sector industrial research to agriculture and (2) spillovers from the region of research conduct to other regions. A growth accounting exercise indicates that the leading contribution to growth comes from EMBRAPA research programs, with 9% of growth in the aggregate; the industry R&D sector presents a similar contribution; state research institutions contributed 5% to growth.

Key words: Factor productivity, Brazilian agriculture, research & development.

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Recebido em agosto de 1997. Aceito em junho de 1998.

1 Introduction

Public sector programs are in continuous need of scrutiny for effectiveness. In the case of programs such as the research and extension programs designed to develop and diffuse improved technology to farmers, effectiveness can be measured in terms of increased farm productivity. In this paper we report statistical estimates of the effectiveness of the National System for Agricultural Research (SNPA) and rural extension enterprises (EMATERs). The SNPA encompasses both the Federal Empresa Brasilera de Pesquisa Agropecuária (EMBRAPA) system and state research units.

The EMBRAPA system has enjoyed good financial support and intellectual leadership since its establishment in the early 1970s. Early studies of the program have shown it to be effective.(Avila *et alii,* 1985; Barbosa *et alii,* 1988; Cruz *et alii,* 1982; Evenson, 1982; Evenson and Cruz, 1989a; Silva, 1984) In the late 1980s and early 1990s, heightened economic problems in Brazil have resulted in criticism of publicly funded programs.(Borges-Andrade and Horton, 1992) It is important that evaluations of these programs be made. Avila and Evenson (1996) completed a recent statistical evaluation of grain productivity in Brazil. The present study is based on an analysis of total factor productivity (TFP) changes over the agricultural census years 1970, 1975, 1980, and 1985 (the 1990 census was not undertaken). It covers both crop and livestock sectors and reports separate estimates for these sectors.

The study keeps estimates of the effectiveness of research and extension programs to guide investment decisions and to guide general policy toward the location and design of research and extension units. Trigo and Kamovitz (1992) have assessed agricultural research programs in Latin America generally and called for reform and redesign of these programs. Regional (e.g., the cerrados region) and geographic spillover issues are important to policy (see Vosti, 1991, Avila and Ayres, 1987: Cruz, 1987; and Evenson and Cruz, 1989a). This paper incorporates spillovers of two types in the analysis: (1) spillovers from private sector industrial research to agriculture and (2) spillovers from the region in which the research was conducted to other regions.

Part 2 of the paper discusses institutional features of the SNPA in Brazil. Part 3 reports indicators of change in Brazilian agriculture. Part 4 develops and reports total factor productivity change indexes for census micro-regions in Brazil. Part 5 outlines the TFP decomposition specification associating research and extension investments with TFP change. Part 6 summarizes variables and the statistical models utilized. Part 7 reports statistical estimates of investment-productivity linkages. Part 8 reports economic calculations based on these estimates.

2 Brazilian agricultural research systems

The Brazilian SNPA encompasses an intricate network of thirty-nine EMBRAPA research centers, located in different country agro-environments, developing technologies of a regional or national scope, and a large set of experimental stations and research centers in almost all of the Brazilian states. The state research institutions are designed to generate agricultural technologies adapted to the local needs (within state). The complete listing of the EMBRAPA research centers and principal state research institutions is presented in Appendix B.

Table 1 provides summary data for investment in EMBRAPA's national and regional centers. The growth in the number of researchers and their academic qualifications indicates the general strengthening of the system. Prior to the development of the EMBRAPA system, Brazil relied on the state research centers. Several of these state programs were strong (notably São Paulo and Rio Grande de Sul), but most were not. The EMBRAPA system provided Brazil with a truly national system.

Table 1
EMBRAPA: Agricultural Research Expenditures and Researchers by Academic Level, 1974-92

Year	Expenditures (US $1,000)	Number of Researchers by Academic Level			
		Bsc	Msc	PhD	Total
1974	70,197	446	385	41	872
1976	195,311	807	464	57	1,328
1978	247,921	542	702	91	1,336
1980	317,369	509	882	162	1,553
1982	402,428	403	968	226	1,597
1984	218,879	320	1,001	298	1,619
1986	283,070	274	1,046	404	1,724
1988	259,965	324	1,088	499	1,911
1990	290,528	435	1,150	561	2,146
1992	241,317	315	1,128	645	2,078

Source: EMBRAPA.

3 The Brazilian agricultural sector: some indicators

In spite of Brazil's socio-economic problems, the agricultural sector has achieved a good performance in the last two decades. Some highlights of this performance can be seen by examining the evolution of some indicators for the period 1970-85, presented in Tables 2 and 3.

Table 2
Land Utilization and Brazilian Agricultural Indicators

Specification	Agricultural Censuses Year				Five Year Rates (%)		
	1970	1975	1980	1985	1970-75	1975-80	1980-85
Area of settlements (millions ha)	294.2	323.9	364.8	376.8	1.95	2.41	0.64
Area Utilized (1,000,000 ha)	89.8	208.5	228.6	239.0	1.90	1.86	0.89
Permanent crops	8.0	8.4	10.5	9.9	0.99	4.54	-1.21
Temporary crops	26.0	31 6	38.6	42.4	3.99	4.09	1.89
Natural pastures	124.4	125.9	113.9	105.5	0.25	-1.99	-1.53
Planted pastures	29.7	39.7	60.6	74.5	5.95	8.83	4.22
Planted forests	1.7	2.9	5.0	6.7	11.55	11.86	5.93
Total of settlements (1,000)	4,924.0	4,993.3	5,159.9	5,832.6	0.28	0.66	2.48
Settlements using fertilizers (1,000)	915.8	1,111.8	1,657.8	1,751.1	3.96	8.32	1.10
Rural laborers (1,000,000)	17.6	20.3	21.2	23.5	2.96	0.79	2.15
Tractors (no.)	165.9	323.1	545.2	666.3	1.14	11.03	4.09
Cattle herd (1,000,000)	78.6	101.7	118.1	128.2	5.29	3.04	1.65

Source: IBGE, *Agricultural Censuses, Brazil* (1992).

Table 3
Evolution and Regional Profile of Brazilian Agricultural Indicators

Specification	Agricultural Censuses Year				Regionalization, 1985				
	1970	1975	1980	1985	North	North-east	South-east	South	Center-west
Land territory used (%)	34.8	38.3	43.1	44.6	17.6	60.1	80.3	85.6	53.0
Used/total area (%)	64.4	64.5	62.6	63.4	38.3	54.5	80.4	79.0	67.4
Pastures/total area (%)	81.2	79.4	76.3	75.3	87.4	70.3	72.0	56.5	88.4
Support capacity	0.51	0.61	0.68	0.71	0.43	0.63	0.84	1.16	0.61
Gini coefficient	0.838	0.850	0.853	0.854	0.79	0.86	0.76	0.74	0.83
Fertilizer used (%)	18.60	22.27	32.13	30.02	3.29	11.77	58.36	60.39	34.72
Workers= productivity	1.93	1.97	2.32	2.22	1.08	1.37	2.85	3.23	5.61
Workers/tractors ratio	106.0	62.97	38.82	35.33	207.2	249.5	19.97	15.68	14.52
Mechanization degree	204.88	123.80	90.06	78.46	223.8	342.3	56.86	50.64	81.47

Source: IBGE, *Agricultural Censuses, Brazil* (1992).

The land data items shown in Table 2 are influenced by the expansion of agricultural land area resulting from the continual advance of the agricultural frontier, mainly to the "cerrados", in the center-west region of the country, and from the introduction of more capital-intensive production techniques, especially in São Paulo and states of the south region. Table 3 presents further indicators showing the wide regional disparities in the Brazilian agricultural sector.

The use of tractors and of fertilizers are examples of the marked imbalance in the modernization process of Brazilian agriculture. In 1985, 43.2 percent of the tractors used in Brazil were concentrated in the south region, with 50.64 hectares per tractor, while in the north and northeast regions this ratio was 223.85 and 342.31 hectares per tractor, respectively. In the case of fertilizer use, the data show the same kind of regional imbalance. Fertilizers were used on only 3.29 percent of the farms of the north region, while this figure was 60.39 percent in the south region.

With regard to fertilizers, the 1980 census data show that their use then was also regionally imbalanced. In the northeast, sugarcane occupied only 6.2 percent of the cultivated area, but consumed 85 percent of the fertilizers used. In the southeast and center-west regions, coffee, sugarcane, soybeans and cotton consumed 75 percent of the fertilizer used, while occupying only 27.2 percent of the cultivated area. In the south, soybeans and wheat were employing 90 percent of the fertilizer used in the region.

4 Total factor productivity in Brazilian agriculture

TFP decomposition is perhaps the most frequently used method for estimating the impacts of agricultural research, extension, schooling and policy actions on agricultural production. Two steps are entailed in TFP decomposition. In the first, TFP indexes are computed in such a way as to isolate the "residual" containing the contributions of the programs and policies being analyzed. In the second, TFP indexes are subjected to a statistical decomposition analysis where timing and geographic spillover weights are incorporated into the specification.

In this section we briefly review the TFP methodology and summarize TFP indexes computed for census micro-regions for four census periods. The TFP residual is readily derived from a simple accounting relationship (or alternatively, from a production or transformation). Two issues for the subsequent decomposition analysis required attention. The first is the curvature or substitution issue. The second is the degree of adjustment for input quality change.

The simplest and least restrictive definition of TFP is derived from a cost accounting framework, which allows one to define a change in TFP from period "*t*-1" to period "*t*" Changes from period to period can then be summed up to create TFP measures when we have more than two periods. If no extraordinary profits exist and returns to all factors are properly measured, the values of all outputs (Y_i) will equal the value of all inputs (X_i)

$$\sum_i P_i Y_i = \sum_j R_j X_j \tag{1}$$

Expression (1) does not impose strict efficiency by all farmers. It is based on an accounting condition that holds in a competitive sector.

Differentiating (1) totally with respect to time, we obtain the following expression:

$$\sum_i P_i \frac{\partial Y_i}{\partial t} dt + \sum_i Y_i \frac{\partial P_i}{\partial t} dt = \sum_j R_j \frac{\partial X_j}{\partial t} dt + \sum_i X_j \frac{\partial R_j}{\partial t} dt \tag{2}$$

For small changes, (2) expresses the relationship between changes in output and input quantities and output and input prices. Now divide (2) by $P_i Y_i$ and multiply the four terms by Y_i / Y_j, P_i / P_j, X_i / X_j and R_i / R_j , respectively. Define the following:

$$P_i Y_i / \sum P_i Y_i = S_i, \quad R_j X_j / \sum P_i Y_i = C_i, \quad (1 / Y_i)(dY_i / dt)dt = \hat{Y}_i$$

and similarly for P_j, X_j *and* R_j

Using these definitions, expression (2) can be written as:

$$\sum S_i P_i + \sum S_i Y_i = \sum C_j R_j + \sum C_j X_j, \tag{3}$$

$$\hat{P} + \hat{Y} = \hat{R} + \hat{X}, \quad where \ \hat{P} = \hat{S_i P_i}, \quad etc. \tag{4}$$

Expression (4) can be written in Total Factor Productivity form as:

$$\hat{Y} - \hat{X} = \hat{R} \quad \hat{P} = \hat{T} \tag{5}$$

Note that (5) is exact for infinitesimal changes. In this case, we are treating this as a valid approximation only for annual changes from year "t" to year "t+1"

The "Tornqvist-Theil" TFP index for multiple periods in logarithmic form is:

$$\lambda v(TFP_t / TFP_{t-1}) = \tfrac{1}{2}\sum_i (S_{it} + S_{it-1})\lambda v(Y_{it} + Y_{it-1}) - \tfrac{1}{2}\sum_j (C_{jt} + C_{jt-1})\lambda v(X_{jt} + X_{jt-1}) \tag{6}$$

The "Tornqvist-Theil" TFP index is a type of "Divisia" index that is consistent with very general production structures and accommodates the substitutability of one input for another.

Many analysts of TFP have attempted to make adjustments to the "raw" TFP measures constructed from data as conventionally measured in censuses or in other measurement systems. Typically these take the form of input "quality" corrections. The most important of these are corrections to the labor input measure to account for changes in age, sex and educational status. We do not deny the usefulness of these adjustments. The failure to deal with quality change in inputs can seriously bias interpretations of TFP measures. In this study we argue that the "raw" uncorrected measure of TFP are appropriate for a decomposition analysis if appropriate "right-hand-side" (independent) variables are developed to deal with input quality (see the next section).

We construct TFP indexes for each census micro-region based on data from the 1970, 1975, 1980, and 1985 Censuses of Agriculture for Brazil. For each micro-region the Tornqvist-Theil index (7) is computed for the three-period changes 1975/1970, 1980/1975, and 1985/1980. These are normalized to an index = 100 for the 1970-75 averages period.

Output index

The output index was constructed including the following products: a) temporary crops - wheat, rice, beans, maize, soybeans, cotton, manioc, onion and tomato; b) permanent crops - cocoa, coffee, sugarcane, banana. citrus and grapes; and c) livestock - beef cattle, milk, swine and eggs. (See Appendix C.)

Input index

The input index was constructed using the following agricultural production factors: a) crops - cultivated area, labor force (permanent, family and temporary), tractors, animal power, fertilizer and chemicals; and b) livestock - natural and artificial pastures, labor force (permanent, family and temporary), tractors, fertilizers, chemicals, feed and animal medicines. In both cases, the prices used were collected from each one of the agricultural census years or from secondary sources.

Table 4 reports changes in the TFP indexes by period, macro-regions and sectors. We note different patterns in crop and livestock TFP. For livestock, large gains were realized in the 1970-75 period and for a few there are no gains since 1975. For crops, TFP gains have been realized most prominently in the 1980-85 period.

Table 4
TFP Index and Rates of Growth: Region and São Paulo State, Brazil, 1970-85 Period

Region	Sector	1970	1975	1980	1985	Annual growth 1970-85 (%)
North	Crops	100.72	99.28	108.06	125.49	1.37
	Livestock	95.52	104.48	109.75	104.55	0.53
	Aggregate	100.20	99.80	111.96	123.75	1.31
Northeast	Crops	92.69	107.31	104.73	125.96	1.99
	Livestock	88.04	111.96	108.09	106.80	1.18
	Aggregate	91.96	108.04	104.74	118.50	1.60
Southeast	Crops	108.00	91.99	105.32	146.96	2.00
	Livestock	72.89	127.11	124.91	120.72	3.65
	Aggregate	90.34	109.66	116.10	140.13	3.06
South	Crops	89.46	110.54	110.17	127.89	2.39
	Livestock	84.59	115.41	96.64	84.23	-0.02
	Aggregate	88.79	11.21	105.13	112.19	1.46
Center-West	Crops	102.97	97.03	115.13	149.50	2.51
	Livestock	77.78	122.22	124.62	137.33	4.25
	Aggregate	87.24	112.76	124.30	146.99	3.80
São Paulo	Crops	97.73	104.27	109.04	128.02	1.87
	Livestock	72.62	127.38	106.09	108.26	2.73
	Aggregate	87.31	112.69	110.41	127.55	2.56

Table 5 summarizes TFP changes for the agricultural sector for twenty-two of the ninety-two Brazilian agro-ecological zones, the more important zones in the context of the agricultural sector. They are responsible for more than 80 percent of the grain, fruit, and animal production.

Table 5
Aggregate TFP Index and Rates of Growth for Selected Brazilian Agro-ecological Zones, 1970-85 Period

Selected Zones	1970 TFP index	1985 TFP index	TFP growth rate (%)
01 Atlantic Coast B RS/SP	94.94	124.55	1.73
15 - Pantanal - MS/MT	86.26	99.08	0.93
17 - Semi-aris (Sertão)	81.45	130.35	3.16
31 - Pará - Northeast Zone	104.44	121.42	1.02
43 - Semi-arid (Agreste)	101.96	85.72	-1.14
54 - RS Campanha	94.70	109.49	0.78
55 - Cerrados Bahia	112.20	116.78	2.66
58 - Tocantins & Goiás	98.64	121.14	1.38
59 - Cerrados North	83.75	138.53	3.41
61 - Cerrados Center-south	83.30	148.67	3.92
67 - RS, SC & PR Forest	90.26	111.93	1 41
70 - RS, SC & PR Fields	91.27	106.15	1.02
71 - West Patos Lagoon	97.33	105.22	0.47
72 - São Paulo Capital Reg.	91.74	135.90	2.64
74 - Minas Gerais	96.20	150.15	3.02
75 - Paraná	82.32	126.89	2.93
78 Northeast Zona Mata	94.21	144.21	2.88
86 Bahia - Cacao Region	86.14	91.64	0.43
87 Center RS & Front. SC	101.01	101.67	0.04
90 São Paulo West	82.78	121.42	2.59
91 Cerrados Center	91.73	130.06	2.36
92 São Paulo Center	82.16	134.73	3.34

It is of interest to note that zones 61 and 59, located in the cerrados region, achieved exceptionally high TFP growth rates. The following zones have achieved high rates of TFP· 17, 74, 75, 78, and 92. By contrast, the following zones have achieved low rates of TFP change: 15, 43, 54, 70, 71, 86, and 87

5 TFP decomposition methods

The TFP measure is by nature a "residual" The economic logic underlying the residual is that the conditions under which input-predicted growth (see (4)) is equal to actual growth do not hold. Specifically this means that one or more of the following production environments has changed:

a) new technology may have become available;

b) new infrastructure may have become available;

c) average farm efficiency may have improved relative to "frontier" or "best"-practice efficiency;

d) markets may have become more (less efficient).

Unfortunately we do not have *direct* evidence as to the contributions of each of these changes, except in some cases where adjustments can be made for changes in the quality of inputs (for example, education adjustment for labor force quality can be made). TFP decomposition is a method for indirectly estimating the contributions of these factors. This method entails a statistical regression of TFP indexes on carefully constructed variables indexing changes in technology, infrastructure, farmer efficiency and market efficiency.

Technology infrastructure and efficiency are not "free" They are produced by investments in capital stocks and by specialized labor services. Technology is produced in research organization (public and private) by skilled scientists using scientific equipment, laboratories, and fields. Farmer efficiency is produced by farmer experiments and information enhanced by schooling and skills. Extension specialists also produce efficiency. Market efficiency is produced by institutional change and is enhanced by infrastructure investments.

Thus, in TFP decomposition we must rely on investment or input data to create relevant variables. And this reliance on input data means that we must address issues associated with the production of these outcomes. Three such issues are particularly critical. The first is the timing relationship between investment and TFP input. The second is the spatial relationship between the location of research or invention and the realization of TFP growth. The third issue is the deflation issue.

5.1 The timing dimension

There is a time lag between the conduct of research activities and the development of improved technology. Experiments require time and evaluation and sequences of experiments and tests must be designed before new technology is developed. Then the technology must be diffused to farmers. Some of this diffusion requires embodiment in farm inputs (seeds) and some is diffused as information (improved practices). Farmers must experiment and evaluate as they adopt technology and modify it for their farm conditions.

The "time-shape" of these lags is thus similar to the classic technology diffusion lag (Griliches, 1967) with a period of little TFP impact after investment, rising to a peak some years later. However, a second factor, depreciation, plays a role in the time-shape also. It is important to distinguish between depreciation and obsolescence in this regard. Technological obsolescence occurs when new technology (say a new variety of rice) is superior to an existing technology and displaces it. If the new technology was developed as an extension of existing technology (i.e., it was an "add-on" to an existing technology) then the investments associated with the development of the existing technology did not depreciate even though the technology becomes obsolete.

Depreciation occurs when (a) there is incomplete additivity in technology development and (b) when there are "exposure" effects to reduce the value of technology after it has been exposed to use. Host plant gemetoc resistance to plant insects and diseases is often reduced by use exposure, and this is an example of depreciation. Changes in prices can reduce (or enhance) the value of technology, and this is a source of depreciation as well (e.g., a rise in energy prices may reduce the value of technology that is highly dependent on energy).

The practical procedure for developing a research stocks variable reflecting the time dimension is to build a research stock with an appropriate time shape.

The formula used to build the research stocks in this study is:

$$StR_t = (ExpRE_{t-4}\ \ 0.2) + (ExpRE_{t-5}\ \ 0.4) + (ExpRE_{t-6}\ \ 0.6) + (ExpRE_{t-7}\ \ 0.8)$$

$$+\sum_{t=8}^{20} (ExpRE_{t-2}\ \ 1.0) \qquad (7)$$

where $ExpRE_{t-4}$ is spending in year t-4 etc.

We built in a time lag of four years between the initial investment in agricultural research (first year of the research project) and the impact on agricultural production at the farm level. The full impact is realized after eight years. Given the relatively recent development of EMBRAPA research, we did not build in a depreciation component. These estimates are based on previous studies (see Evenson and Cruz, 1989a).

For rural extension services, the timing between the investment (diffusion of new technologies, training etc.) and the impact at the farmers' level (increases output) is shorter than in the agricultural research case. Normally, most of the results of extension appear in the first three years after new techniques are made available to farmers.

The formula used to construct the stock for rural extension services is based on the staff of technical personnel working close to farmers (personnel at the municipalities or county office levels). The stock formula based on staff personnel is presented below:

$$StExt_t = (StaffExt_t \quad 0.25) + (StaffExt_{t-1} \quad 0.50) + (StaffExt_{t-2} \quad 0.25). \qquad (8)$$

This specification presumes that extension serves to speed up the adoption of technology. After three years the extension impact is zero on the presumption that other information sources and institutions would have been sufficient to enable adoption by them. (This may be too conservative because extension may have more permanent effects.)

5.2 The spatial dimension

Research conducted in one location will produce technology that is useful in other locations. But it is not necessarily equally useful in all other locations. We know that plant and animal performance is sensitive to climate and soil factors. The natural selection model of Darwin tells us that genetic diversity is associated with a high degree of location specificity of plants and animals to environmental niches. Modern plant and animal breeding programs have only partially overcome this "Darwinian" phenomenon. Research systems in Brazil have incorporated Darwinian targeting into their structure. EMBRAPA has a number of national commodity research centers and a number of ecoregional centers. Each state has state research programs and a number of branch or sub-state research locations are maintained as well.

The problem that we face in this study is to assign the research stocks from the national centers, regional centers and state programs to specific micro-regions (our unit of analysis). In practice, there are two methods for doing this. One is the technology distance method (first introduced by Evenson and da Cruz, 1988) where research conducted in region "*j*" is assigned to region "*i*" in proportion to a technology distance index between them. Technology distance indexes are measures of the performance of region *j*'s best technology in region *i* relative to region *i*'s best technology in region *i*.

The second method used in this study is to "test" alternative assignments of research based on geo-climate and priority zone evidence. For example, in the work reported below we construct three alternative assignments for EMBRAPA national program research. They are:

(1) Assignment 1 where all micro-regions in the country are assigned the national program research stock. This is consistent with a complete "spill-over" of national program research from the national commodity center to other locations.

(2) Assignment 2 where national program research is assigned to "priority zones" as identified by national product center staff. This is a sub-set of the 92 agro-ecological zones (on average 40 percent). This assignment is consistent with spill-overs limited to these priority zones.

(3) Assignment 3 where national program research is assigned only to micro-regions in the agro-ecological zone in which the national research center program is located. This is consistent with very limited spill-over of research benefits.

A similar procedure is applied to EMBRAPA regional center research where a test is made between assignment to the region as defined by EMBRAPA and the assignment 3.

Mean square error tests are performed to select the assignment most consistent with the data. As we note below, these tests show that assignment 1 was best for national program livestock research. Assignment 2 was best for crop and agricultural research generally. For regional center research, assignment to the region was best. State research assignment to all micro-regions in the state was best. For the extension and infrastructure variables, no spill-over was specified.

5.3 Deflators (spill-over between commodity programs)

Crop and livestock research programs have components that are specific to each crop and components that are general in their impact. If specific components dominate and there is little spill-over between commodities, the appropriate aggregated research stock for a micro-region is "share-weighted" by the micro-region crop and livestock production shares. This implicitly assumes that the commodity programs assigned to the micro-region have equal impacts on TFP over commodities. This procedure indirectly deflates the research stocks. A region with a low share for rice, for example, will not be affected by the level of rice research. As with spill-in assignments, tests of weighted and unweighted research variables were made. For state livestock research the unweighted stock performed best. For others, the weighted stocks performed best. For extension, two deflators, area and number of farms were used (see below).

6 Variables and model specification

Table 6 provides a summary of variables used in the study. They are classified as endogenous (dependent) variables and exogenous (independent) variables. There are four endogenous variables including the three TFP indexes and the extension contact variable, EXTC85. The analysis proceeds in two stages. First, an extension contact analysis is undertaken. Second, the TFP decomposition specifications are estimated including a predicted extension contact variable. Observations are on micro-regions as defined in the agricultural censuses. The Federal District and micro-regions, where matching between censuses was impossible, were not included. A total of 370 micro-regions were included in each of the four years.

Table 6
Variables Used in TFP Decomposition Analysis Definitions and Means 1970, 1985

Variables	Definition	Means 1970	Means 1985
I. Endogenous Variables			
CROPTFP	TFP index (1975 = 100) for Crops	97.81	132.40
LVSTKTFP	TFP index (1975 = 100) for Livestock	81.71	108.94
AGRTFP	TFP index (1975 = 100) for Agricultural Sector (Aggregate)	89.56	127.10
EXTCTC85	ln (*P*(1-*P*) where *P* is the percent of farmers in 1985 with extension contact (from 1985 Agricultural Census)		-3.20
II. Exogenous Variables: Extension Contact Analysis (Stage 1)			
POPDEN	Rural Population in 1985/state area	0.14	0.08
RURSCHOOL	Average years of schooling of rural population over age 10 (IBGE)	1.04	2.35
EXTFARM	Extension Staff (stocks)/number of farmers in 1980	0.415	0.1057
EXTAREA	Extension Staff (stocks)/area in farms	0.00001	0.00025
LIVSHARE	The share of livestock products in total agricultural value of product	0.3522	0.3917
AGRTFP(L)	Lagged AGRTFP	0	17.61
HZONE2	Dummy = 1 if micro-region is in macro climate zone 2	0.20	0.20
HZONE3	Dummy = 1 if micro-region is in macro climate zone 3	0.50	0.50

Table 6, continued

Variables	Definition	Means 1970	Means 1985
III – Exogenous variables: TFP Decomposition			
POPDEN, ZONE2, HZONE3	Same as in II		
PREDEXTC	Predicted extension contact (from extension contact analysis (Stage 1))	1.293	5.675
ROADDEN	Kms of federal roads in state/state area	0.0040	0.0046
INDCROP	Industrial research stock for crops (weighted)	0	877
INDAGR	Industrial research stock for all agriculture (weighted)	0	719
EMBNPCROP	EMBRAPA National Prog. Res. Stock – Crops		
All areas	Assigned to all micro-regions	0	35,276
Priority areas	Assigned to micro-regions in the priority areas	0	13,336
Agro-zone	Assigned to micro-region in one agro-zone	0	2,742
EMBNPLVSTK	EMBRAPA Nat. Prog. Res. Stock – Livestock		
All areas	Assigned to all micro-regions	0	92,831
Priority areas	Assigned to micro-regions in the priority areas	0	13,260
Agro-zone	Assigned to micro-region in one agro-zone	0	5,749
EMPNPAGR	EMBRAPA Nat. Prog. Res. Stock – Aggreg.		
All areas	Assigned to all micro-regions	0	57,522
Priority areas	Assigned to micro-regions in the priority areas	0	13,122
Agro-zone	Assigned to micro-region in one agro-zone	0	4,603
EMRCPCRP	EMBRAPA Reg. Centers Crop Res. Stock		
Region	Assigned to micro-regions in the region	0	4,262
Agro-zone	Assigned to micro-regions in the agro-zone	0	1,918
EMRCPLVSTK	EMBRAPA Reg. Centers Livestock Research		
Region	Assigned to micro-regions in the region	0	3,748
Agro-zone	Assigned to micro-regions in the agro-zone	0	1,695
EMRCPAGR	EMBRAPA Reg. Centers Agric. Research		
Region	Assigned to micro-regions in the region	0	8,489
Agro-zone	Assigned to micro-regions in the agro-zone	0	3,834
STATECROPR	State research stock on crops assigned to all micro-regions in state	1,020	57,751
STATELVSTKR	State research stock on livestock assigned to all micro-regions in state	4,836	48,937
STATEAGRR	State agricultural research stock assigned to all micro-regions in state	858	34,937
FERT2-FERT7	Dummy variables = 1 if micro-region is classified in soil fertility regions 2 through 7		
TEXT2-TEXT7	Dummy variables = 1 if micro-region is classified in soil texture regions 2 through 7 (TEXT1 is the reference class)		
DRAIN2-DRAIN6	Dummy variables = 1 if micro-region is classified in soil 2 through 6 (DRAIN1 is the reference class)		
Y70, Y75, Y80	Dummy variables = 1 if year = 1970, 1975 and 1980 (Y85 is the reference category)		

6.1 The extension contact analysis variables

The 1985 Agricultural Census reports the proportion of farmers contacted by the extension service. This variable is subject to two problems as a prediction of TFP change. First, it is endogenous in that it is at least partly determined by farmers. Second it is available only for 1985. Both problems can be solved by developing a prediction specification for the 1985 data and then using the prediction variables (which are available for other years) to predict extension contacts for all four census years. In this way we can take advantage of the richness of the 1985 data and avoid the endogeneity problem.

The form of the EXTCTC85 variable is logistic (ln (P/ (1-P)) on the grounds that extension contacts are diffused through the farm population in the same way that technology is diffused.

The specification of the extension contact equation attempts to correct for the simultaneity bias between productivity change and extension activity. We hypothesize that farmer's demand for extension is primarily a function of two things: farmer's schooling and past experience with technology and productivity change. Accordingly we include a farmer's schooling variable, RURSCHOOL, and lagged (five years) productivity change AGRTFP(L) (for 1970 we use current AGRTFP), as predicting variables.

The supply of extension services is measured by the EXTFARM and EXTAREA variables. The population density (POPDEN) and LIVSHARE variables control for broad general differences between regions and crop-livestock extension differences. The zone variables are designed to pick up differences associated with broad agro-ecological conditions.

6.2 The TFP decomposition variables

The TFP decomposition variables include:

a) The predicted extension contact variable (from stage 1).

b) EMBRAPA national program research variables with three assignment options as discussed above.

c) EMBRAPA regional center research variables with three assignment options as discussed above.

d) State research variables.

e) Industrial research variables (Discussed further below).

f) Infrastructure variables (POPDEN and ROADDEN).

g) Agro-climate variables, FERT2-FERT7, TEXT2-TEXT7, DRAIN2-DRAIN6.

h) Year variables: Y70, Y75 and Y80.

The dependent variables were constructed for each micro-region. Accordingly, we are not analyzing cross-section differences in productivity. We are analyzing changes in TFP over the 1970-1985 period. This is not a full "fixed effects" model, however, because we are taking advantage of cross-section variation in the independent variables. Specifically, we take advantage of the fact that some regions have low research investments, others have high levels of investment. If we were to index our research variables in fixed effects style (as with our dependent variable), we would have only the rate of change in research stocks to predict changes in TFP.

We do, however, attempt to control for cross-section heterogeneity by including very detailed soil drainage, texture, and fertility class dummy variables. These class are summarized in Table 7. We also include year dummy variables.

Table 7
Agro-climate Variables: Soil Drainage, Texture and Fertility Classes

Soil Class	Texture	Drainage	Fertility
1	Indiscriminate texture	Imperfect to bad drainage	Very low fertility
2	Sandy	Imperfect to drained	Very low to low & low to very low
3	Medium sandy	Bad drainage	Low
4	Sandy to clay & sandy to very clay	Moderate drainage to imperfect/bad drainage	Low to high & very low to high
5	Medium to clay & medium to very clay	Bad to well drained & well drained to bad drainage	Low to medium
6	Medium	Moderate to well drained	Medium
7	Clay to silty & clay to very clay	Moderate to well drained	Medium to high fertility
8	Clay	Well drained	High fertility

Source: EMBRAPA/SNLCS - Delineamento Macroagroecológico do Brasil, 1992/93.

The rationale for the extension and EMBRAPA and state research variables has been given above. The industrial research variables are important to this analysis because the industrial sector undertakes R&D to improve farm inputs sold to the agricultural sector. Because these firms do not "capture" or appropriate the full value of the improvements made by their R&D investments, these investments contribute to agricultural TFP. A simple example shows how this is so. Suppose a firm in Brazil develops as improved farm implement that in real term produces a service flow that is 10 percent greater than the service year from an existing implement. If it were to price its new machine at 10 percent higher than the new machine, it would have few sales. Thus it will price its new machine at less than ten percent over the existing machine because of its interest in promoting sales and because competitors are developing new machines. The firm's failure to capture the full ten percent improvement means that in TFP accounting in the agricultural sector, the new machine is counted as having a less than 10 percent higher service flow. And this results in TFP growth in the agricultural sector.

The INDCROP variable was constructed from the data in Table 8 on invention potential in Brazil. These inventions originate both in Brazil (50 percent) and abroad. (The U.S. is the major source - see Evenson and Putnam, 1990.) Brazilian inventions were weighted to be three times as valuable as foreign inventions in chemicals and two times as valuable as a foreign invention in other fields. A cumulated stock of inventions was constructed assuming 1970 to be one half of 1975 for each type of invention. INDCROP was created at the micro-region level by using micro-region cost share weights: chemicals and fertilizer for chemical inventions; tractors for machine inventions; animal power for animal husbandry inventions; and the output share of permanent and vegetable crops for horticulture inventions. We were not able to construct a satisfactory INDLVSTK variable, but in the INDAGR variable, the animal husbandry inventions are given additional weight through animal production shares. Both livestock and crop, as well as chemical, tractor and machine shares are used in INDAGR.

Table 8
Invention Patents Granted in Brazil (National and Foreign)

Field	1975	1980	1985
Chemicals	811	2,106	3,950
Machinery	218	556	1,032
Animal Husbandry	32	82	151
Horticulture	77	288	571

Source: Evenson and Putnam (1990).

Finally, we have included the POPDEN and ROADDEN variable as proxies for infrastructure and related investments.

7 Estimates

7.1 The extension contact analysis

Table 9 reports estimates for the extension contact specification. The most important finding here is that farmer's schooling levels (RURSCHOOL) lead to increased extension contacts. The coefficient on schooling is large and highly significant. Since extension supply (EXTAREA) is also significant (and held constant), this reinforces the interpretation of the schooling coefficient as reflecting farmer demand for extension services.

Table 9
Extension Contact Estimates, Agricultural Census 1985
Dependent Variable: EXTCTC85

Independent variables	Coefficient	"t" ratios
Intercept	-1.948	(0.61)
POPDEN	19.42	(0.61)
RURSCHOOL	4.500	(10.74)
EXTFARM	-0.497	(1.25)
EXTAREA	61.007	(2.16)
LIVSHARE	2.743	(1.67)
AGRTFP(L)	0.0206	(1.59)
HZONE2	1.676	(1.74)
HZONE3	2.986	(3.60)
R^2	0.3932	
AdjR^2	0.3783	
F value	26.40	
Prob F	0.0001	

The second variable, past TFP change (AGRTFP(L)), is only marginally significant (p = 0.11), but does support the proposition that successful past productivity experience creates demand for extension services. The negative coefficient on the livestock share (LIVSHARE) indicates a lower demand for extension by livestock producers (although this may also affect lower supply, since the supply variable, EXTAREA, does not distinguish between crop and livestock extension). It appears that there are some differences in extension contact by agro-climate zone.

In the productivity decomposition analysis, a predicted extension contact variable (converted from logistic form to predicted percent of farms contacted) was created for all four years. Since schooling plays such a large role in the specification, this variable is perhaps best thought of as a farmer human capital variable.

7.2 TFP decomposition analysis

Tables 10, 11, and 12 report TFP decomposition estimates for the crops sector, the livestock sector and the aggregate agricultural sector, respectively. Each table reports a specification including the predicted extension variable and a specification excluding it. This is done in view of the relatively low levels of significance of the predicted extension variable to demonstrate that the exclusion of the variable has little effect on other coefficients. The coefficients for the year dummies, the soils dummies, and the intercepts are not reported as we do not consider them to have policy importance.

7.2.1 TFP decomposition for the crop sector

Crop sector TFP decomposition estimates reported in Table 10 shows the following:

a) All research programs contributed to TFP growth. This includes industrial R&D, EMBRAPA national program research, EMBRAPA regional centers and state research programs.

b) Mean square error tests for crop share weighting showed that weighted variables for all research categories outperformed unweighted variables indicating low levels of common research impact over crops.

c) Mean square error tests on spill-over assignments showed that assignment 2 (i.e., to priority zones) for national programs outperformed assignment 1 (to all zones) and assignment 3 (to zone of location) indicating that national programs do not serve all zones equally, but that they do have impact outside the zone of location (priority zones are approximate 37 percent of all zones). For regional centers, tests indicate that the centers serve the full region which includes more than the zone of location. State programs serve all the state micro-regions.

d) Industrial research has a significant impact on TFP growth in the crop sector.

e) The human capital-predicted extension variable is marginally significant ($P = 0.18$). This may reflect the fact that measures of extension activities are not very accurate. We do, however, consider this estimate to support the contention that human capital in agricultural is important to growth and efficiency.

f) The road density variable appears to indicate an infrastructure contribution. There appear to be no population density effects.

Table 10
Crop TFP Decomposition Estimates, Brazilian Agricultural Census Data: 1970-75-80-85 Years
Dependent Variable: Crop TFP Index (equal to 100 in 1975)

Independent variables	Specification (1) without extension	Specification (2) with extension
Population Density (POPDEN)	5.082 (0.37)	4.453 (0.33)
Road Density (ROADDEN)	232.47 (2.38)	227.77 (2.33)
Industrial Research (INDCROP)	0.00797 (2.74)	0.00650 (2.09)
EMBRAPA National Centers (EMBNPCRP) (Priority zones)	0.00022 (1.78)	0.00021 (1.71)
EMBRAPA Regional Centers (EMBRCCRP) (Region)	0.00194 (4.21)	0.0204 (4.37)
State Research (STATECROPR) (State)	0.0000248 (4.48)	0.0000252 (4.53)
Extension Contacts (PREDEXT) (Predicted logit)	-	0.575 (1.32)
R^2	0.2081	0.2092
AdjR^2	0.1906	0.1910
F value	11.87	11.54
Prob F	0.0001	0.0001

Notes: "*t*" ratios in parentheses. Soil conditions, zone and year intercepts included but not reported.

Table 11
Livestock TFP Decomposition Estimates, Brazilian Agricultural Census Data: 1970-75-80-85 Years
Dependent Variable: Livestock TFP Index (equal to 100 in 1975)

Independent variables	Specification (1) without extension	Specification (2) with extension
Population Density (POPDEN)	7.670	6.979
	(0.67)	(0.66)
Road Density (ROADDEN)	-13.94	-18.57
	(0.17)	(0.23)
EMBRAPA National Centers (EMBNPLSTK) (Priority zones)	0.000545	0.000562
	(6.01)	(6.01)
EMBRAPA Regional Centers (MBRCLVSTK) (Region)	0.00103	0.0107
	(1.76)	(2.84)
State Research (STATELVSTKR) (State)	0.0000357	0.0000302
	(2.02)	(1.58)
Extension Contacts (PREDEXT) (Predicted logit)	--	0.2817
		(0.75)
R^2	0.2914	0.2917
AdjR^2	0.2762	0.2760
F value	19.25	18.60
Prob F	0.0001	0.0001

Notes: "t" ratios in parentheses. Soil conditions, zone and year intercepts included but not reported.

Table 12
Aggregate Agricultural TFP Decomposition Estimates, Brazilian Agricultural Census Data: 1970-75-80-85 Years
Dependent Variable: Agricultural TFP Index (equal to 100 in 1975)

Independent variables	Specification (1) without extension	Specification (2) with extension
Population Density (POPDEN)	3.992	3.877
	(0.41)	(0.40)
Road Density (ROADDEN)	206.83	205.89
	(3.00)	(2.98)
Industrial Research (INDAGR)	0.01653	0.01618
	(5.52)	(5.20)
EMBRAPA National Centers	0.00014	0.00014
(EMBNPAGR) (Priority zones)	(1.84)	(1.82)
EMBRAPA Regional Centers	0.00050	0.00051
(EMBRCAGR) (Region)	(3.17)	(3.19)
State Research (STATEAGR)	0.0000186	0.0000187
(State)	(2.51)	(2.52)
Extension Contacts (PREDEXT)	--	0.1276
(Predicted logit)		(0.42)
R^2	0.3128	0.3129
AdjR^2	0.2976	0.2971
F value	20.56	19.87
Prob F	0.0001	0.0001

Notes: "*t*" ratios in parentheses. Soil conditions, zone and year intercepts included but not reported.

7.2.2 TFP decomposition for the livestock sector

Livestock TFP decomposition estimates reported in Table 11 show the following:

a) All public sector research programs contribute to TFP growth.

b) Mean square error tests for product share weighting showed that weighted variables for the two EMBRAPA variables outperformed the unweighted variable. The state unweighted variable, however, performed best. This may indicate that state livestock research programs are more oriented toward general livestock management issues and lack commodity specificity.

c) Mean square error tests showed that for EMBRAPA national programs, assignment 1 (to all zones) performed best. This is consistent with other evidence that livestock research is less location specific than crops research. For EMBRAPA regional centers, assignment 2 performs best indicating that these centers serve all zones in the region. State research serves the state.

d) The human capital-predicted extension variable, while positive, is not statistically significant ($P = 0.45$). This may reflect weak livestock extension, which is consistent with the extension contact analysis where the livestock share had a negative impact on contacts. It may also reflect measurement error.

e) We do not find population density and road density effects.

7.3 TFP decomposition in the aggregate agricultural sector

Aggregate agricultural TFP decomposition estimates are reported in Table 12. These estimates show the following:

a) All research programs contributed to TFP growth.

b) Mean square error tests showed that all share weighted research variables outperformed unweighted variables.

c) Mean square error tests for assignments showed that assignment1 (to all zones) for EMBRAPA national program research performed best. This is reflecting the livestock sector results to a considerable extent. For EMBRAPA regional programs, assignment 2 (to all zones in the region) performed best. State research served the state. Thus we have evidence of quite pervasive impacts over many zones for EMBRAPA research programs.

d) Industrial research has contributed to TFP growth in agriculture in a significant way.

e) As in the livestock estimate, the human capital-predicted extension variable is of the expected sign, but is not statistically significant.

f) Road infrastructure has contributed to TFP growth. Population density is unrelated to TFP growth.

8 Economic implications of the TFP decomposition estimates

8.1 Economic measures

The estimates reported in Tables 10, 11 and 12 enable us to compute the following economic measures of investment success:

a) **EMPE: Estimated marginal productivity elasticities**

The EMPE is defined as:

$$\theta_x = (dTFP / TFP) / (dX / X)$$

These can be calculated for each investment category (EMBRAPA national programs. EMBRAPA regional centers, state research, extension, industrial R&D etc.).

b) **EMP: Estimated marginal products**

The EMP is defined as:

$$EMP = dQ_X / dX$$

For stock variables, this is the marginal product of a stock. However, it is also the marginal product of an increment to the stock since an investment in X in time "t" contributed to the stock in a cumulative way. Thus:

$$dX / dI_x = X / I_x$$ and this implies:

$$dQ_x / dX = dQ_x / dI_x$$

This generates a "stream" of benefits over time associated with the time shape weights W_t

c) **EM(B/C): Estimated marginal benefit/cost ratio**

Where:

$$B_0 = \sum_j^n W_t \left(dQ_x / dX\right) / \left(1 + \gamma\right)^j \Big)$$

$$C_0 = I_{xt}$$

In this case γ is an external rate (chosen to be ten percent).

d) **EMIRR: Estimated marginal internal rate of return**

This is defined as the rate *I* that solves:

$$I_{xt} = S\, W_{t+j} (d\, Q_x / dX) / (1 + i)^j$$

Table 13 reports estimates of EMPE, EMP, EM(B/C) and EMIRR obtained from this study.

There is considerable variation in the estimates. The reader is reminded that these are based on estimated coefficients and that the standard errors ("t" ratios) of those coefficients indicate different degrees of confidence in the estimates.

Taken as a group, these estimated returns to investment are comparable to estimates obtained elsewhere (Appendix A provides a brief review of other studies undertaken in Brazil).

Perhaps the chief anomaly of these estimates are the lower EMPEs and EMPs for state research in the aggregate results than for the crops and livestock estimates. The same can be said for extension impacts. A further anomaly is the higher impact of private research in the aggregate estimates than in the crop estimate. To some extent, these anomalies are the result of our effort to obtain separate estimates for the impacts of very similar programs. EMBRAPA and the states have similar objectives.

Table 13
Economic Calculations for Brazilian Research and Extension

Variables	EMPE	EMP	EM(B/C)	MIRR	Growth expanded	
					Percent	Share of
I. Crop Sector						
EMBRAPA Research:						
National Programs	0.00596	2.16	12.5	38	2.80	.08
Regional Centers	0.00675	12.21	70.7	75	3.23	.09
State Research	0.00234	1.17	6.8	29	1.43	.04
Industrial Research	0.00265	2.65	15.4	44	5.70	.17
Extension	0.01353	1.35	7.8	33	2.52	.07
					18.91	.55
II. Livestock Sector						
EMBRAPA Research:						
National Programs	0.05726	27.90	16.1	90	11.24	.48
Regional Centers	0.00370	1.10	6.4	25	.57	.02
State Research	0.0091	6.36	36.8	63	1.32	.05
Extension	0.0063	0.60	30.5	23	1.36	.05
					14.40	.53
III. Agricultural Sector						
EMBRAPA Research:						
National Programs	0.0121	4.98	28.8	56	7.94	.24
Regional Centers	0.00356	2.93	17.0	46	.99	.03
State Research	0.00115	0.51	2.9	19	.65	.03
Industrial Research	0.00485	4.85	28.1	45	11.63	.31
Extension	0.0028	0.51	2.9	19	.62	.02
					15.63	.42

8.2 Growth accounting

It is important in TFP decomposition work that we achieve consistency between our estimates and actual growth experience. Growth accounting enables us to do this. The growth attributable to an explanatory variable is the growth in the variable times the EMPE for the variable. The two right-hand columns in Table 13 report our growth accounting based on estimated EMPE and mean changes in the relevant growth decomposition variables.

The growth accounting presented in Table 13 shows that our major variables "explain" half of actual growth. The leading contributors to growth are the EMBRAPA research programs, where from 6 to 12 percent of growth (9 percent in the aggregate) can be attributed to these programs, and the industrial R&D sector where a similar contribution is estimated. State research institutions probably contributed 5 percent to the 1985/1970 growth. If we consider our crops sector estimates, extension and human capital have probably contributed another 3 percent.

Bibliography

Avila, A F. D. & Ayres, C. H. S. Productivity-based ex-post studies of Brazilian agricultural research impact. *In*: Evenson, R. E., Cruz, E. R. da; Avila, A. F. D., Palma, V (eds.), *Economic evaluation of agricultural research: methodologies and Brazilian applications*. Brasília and New Haven: EMBRAPA; Yale University, Economic Growth Center, 1987, Chapter VII.

Avila, A. F. D.; Irias, L. J. M. & Paiva, R. M. *The socio-economic impact of investment in research by EMBRAPA: Results obtained, profitability and future prospects*. Brasília: EMBRAPA/DEP, 1985, 44p. (EMBRAPA/DEP. Documentos, 20).

Avila, A. F. D *Impact of public agricultural research in Brazil: Ex-post evaluation and technological spill-over analysis*. Paper presented at the 1993 Fall Seminar at The University of Connecticut, December 1st, 1993.

Barbosa, M. M. T. L., Avila, A. F. D. & Cruz, E. R. da. Benefícios sociais e econômicos da pesquisa da EMBRAPA: uma reavaliação. *In*: Yeganiantz, L. (org.), *Pesquisa Agropecuária: questionamentos, consolidação e perspectivas*. Brasília: EMBRAPA/DEP, 1988, p. 339-52. (EMBRAPA/DEP. Documentos, 35).

Borges-Andrade, J. E. & Horton, D. *Planning, monitoring and evaluation in EMBRAPA, Brazil*. Paper presented at the ISNAR-INIFAP Regional Workshop: Planning, Monitoring and Evaluation Agricultural Research Experiences in the Americas. CIMMYT, Mexico, October 15-22, 1992.

Cruz, E. R. da. *Transferência inter-regional de ganhos de produtividade da terra e política tecnológica para a agricultura.* Brasília: EMBRAPA. 1987 47p. (EMBRAPA/DEP. Documentos, 28)

Cruz, E. R. da; Palma, V & Avila, A. F. D. *Rates of return on EMBRAPA's investments: total investments and physical capital.* Brasília, 1982, 48p. (EMBRAPA/DDM. Documentos, 19).

Evenson, R. E. Observations of Brazilian agricultural research and productivity. *R. Econ. Rural,* v. 20, n. 3, p. 367-401, 1982.

Evenson, R. & Cruz, E. R. da. Technology transfer (spillover) methods of analysis with examples from Brazil. *In: II Encontro sobre Metodologias de Avaliação Socioeconômica da Pesquisa Agropecuária.* Bento Gonçalves: EMBRAPA, 1989a.

_______. *The impacts of technology PROCISUR Program: an international study.* New Haven (USA): IICA/BID/PROCISUR, June 1989b, 70p.

Evenson, R. E. & Putnam, J. Intellectual property management. *In:* Persley, G. J. (ed.), *Agricultural biotechnology: opportunities for international development.* CAB International, 1990, p.332-366.

Silva, G. S. P. Contribuição da pesquisa e da extensão rural para a produtividade agrícola: observações no caso de São Paulo RURA. *In:* Congresso Brasileiro de Economia e Sociologia Rural, 22. Salvador. 1984, *Anais.* Brasília: SOBER, 1984, Vol.2, p. 343-78.

Trigo, E. & Kaimowitz, D. *National agricultural systems of agricultural technological generation and transfer in Latin America and Caribbean in the decade of nineties.* San Jose: IICA, mimeo, 1992.

Vosti, S. Yield variability within and across agroecological zones in Brazil: 1970-80. *In: First Amendment to the EMBRAPA/IFPRI Collaborative Research Contract: Final Report.* Washington, DC.. IFPRI, February 1991.

Appendix A
Brazilian studies of economic impact evaluation of agricultural research

Table 1A
Brazilian Agricultural Research Evaluation: EMBRAPA's Experience

Authors	Specification Area	Period	IRR (%)
Cruz, Palma & Avila (1982)	Total Investment	1974/92	22-43
Cruz & Avila (1983)	World Bank Project I	1977/82 1977/91	20 38
Avila, Borges-Andrade, Irias & Quirino (1984)	Human Capital: Res. Training	1974/96	22-30
Roessing (1984)	Soybeans Res. Center: Total Investment	1975/82	45-62
Ambrosi & Cruz (1984)	Wheat Res. Center: Total Investment	1974/82	59-74
Avila, Irias & Veloso (1985)	IDB Project I: EMBRAPA Research Res. South System	1977/96 1974/96	27 38
Barbosa, Cruz & Avila (1988)	Total Investment: New Evaluation	1974/96	34-41
Kitamura *et alii* (1988)	EMBRAPA research: North Region	1974/96	24
Santos *et alii* (1988)	EMBRAPA research: Northeast Region	1974/96	25
Teixeira *et alii* (1988)	EMBRAPA research: Center-West Region	1974/96	43
Lanzer *et alii* (1988)	EMBRAPA research: South Region	1974/96	45
Barbosa, Avila & Motta (1988)	World Bank Project II	1982/87	43
Kahn & Souza (1991)	Manioc: Northeast Region	1987/97	29-46

Source: Avila (1993).

Table 1B
Brazilian Agricultural Research Evaluation: Others Studies

Authors	Specification Area	Product	Period	IRR (%)
Ayer & Schuh (1972)	São Paulo	Cotton	1924/67	77
Monteiro (1975)	Brazil	Cocoa	1923/75	16-18
Fonseca (1976)	Brazil	Coffee	1933/95	23-26
Moricochi (1980)	São Paulo	Citrus	1933/85	78-28
Avila (1981)	Rio Grande do Sul	Rice	1959/78	87-119
Monteiro (1985)	Minas Gerais & Esp. Santo	Cocoa	1958/85	61-79
Gonçalves, Souza & Rezende (1989)	São Paulo	Rice	1876/88	85-95
Evenson (1982)	Brazil	Aggregated	1966/79	69
Silva (1984)	Brazil	Aggregated	1970/80	60
Pinazza *et alii* (1984)	Var. NA5679: São Paulo	Sugarcane	1972/82	35
Ayres (1985)	Brazil & States:	Soybeans	1955/83	46
	Paraná			51
	São Paulo			23
	S. Catarina			31
	Rio G. do Sul			53
Evenson & Cruz (1989a)	Brazil	Wheat	1966/88	39
		Maize		30
		Soybeans		50
Evenson & Cruz (1989b)	PROCISUR Region (**)	Wheat	1969/88	110
		Maize		191
		Soybeans		179
Evenson (1990a)	Brazil	Field crops	1970,1975 & 1980	41-141
Evenson (1990b)	Brazil:	Field crops	1970,1975 & 1980	68-75 & 71-78
	South-Center	Livestock		
	Northeast	Per. Crops		

* Marginal internal rate of return.

** Cooperative Program in Agricultural Research for the South Cone of South America, including the national institutions of Brazil, Argentina, Uruguay, Paraguay, Bolivia and Chile.

Source: Avila (1993).

Appendix B
Brazilian agricultural research system

1. EMBRAPA DECENTRALIZED UNITS

a) Agroforestry or Agricultural Ecoregional Research Centers

CPAA - Agroforestry Research Center for Western Amazonia

CPATU - Agroforestry Research Center for Western Amazonia

CPAC - Cerrados Agricultural Research Center

CPAF-AC - Agroforestry Research Center of Acre

CPAF-RO - Agroforestry Research Center of Rondônia

CPAF-RR - Agroforestry Research Center of Roraima

CPAF-AP - Agroforestry Research Center of Amapá

CPAP - Pantanal Agricultural Research Center

CPAMN - Center for Agricultural Research in the Mid-North

CPAO - Center for Agricultural Research in the Mid-West

CPATC - Center for Agricultural Research of the Coastal Tablelands

CPACT - Agicultural Research Center for Temperate Climate

CPATSA - Semi-arid Agricultural Research Center

CPPSE - Center for Research on Cattle Raising in the Southeast

CPASUL - Center for Research on Cattle Raising in Southern Fields

b) National Commodity Centers

CNPA - National Research Center for Oleaginous and Fibrous Plants

CNPAF - National Rice and Beans Research Center

CNPC - National Goat Research Center

CNPF - National Forestry Research Center

CNPGC - National Beef Cattle Research Center

CNPGL - National Dairy Cattle Research Center

CNPH - National Vegetable Crop Research Center

CNPMF - National Cassava and Tropical Fruit Research Center

CNPMS - National Corn and Sorghum Research Center

CNPSO - National Soybean Research Center

CNPT - National Wheat Research Center

CNPSA - National Pig and Poultry Research Center

CNPUV - National Grape and Wine Research Center

c) Basic Theme Research Centers

CENARGEN - Nat. Genetic Resource and Biotechnology Research Center

CNPAB - National Agro-biology Research Center

CNPAT - National Research Center for Tropical Agroindustry

CNPDIA - National Center for Research and Development of Agric. Instrumentation

CNPMA - Nat. Res. Center for Monit. and Assessment of Environmental Impact

CNPS - National Soil Research Center

CNPTIA - National Center for Technological Research on Information in Agriculture

CTAA - National Agro-industrial Food Technology Center

d) Special Services

SPI - Information Production Service

SPSB - Basic Seed Production Service

NMA - Nucleus for Satellite Monitoring of Environment and Natural Resources

2. STATE RESEARCH INSTITUTIONS

a) South Region

IPAGRO - Agricultural Research Institute, RS State

IRGA - Rio Grande do Sul Institute of Rice, RS State

FUNDACEP - Agricultural Research Center Foundation, RS State

EPAGRI - Agricultural Corp. for Research and Development, SC State

IAPAR - Agricultural Research Institute of Paraná, PR State

OCEPAR - Cooperative Organization of Parana (Agric. Research Units), PR State

b) Southeast Region

IAC - Agronomic Institute of Campinas, SP State

IB - Biological Institute, SP State

IZ - Zootecnical Institute, SP State

PESAGRO - Agricultural Research Corp. of Rio de Janeiro, RJ State

EMCAPA - Corporation of Espírito Santo for Agric. Research, ES State

EPAMIG - Corporation for Agric. Research of Minas Gerais, MG State

c) Northeast Region

EBDA - Agricultural Research and Development Corp. of Bahia, BA State

EMDAGRO - Corporation for Agricultural Development, SE State

EPEAL Corporation for Agricultural Research of Alagoas, AL State

IPA - Agricultural Research Corporation of Pernambuco, PE State

EMPARN - Agricultural Research Corp. of Rio Grande do Norte, RN State

EMEPA - Corporation of Paraíba for Agricultural Research, PB State

EPACE - Corporation of Ceará for Agricultural Research, CE State

EMAPA - Corporation of Maranhão for Agricultural Research, MA State

d) North Region

The states in this region do not develop agricultural research. EMBRAPA research centers are responsible for the agricultural research.

e) Center-west Region

EMGOPA - Agricultural Research Corporation of Goiás, GO State.

EMPAER/MT - Corp. for Agric. Research and Rural Ext. of Mato Grosso, MT State

EMPAER - Corp. for Agric. Res. and Rural Ext. of Mato G. do Sul, MS State.

Appendix C
Total factor productivity index: input index

The input index was calculated with data from the Brazilian agricultural censuses taken at five-year intervals between 1970 and 1985 and from supplementary sources. This new input index for Brazilian agriculture should constitute an improvement over earlier indexes constructed from this source. Not only does it include data from the 1985 census, but it made use of additional state and municipal data from earlier years. Furthermore, separate input indexes have been constructed for crop and livestock production by allocating total inputs between crop and livestock raising activities.

That said, the index was computed under a number of data handicaps. Census takers seldom gather precise and consistent data on all of the aspects of economic activity in which we might be interested. The coverage of the agricultural censuses has changed over time as have the definitions and measurement units of the items actually collected. In general, the amount of information about inputs has increased with each succeeding census, especially between 1975 and 1980. For 1970, and to a lesser extent for 1975, the municipality data from the census computer tapes available at Yale University did not include a number of inputs, and proxies had to be constructed from the published state data or data from other years. The lack of consistency in measurements has created additional difficulties as it has been necessary to make certain adjustments to the census data in some years in order to maintain consistency with others.

In terms of accuracy of the census data, of most concern were the municipality-level value and expenditure data. When taken together with the enumerated quantities, the imputed prices varied enormously. It is not clear whether this was due to reportage of historical values of costs by some farmers or some other reason. In consequence, the use of census value and expenditure data has been avoided where possible and in their place prices collected at the same time as the censuses have been used to calculate expenditures on inputs. In other places, state-level value data from the published censuses available at Yale University libraries have been used in place of municipality data. In the case of feed, vaccines, herbicides and pesticides, expenditure data were used in conjunction with price data to calculate input quantities. In these last cases, whether because of the seasonal nature of these inputs or some other reason, the input quantities and expenditure shares were fairly consistent over time, giving some confidence in their use for this purpose.

Given the incomplete nature of the data and the other problems outlined above, there were usually a number of reasonable ways to generate proxies from what data were available in the census and other sources. The purpose of this appendix is to explain how the input index was computed and why it was computed as it was. As the calculations did not vary much from census year to census year, the discussion is organized by input rather than year, with exceptions in some years noted.

Labor

The Brazilian agricultural census reports the number of family workers, permanent workers and temporary workers in each municipality, but the numbers of workers engaged in crop-raising, livestock- raising and forestry activities are available only at the state level. Unfortunately, there was no clear way to determine in which of a state's municipalities the forestry workers were concentrated, but at least the number of forestry workers was small in most states. The percentage of each of the classes of workers engaged in forestry activities was calculated for each state under the assumption that the proportion of forestry workers in each category was the same in all the municipalities in the state. Each class of worker at the municipality level was then divided between the two remaining activity categories using the state data.

For crops, the number of workers in each class at the state level was divided by the number of hectares of cropland in the state and then multiplied by the number of hectares of cropland in the municipality. For livestock, the number of workers in each class at the state level was divided by the value of non-work livestock at the state level then multiplied by the value of non-work livestock in the municipality. From this the percentage of each class of workers engaged in each activity was calculated. This was multiplied by the number of workers of that class in the municipality.

The estimated number of full-time worker equivalents and expenditures on workers were calculated from these estimates. Each family worker was considered to be two-thirds of a permanent worker since family workers included many women and children who presumably did not work full-time in agriculture. Permanent workers were considered full-time workers. Temporary workers required special treatment as there were no data upon which some estimate might be made as to how much they worked relative to other classes of workers. Temporary workers do not work as regularly as permanent workers but earn more per day as they often work only at times of peak labor demand. In 1975, 1980 and 1985, the census contains expenditures on temporary and permanent workers. From these expenditure figures, the ratio of expenditures per temporary worker to expenditures per permanent worker by state was used to get an idea of how much work temporary workers did relative to permanent workers.

Temporary workers were taken to be two-thirds of the median 1980 state relative expenditure, or two-thirds of 0.3233. Expenditures were the number of full-time equivalent workers multiplied by the monthly wage of a permanent worker multiplied by twelve.

For 1970, the state data were not available so the distribution of workers between activities by state was calculated using the 1975 state activity and class distribution but adjusting the total worker population. Similarly, as there were no state livestock values, the 1975 proportion of non-work animals to total livestock value was applied to the 1970 municipality-level data. In 1970, the number of permanent and temporary workers was listed separately by activity. However, these data were inconsistent with the total number of permanent and temporary workers given for the municipalities. For the sake of consistency, therefore, we did not use these data and computed 1970 as for other years.

Tractors

There was little usable data in the census on agricultural machinery other than tractors. Tractors appear in the census in several horsepower categories so it was necessary to convert these numbers to the number of same horsepower equivalent tractors. As only the prices for 75 horsepower tractors were available, the number of 75 horsepower equivalent tractors was computed. The number of tractors in each class was multiplied by the midpoint of that class, summed over all classes, and divided by 75. The percentage of tractors used in livestock and crops was then used to divide total tractors between crop and livestock production. Expenditures are the price of tractors multiplied by the number of tractors. Annual depreciation and operating costs were assumed to be equal to the purchase price.

For 1970 no municipal tractor data were available on tape. The number of tractors in each state in 1970 is available in the published census. Using the size distribution of tractors from 1975, the number of 75 horsepower equivalent tractors was derived from this figure.

For 1975 the published census lists categories of tractors under 10 horsepower, 10-50 horsepower, 50-100 horsepower, and over 100 horsepower. On the computer tape, the first two categories were consolidated. The resulting classification for tractors in 1975 is given below:

Horsepower category weight

Under 50	50-100	Over 100
25	75	100

The classification for tractors in 1980 and 1985 is given below:

Horsepower category weight given

Under 10	10-20	20-50	50-100	Over 100
5	15	35	75	110

NOTE: To test whether the new tractor classes had any impact on the final results, comparable measures to those available in 1975 were generated by adding up the bottom three categories and recomputing. These results were not substantially different from those calculated using all of the classes as given.

Animal power

There was only sufficient data to compute an animal input into crop production, not for livestock. The quantity of work animals is the number of oxen plus the number of horses at the state level divided by the number of hectares in the state planted in annual crops, or in annual crops but left fallow, multiplied by the number of such hectares in each municipality. The value of work animals in the state per hectare of annual crops and fallow was multiplied by the number of hectares in each municipality to find the value of the annual input. Expenditures were taken to be 20% of the value for depreciation and upkeep.

For 1970, there were only data on the number of oxen and the total number of horses by state. The number of work horses was calculated as the total number of horses multiplied by the 1975 ratio of work horses in the state. The value per hectare was taken to be the value of all livestock in 1970 multiplied by the 1975 share of work animals in the total value of livestock.

Land

The land input was taken to be the sum of hectares of land in permanent and temporary crops, weighted equally. Land given over to livestock production was taken to be the sum of natural and artificial pasture, again weighted equally. Expenditures are calculated from the state rental rate for land in crops and livestock multiplied by the number of hectares in each category in each municipality.

There is also data on land rented and expenditures on rent after 1970. This is missing for a sizeable number of municipalities and did not generate very consistent imputed rents, so the price series was used in its place. The same problem occurred when the rents were calculated at the state level.

Fertilizer

The quantity of fertilizer applied is not given in the census. However, the census does record the expenditure on fertilizer for each municipality. The quantity was derived by dividing local expenditure by the price of the most commonly used fertilizer in the state. The quantity of fertilizer used in crops at the municipality level was taken from the percentage of fertilizer used for crops at the same level. Likewise for livestock. Expenditure data were as given in the census.

Chemicals

The quantity of herbicides and pesticides applied is not given in the census, only the expenditure on chemicals for each municipality. The price used was that of a common chemical input. Calculations were the same as for fertilizer.

Feed

The quantity of feed given to livestock is not given in the census, only the expenditure on feed for each municipality. The price is the price of feed for the state. Feed is considered to be used only for livestock production. Calculations were the same as for fertilizer.

Vaccines

The quantity of vaccine given to livestock is not given in the census, only the expenditures on vaccines for each municipality. The price used was that of a common cattle vaccine. This input is considered to be used only for livestock production. Calculations were the same as for fertilizer.