Assessing and Attributing the Benefits from Varietal Improvement Research in Brazil

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Lídia Pacheco Yokoyama, 1956–2002
To our friend and colleague, Lídia, who exemplified all the best of an economist working for the public good.

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Acronyms and Abbreviations

AES	Agricultural Experimental Station
BA	Bahia
CAC	Cooperativa Agrícola de Cotia (Agricultural Cooperative of Cotia)
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Tropical Agricultural Research and Higher Education Center)
CEFET-PR	Centro Federal de Educação Tecnológica do Paraná (Federal Center for Technical Education of the State of Paraná)
CENARGEN	Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia (National Center for Research on Genetic Resources and Biotechnology)
CEP	Centro de Experimentação e Pesquisa (Research and Experimentation Center)
CEPEC	Centro de Pesquisa do Cacau (Research Center for Cacao)
CGIAR	Consultative Group on International Agricultural Research
CIA	Centro de Investigaciones Agronómicas (Agronomic Research Center)
CIAT	Centro Internacional de Agricultural Tropical (International Center for Tropical Agriculture)
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement (International Cooperation Center of Agronomic Research for Development)
CNEPA	Centro Internacional de Enseno e Pesquisas Agronómicas (National Center of Agricultural Training and Research)
CNPAF	Centro Nacional de Pesquisa de Arroz e Feijão (National Center for Research on Rice and Beans)
CNPSo	Centro Nacional de Pesquisa de Soja (National Center for Research on Soybean)
CNPT	Centro Nacional de Pesquisa de Trigo (National Center for Research on Wheat)
COMTRADE	Commodity Trade Statistics Database
CONAB	Companhia Nacional de Abastecimento (National Food Supply Company)
COODETEC	Cooperativa Central Agropecuária de Desenvolvimento Tecnológico e Econômico (Central Agricultural Cooperative for Technology Development and Economics)
COOPADAP	Cooperativa Agropecuária do Alto Paranaíba (Agricultural Cooperative of Alto Paranaíba)
CPAC	Centro de Pesquisa Agropecuária dos Cerrados (Center for Agricultural Research on the Savannas)
CPAO	Centro de Pesquisa Agropecuária do Oeste (Center for Agricultural Research of the West)
DF	Distrito Federal (Federal District)

DNPEA	Departamento Nacional de Pesquisa Agropecuario (National Agricultural Research Department)
DPEA	Departamento de Pesquisas e Experimentação Agropecuária (Department of Agricultural Research and Experimentation)
EAP	Escuela Agrícola Panamerica (PanAmerican Agricultural School)
EEA	Estación Experimental Agrícola (Agricultural Experimental Station)
EEP	Estación Experimental de Patos (Experimental Station of Patos)
Embrapa	Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Corporation)
EMGOPA	Empresa Goiana de Pesquisa Agropecuária (Agricultural Research Corporation of the State of Goiás)
EMPAER	Empresa de Pesquisa Agropecuária, Assistência Técnica e Extensão Rural (Corporation for Agricultural Research, Technical Assistance, and Rural Extension)
EPABA	Empresa de Pesquisa Agropecuária de Bahia (Agricultural Research Corporation of the State of Bahia)
EPAMIG	Empresa de Pesquisa Agropecuária de Minas Gerais (Agricultural and Livestock Research Corporation of the State of Minas Gerais)
EPE	Escritório de Pesquisa e Experimentação (Research and Experimental Office)
ESAL	Escola Superior de Agricultura Lavras (Higher Education School of Agriculture of Lavras)
EUA	Estados Unidos da América (United States of America)
FECOTRIGO	Federação das Cooperativas de Trigo do Rio Grande do Sul (Federation of Wheat Cooperatives of the State Rio Grande do Sul)
FEPAGRO	Fundação Estadual de Pesquisa Agropecuária (State Agricultural Research Foundation)
FLAR	Fondo Latinoamericano para Arroz de Riego (the Latin American Fund for Irrigated Rice)
FT	FT Pesquisa e Sementes (FT Research and Seeds)
FTE	Full-time equivalent
GO	Goiás
IAC	Instituto Agronómico de Campinas (Agronomic Institute of Campinas)
IBGE	Instituto Brasileiro de Geografia Estatística (Brazilian Institute of Geography and Statistics)
ICA	Instituto Colombiano Agropecuario (Colombian Institute for Agriculture and Livestock)
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
INDUSEM	Indústria e Comércio de Sementes Ltda (Industry and Commerce of Seeds)
INIA	Instituto Nacional de Investigaciones Agropecuarias (National Agricultural Research Institute)
IPA	Instituto de Pesquisa Agropecuária de Pernambuco (Agricultural Research Institute for the State of Pernambuco)
IPEA	Instituto de Pesquisa e Experimentação Agropecuária (Agricultural Research Institute)
IPEACO	Instituto de Pesquisa e Experimentação Agropecuária do Centro Oeste (Agricultural Research Institute for the Center West Brazil)

IPEAME	Instituto de Pesquisas Agropecuarias Meridional (Agricultural Research Institute for Southern Brazil)
IPEAS	Instituto de Pesquisas Agropecuarias do Sul (Agricultural Research Institute for South Brazil)
IRAT	Institut de Recherche en Agronomie Tropicale (Tropical Agronomic Research Institute)
IRGA	Instituto Rio-Grandense do Arroz (Rio Grande Rice Research Institute)
IRRI	International Rice Research Institute
MA	Maranhão
MG	Minas Gerais
MT	Mato Grosso
NAPE	Nickerson American Plant Breeders
OCEPAR	Organização das Cooperativas do Estado do Paraná (Organization of the Cooperatives of Paraná)
PA	Pará
PI	Piaui
PR	Paraná
R&D	Research and Development
RS	Rio Grande do Sul
RO	Rondônia
SC	Santa Catarina
SEA	Secretaria de Administração Estratégica (Secretariat for Strategic-Management)
SITC	Standard Industrial Trade Classification
SP	São Paulo
TO	Tocantins
UEPAE	Unidade de Execução de Pesquisa de Âmbito Estadual (State Level Research Unit)
UFLA	Universidade Federal de Lavras (Federal University of Lavras)
UFV	Universidade Federal de Viçosa (Federal University of Viçosa)
UNESP	Universidade Estadual Paulista (State University of Sao Paulo)
UNSD	United Nations Statistics Division
UREMG/ESA	Universidade Rural do Estado de Minas Gerais/ Escola Superior de Agricultura (Rural University of the State of Minas Gerais/Higher Education School of Agriculture)
USDA	United States Department of Agriculture

Foreword

As the number and variety of interconnected sources of agricultural innovations have continued to grow and evolve, so too have the demands for meaningful evidence of both the total payoff and the specific impacts of individual research providers. Important policy and practical funding decisions require a clear understanding of the shares of the overall benefits from investments in R&D attributable to domestic versus foreign and public versus private agencies, or even to individual agencies, as well as the total benefits accruing from innovation.

This report provides a detailed economic assessment of the magnitude and sources of the economic benefits to Brazil since the early 1980s from varietal improvements in upland rice, edible beans, and soybeans—crops that span a range of interests from domestic (or even more localized) food security concerns, as with rice grown in typically rainfed, upland production systems, to crops with important international trade implications such as soybeans.

The authors of this study pay particular attention to isolating the benefits from genetic improvement, distinct from other factors that change grain yield or quality. They use detailed information of the genetic and breeding histories of each crop and the institutional arrangements for more contemporary crop-improvement research in Brazil to attribute parts of the overall benefits to the research done by various agencies within Brazil, in particular the Brazilian Agricultural Research Corporation (Embrapa, Empresa Brasileira de Pesquisa Agropecuária).

Notably, the balance of local versus international spillin contributions to the improvement of each crop is sensitive to the particular crop and time period under consideration. Moreover, the estimated returns to research are especially sensitive to approaches taken to account for the multiplicity of past and present research providers involved in Brazilian crop improvements. Ignoring the efforts of others results in markedly upward-biased estimates of the returns to Embrapa research. Importantly though, even after attributing the overall benefits among the myriad of research providers, the returns to investments in Embrapa research on the three study crops are still substantive.

As well as providing new and important evidence on Embrapa's crop-improvement programs and their payoffs, this report provides more general insight into the importance of addressing attribution questions in evaluating public research investments, develops some methods for doing so, and illustrates how to apply them.

Joachim von Braun
Director General, IFPRI

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Summary

We estimate that Brazil received $16 of benefit from every dollar invested by Embrapa in improving upland rice, edible beans, and soybean varieties. The total research benefits over the period 1981–2003 amounted to $14.8 billion in present value (1999 prices) terms—or 6.1 percent of the corresponding value of crop output—of which $3.1 billion were attributed to the efforts of Embrapa. These benefits to Brazil came from either maintaining yields in the face of pressures that would otherwise cause them to fall, or improving the yield performance over time relative to base-year yields. They represent the gains from varietal improvement research alone, abstracting from other factors that can affect yields. The upland rice program has also substantially emphasized the need to improve the quality of the grain. We estimated the benefits arising from this aspect of that research amounted to $233 million, in addition to the $1.68 billion attributable to the yield-enhancing aspects of the rice research.

Embrapa's varietal improvement research investments have been profitable overall, primarily because of a very high benefit–cost ratio for soybean research. Although the quantitative details may change, the qualitative pattern was preserved when we investigated the sensitivity of the estimates to changes in the interest rate used to discount the benefit and cost streams (4 versus 10 percent), and the length of the benefit stream (benefits truncated in year 1998 versus 2003). These benefit–cost ratios are backward looking: they reflect the benefits accruing to the past investments, specifically the investments made between 1976 and 1998. Nonetheless, to the extent that the future can be expected to be like the past, they provide an indication that crop improvement research by Embrapa, especially research on developing improved soybean varieties, would be a very profitable investment of public funds in the future. As such, the results here provide strong support for claims to sustain and even increase funding for all three programs of research, especially varietal improvement research on soybeans.

Although the benefits attributable to Embrapa are large absolutely and relative to the size of the costs of research, the results indicate that sources other than Embrapa contributed significantly to the benefits. In addition, the share of total benefits attributable to Embrapa versus other agencies varied among the different crops and periods considered. The evidence indicates that CNPSo (the Embrapa soybean center) accounted for a sizable and increasing, but not dominant, share of the benefits from improved soybean varieties since 1981—using a geometric attribution rule to apportion the contributions of past breeders to each improved variety of commercial consequence, 9 percent of the benefits for 1981–85 and 28 percent for 1993–98. The genetic material underpinning all these gains drew heavily on material from non-Embrapa sources (significantly, the United States). The non-Embrapa content of upland rice varieties was much more reliant on domestic sources compared with soybeans, whereas edible bean varieties drew more heavily than either rice or soybeans on foreign sources—CIAT, Colombia has been a major source of the pedigree material used by CNPAF (the Embrapa rice and bean center)—and other local breeders, and a nontrivial amount of foreign-sourced edible bean varieties were used directly by Brazilian farmers.

Some are skeptical about the often high reported rates of return to agricultural research, and we were mindful of the issue in developing our own estimates. Our results indicate that some of these high reported rates of return may arise from mismatching the benefits from research and development (R&D) and the costs that brought them about. In this study, if all of the varietal improvement benefits accruing to Brazil were attributed to Embrapa, a public research corporation accounting for more than half Brazil's agricultural R&D spending, the benefit–cost ratio would be 78:1. When a geometric attribution rule based on genetic histories is used in conjunction with quantitative evidence on the extent of research collaborations to account for the innovative effort of others, the ratio drops substantially to 16:1, or an internal rate of return of 38.7 percent per annum. Notably, the social returns to the Embrapa R&D being evaluated are substantial, even after considerable care was taken both to isolate the effects of research from other factors that would cause crop yields to rise and to account explicitly for the contributions of many public, private, and international agencies besides Embrapa in the development of improved crop varieties.

CHAPTER 1

Introduction

A feature of the 10,000-year history of agriculture has been the substantial contribution of biological innovations, especially crop varietal changes, to yield and output growth.[1] For a large number of crops in many, but certainly not all, countries, yields increased during the latter half of the twentieth century to historically unprecedented levels (Pardey and Wright 2002), with research and development (R&D) accounting for a substantial share of the measured gains (Alston et al. 2000b). Although there is a clear consensus that the payoffs to R&D have been high, and appear to remain so, far less is known about the precise origins of the relevant R&D or sources of the varietal innovations that gave rise to the growth in yields of a particular crop in a particular country, or of how those sources of innovations have changed over time. Are the gains attributable to homegrown technologies or to spillins developed elsewhere? What share of the gains is attributable to efforts by farmers, or to public versus private research, or to research conducted by particular agencies, and do these dimensions remain stable over time or vary among crops? Answers to these questions have important implications in terms of the amount of public investment in R&D, the right balance of the research in terms of local innovation versus tapping technologies developed elsewhere, and the design of policies and institutions to facilitate effective partnerships among public and private agencies.

According to national totals for 1996, the latest year for which these data are available, Brazil employs more than 5,000 full-time equivalent researchers and spends more than $1 billion (1993 international dollars) on agricultural R&D (Beintema et al. 2001). Thus Brazil is important regionally—accounting for about one half of the total agricultural research spending in Latin America—and globally as well, spending more on agricultural R&D than most other developing countries, except China and India, and many developed countries, including Australia, Canada, Italy, the Netherlands, and the United Kingdom. Most of Brazil's research expenditures are undertaken by public agencies; 79 percent of these are federal and state organizations and 15 percent are higher education institutions. Embrapa, a corporation established by the federal government in 1972, is still the country's dominant research agency, accounting for 57 percent of total spending in 1996 (slightly higher than its spending share of two decades earlier). About one half of Embrapa's research is concerned with crops and more than one third of that research deals directly with crop genetic improvement, that is, breeding and related research.

[1]Smith (1998) describes the origins of plant and animal domestication and Diamond (1997) their subsequent spread worldwide. Evans (1993) investigates the nature, rate, and sources of crop yield growth, while Olmstead and Rhode (2002), using the example of wheat, reexamine the timing and magnitude of the effects of biological innovations in U.S. agriculture.

Although Embrapa still accounts for the lion's share of agricultural R&D conducted in Brazil, the domestic and international research scene is changing, with a still small but gradually greater presence of private for-profit and private nonprofit agencies, a fairly pervasive contraction in the funding of state research and extension, and pressures to change Embrapa's priorities involving reductions in funding for some centers, increases for others, and shifts in the focus of research generally. This study assesses the magnitude of the benefits derived from various crop-improvement programs over the past several decades and attributes these benefits to the work of Embrapa and others as a basis for accounting for past research and as an aid to formulating priorities and policies for future research by Embrapa and other agencies. The attribution methods developed and applied here are also relevant for related studies on other crops and for other countries where there is value in assessing the share of benefits attributable to different agencies, whether they are local or situated in other countries.

Research Objectives and Scope of the Report

Agricultural R&D, and especially crop-improvement research, is a cumulative and often collaborative endeavor. New crop varieties draw directly on breeding lines and commercial varieties developed earlier, and much of the crossing, testing, and selection of new varieties involves collaboration among multiple public and private agencies. This study deals with attributing the credit for varietal improvements in Brazil to research expenditures undertaken at different times, in different places, and by different agencies. It is relatively straightforward in principle, and in practice if suitable data are available, to obtain a measure of the total benefits from the adoption of new, improved crop varieties. It is more difficult to measure the benefits attributable to any one agency such as Embrapa in Brazil when some of the benefits are attributable to other private and public research institutions in Brazil and elsewhere. When assessing crop improvement research, the *attribution* problem is to determine which crop varieties are attributable to Embrapa (or, if partially attributable, to what extent) and how much of the overall yield improvement is attributable to those varieties. Further challenges arise in defining the relevant counterfactual scenario—what is it reasonable to assume would remain constant, and what else would be different if Embrapa's research investment had been different? A related problem is to define the relevant costs, apportioning costs among the different activities undertaken by research institutions, and some other considerations in measuring the costs associated with a particular stream of research benefits.

We addressed the benefit attribution issue by using a combination of hard data and estimates, applying both new and conventional methods for three crops: upland rice, edible beans, and soybeans. In particular, spatially disaggregated data on experimental yields, and state-specific estimates on varietal adoption, were used to apportion the gains in state-specific industry yields among individual varieties of the crops studied. Information on pedigrees of varieties and varietal releases, as well as information on shares of effort provided by research partners, was used to apportion credit for the development of the individual varieties between Embrapa and other institutions.

On the cost side, we compiled detailed information on research costs at each center, by type of cost (for example, personnel versus capital, and so on), and the proportion of those costs attributable to varietal research, for each year for the period 1976–98. Effort was directed to establishing the elements of costs attributable to the crop-improvement programs alone (and, at the rice–bean center, the allocation between the two crop-improvement programs). This meant allocating a share of each center's overhead as well as the program-specific operating costs, based in part on information collected on the numbers of different types of staff employed. In addition, effort was made to apportion an appropriate share of Embrapa's head office expenses and the costs incurred by CENARGEN, the agency's center for genetic resource and biotechnology research, to be borne as a type of overhead by each of the specific breeding programs.

Data on experimental yields of the individual varieties were not available for every location and year analyzed. A modeling approach was developed so that regression techniques could be used to develop a set of experimental yield projections for every variety included in each year and each location. Using these projected experimental yields, and estimates of the area planted to each of the varieties, we were able to compute an index of the yield gain for each year, relative to the mix of varieties planted in the "base year" for each crop (1984 for upland rice, 1985 for edible beans, and 1981 for soybeans; use of different base years is the result of differences in data availability). By combining this index with the observed industry yield, we were able to estimate the increase in commercial yield attributable to the adoption of the new varieties. These yield gains were valued using world market prices expressed in U.S. dollars in real (1999) terms, which were assumed to be unaffected by the enhancement to Brazilian supply and exports.

Information on pedigrees and whether each variety was released by Embrapa or from some other source was used to determine the extent of "Embrapa-ness" of each variety under various attribution rules. For soybeans, 50 percent of the area planted in the most recent year analyzed, 1998, was planted to varieties released by Embrapa; 49 percent for edible beans, and 73 percent for upland rice. The corresponding figures for Embrapa releases as a share of varieties planted in the crop-specific base years (1981 for soybeans, 1984 for upland rice, and 1985 for edible beans) were 9.6 percent for soybeans, 0 percent for edible beans, and 10 percent for upland rice.

To measure the benefit from varietal improvement that should be attributed to Embrapa, three alternative partitions of benefits were computed. The first simply measures the total benefits from improved varieties and attributes all of those benefits entirely to Embrapa. This measure represents an upper bound to the benefits that might be attributable to Embrapa, some of which must surely be due to the efforts of others. The second uses a last-cross rule to attribute benefits, assigning Embrapa 100 percent of the credit for Embrapa releases but no credit for varieties bred by others from Embrapa releases. The third uses geometrically declining weights: one half to the variety itself, one eighth to each of its two parents, and one sixteenth to each of its four grandparents. These weights are used to assign credit for the benefits attributable to a variety among the institutions releasing the variety, its parents, and its grandparents. Having made efforts to account for the contribution of past breeders, we made additional efforts to account for the contribution of those agencies directly partnering with Embrapa to develop its varietal releases.

Research cost and benefit streams were expressed in year 1999 present values, and various benefit–cost ratios and internal rate of return measures were developed to illustrate the sensitivity of the results to different attribution rules and provide alternative perspectives on the contributions made by Embrapa and others over the past three decades to varietal improvements in upland rice, edible beans, and soybeans. Finally we investigated the sensitivity of the results to changes in the discount rates used to calculate present values and to variations in the length of the benefit streams.

Overview of the Report

The substantial content of the report begins, in Chapter 2, with an overview of agriculture and agricultural R&D in Brazil. The purpose of this chapter is to provide a global context for the analysis, which is relevant for the market model used to value varietal change and for understanding the international flows of commodities as well as technologies and ideas. This chapter also describes agricultural research institutions and investments in Brazil—again, in a global context. In considering the agricultural industry in the broader domestic and global economy, as well as the agricultural R&D setting, particular emphasis is given to the commodities that are the subject of the specific analysis in later chapters.

Next, in Chapter 3 we review principles and practice for the evaluation of varietal improvement research. First, we discuss the measures of total benefits from technical change associated with the adoption of new crop varieties, drawing on previous work in the area conducted by participants in this study and others. In the case of Brazilian adoption of new crop varieties, that might be a relatively straightforward analysis—or at least it would be if we could treat changes in yields over time as a measure of yield improvement associated with new varieties (that is, if we could ignore yield-reducing effects of evolving pest problems, and could assume no changes in the use of fertilizers and other inputs).

Chapter 4 reports our application of the methods described in Chapter 3 to varietal improvement work done by Embrapa and others on edible beans, upland rice, and soybeans. Several elements underpin the analysis. First, a general overview of each of the relevant Embrapa centers is provided, including a brief history of the center and its research activities, a description of the research (and other) products generated by the center, and a depiction of the relationship between the center and other competing and complementary contributors to varietal improvement now and in the past. Second, the chapter includes detailed documentation of research costs at the center over time, by type of cost (for example, personnel vs. capital, and so on), and the proportion of those costs attributable to yield-enhancing varietal improvement research. Third, a detailed crop-specific analysis of research benefits is provided. This entails the documentation of details on (a) the varieties released over time, (b) yield gains associated with those varieties, (c) the adoption of those Embrapa varieties and other varieties, (d) the commercial yield gains associated with the adoption of the important varieties, and (e) the value of those commercial yield gains and the share of that value attributable to Embrapa releases over time. Fourth, the information on research costs and benefits is combined into a benefit–cost analysis. Finally, to conclude the chapter, we synthesize and summarize the results from the benefit–cost analysis for the individual crops, ascertain the sensitivity of the results to changes in various elements (such as the rate of interest used to estimate the present value of costs and benefits and the length of the period over which benefits accrue), and make cross-commodity comparisons of the returns to past investments by Embrapa in varietal-improvement research. We provide some concluding remarks in Chapter 5 of this report.

CHAPTER 2

Market and Research Contexts

The soybean, upland rice, and edible bean economies of Brazil have evolved since the early 1960s, as have the domestic and foreign agricultural research investments and the institutions that affect these crop economies.

Production and Productivity Patterns

Overall Trends

Brazil produced significantly more beans and soybeans in 2001 than it did in 1961 (Table 2.1). The growth in Brazilian soybean production has been spectacular, averaging 12.7 percent per year from 1961 to 2001, compared with 0.79 percent per year for edible beans. In contrast, production of upland rice declined by 1.85 percent per year (from 1975 to 2000, the period for which a time series of data was available),[2] while total rice production trended steadily upwards from 1961 to the late 1980s, with no clear pattern of further growth thereafter. Thus over the past few decades, an increasing share of Brazilian rice production has come from areas other than rainfed, upland production systems. In 1998, upland rice production accounted for only 34 percent of total Brazil rice output, compared with nearly 60 percent in 1976.

Yield Trends

Figure 2.1 gives the national average yields for Brazil for each crop since 1961. Average soybean and upland rice yields for Brazil have all trended up over time, although with substantial year-to-year variation in yields (and especially large yield declines in 1978, 1986, and 1991). Notably, yields for both crops grew faster during the 1990s than in earlier decades, giving no indication of a Brazilian yield plateau for these crops, in contrast to the conventional wisdom regarding expectations for the developing world more generally (see, for example, Pingali and Heisey 2001 or Conway 1997). Edible bean yields also recovered during the 1990s after generally declining during the preceding three decades, so that the yields in the late 1990s matched those obtained during the 1960s.

How do yields compare between Brazil and other regions of the world? Panels a–c in Figure 2.2 give comparative yields for each crop since 1961, but with inclusion of overall, not

[2]Upland rice production data for 1967, 1981, 1989, and 1995 were available from Sanint (1999, pers. comm.) and for the period 1986–2000 from IBGE (Instituto Brasileiro de Geografia Estatística). Data for the period 1975–85 were constructed by applying state-specific upland to total rice production shares for 1986 to the respective rice production totals for the years 1985–2000.

Table 2.1 Quantity produced and yield—Brazil and other regions, 1961–2001

	1961	1971	1981	1991	2001	Annual rate of growth[d]
			(thousands metric tons)			(percentage)
Total rice						
Brazil	5,392	6,593	8,228	9,488	10,301	1.51
Rest-of-LAC	2,721	4,231	7,583	7,952	11,459	3.69
LAC	8,113	10,824	15,811	17,440	21,759	2.45
World	215,655	317,762	410,029	518,575	585,593	2.53
Upland rice						
Brazil	5,511[a]	n.a.	5,773	5,026[b]	3,599[c]	n.a.
Rest-of-LAC	n.a.	n.a.	391	571[b]	592[c]	n.a.
LAC	5,511	n.a.	6,164	5,597[b]	4,190[c]	n.a.
World	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Edible beans						
Brazil	1,745	2,688	2,341	2,745	2,661	0.79
Rest-of-LAC	1,254	1,585	2,287	2,515	2,041	1.44
LAC	2,998	4,273	4,628	5,260	4,702	1.07
World	11,173	12,497	15,024	16,340	18,005	1.21
Soybeans						
Brazil	271	2,077	15,007	14,938	36,815	12.72
Rest-of-LAC	46	498	5,487	13,821	30,185	16.28
LAC	317	2,576	20,494	28,759	66,999	13.77
World	26,882	45,618	88,523	103,306	171,847	4.65
			(kg/ha)			
Total rice						
Brazil	1,699	1,384	1,349	2,302	3,224	1.78
Rest-of-LAC	2,042	2,707	3,520	3,646	4,528	1.96
LAC	1,800	1,711	1,915	2,767	3,800	2.05
World	1,867	2,358	2,822	3,536	3,852	1.94
Upland rice						
Brazil	1,412[a]	n.a.	1,051	1,223[b]	1,319[c]	n.a.
Rest-of-LAC	n.a.	n.a.	1,340	1,805[b]	1,852[c]	n.a.
LAC	n.a.	n.a.	1,066	1,264[b]	1,375[c]	n.a.
World	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Edible beans						
Brazil	676	683	466	505	705	–0.26
Rest-of-LAC	507	527	720	745	689	0.99
LAC	593	615	564	597	698	0.28
World	493	541	578	624	699	0.93
Soybeans						
Brazil	1,127	1,210	1,765	1,553	2,680	2.25
Rest-of-LAC	1,598	1,776	1,971	2,269	2,466	0.95
LAC	1,177	1,290	1,816	1,831	2,579	1.99
World	1,129	1,519	1,754	1,880	2,250	1.62

Source: With the exception of upland rice, all data were taken from FAOSTAT (2002). Upland rice data were obtained from Sanint (1999, pers. comm.) based on Sanint and Wood (1998).

Note: n.a. indicates not available. LAC indicates Latin America and Caribbean.

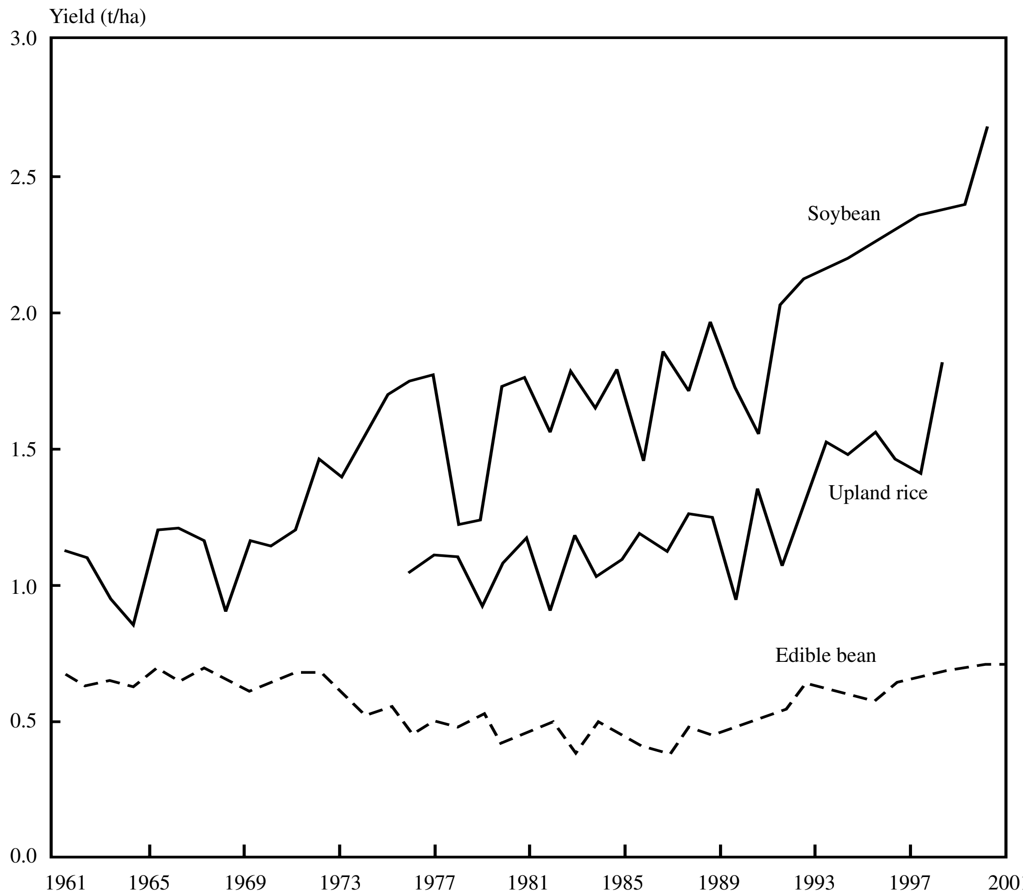
[a] 1967 estimate. The comparable total rice production figure for 1967 is 6,792 thousands of metric tons, and the average yield of all rice is 1,583 kilogram per hectare.

[b] 1989 estimate.

[c] 1995 estimate.

[d] Growth rates calculated by least-squares regression method.

Figure 2.1 Brazilian bean, soybean, and upland rice yields, 1961–2001



Source: With the exception of upland rice, all data were taken from FAOSTAT (2002). Upland rice data are based on authors' estimates and from data obtained from IBGE (various years).

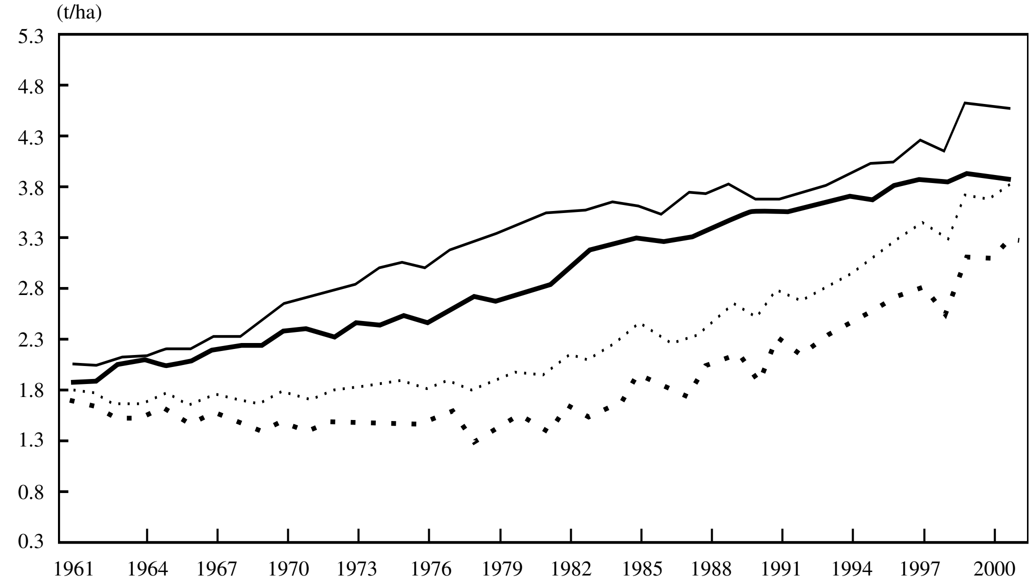
upland, rice yields because of a lack of comparable upland rice data for other parts of the world.[3] Brazilian soybean yields have edged up over time relative to yields elsewhere in the world—they are now generally higher than world average yields whereas in the early 1960s they were around the world average. The slide in Brazilian edible bean yields from 1961 through to the late 1980s is not reflected in the rest-of-Latin America and Caribbean (LAC) figures nor in the corresponding world average, which trended up since the early 1960s. Brazilian rice yields dropped slightly during the 1960s, leveled off during the 1970s, and grew throughout the subsequent two decades although they are still well below world (and Latin American) average yields.

Has the change in output for each crop been primarily a yield or an area phenomenon? The sources of output growth varied markedly among these three crops. The area under edible beans shrank, but was offset by a much greater rate of gain in yields so that production overall expanded. Soybean yield and area harvested both grew, but 59 percent

[3]In 2000, we estimate that Brazilian upland rice yields were 1.9 tons per hectare compared with an average of 5.2 tons per hectare for the remaining rice produced (which comes mainly, but not entirely, from irrigated areas).

Figure 2.2 Crop yields for Brazil and other regions, 1961–2001

a. **Total rice**



b. **Edible beans**

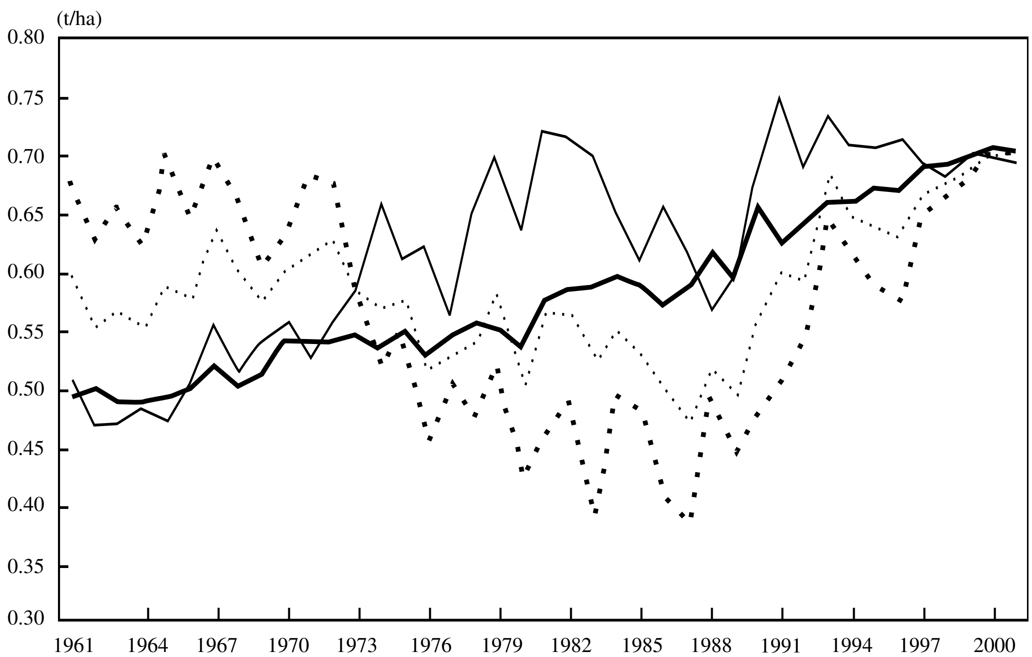
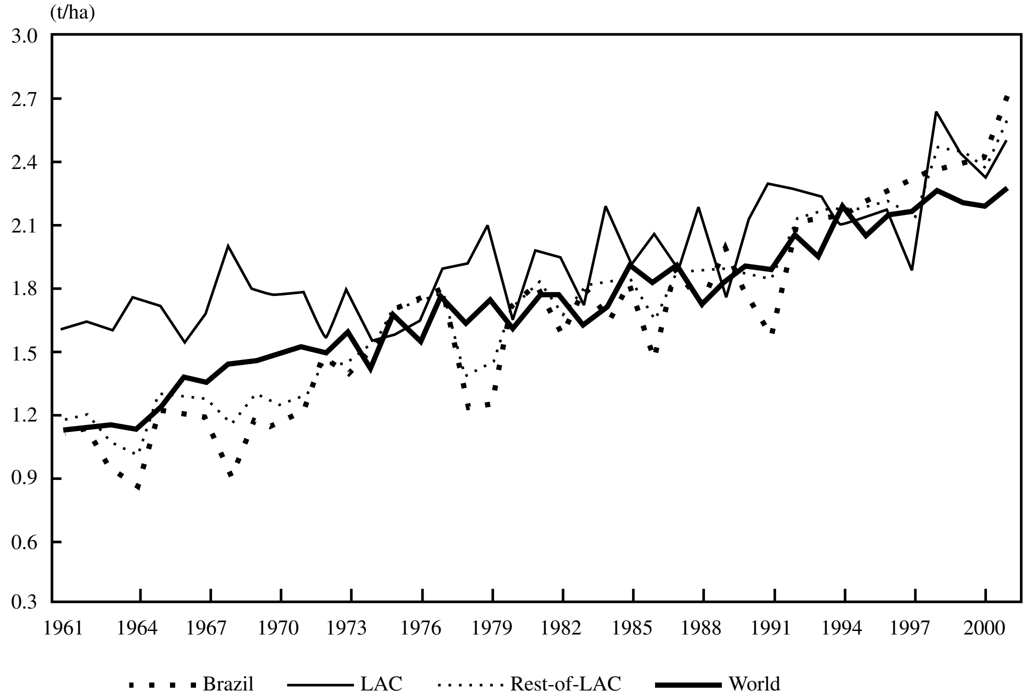


Figure 2.2—Continued

c. **Soybeans**



Source: FAOSTAT (2002).

of the substantial growth in soybean production was the result of an expansion in the area harvested rather than a growth in average national yields. The rate of increase in upland rice yields was overwhelmed by the contraction in area, so that the production of upland rice shrank by an average of 1.85 percent per year since 1975.

International production shares. A potentially important element of an R&D evaluation exercise concerns the international price consequences of changes in Brazilian production. If Brazilian production has measurable effects on world prices then this needs be to part of the evaluation framework if we are to attribute correctly gains from Embrapa research to Brazilians versus others in the world (see Chapter 3). Brazil's share of world production gives an indication of the likely magnitude of the international price effects of Brazilian R&D. Table 2.2 reports Brazil's share of Latin American and world output since 1961. Brazil's overall economy is large, especially by Latin American standards, so it is of no surprise, perhaps, that the country accounts for a dominant share of the region's upland rice production (although less of the region's overall rice output) and more than half the region's edible bean and soybean production. Notably, despite the rapid growth in soybean production in Brazil over recent decades, it lost regional market share, down from 86 percent of LAC production in 1961 to 55 percent in 2001. This reflects the even more dramatic increase in production in Argentina throughout this period.

Like most countries, and for most crops, Brazil is a much less important player in world markets. Since the early 1960s it has accounted for about 15 to 17 percent of global production of edible beans. It has a negligible and shrinking share of global rice

Table 2.2 Brazilian crop production as a share of Latin American and global totals

	1961	1971	1981	1991	2001
			(percentage)		
Total rice					
LAC	66.5	60.9	52.0	54.4	47.3
World	2.5	2.1	2.0	1.8	1.8
Upland rice					
LAC	n.a.	n.a.	93.7	89.8[a]	85.9[b]
World	n.a.	n.a.	n.a.	n.a.	n.a.
Edible beans					
LAC	58.2	62.9	50.6	52.2	56.6
World	15.6	21.5	15.6	16.8	14.8
Soybeans					
LAC	85.6	80.7	73.2	51.9	54.9
World	1.0	4.6	17.0	14.5	21.4

Source: With the exception of upland rice, all data were taken from FAOSTAT (2002). Upland rice data were obtained from Sanint (1999, pers. comm.) based on Sanint and Wood (1998).

Note: n.a. indicates not available. LAC indicates Latin America and Caribbean and is used interchangeably with Latin America.

[a] 1989 estimate.

[b] 1995 estimate.

production (accounting for less than 2 percent of global production in 2001), but a sizable and generally growing share of world soybean production.

The Location of Production

The yield and quality of crops is affected by variations in climate and soils, the incidence of pests and disease, and the inputs and management practices designed to overcome or ameliorate these natural constraints to production. Much agricultural R&D is designed to deal with variations in the natural aspects of production. Crop varieties are bred to resist ever-evolving pests and diseases, to compete better with weeds, to perform better in soils with higher degrees of acidity or salinity or lower levels of certain macro- or micronutrients, to withstand drought at key points in their growth cycles, and to resist lodging in high winds, among other considerations. All of these factors vary by location, so it matters where crops are grown as well as how much is grown in total. Thus moving beyond the national totals to pay attention to the location of production provides a much richer and, at least for R&D evaluation purposes, more relevant perspective on agricultural production in Brazil.

This is especially true when one of the principal purposes of research is to develop improved crop varieties and associated crop management practices that would allow certain crops to be grown profitably in locations that were hitherto unsuitable for production. The development and local adaptation of various soil management technologies (including locally optimal liming regimens as well as minimum tillage and irrigation practices) to enable effective use of acidic tropical soils, were essential complements to the varietal selection and improvement efforts for soybeans and other crops that have transformed the Cerrados region within Brazil over the past several decades.

Crop yields are not the only aspects affected by location-specific environmental factors. The environment also influences grain quality, especially grain size, shape, protein, fiber, and nutrient content. Some of these aspects and others such as color have a genetic basis as well, and are also of interest to plant breeders, especially when a commercial advantage or price premium can be gained for a specific trait. Upland rice research at Embrapa has placed a particular emphasis on developing finer-grain upland rices with greater market appeal.

Trends in state-specific production shares are summarized graphically in panels a–c of Figure 2.3. For all crops, these top ten states account for approximately 90 percent of Brazil's current output. Soybean production is the most spatially concentrated—just five states produced 83 percent of the national total in 2000, and only three states (Mato Grosso, Paraná, and Rio Grande do Sol) accounted for almost two thirds of that year's total. Notably, in the mid-1970s, almost all (84 percent) of Brazil's production occurred in the southern states of Rio Grande do Sul and Paraná; now the Cerrados states of Goiás, Mato Grosso, and Mato Grosso do Sul account for 47 percent of national production.

State shares of edible bean production are comparatively stable, and this crop is more evenly spread throughout Brazil—the top three producing states accounting for only 49 percent of total production in 2000. The degree of concentration in terms of area harvested is similar to the spatial pattern of production, although the area harvested for edible beans is a little less concentrated than is production. Some significant differences are notable in the ranking of states by area harvested and quantity produced. For example, in 2000 Rio Grande do Sul ranked first in terms of soybean area harvested (22 percent of the total) but only third in production (14.6 percent); Pernambuco had the fourth-largest harvested area of edible beans (6.4 percent) but ranked ninth in terms of crop production (3.5 percent). Spatial differences in yield account for the mismatch between spatial patterns of production and area planted/harvested.

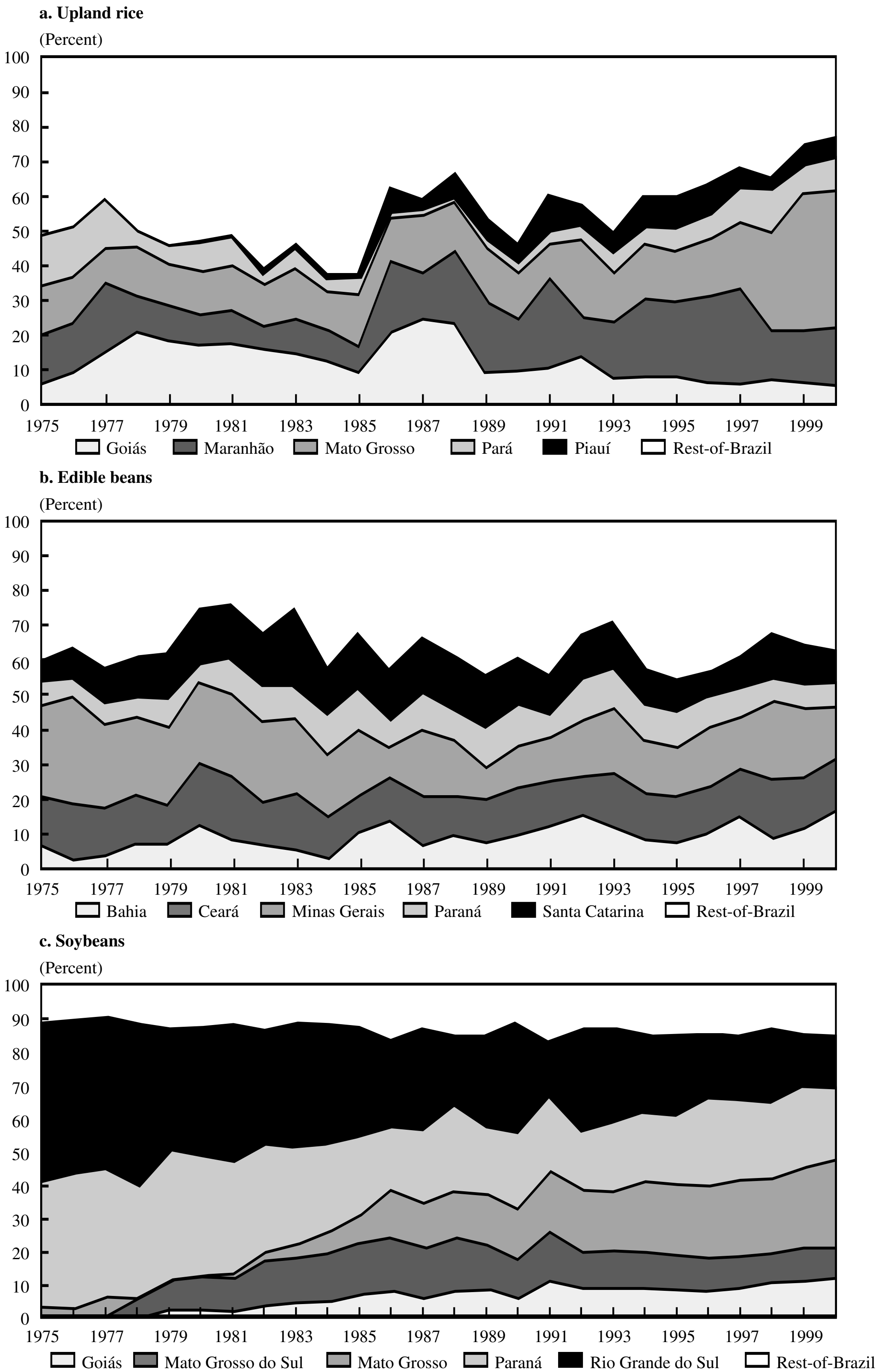
Changes in yields, as well as yield levels, vary markedly over space. Figure 2.4 is a series of frequency distributions, one for each crop, which indicates the amount of production taken from areas grouped according to their annual change in crop yields over the 1975–95 period.[4] A large spatial variation in the performance of the crops studied here is clearly evident. Substantial areas under beans experienced substantial yield declines (greater than 3 percent per annum) since the mid-1970s, yet about 22 percent of the bean area had yield gains in excess of 3 percent per annum. The spatial variation in soybean yields was much more muted—more than 55 percent of the soybean area had yield gains in the range of 0 to 2 percent per annum.

Trade Trends

Brazil, together with many other countries, both imports and exports all three crops (Table 2.3). This reflects seasonal differences in production and differences in the quality and form of the crops being traded, as well as localized cross-border trade. During much of the 1960s and 1970s, Brazil was a net exporter of edible beans but is now a net importer. The country shifted from being a net importer to a net exporter of rice over the past several decades. Soybeans are the only crop among the three studied here for which Brazil had a persistent and sizable positive balance of trade since 1961 (that is, the value of exports exceeds the value of imports). In terms of traded values, roughly equal shares of soybeans are

[4]The edible bean and soybean distributions are developed from Alston et al. (2000a).

Figure 2.3 State production shares, 1961–2000



Source: With the exception of upland rice, all data were taken from IBGE (various years). Upland rice data are based on authors' estimates and from data obtained from IBGE (various years).

Figure 2.4 Municipality production stratified by growth in yields from 1975 to 1995

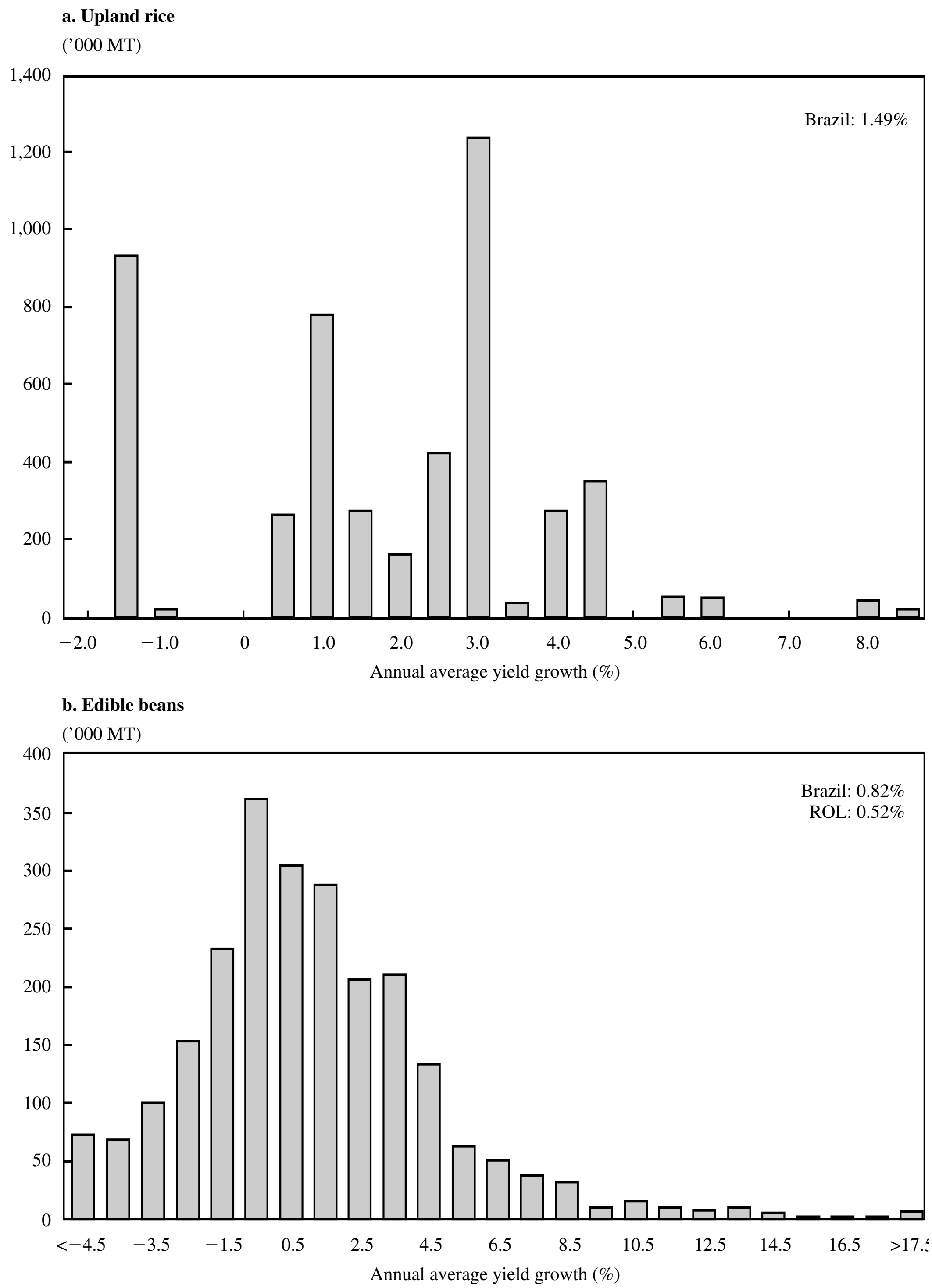
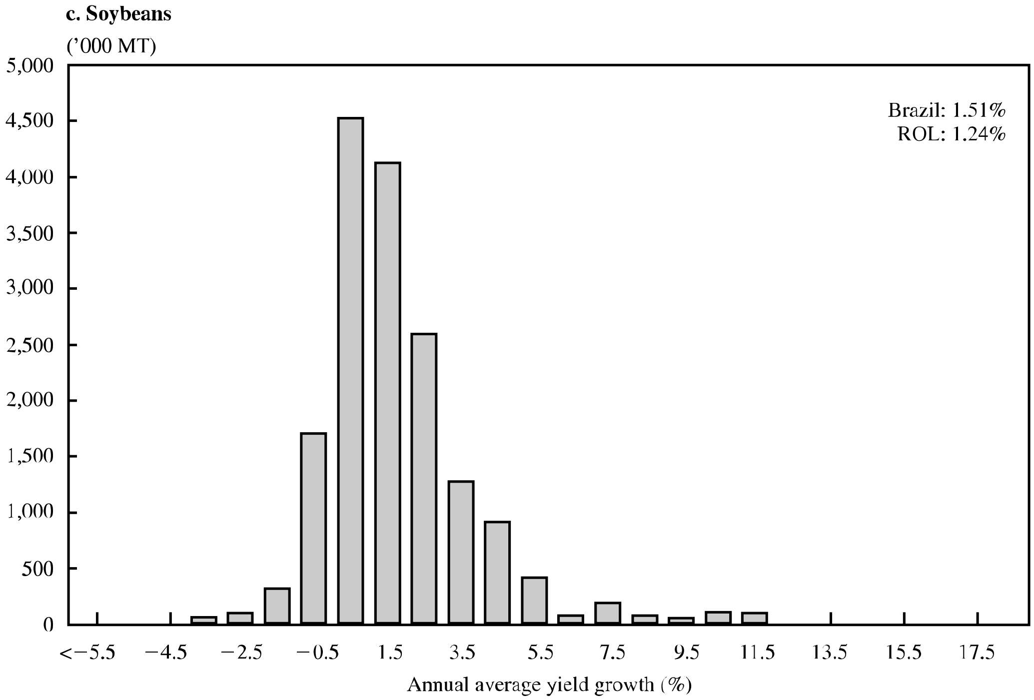


Figure 2.4—Continued



Source: With the exception of upland rice, all data were taken from sources cited in Pardey, Chan-Kang, and Wood (2000). Upland rice data are based on authors' estimates and from data obtained from IBGE (various years).

Note: ROL refers to rest-of-LAC.

shipped as grain and cake, with a significant but much smaller share of the total value of exports (18 percent in 1999) exported in oil form.

In 1999, Brazil accounted for more than one third of Latin America's entire bean imports (by value), one-fifth of its edible bean imports and a negligible share of the region's exports of both crops. In terms of global trade, Brazil accounted for less than 6 percent of total world imports of beans and rice in 1999, but 47 percent of Latin America's soybean exports (summing across exports in all forms) came from Brazil—a large share, but significantly less than the corresponding share for the early 1960s, when Brazil accounted for virtually all of the region's exports of this crop. The rate of growth in Argentina's soybean exports has been even greater than that of Brazilian soybean exports noted previously, and Argentina now accounts for about 44 percent by value of the region's soybean exports, irrespective of form. In terms of world trade, by the late 1990s Brazil accounted for 21 percent of global exports, and Argentina for about 20 percent.

The lion's share of Brazil's imports of all three crops comes from developing countries; specifically, Argentina is the principal source of bean imports, Uruguay supplies rice (with Argentina second on this list), and the soybean imports come mostly from Paraguay.[5] Western Europe is the major

[5]To quantify bilateral trade flows between Brazil and other countries, we used the Commodity Trade Statistics Data Base (COMTRADE) compiled by the United Nations Statistics Division (UNSD).

Table 2.3 Quantity of rice, edible bean, and soybean exports and imports

	Exports					Imports				
	1961	1971	1981	1991	1999	1961	1971	1981	1991	1999
	(thousands metric tons)									
Rice (paddy equivalent)										
Brazil	193.8	217.1	64.2	2.6	76.3	0.0	2.2	209.6	1,410.8	1,437.9
Rest-of-LAC	268.5	424.7	877.1	819.4	2,643.9	529.7	693.3	1,028.3	1,700.9	2,513.9
LAC	462.3	641.8	941.3	822.0	2,720.2	529.7	695.6	1,237.9	3,111.7	3,951.8
World	9,215.1	12,567.6	19,074.6	20,058.0	39,907.7	9,312.6	12,004.7	19,565.1	18,904.7	38,919.3
Edible beans										
Brazil	7.3	0.2	0.0	0.8	2.5	0.2	2.1	5.6	96.8	92.8
Rest-of-LAC	41.1	72.6	202.3	296.9	349.7	47.6	58.9	613.0	146.3	337.7
LAC	48.3	72.9	202.3	297.8	352.3	47.8	61.0	618.6	243.1	430.5
World	510.7	659.7	1,616.9	1,889.9	2,495.6	386.1	581.4	1,667.3	1,559.2	1,801.2
Soybean (unprocessed)										
Brazil	73.3	214.4	1,449.7	2,020.5	8,917.4	0.0	1.3	931.3	281.8	582.3
Rest-of-LAC	0.3	24.9	2,458.8	5,587.7	5,314.6	21.9	191.4	1,303.5	1,946.7	5,186.1
LAC	73.5	239.2	3,908.5	7,608.2	14,231.9	21.9	192.7	2,234.8	2,228.6	5,768.4
World	4,167.3	12,369.7	26,235.4	27,238.3	40,495.7	4,073.4	12,661.9	26,267.5	26,482.4	41,917.0
Soybean cake										
Brazil	33.0	901.4	8,891.4	7,488.6	10,430.9	0.0	0.0	0.0	0.0	78.1
Rest-of-LAC	0.0	29.6	550.9	6,241.4	14,000.3	44.9	194.7	857.4	1,640.9	3,133.9
LAC	33.0	931.0	9,442.3	13,730.0	24,431.2	44.9	194.7	857.4	1,640.9	3,212.0
World	1,189.3	6,278.0	20,120.0	26,762.9	39,118.5	1,228.5	6,108.2	18,931.6	26,189.5	37,312.6
Soybean oil										
Brazil	0.0	6.7	1,285.6	512.3	1,556.3	0.1	2.8	0.0	67.6	159.6
Rest-of-LAC	0.0	0.8	73.6	1,291.2	3,250.9	39.6	96.2	432.5	521.4	1,025.5
LAC	0.0	7.5	1,359.2	1,803.4	4,807.2	39.7	99.1	432.5	589.0	1,185.0
World	420.9	1,681.0	4,108.3	3,750.7	8,543.2	514.6	1,440.6	3,456.4	3,488.6	8,144.1

Source: FAOSTAT (2002).
Note: LAC indicates Latin America and Caribbean.

destination for Brazil's bean and soybean exports, while rice is exported to a number of South American countries. None of the transitioning economies of the former Soviet Union figure in Brazil's export or import balance sheets.

R&D Patterns

Agricultural research in Brazil started in approximately the mid-1800s, at the time when public agricultural research institutions in the United States and Europe were first set up.[6] The Emperor of Brazil[7] approved the establishment of five Imperial Research Institutes, although only two of these institutes, one in the province of Bahia and the other in Rio de Janeiro, became operational. They focused their research on estate crops such as coffee and sugarcane destined mainly for export markets, as did many of the research stations that were formed over the subsequent century, most of which were located in the richer states in the southeastern part of the country.

Despite this early (by world standards) start, the elements of a national research effort did not really begin taking shape until the late 1930s and early 1940s. In 1939 the Ministry of Agriculture formed the National Center of Agricultural Training and Education (CNEPA), which evolved into the Department of Agricultural Research and Extension (DPEA) in 1962. DPEA (renamed the Research and Experimental Office, EPE) moved its headquarters to Brasilia in 1967, and grew into a national network of nine research institutes—organized on a regional basis—supported by 75 experiment stations. In 1971, EPE was renamed the National Agricultural Research and Experiment Department (DNPEA) and, with the addition of some new central units, became the institutional and operational basis for Embrapa, which assumed DNPEA's facilities and commenced operation in April 1974 after Congressional approval in December 1972.

Embrapa was established as a governmental corporation, with administrative flexibility beyond that typical for a government agency. By 1999 it had grown into an organization with 37 research centers employing 2,064 scientists and a total staff of 8,619. Although it is definitely the largest agricultural research agency in Brazil, Embrapa is by no means the only such agency. A sizable investment is also made in agricultural research conducted by state government agencies and universities. Beintema et al. (2001) estimate that by 1996, Embrapa accounted for 52 percent of the publicly performed agricultural R&D in Brazil, state governments 20 percent, and universities about 21 percent. Although public research predominates, some private research related to agriculture is performed in Brazil.

Some basic institutional details for the two Embrapa centers evaluated in this study are given in Table 2.4. The rice and bean and soybean centers were established as entirely new facilities, whereas many other centers had inherited facilities and some of the former DNPEA staff. In 1998, these two centers combined accounted for 4.6 percent of total Embrapa spending and 5.8 percent of total scientific staff, and are among the larger centers within Embrapa.

Both centers focus on crop-improvement research, with an emphasis on crop breeding. Crop research constitutes nearly one half of all Embrapa research, and about the same share of university and state government research. About one third of all crop research in Embrapa and the state agencies is genetic-

[6]The authors are grateful for the assistance they received from Nienke Beintema in preparing this section.

[7]Brazil gained independence from the Portuguese in 1822 and two Emperors ruled until 1889, when the country became a republic (Skidmore and Smith 1997).

Table 2.4 Institutional profile of Embrapa centers, 1996

Name			Research Focus	Location		Researchers		Expenditures	
Acronym	Portuguese	English		State	Region	Total	Share	Total	Share
						(FTEs)[a]	(%)	(million reais)	(%)
CNPAF	Centro Nacional de Pesquisa de Arroz e Feijão	National Center for Research on Rice and Beans	Upland rice Beans	Goiás	Center West	52	2.5	11.7	2.2
CNPSo	Centro Nacional de Pesquisa de Soja (1975)	National Center for Research on Soybean	Soybeans Sunflower	Paraná	South	61	3.0	12.9	2.4
CENARGEN	Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia	National Center for Research on Genetic Resources and Biotechnology	Genetic Resources, Biotechnology	Distrito Federal	Center West	114	5.5	19.5	3.6
Sede	—	Headquarters	—	Distrito Federal	Center West	88	4.3	136.0	25.4
Embrapa, total	Empresa Brasileira de Pesquisa Agropecuária	Brazilian Agricultural Research Corporation		—	—	2,063	100	535.6	100

Source: Beintema et al. (2001), adapted from Appendix Table B.1.
[a] FTE indicates full-time equivalent.

improvement research, whereas only one quarter of the crop research done in the universities is so oriented.

Although Embrapa is a significant research organization in Brazilian (and even in world) terms, much of the research that is conducted in Brazil and (elsewhere in the world) does not directly involve Embrapa. According to estimates made by Pardey and Beintema (2001), in 1996 (the latest year for which internationally comparable data are available), Embrapa provided about 30 percent of public research in Latin America and 3 percent of all public research conducted worldwide. Thus the prospects for tapping technologies developed elsewhere are large: scouting for and screening these technologies to speed up the international transmission of new knowledge has real value. For example, a collaborative joint program of research began in early 1998 with several Embrapa staff outposted to the U.S. Department of Agriculture's (USDA's) headquarters facility in Beltsville, Maryland. A similar joint program involving outposted Brazilian staff was launched with Agropolis in Montpellier, France in 2001. In addition, a sizable share of Embrapa's research is conducted in direct partnership with other Brazilian state agencies, universities, and some private nonprofit and for-profit agencies, including domestic companies and international firms with local operations.

Brazil has a substantial number of universities, with more than 100 faculties or schools of agricultural science that conduct research. Most of these are federal and state universities; only a few of the private universities offer training and research in the agricultural sciences (Alves 1992). Beintema et al. (2001) identified five Brazilian nonprofit institutions engaged in agricultural research in the late 1990s. One of these, the Instituto Rio-Grandense de Arroz (IRGA), is an autonomous public agency established in 1938 under state law to conduct research on irrigated rice production in Rio Grande do Sul, a state that in 1998 accounted for 50 percent of Brazil's total rice production. In addition to rice research, IRGA also carries out a certain amount of research on maize, sorghum, and soybeans. Since its inception, it has released a total of 30 rice varieties. During the 1980s, some of these varieties were developed jointly with Embrapa (such as *BR-IRGA 409, 410,* and *414*) and later became commercial successes—for instance, the variety *BR-IRGA 409* was planted on upwards of 60 percent of the state's rice area in the mid-1980s. The variety *BR-IRGA 414,* released in 1987, was the last of these joint products; more recent releases such as *IRGA 416* (commercialized in 1991), *IRGA 417* (released in 1995), and *IRGA 418, 419,* and *420* (all released in 1999) were developed by IRGA without direct engagement with Embrapa.

Brazil has an active and growing private sector providing technologies and technical services concerned mainly with farm inputs (including agrichemicals, animal feeds and breeding services, fertilizers, seeds, veterinary medicines, and machinery) and food processing. Little specific information is available on the local research underpinning these technologies, but the impression gleaned by Beintema et al. (2001) is that many of the technologies represent spillins to Brazil from research done elsewhere.[8] Some of the national seed companies do conduct some research in Brazil, much of which involves local testing and screening of improved germplasm developed elsewhere. Since the mid-1990s a considerable number of these national seed companies, especially those marketing corn and soybeans, have been taken over by multinational corporations. For example, Sementes Agro-

[8]Roseboom (1999) reached a similar conclusion in a separate study of the sources of Brazil's agricultural technologies.

ceres, Braskalb (the Brazilian operations of DeKalb), Cargill's local seed operations, and FT Sementes were all acquired by Monsanto (in which Pharmacia acquired an 85 percent stake in October 2000, only to spin off its holdings in August 2002, reestablishing Monsanto as an independent trading entity). As a result of its Brazilian acquisitions, Monsanto accounted for 63 percent of the Brazilian seed corn market during 1998–99, various other foreign firms had 22 percent, and Brazilian seed companies supplied the remaining 15 percent (which includes Unimilho, an association of local private firms that adapt and market seeds based on material supplied by Embrapa) (Filho and Garcia 2000). Other noteworthy firms are Souza Cruz (part of British-American Tobacco), which has five experiment stations engaged mainly in breeding new tobacco varieties, as does Profigen, a U.S. company. Agristar, together with SVS do Brasil (the Brazilian branch of the firm Seminis, which includes Asgrow, Horticeres, Petoseed and Royal Sluis), have developed a range of improved vegetable varieties.

CHAPTER 3

Economic Evaluation of Varietal Change

The relevant precedent literature is large; Alston et al. (2000b) identified 165 studies of "rates of return" to agricultural research dealing with field crops, of which 38 dealt specifically with the three crops included in this study. However, surprisingly little of that literature sought to identify the institutional origins of the benefits from R&D, an especially telling omission if research spillovers among groups of research providers—whether domestic or foreign—are deemed important. Given our interest in assessing the benefits attributable to *specific* groups of research providers, we directed our research degrees of freedom to accounting carefully for these interinstitutional effects. Our procedures for measuring the overall Brazilian benefits attributable to improved crop varieties were designed to achieve parsimony without compromising precision or introducing biases—and, where possible, to improve the accuracy of the estimates compared with typical past practice.

Brazilian Benefits Overall

We use an approximation that was first used by Griliches (1958) in his study of hybrid corn to measure the total benefits to Brazil from varietal improvement. We assume that total gross annual research benefits (GARBs) are approximately equal to the value of the additional output, measured by the value of production (PQ) multiplied by the proportional gain in yield (k), associated with the adoption of new varieties—that is, $GARB = kPQ$, where P is the price and Q is the quantity of the crop. This is a reasonably intuitive measure, but is open to some criticisms, as discussed in Alston et al. (1995), for instance. It will provide a very good approximation in the case of linear supply curves shifting in parallel, but yield gains might not translate well into supply shifts (they are likely to understate supply shifts because they do not allow for economizing responses), and they might not be parallel (a measure that is good for parallel shifts would substantially overstate benefits associated with a pivotal supply shift).[9]

We acknowledge the measure is subject to error, but suggest that the multiple sources of errors of approximation in this measure might to some extent offset one another, and that the errors from this source might not be too serious compared with other potential sources of error in the analysis. In any event, information is not available on the size or nature of the shifts of

[9]More recent work by Martin and Alston (1997) suggests that the measure may be better than previously suggested. Martin and Alston (1997) showed that the same approximation to producer surplus—that is, the increase in supply multiplied by the price—would be an *exact* measure of the change in producer profit when technical change variables are incorporated directly into a linear-quadratic profit function, which implies linear output supply shifting in parallel as a result of research, and would be a first approximation with factor-augmenting technical change in the same profit-function setting.

supply associated with new crop varieties in Brazil, so some assumptions are inevitable and the measure we use is consistent with the most common assumptions used in measures of research benefits.

The use of the preceding approximation to GARB avoids the need to measure the price and quantity effects of research, but this advantage is lost if one is interested in measures of the distribution of benefits either within a country or among countries. Here we are interested in measuring the total benefits to Brazil from varietal innovations, and even though we are not interested in the functional distribution of benefits within Brazil, we have to take account of the international distribution if GARB includes some benefits accruing to producers or consumers in other countries, given that we are dealing with innovations for imported goods, such as edible beans or rice in the Brazilian economy, or an exported good, such as soybeans in the Brazilian economy.

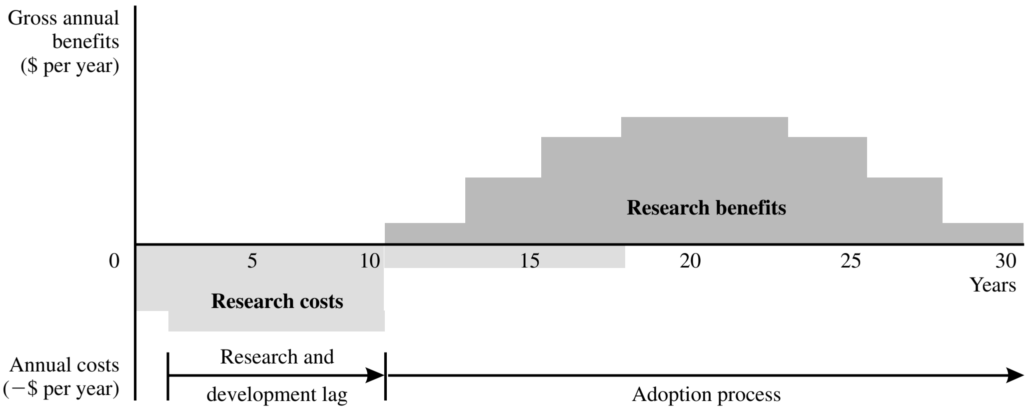
These consequences will be important if the technological change causes changes in the world market price or if there are international technology spillovers (that is, if other countries adopt the results from Brazil's R&D).[10] When producers in more than one country can adopt and benefit from the new technology, it is the consequent increase in *worldwide* production that determines the price effects of new varieties. The international distribution of the benefits and costs of the new varieties depends on the global pattern of trade in the commodity and the applicability of the new technology in different places, reflected in the pattern of adoption, as well as the change in the world price. Hence, if the technological change leads to significant changes in the world price, we need to measure this price change, and pay attention to the difference between quantities produced and consumed, in order to measure the total domestic benefits.

We maintain that Brazilian varietal innovations have had negligible effects on world market prices for upland rice, edible beans, and only modest effects on soybean prices, reflecting the fact that Brazil's output has modest consequences for world market prices, and that the extent of technology "spillouts" of crop varieties from Brazil to other countries is not likely to have been large enough to have had important impacts on world prices for the commodities of interest. Our measure of total research benefits, given by an index of yield gain multiplied by Brazil's value of production, will overstate Brazil's gains in the case of soybean research given that Brazil is an exporter and some of the benefits from the resulting lower prices would accrue to consumers outside of Brazil.[11]

[10]Of course, technology spillovers can run in either direction. In this study, it is important to allow for "spillins" of technology to Brazil from other countries (especially for soybeans) and from the international agricultural research (or CGIAR) centers (especially for beans and rice) in determining the part of the total technological improvement in Brazil that is attributable to Embrapa's research investment.

[11]In 1998, Brazil exported 9.274 million metric tons (mmt), 30 percent of its production of soybeans; 10.447 mmt, 61 percent of its production of soybean cake; and 1.365 mmt, 33 percent of its production of soybean oil (FAOSTAT 2002). Although the export market is clearly important to Brazil, it is Brazil's production as a share of global production that determines the extent of Brazil's ability to influence the world price. In 1998, Brazil's shares of global production were 5.8 percent for soybeans, 10.2 percent for soybean cake, and 5.8 percent for soybean oil. If the elasticity of final demand for these products were, say $\eta = -0.5$, then in the very short term (that is, holding total supply constant) elasticity of demand facing Brazil, η_B would be approximately equal to the overall demand elasticity divided by Brazil's share of world production (s_B = 0.058 to 0.102): $\eta_B = \eta/s_B = -4$ to –9. This is a very short-term elasticity because it does not allow for any supply response in other countries; allowing for other countries' supply response would make the demand facing Brazil even more elastic. Elasticities as low as –4 to –9 mean that a 10 percent increase in Brazil's supply of soybeans might give rise to a fall in the world price of 1 to 3 percent, which is not negligible but would not have a very great effect on the measure of research

Figure 3.1 Research benefits and costs over time



R&D Lags

Evaluations of the economic effects of research involve procedures to account for the timing of streams of benefits and costs, as there may be lengthy lag times between the initial investment in research, the eventual adoption of research results, and the flow of research benefits. Figure 3.1 represents schematically the timing of flows of benefits and costs from a successful investment in developing a new plant variety.[12] The vertical axis represents the *flow of benefits and costs* in a particular year and the horizontal axis represents years after the commencement of the project.

Initially, the project involves expenditure without benefits so that, during the *research lag* period (say 3 to 10 years), the flows of net benefits are all negative. Then, after the research lag there may be a further delay, a *development lag* of several years, involving field trials for testing, certification, and approval of the variety and for multiplication of seed. Even when a commercial product is available, there are further lags before the maximum adoption of the new technology is achieved. The *adoption lag* may involve several years. Eventually, as shown in Figure 3.1, the annual flow of net benefits from the adoption of the new technology becomes positive (at least, for a profitable investment this is true). In most cases the flow of benefits will eventually decline as the new variety is progressively abandoned when it becomes obsolete (for example, as newer and better varieties evolve) or depreciates (for example, as pests evolve), or becomes uneconomical for some other reason. A plant-breeding *program* involves an ongoing stream of costs and an ongoing stream of benefits given by the progressive development, release, and adoption of new varieties in sequence. Such a program could be represented by combining multiple versions of Figure 3.1, one per specific variety (including unsuccessful ones), or by developing a representative overall picture. Either way, it is important to be able to match the timing of benefits to the timing of the costs of the investment that is responsible for the benefits.

Figure 3.1 shows the flows over time of net annual benefits attributable to an R&D project. They represent the sum of benefits

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benefits; larger demand elasticities reflecting rest-of-world supply response would imply even smaller price effects. For the other commodities, Brazil imports a small but significant share of its consumption (about 7 percent for beans and 17 percent for rice in 1998). Moreover, these imports represent a very small fraction of the world market, and so it is reasonable to treat Brazil as a price taker.

[12]Many new varieties are not successful in the sense that they are never developed for commercial use or adopted in the field. The figure refers to a new variety that is successful, and adopted.

across individuals in the society, accruing in each year, relative to the situation if the project had not been undertaken. The relevant basis for comparison is with and without the R&D, not simply before and after it. In many cases the relevant alternative would not be constant yields but falling yields. Indeed *maintenance research,* research directed at maintaining yields and profitability in the face of pressures that would lead them to fall otherwise, is a major component of agricultural R&D.[13]

Relevant Alternatives and *Ceteris Paribus*

When using aggregate industry yields to determine the value of yield-improving research it is necessary somehow to hold constant the effects of other factors—the so-called *ceteris paribus* conditions. We have data "before and after" new varieties were released and we attempt to infer from that a comparison of yields "with and without" the new varieties. But other things were not constant. In many settings, as noted previously, rather than stay constant yields may have fallen if the variety (or other aspects of technology) were held constant, owing to the buildup of variety-specific pests. So-called "maintenance" research is necessary just to stay level. In addition, other factors change over time affecting industry average yields, and their effects must be removed in order to isolate the effects of variety changes per se. These include such factors as other aspects of technology, weather, pest infestations, quantities of other inputs changing in response to prices or other events (for example, changes in availability of irrigation water), and changes in input quality (for example, lower average land quality when sown area expands into marginal areas in response to high prices), sometimes in interaction with one another.

When we translate yield changes into changes in costs, to compare the profitability of different varieties, we may encounter another problem. We may find it necessary to allow for different optimized quantities of inputs for different varieties that respond differently to, say, fertilizer or irrigation. The well-known problem of how to translate experimental yield differences into cost differences realized on farmers' fields (see Alston et al. 1995) is confounded further when the new technology changes the responsiveness of a plant to the water, fertilizer, or chemicals used to control pests and diseases in ways that are sensitive to the amounts of these more conventional inputs used in production. For example, the yield differential between conventional and semidwarf varieties of wheat and rice typically increases as the amount of fertilizer increases, at least up to some optimum amount of fertilizer use. When adoption of a technology changes the economically optimum amount of conventional input, it is doubly difficult, with generally available data, to identify a shift in a yield response curve resulting from new technology, as distinct from a movement along a response curve resulting from changes in the amount of conventional input, and to link the observed "before-and-after" change of yields and costs of production to the difference in yields and costs "with and without" the new technology.

Quality differences between varieties are directly analogous to yield differences, in ways that mean analogous conceptual and measurement problems arise. We wish to measure quality "with and without" variety improvements but our industry-level data

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[13]Maintenance research is very important. If R&D was to cease altogether, the likely scenario would be more variable and declining yields and rising costs, not simply a continuation of current (or baseline) yields and costs. Significant investments in maintenance research, particularly in plant breeding, plant pathology, and entomology, are required just to maintain current productivity. Estimates indicate that 35 to 70 percent of U.S. agricultural research is needed to maintain previous research gains (Heim and Blakeslee 1986; Adusei and Norton 1990).

are in the form of "before and after" and so we have to deal with the effects of other variables that may affect quality and did not remain constant—often the same variables that affect yield. In translating yield into cost changes or shifts in supply, we need to account appropriately for any attendant changes in variable factors. Similarly, in translating quality change into demand shifts, we may need to account for multi-dimensional aspects of quality, that may not be valued independently (that is, the value of a particular combination of characteristics may not be simply the sum of the values of the components). Often, in practice, usually as a result of inadequate data, we cannot deal with these elements as flexibly as we may wish, and simplifying assumptions are usually necessary.

Matching Benefits with Costs

To evaluate the contribution of Embrapa-developed technologies to the Brazilian economy we need to be able to match the different elements of benefits to their corresponding costs. Suppose we can measure the benefits of soybean or rice variety improvement in Brazil, including yield and quality changes, how do we isolate the effects of particular past research investments in contributing to that improvement? One approach is to try to isolate the effects of particular R&D contributions to new varieties before evaluating the resulting benefits. Another approach is to measure the total benefits from all such investments, regardless of who made them, and subsequently, somehow, to partition the benefits among the investments. The latter approach seems more feasible as a practical matter.

Lags. We have so far discussed the dynamic nature of the research-development-adoption continuum relevant to evaluating new technology from a conceptual perspective. In an empirical setting, it is necessary to quantify the lengths of the lags between the investments in R&D and their consequences in terms of streams of productivity and benefits. In the context of new plant varieties we may have data on when new varieties were released and adopted, but we may not know exactly when the relevant expenditures were made that resulted in a particular new variety. It is often necessary to rely on advice from scientists to determine a reasonable estimate of typical R&D lag lengths, but data can be used to determine the (variety-specific) adoption lags. The same lag profile is appropriate for a *particular* new variety whether we are measuring the gains from quality improvement or yield improvement. When we aggregate across varieties, there may be different relevant lag structures for yield versus quality improvement.

Indexes of Varietal Improvement

Measuring varietal improvement involves comparing individual varieties, or indexes that aggregate across varieties, with some base or numeraire variety or index. An advantage of using experimental data is that many of the variables that influence yields are deliberately held constant, a practice that helps to isolate the effect of the variety per se but that also means that variable inputs are not "optimized" differentially among the varieties, so the cost differences between varieties cannot be inferred directly. On the other hand, it is industry yield that is really relevant for measuring benefits.

Industry yields are generated, *mutatis mutandis*—that is, where input use varies for all sorts of reasons (for example, weather, changes in relative prices of inputs and outputs, technical change, and so on), both within and among seasons and across locations. Typically, and up to a point, inputs are chosen jointly with varietal use decisions, thus also varying as a consequence of varietal choice. Experimentally derived varietal yields are more likely to be generated *ceteris paribus,* although the treatment regimens (fertilizer rates, weather, pest and disease control aspect, and so on), which are typically held comparable in conducting side-by-side varietal comparisons, may well change over time and across locations. It is likely that the variation in experimental treatment regimens is much more muted than comparable industry input choices (especially within a season, but over time as well) and thus experimental yields stand a better chance of revealing differences attributable to varietal effects, *ceteris paribus* (Alston, Norton, and Pardey 1998, pp. 338–340 and Appendix A5.3, explore this issue in some detail).

Typically, experimental yields are substantially higher than average or representative yields found in farmers' fields. But it is yield gains or differences in yields between, say, new and old crop varieties, not yield levels, that are relevant here.[14] There may be grounds for scaling down experimental yield gains to better reflect yield gains on-farm—but it would probably be an overcorrection to scale down the gains in proportion to the usual differences between experimental and industry yields. Nevertheless, we apply an index of proportional growth of experimental yields to industry output, which is consistent with an assumption that the rate of change in industry yields attributable to varietal change is proportional to the rate of change in experimental yields attributable to varietal change.

Aggregate industry-wide yield data show the changes in yields over time, representing "before-and-after" measures of yield change associated with varietal adoption and other changes, whereas we are looking for a "with-and-without" measure of the effect of varietal change. That is, we wish to know the answer to counterfactual questions of the form: (a) What would yields have been if there had not been any change in varieties over the period since Embrapa began to release varieties?, or (b) What would yields have been if there had been *some* varietal change, associated with the release and adoption of non-Embrapa varieties, but no adoption of Embrapa varieties? To answer either of these questions requires information on the adoption of varieties over time, and, for question (b), whether they were Embrapa releases, and measures of varietal performance.

We define an index of experimental yield performance in region r in year t, given the *actual* adoption pattern and the observed experimental yields as

$$Y^a_{rt} = \sum_{i=1}^{n} Y_{irt}\,\pi_{irt}, \tag{1}$$

$$\text{where } \pi_{irt} = \frac{A_{irt}}{A_{rt}} \quad \text{and } A_{rt} = \sum_{i=1}^{n} A_{irt}$$

where Y_{irt} is the experimental yield of variety i in region r in year t, and π_{irt} is the proportion of area in region r in year t, A_{rt}, sown to variety i. An alternative index of experimental yield performance in region r in year t, given a *counterfactual* adoption pattern would differ in terms of the adoption weights applied to the same experimental yields. Specifically, to represent a counterfactual scenario of no change in varieties over time, we would hold the adoption proportions constant over time at their values in the base year (that is, in the above equation, setting $\pi_{irt} = \pi_{irb}$ for all years, t, where π_{irb} represents the share of the total area planted to variety i in region r in the base year).

$$Y^b_{rt} = \sum_{i=1}^{n} Y_{irt}\pi_{irb} \tag{2}$$

In comparing the counterfactual yield measure of what yields would have been in the absence of any varietal innovations, to the actual yield measure, the proportional gain in experimental yield attributable to varietal improvement, for each region is given by:

$$k_{rt} = \left(\frac{Y^a_{rt} - Y^b_{rt}}{Y^a_{rt}}\right) \tag{3}$$

[14]Alston et al. (1995, 338–340), and the references cited therein, discuss these issues in more detail.

where, as defined previously, Y_{rt}^b denotes an index of experimental yield computed using the base-year area weights (that is, in the absence of changes in varieties), and Y_{rt}^a denotes an index of experimental yield computed using the actual area weights (that is, reflecting the adoption of new varieties).

These measures rest on having a full set of observations of experimental yields by region (if we are taking regional measures) for every variety adopted, but usually the "experimental design" is incomplete and lacking data on performance of every variety for every location and in every year, as is the case for our Brazilian data on experimental yields. To address this data deficiency, we adopt an approach that was developed and applied by Venner (1997) and James (2000) and described in detail below.

The estimate of k from equation (3) can be used to measure the proportional increase in production, holding inputs constant, as a result of the actual varietal adoption pattern relative to the counterfactual alternative scenario of no varietal change.[15] Multiplying this factor times the actual value of production yields a measure of the additional value of production attributable to the adoption of new, higher-yielding varieties. That is, the total benefits from varietal improvement in region r in year t, may be written as:

$$B_{rt} = k_{rt} P_t Q_{rt} \quad (4)$$

Attribution of Credit for Yield Gains

The aforementioned measure of total benefits from varietal improvement research could be used as a measure of gains attributable to Embrapa if it were reasonable to attribute all of the credit for the gains to Embrapa's research. Alternative measures can be developed by giving partial credit to Embrapa for individual releases, based on the extent to which the breeding of the parents, grandparents, and so on of a variety, as well as the variety itself, was done by Embrapa or another research institution in Brazil or elsewhere. Such considerations are important if we believe that the credit for the value of a particular variety should be partitioned between the breeders at the institution that released it and those who were involved in prior stages of the varietal improvement process or collaborated with Embrapa in the development of a new variety. Suppose only a fraction, E_i, of the credit for variety i is attributable to Embrapa. Then, a measure of the share of the total benefits attributable to Embrapa can be defined by weighting each of those variety-specific fractions by the proportion of total area planted to that variety. Hence, the benefits attributable to Embrapa are defined as

$$B_{rt}^E = B_{rt} \sum_{i=1}^{n} E_i \pi_{irt} \quad (5)$$

Defining Attribution Weights

Embrapa's varietal improvement research is not conducted in isolation from the research that preceded it or from the contemporary research done by others. Some of Embrapa's research draws on this contemporary research in an arms-length fashion, and some is carried out as joint research. Here we discuss two options for estimating attribution

[15]Typically there will be a link between yields and varietal adoption. Farmers may opt not to change their varietal mix over time or, for reasons they do not control, be unable to do so. In this case, changes in the counterfactual index of yields would arise only from changes in yields of the base-year varieties over time, and the ratio of indexes of actual and counterfactual yields would be constant over time. Typically, but not always, the yields of base-year varieties tend to deteriorate over time or decline relative to the yields of newly released varieties with superior yield prospects. In this case, farmers would change their varietal mix over time and the index of counterfactual yields would diverge from the index of actual yields because of changes in both variety-specific yields and in the varietal mix.

weights (that is, the E_is) that reflect the contribution of these other participants.

Genetic attribution of benefits. One approach is to share the *genetic* content of a variety equally between (the breeders of) its parents, and by serial division, among all its antecedents. But the contribution of the parents, grandparents, and so on to the offspring's yield cannot be attributed accurately in this fashion. The difficulty is that, absent information that allows a direct translation of genetic content into performance in the field, mechanistic rules such as serial division are all that remain for quantitative allocation of credit among the sequential plant-breeding innovations that have led to a particular variety.

A multiplicity of rules has been used in the past to attribute benefits from varietal improvement across stages of varietal development (Pardey et al. 1996a and b).[16] In essence, these rules vary in terms of the benefits they ascribe on the basis of breeders' efforts (for example, using crosses as the basis of attribution) and on the basis of various views on genetic content (for example, using genealogies or heritability of important traits as the basis of attribution), and also vary in terms of the weight given to more-recent versus distant-past aspects of the development of the new variety. Plausible arguments could be made in support of any one of these rules—which has major implications for the attribution of benefits—but the choice of a particular rule is essentially arbitrary. In this study we applied two rules, in which the attribution weights were dictated by the incidence of "Embrapa-ness" in the pedigrees of the crop varieties that were of commercial significance. These were a "last-cross" rule and a truncated variant of a "geometric rule," specifically:

Rule 1: Last-cross rule. This rule gives all the credit for a particular variety to the breeder who produced it, apportioning none of the benefits to any of its ancestors that still exist as varieties in their own right.[17] This is a zero or one index, which is one for varieties (or breeding lines) released by the program and zero for all others. This rule has the virtue that it is inexpensive to compute, but would give no credit to an Embrapa program that released no varieties directly, but instead made significant contributions of germplasm to, for example, the breeding of varieties by state agencies or universities throughout Brazil.

Rule 2: Geometric rule. This rule uses a geometrically declining set of weights, mimicking somewhat the share of genetic material carried forward from earlier nodes in the pedigree into the present variety according to Mendel's law of heredity. It can also be thought of as a weighting scheme that assigns declining weight to the efforts of those who bred successively older cohorts in the pedigree. In this rule, 50 percent of the benefits from a variety are attributed to its breeder, 1/8 to the breeder of each of its parents, 1/32 to the breeder of each of its grandparents, and so on. In general, at generation g, $1/2^{(2g+1)}$ of the benefits from a variety are attributed to the breeder of each ancestor. When the allocation stops at generation G, $1/2^{(2G)}$ of the benefits are

[16] Brennan and Fox (1995), for example, applied two variants of a "binary rule" at the level of parents. One variant assigned benefits equally to each parent depending on the source of the parent (thus, in attributing benefits to CIMMYT, a CIMMYT-bred parent was assigned 50 percent of the benefits). The other variant also shared benefits equally among each parent, but in this case 50 percent of the benefits went to CIMMYT if a parent had any CIMMYT "blood" in its pedigree. Brennan (1986, 1989) used this varietal parentage approach to partition benefits to Australia for the 1973–84 period, assigning two thirds of the US$747 million savings in production costs to the contributions of CIMMYT and one third to the efforts of Australian wheat breeders.

[17] An alternative extreme rule is to give all credit to the "first" documented cross. This involves, in effect, tracing a variety all the way back to its "original" parents and assigning all credit to those parents, in some fashion.

attributed to that generation, in order to arrive at attribution shares that sum to 1. Thus, applying the rule through the level of grandparents as we did in this study, $1/2^3 = 1/8$ of the benefit would be attributed to the breeders of each of the parents (generation 1) and $1/2^4 = 1/16$ to the breeders of each of the grandparents (generation 2).

Institutional attribution of benefits. Another, sometimes complementary, approach is to attribute benefits on an *institutional* basis, recognizing the contemporary role of other agencies in the conduct of Embrapa research, in addition to the prior role of other agencies in developing the genetic material used by Embrapa and its partner agencies, as just discussed. Indeed, Embrapa collaborates with various state agencies and universities, and even with some private firms, in the development of improved crop varieties, many of which are subsequently released jointly with Embrapa. One simple option would be to prorate the benefits on the basis of the number of partners (that is, attributing to Embrapa half the total benefits from a new variety if Embrapa collaborated with another agency in its development, one third of the benefits if two research partners were involved, and so on). However, the contributions of the partners may not be equal in terms of the financial or genetic resources provided, the breeding acumen brought to bear on the exercise, or some other factor, and taking account of these unequal contributions may be more appropriate. For each of the new varieties included in this study, we elicited a set of weights from CNPAF and CNPSO scientific staff designed to reflect the perceived importance of Embrapa regarding the scientific outcomes of the research. This approach involves more subjectivity than the genetic attribution rules (given that the existence or extent of collaboration regarding a specific variety is, perhaps, in the eye of the beholder), but neither rule is intrinsically better or worse than the other and they can be used in conjunction with one another, as we do in this study.

Attribution between research and extension. Extension is intended primarily to speed up the process of adoption—and, to the extent that it does so, it can substantially increase the benefits from varietal improvement. Extension investments might also have changed spatial adoption patterns and raised the ceiling rates of adoption for some varieties, further adding to the benefits associated with particular varieties. If the costs of extension investments are not counted, then we will have underestimated the full costs of public investments that contributed to the overall result (alternatively, it can be said that we will have overestimated the benefits associated with public investment in research if we have not deducted the effects of extension investments on the pattern of adoption and thus benefits). Similarly, certain types of overhead expenses such as basic research or head-office costs might also be charged against variety improvement research.

Yield Data

These measures rest on having a full set of observations of experimental yields by region (if we are taking regional measures) for every variety adopted. Usually, however, the "experimental design" is incomplete in that we do not have data on performance of every variety for every location and in every year. One reason is that some varieties were developed later than others, but also it is common to drop varieties from the experimental design once farmers have abandoned them.

Estimating Experimental Yields

Given data on yields of several varieties of varying release vintages, each possibly grown on several sites (each found in one of various regions), in each of several years we can estimate a regression model of the form:

$$Y_{klm} = \sum_{i=1}^{I} \alpha_i DV_i + \sum_{j=1}^{T} \beta_j DA_{j(k)} + \sum_{s=1}^{S} \delta_s DS_s + \sum_{t=1}^{T} \gamma_t DT_t + \phi_{r(l)} W_{r(l)m} + \varepsilon_{klm} \qquad (6)$$

where the variables in the regression are defined as follows: Y_{klm} is the experimental yield of variety k at site l (which is within region r), in a trial conducted in year m; DV_i is a dichotomous dummy variable set equal to one for variety i and zero otherwise, and there is one such dummy variable for each of the I total varieties in the data set; $DA_{j(k)}$ is a dichotomous dummy variable set equal to one if variety k was released in year j and zero otherwise, and there is one such dummy variable for each of the T years covered by the data set; DS_s is a dichotomous dummy variable set equal to one for site s and zero otherwise, and there is one such dummy variable for each of the S total number of sites in the data set; DT_t is a dichotomous dummy variable, equal to one if the year of the trial is t and zero otherwise, and there is one such dummy variable for each of the T years covered by the data set; $W_{r(l)m}$ is an index of weather in region r (that contains site l) in year m; and e_{klm} is the residual from the model.

Then, taking the estimated parameters of the model we can compute fitted values for the experimental yields of each variety included in the sample, for every year and every site:

$$\hat{Y}_{ist} = \hat{\alpha}_i + \hat{\beta}_{j(i)} + \hat{\delta}_s + \hat{\phi}_{r(s)} W_{r(s)t}, \qquad (7)$$

where, given that variety i was released in year j, $\hat{\beta}_{j(i)} = \hat{\beta}_j$. Finally, to obtain estimates of variety-specific fitted yields at the level of regions (say, states, as in our application), we can use either the fitted yields from a representative site for each region or an average of the fitted yields across sites within a region. We chose the second option.

Having obtained fitted values for yields for all varieties by region and year, we substituted the fitted values for their counterparts in equations (1) and (2) to compute the yield indexes using the actual and base values of areas of adoption:

$$\hat{Y}^a_{rt} = \sum_{i=1}^{n} \hat{Y}_{irt} \pi_{irt}. \qquad (1')$$

$$\hat{Y}^b_{rt} = \sum_{i=1}^{n} \hat{Y}_{irt} \pi_{irb}. \qquad (2')$$

In turn, we used these estimated experimental yields in equation (3):

$$\hat{k}_{rt} = \left(\frac{\hat{Y}^a_{rt} - \hat{Y}^b_{rt}}{\hat{Y}^a_{rt}} \right) \qquad (3')$$

The estimate of k from equation (3′) can be used to measure the proportional decrease in production, holding inputs constant, in the counterfactual alternative scenario of no varietal change compared with the actual varietal adoption pattern. Multiplying this factor times the actual value of production yields a measure of the value of production foregone if the new, higher-yielding varieties had not been adopted. That is, the total benefits from varietal improvement in region r in year t may be written as:

$$B_{rt} = \hat{k}_{rt} P_t Q_{rt} \qquad (4')$$

Industry Yield Data

Industry-level yield data offer different options. When we know the fraction of each variety, i grown in region r in year t, π_{irt}, a regression model may be formed in which the annual average yield (across all varieties) for a region, r, is regressed against the fraction planted to the different varieties, and other variables as follows:

$$Y_{rt} = \gamma_{0r} + \sum_{i=1}^{I} \gamma_{ir} \pi_{irt} + \sum_{s=1}^{S} \beta_{r(s)} (W_{st} - \bar{W}_{r(s)t}) + \varepsilon_{rt} \qquad (8)$$

where $\bar{W}_{r(s)t}$ is an index of weather averaged across sites (denoted by s) in region r in year t. This is a region-specific model in which the parameters and data are specific to region *r*. The same model could be estimated jointly for several regions as a seemingly unrelated regressions (SUR) setup, with some potential for gains in efficiency. In addition, some parameters may be equal across regions (for example, the weather effects on yields may be common to some regions or the variety response parameters, γ_{ir}, may be equal across regions). From this regression, a prediction of the "expected" yield of a variety, *i* in region *r* in year *t* is given by

$$\hat{Y}_{irt} = \hat{\gamma}_{0r} + \hat{\gamma}_{ir} + \sum_{s=1}^{S} \hat{\beta}_{r(s)}(W_{st} - \bar{W}_{r(s)t}) + \varepsilon_{rt} \qquad (9)$$

where the "hats" denote estimated values. The expected value in a normal year is given by

$$\hat{Y}_{ir} = \hat{\gamma}_{0r} + \hat{\gamma}_{ir} \qquad (10)$$

While this approach using industry data would appear to be a reasonable alternative, it is likely to be difficult to obtain reasonable, plausible, and precise estimates of location-specific yields for a large number of varieties with the types of industry-wide average yield and region-specific adoption data that we can anticipate being able to obtain. Hence, the approach based on the statistical analysis of experimental yields is likely to be preferable in most applications, and better in the present application.

Quality Differences

Like yields, quality differences among varieties may be measured using either experimental data or industry-wide data. Experimental data have the advantage that many of the variables that influence grain quality are deliberately held constant, a practice that helps to isolate the effect of the variety per se but that also means that variable inputs are not "optimized" for quality or yield differentially among the varieties, so the true differences in quality between varieties cannot be inferred directly. Industry-level grain quality may be more relevant for measuring benefits. In this study, as for yield impacts, both types of data may be used in a complementary approach to study grain quality. The various approaches described earlier could be applied in essentially the same ways to develop indexes of grain quality improvement, rather than yield improvement. These indexes rest on measures of quality (as compared with yield) for individual varieties, and if these were not available directly they could be estimated statistically using fitted values from models using experimental data or industry data. As a practical matter, in the current application, it is felt that the preponderance of varietal improvement research has not been directed at grain quality improvement. The notable exception is in relation to upland rice, where improving the quality of grain has been a major objective of research and even that exception has had commercial consequences only in very recent years. Some soybean research has also been directed at improving the quality of the grain.

Gains from variety-specific quality enhancement can be measured using data on price premia. Such data are available only at the level of varietal classes, so varieties either qualify for a premium or they do not. Assuming that yields are not very different between premium and nonpremium varieties, the additional benefits in region *r* in year *t* from having adopted varieties that attain a price premium can be approximated by multiplying the total value of production by the fraction of the total area that is planted to premium varieties (f_{rt}), times the proportional price premium (p_t). That is,

$$G_{rt} = P_t Q_{rt} p_t f_{rt} \qquad (11)$$

The benefit from quality-enhancing research attributable to Embrapa can be computed as:

$$G^E_{rt} = P_t Q_{rt} p_t \sum_{i=1}^{n} E_i \delta_i \pi_{irt} \qquad (12)$$

where $\delta_i = 1$ if variety i is a premium variety, and is zero otherwise (and $E_i = 1$ for Embrapa releases, zero otherwise). It can easily be seen that this same result can be expressed in terms of a proportional supply (or demand) shift, g, as

$$G^E_{rt} = g^E_{rt} P_t Q_{rt}, \quad (13)$$

$$\text{where } g^E_{rt} = p_t \sum_{i=1}^{n} E_i \delta_i \pi_{irt}$$

Costing Varietal Improvement Research

Just as factors other than research affect crop yields and quality, thereby confounding estimates of the benefits attributable to research based on observed differences in yields and grain quality, there are analogous, complicating factors to deal with when estimating the costs of that research. In addition, decisions on how to treat costs are best made in light of decisions on how to measure benefits, and both sets of decisions affect the comparisons of benefits and costs and the management and policy interpretations of those comparisons. In the preceding sections we described methods for estimating the economic benefits arising from a stream of varietal improvements and attributing a share of those benefits to the efforts of specific Embrapa centers. Here we first raise some conceptual issues related to costing that research, and then describe some of the mechanics of measuring Embrapa costs.

Conceptual Issues in Costing Research

To motivate the discussion, consider the costs involved in developing a single new variety. Crop improvement, like much of science, is a cumulative endeavor in which contemporary research builds on the long history of varietal change that preceded it (Alston and Pardey 2001). Even so, typically there is a considerable length of time —often 3 to 10 years—between the point at which a new cycle of research begins and the time when a resulting new variety is ready for release. Screening for and selecting locally superior lines from nurseries or other material obtained from farmers' fields or other research programs generally can be accomplished in just a few years. Crossing various breeding lines takes longer, for example, up to seven generations, before stable, segregating populations are obtained, and considerably longer when some of the crosses involve wild relatives or landrace material. In an ongoing program of research that develops multiple new varieties it is difficult, and for many purposes not necessary, to pinpoint precisely the beginnings or subsequent scope of the research that led to a *specific* new variety. Rather, it is sufficient to estimate the stream of costs that gave rise to a corresponding stream of varieties, some of which later achieved commercial significance and thereby yielded measurable economic benefits.

A compelling conceptual basis exists for evaluating and costing research in this more aggregative fashion. In some senses varietal improvement research, like much biological research, is a large numbers game, yielding few commercial successes and many scientific and commercial failures. Comparatively few improved lines lead to released varieties, and fewer still are adopted in any significant sense. Juxtaposing the whole of the costs against the benefits arising from the few commercially successful varieties is a more natural and meaningful way to evaluate a program of research, or the research center that supports that program, than taking a narrow estimate of only those costs that gave rise to the commercially successful varieties.

Costs can be broken down into their direct and indirect (or overhead) components as well as into functional classes such as labor, capital, and operational costs. Agricultural research is a labor-intensive undertaking, but costing varietal improvement research involves much more than estimating the costs of the crop breeders involved. Significant inputs also include the agronomists, plant pathologists, entomologists, and the like, as well as their support staff, and the cost of employing field hands and others involved in carrying out the research. A full accounting of labor costs also includes the overhead costs of the managerial, library, and other elements of support, including the costs of the fringe benefits (a type of indirect cost) accorded all the labor involved. To these labor costs must be added the operational costs of chemicals, energy, and other laboratory and field supplies as well as the costs of the capital such as land, buildings, and equipment.

Mechanics of Costing Embrapa Research

The existence of a comprehensive, Embrapa-wide, activity- or project-based accounting framework would have greatly facilitated this costing exercise. In its absence, we developed various methods to address various data constraints. Broadly, one set of methods was used to estimate labor costs, another the cost of capital, and a third method was used for estimating operational expenses. These methods emerged after considerable trial and error, during which it became clear that the reported budgets or expenses for each Embrapa center are accounting constructs that do not always provide a proper basis for fully costing the research conducted at each center or, more precisely, identifying the full costs that gave rise to the benefits from varietal-improvement research that are attributed to each center.

Labor costs. To estimate a crop- and activity-specific set of labor costs we began by developing an inventory of staff at each of the centers (CNPAF and CNPSo) for each of the years 1976–98. For CNPAF researchers, individual staff were identified according to their disciplinary classification (for example, plant breeder, pathologist, or agronomist) and qualification status (for example, Ph.D., M.Sc., B.Sc., and various support staff categories) as well as an estimate of the share of time they each spent during each year on crop-improvement research, which was considered 100 percent for plant breeders but not necessarily so for agronomists, entomologists, and such who typically are also engaged in research not directly leading to the development of improved crop varieties. For CNPSo, we were provided information on the total number of personnel working in each research specialty along with the share of time devoted to crop improvement research. These data allowed us to account explicitly for changes over time in the total number and composition of scientific staff, with both aspects having a significant bearing on labor costs. For both centers we also obtained data on the numbers of laboratory assistants, field workers, and other support staff (which includes secretaries and various other administrative support staff, drivers, cleaners and such).[18]

Using corresponding salary data,[19] w_{qct}, for qualification class, q, each crop, c, and each year, t, we estimated the share of labor cost devoted to crop improvement research as follows

$$SCI_{ct} = \frac{\sum_q w_{qct} s_{qct} L_{qct}}{\sum_q w_{qct} L_{qct}} \tag{14}$$

[18]Within Embrapa, senior professional staff includes both "researchers" and "technical" staff. Technical staff hold the same range of university qualifications as researchers, the distinguishing characteristic is that professional staff who successfully sit the public-service *concurso* exam or who gain sufficient merit increases are promoted to the rank of researcher.

[19]We took the wage rate of field workers and other support staff to be 30 percent below the secretarial wage rate whereas the wage rate of laboratory assistants was deemed to be 30 percent above the secretarial wage rate.

where s_{qct} was provided to us as an estimate of the share of each respective labor class devoted to crop improvement research in each year.[20] From the data underpinning the report by Beintema et al. (2001), we obtained a center-specific time series of total labor cost for each crop for the period 1976–99,[21] TL_{ct}, which was used to estimate the corresponding crop-improvement labor cost (that is, $CI_{ct} = SCI_{ct} \times TL_{ct}$).

Operating costs. Operating costs include the costs of field and laboratory chemicals, fuel and energy, and various other supplies required to undertake the crop-improvement research. Total operating costs for each center for the years 1975–98 were provided to us from unpublished data files maintained by SEA. To form an estimate of the operational costs pertaining only to crop-improvement research we first compiled a comprehensive list of subproject budget sheets (*programa annual de trabalho, PAT*), which were available for most but not all years from 1985 to 1998 for each of the centers included in our study. From these budget sheets we estimated the annual shares of *budgeted* operational expenses directly related to crop-improvement research. We were provided with similar (synthetic) estimates of operational cost shares by center staff for selected years prior to 1985 for which PAT budgets were available. Using the median of these operational cost shares for each center, in conjunction with the corresponding total operational costs for each center, for each year we generated an estimate of the operational costs related directly to crop-improvement research.

Capital costs. Measures of the annualized cost of capital were developed using data on the value of the initial capital stock at each center and subsequent annual purchases of various classes of capital, specifically land, buildings, and other physical assets (mainly machinery and equipment). Presuming the intensity of factor use was the same for varietal improvement research as for crop research more generally, we prorated the total value of capital to crop-improvement research according to the corresponding shares of labor plus operational costs for each center. We then calculated the value of the capital stock used for crop-improvement research for each crop for each year as follows:

$$S_{ct} = \sum_k (1-d_k)\, S_{kc(t-1)} + \sum_k I_{kct} \qquad (15)$$

where S_{kct} is the stock of capital and I_{kct} the investment in capital of class k for crop c at time t; d_k is the annual rate of capital depreciation (capital of class k), which is taken to be 0 percent for land, 3 percent for buildings, and 10 percent for other investments. The annualized user cost of capital consists of two parts: (a) depreciation costs, and (b) the opportunity cost of earnings forgone from resources tied up in durable assets (Robison and Barry 1999). Presuming a geometrically declining depreciation profile, then:

$$UC_{ct} = \sum_k S_{kct}(d_k + r_k) \qquad (16)$$

where UC_{ct} is the user cost of capital for crop c at time t, and r, the discount rate

[20]Absent relevant data, we took the share of support staff time engaged in crop improvement research to be equivalent to the share of time of postgraduate researchers dedicated to crop improvement research.

[21]The *TL* series for each center was obtained in nominal local currency units. It was first converted to U.S. dollars using annual average market exchange rates taken from Fundaçao Gutúlia Vargas (FGV) and then deflated to base year 1999 prices using the U.S. implicit GDP deflator published by the U.S. Bureau of Economic Analysis (BEA).

representing the opportunity cost of foregoing earnings, is assumed to be 4 percent.

Other aspects of costs. Estimating the costs attributable to an Embrapa center is not necessarily the same as estimating the costs corresponding to the research benefits attributable to an Embrapa center. There are several aspects to this mismatch in costs and benefits; most arise from the multicenter structure of Embrapa. First, certain costs, such as the interest charges on the loan funds from agencies such as the World Bank and the Inter-American Development Bank that partially underwrite Embrapa research, the implicit subsidies provided Embrapa staff via the agency's lunch program, and various other items, are expensed against Sede's (Embrapa headquarters') budget but really constitute an additional cost of research that should be shared among the Embrapa centers. Second, the cost of the system-wide management and board-related functions carried out by Sede represents a type of overhead charge on the operations of the individual centers. Third, the molecular biology research carried out by CENARGEN also represents a type of overhead cost on the operations of the crop-improvement centers within Embrapa.

For these reasons we developed an "augmented cost" series for each of the three centers in this study that includes (a) a prorated share of Sede costs based on the share of each center's costs in total Embrapa (net of Sede) costs and (b) a prorated share of CENARGEN's costs based on the cost share of each crop-improvement center in a total that represents the sum of spending by Embrapa centers engaged in crop-improvement research.[22]

As described in Chapter 2, the substantial growth in Brazilian soybean production (as well as of some other crops) in the past several decades involved a shift in the location of production from mainly southern states to more tropical regions. Some of this was made possible by the soils research conducted by CPAC (Embrapa's Cerrado Agricultural Research Center), which made it feasible to crop the naturally degraded subtropical soils more intensively and continuously—especially the oxisol soils with low fertility, low pH, and saturated in aluminum, but mostly well drained and with good physical characteristics that make up nearly half the Cerrados soils.[23] Thus CPAC's soils management research could also be viewed as another type of overhead cost to be charged against the research benefits reported in this study. But it would be a mistake to charge all (and, perhaps, even much) of these costs against our measured benefits for several reasons. First, the crop management research was not specific to soybean production. Second, given that we calculated the benefits on a state-specific basis, only part of the varietal benefits is

[22]There are other complicating factors that we side-stepped in this study. For example, the cost of Embrapa personnel outposted to state institutions is charged against Sede's budget. Below we make some adjustments on the benefit side for collaboration between Embrapa and other Brazilian agencies when attributing benefits, but have not made any adjustments on the cost side. In addition, Embrapa has made very considerable investments over the years in training its staff. These costs are apparently embedded in the center-specific costs included in our research cost estimates. However, investing in training is a type of capital cost that may best be charged against the benefits arising from research in the future conducted by those who were trained, rather than treating it as a current labor cost as we have implicitly done here. In other words, the timing of the costs and commensurate benefit streams may vary according to the type of expenditures in ways not captured by our evaluation methods.

[23]CPAC was instrumental in important parts but not all of the relevant soil management research. Some of the credit is due to research conducted early on at the Agronomic Institute in Campinas (IAC), São Paulo (Warnken 1999, 50), and others elsewhere in the world (Borket and Sfredo 1994).

attributable to production on tropical soils. Third, our use of localized experimental data to measure the yield consequence of varietal change was expressly intended to hold constant other factors that affect crop yields.

Comparing Benefits and Costs

To compare projects with different time patterns of costs and benefits, requires aggregating over time. Capital budgeting techniques are appropriate, and the relevant techniques are well known and documented.[24] If a dollar were worth the same to the recipient, regardless of when it is received, we could simply add up annual flows of net benefits over time. Capital budgeting addresses explicitly the idea that a dollar today is worth more than a dollar tomorrow, or in 10 years' time. In capital budgeting, we discount future benefits, and compound past benefits, relative to current benefits. That is, we express all past and future flows of benefits and costs in *present value* terms.

Net Present Value

The present value, in year t, of a stream of research benefits (B_{t+j}, the benefit in year $t+j$) over the next n years, can be expressed as

$$PV(B)_t = B_t + B_{t+1}/(1+i) + B_{t+2}/(1+i)^2 + \ldots + B_{t+n}/(1+i)^n \quad (17)$$

where i is the interest rate used to discount future benefits. More compactly, we can write

$$PV(B)_t = \sum_{j=0}^{n} B_{t+j}/(1+i)^j \quad (18)$$

Comparing streams of benefits (B) and costs (C) of a project, the *net present value* is equal to

$$NPV_t = PV(B)_t - PV(C)_t = \sum_{j=0}^{n} (B_{t+j} - C_{t+j})/(1+i)^j \quad (19)$$

That is, the net present value is equal to the present value of the stream of net benefits. An investment is profitable if the net present value is positive (in other words, if the present value of the benefits exceeds the present value of the costs).

Several conceptual and measurement issues are implicit in this formula and should be made explicit. First, whether we are interested in *social* benefits and costs (the sum of those accruing to any member of the society), as opposed to *private* benefits and costs (the sum of those accruing only to a particular group in the society), does not affect the formula. It does determine how we measure the relevant streams of benefits and costs. In deciding what to include and how to interpret the resulting estimates, it is important to be clear about what we intend to measure.

Second, the discount rate, i, should be defined and measured in a way that is consistent with the measures of benefits and costs. In particular, if the streams of benefits and costs are defined in *nominal* terms, which means that they are expressed in currency values that are observable in the marketplace and not adjusted to remove the effects of inflation, then a *nominal* discount rate is appropriate. To represent the nominal risk-free real rate of return it is common to use the interest rate on long-term government bonds, for instance. If it is desired to use a real discount rate but the streams of costs and benefits are in nominal terms, the value

[24]For instance, see Robison and Barry (1996) for a comprehensive treatment or Alston et al. (1995, 362–364) for a discussion of applications to agricultural research evaluation and priority setting.

streams can be converted to real terms by dividing by a general price index such as the consumer price index. Typically, real risk-free rates of interest are more like 2 to 5 percent.[25] In this study we express the streams of benefits and costs in real U.S. dollars, and accordingly we use a real discount rate of 4 percent (and conduct some sensitivity analysis using a rate of 10 percent).

Third, several issues arise in the interpretation of the net present value. It can be an *average* net present value, in the sense that it reflects all the costs and all the benefits from a particular project or program of work, compared with what would happen if *no* such investment were made. Or, it can be a *marginal* net present value, reflecting the benefits from a comparatively small change in the total investment. Both marginal and average measures of profitability may be of interest, but for different questions: for example, should the research be shut down entirely or should it be reduced? Marginal and average net present values are not really comparable, as they refer to different scales of investment, but marginal and average rates of return or benefit–cost ratios are adjusted for the scale of the project, seem comparable, and could be confused for one another. It is useful to know what is being measured, accordingly, in settings where the marginal and average measures may differ.

Finally, in some priority-setting contexts, where the total budget to be allocated—or some other relevant factor—is fixed, resources might be allocated among projects ranked according to the net present value per unit of the constrained resource (see Robison and Barry 1996, for instance).

Benefit–Cost Ratio

Although the net present value is usually regarded as the best measure for most purposes, two other measures are used more commonly, largely because they are more readily comparable across investments. A benefit–cost ratio is given by the ratio of the present value of benefits to the present value of costs, rather than the difference between them. That is,

$$BC_t = PV(B)_t \div PV(C)_t \qquad (20)$$

According to this criterion, an investment is profitable if the benefit–cost ratio is greater than 1 (that is, again, if the present value of benefits exceeds the present value of costs).

Internal Rate of Return

A third, alternative way of representing the same information is the internal rate of return, *irr*. This is defined as the discount rate that yields $NPV = 0$. That is,

$$0 = \sum_{j=0}^{n} (B_{t+j} - C_{t+j})/(1 + irr)^j \qquad (21)$$

An investment that has a $NPV > 0$, given a discount rate of i, will also have an $irr > i$. Thus, according to the internal-rate-of-return criterion, an investment is profitable if the computed internal rate of return is greater than the required (market) rate of return: $irr > i$. As described here, the three criteria ($NPV > 0$; $BC > 1$; $irr > i$) are equivalent, and in many instances they will be so. But in some instances they are not equivalent. For instance, when the stream of *net* benefits changes sign, so that multiple (and sometimes negative) *irr*s satisfy equation (21), it is difficult to interpret the estimated *irr*s. An additional complication concerns an assumption of implicit reinvestment—that is, in the *irr* computation of equation (21) the compounding and discounting procedure means that the research benefits generated for each period must be reinvested at the

[25] Another issue concerns risk itself. Should the discount rate include a premium to account for the fact that investing in research is a risky business? Alston et al. (1995) reviewed the arguments, and concluded that public R&D investments should be evaluated using risk-free discount rates (although the issue of whether R&D leads to changes in farmers' risks remains relevant).

irr rate (Robinson and Barry 1996, Chapters 2 and 3). This assumption is relatively innocuous for evaluation of private investments or for public investments yielding normal rates of return. It is less likely that the consumers and farmers who are the beneficiaries from agricultural research can achieve (private) reinvestment rates of return that are comparable to the very high (social) internal rates of return to research reported in many past studies.

Summary Statistics Adopted in the Present Study

In this study we have made the following explicit choices about the summary statistics to be measured. First, all of the measures are defined in real (that is, inflation-adjusted) terms, and so the relevant discount rate is a real social rate. We used a base rate of 4 percent per annum. Second, we are measuring the total (or average) returns associated with Embrapa's past expenditures on the research activities in question, rather than marginal returns associated with incremental changes. Third, we rely mainly on present value measures for the reasons described immediately above, but for comparisons with other studies various internal rates of return estimates are also reported. These measures are expressed as (a) present values of benefits (under various alternative attribution rules), (b) present values of costs (under various alternative assumptions), and (c) various benefit–cost ratios to facilitate comparisons among centers by expressing measures on comparable scales.

CHAPTER 4

Evaluation Elements: Data Details, Results, and Interpretation

In this chapter we first describe the data underlying our economic evaluation of Embrapa's varietal improvement research on upland rice, edible beans, and soybeans. Then we present estimates of the research benefit and cost streams, and the implied net present values and other benefit–cost comparisons, highlighting the consequences of attributing benefits to Embrapa programs and research centers, which are made distinct from benefits attributable to the research of others.

Varietal Improvement Research: Institutional Background

Embrapa's Upland Rice and Bean Research Center (CNPAF) was formally established in 1974. The Rice Research facility became operational in 1974 and the Bean Research facility one year later. This center is headquartered in Goiânia, Goiás, with experiment stations located in Goiás, Tocantins, and Mato Grosso (Embrapa-CNPAF various years).

Embrapa's Soybean Research Center (CNPSo) was formally established in 1975. The center is headquartered in Londrina, Paraná, along with most of the center's staff, but it also maintains several outlying experiment stations (Embrapa-Soja, various years). Some CNPSo staff are also based at and undertake collaborative research with state research agencies in São Paulo, Minas Gerais, Goiás, Mato Grosso, Mato Grosso do Sul, and Rio Grande do Sul, and also conduct joint research with faculty at some federally funded agricultural universities, especially those in Rio Grande do Sul, and Minas Gerais (Ayres 1985; Warnken 1999).

In addition to researching soybeans, CNPSo undertakes some research on other oilseeds (most recently, sunflowers) and wheat. Embrapa's Cerrado Agricultural Research Center (CPAC), located about 18 kilometers north of Brasília, also conducts research related to soybeans, focusing mainly on soil-management research and some breeding work to adapt varieties developed elsewhere to local conditions. As one would expect, the focus of the research varies substantially across centers at any given point in time, and over time for particular centers.

Soybeans are highly sensitive to day length. Breeding soybeans suitable for the tropics requires modifying the plant's juvenile period. This involves specifically extending the growth period before the plant flowers to prevent premature flowering and to avoid the development of short plants that have lower yields and are not amenable to mechanical harvesting. Varieties with this trait were developed for the southern United States by breeders from the USDA and universities of Illinois and Mississippi from research dating back to the 1950s, and this material and know-how (involving continuing and close collaboration with U.S. scientists throughout the 1960s and 1970s) became the genetic basis for the take-off of tropical soybean production in Brazil (Warnken 1999, p. 45). However, day-length-insensitive varieties alone were insufficient to spur tropical soybean production in Brazil. A good deal of work was also required to develop soil-management and fertilizer practices that dealt with the low pH and low fertility of soils in the Cerrados and to develop varieties that resist a range of pests and diseases, such as mosaic virus, frogeye leaf spot, stem canker, and, more recently, cyst nematodes (Warnken 1999).

It is also important to note that commodity characteristics aside from productivity or yields (the primary focus of this research effort) guide varietal improvement research, and that priorities over these characteristics, too, vary over time. When setting the Embrapa upland rice research agenda, scientists considered various plant attributes, including disease resistance and grain quality, as well as changes in these priorities between the 1980s and 1990s. The major shift was from a focus on productivity issues to one on grain quality; the development of an upland variety of rice capable of yielding a *longo fino* grain with good cooking quality was central to research in the 1990s.

Research Partnerships

All Embrapa centers have a broad array of collaborating organizations, in part because many of the centers deal with commodities that are produced and consumed in most parts of Brazil. For this study, collaborators were grouped into four broad categories: various public agencies, local private entities, international organizations, as well as Embrapa and a number of universities and state agencies that collectively are known as the National Agricultural Research System (or SNPA, its Portuguese acronym). From the broad array of Embrapa collaborators we identified the subset with which Embrapa centers interact strategically and intensively in the generation of new seed varieties, and how this subset changes over time and in response to which factors. This subset of key collaborators varies across centers at any given point in time, and over time for given centers for various reasons.

First, Embrapa research centers were created for essentially the same reasons, but in different places and at different points in time. An overarching objective was to draw together disparate research programs and researchers within a single agency to improve the effectiveness of hitherto disparate research activities (Beintema et al. 2001). Some centers were located in traditional production areas and inherited research facilities, programs, and staff that were in place long before Embrapa was created. Other centers such as the Rice and Bean Center and the Soybean Center were created in frontier agricultural areas, hence requiring the establishment of new research infrastructure and the recruitment and training of research staff, although research programs located in traditional production areas focusing on these commodities often provided at least the first groups of core researchers and the first sets of research priorities. These newly founded Embrapa centers often established their earliest and most intense collaborative links with pre-Embrapa organizations (for example, the IAC for the rice and bean center) that continue to carry on state-level research.

Second, the amount and types of germplasm development undertaken by other agencies varied substantially among commodities and over time, generally in response to market forces. Private-sector activity in maize germplasm, for example, started relatively early because of the proprietary nature of hybrid maize seed, and quickly gained considerable market share. The same is not true for private research on upland rice and edible beans, which continues to rely on Embrapa as a source for new material and systematic varietal trials.

Third, links with universities can be strong, especially when universities are located near research centers, and Embrapa researchers teach and supervise theses and dissertations focused on varietal improvement research. Fourth, funding cuts at all Embrapa research stations have provided incentives to diversify collaborative links and prioritize those capable of generating resources to support research. The private sector has been targeted and has responded, and all centers are experimenting with different modes of collaboration and for sharing of responsibilities and benefits.

Estimating Research Costs

Research Personnel

Table 4.1 summarizes the changing structure of the labor used in varietal improvement research, highlighting differences in the amount and composition of this labor for the three crops in this study. The entries in the table represent full-time equivalents

Table 4.1 Labor used in varietal improvement research

Categories	1976	1980	1985	1990	1995	1998
			(full-time equivalents)			
Upland rice						
Research staff	4.8	5.2	6.2	8.3	9.8	8.7
B.Sc.	3.2	0.2	0.2	0.2	0.1	0
M.Sc.	1.4	4.4	2.0	3.2	1.3	1.3
Ph.D.	0.2	0.7	4.1	5.0	6.2	5.2
Technical staff[a]	0.0	0.0	0.0	0.0	2.1	2.1
Other labor[b]	24.6	36	59.7	63.2	58.1	52.1
Total staff	29.4	41.2	65.9	71.6	67.8	60.8
Edible beans						
Research staff	4.3	7.8	7.1	7.8	8.7	7.6
B.Sc.	0.8	1.3	0.9	0.1	0.1	0
M.Sc.	3.4	5.4	2.7	3.4	2.3	2.3
Ph.D.	0.1	1.2	3.6	4.3	4.5	3.5
Technical staff[a]	0.0	0.0	0.0	0.0	1.8	1.8
Other labor[b]	17.2	20	33.3	37.0	34	30.5
Total staff	21.5	27.8	40.4	44.8	42.7	38.1
Soybeans						
Research staff	9.0	12.0	10.1	15.4	16.4	16.5
B.Sc.	7.5	2.9	0.5	3.6	0.0	0.0
M.Sc.	0.5	6.1	8.2	8.2	11.7	8.5
Ph.D.	1.0	3.0	1.5	3.7	4.7	8.0
Other labor[b]	22.8	48.0	52.1	98.5	97.1	83.4
Total staff	31.8	60.0	62.2	113.9	113.4	99.9
Research staff as a share of three-commodity total[a]						
			(percentages)			
Upland rice	26.6	20.8	26.4	26.4	28.0	26.4
Edible beans	23.8	31.2	30.4	24.7	24.9	23.2
Soybeans	49.6	48.0	43.1	48.9	47.0	50.4

Source: Authors' calculations drawing on unpublished Embrapa data files.

[a] Includes TNS (superior level technicians) and T. Esp (specialized technicians), who are not formally classified as Embrapa researchers but effectively perform as such.

[b] Includes field workers, laboratory staff, administrative staff, and other support staff. We assumed the ratio of graduate-degree researchers engaged in varietal improvement research relative to the total number of full-time equivalent researchers with either M.Sc. or Ph.D. degrees was also representative of the deployment shares of "other labor." Thus we allocated the other-labor totals to the respective crop improvement programs by multiplying these totals by the corresponding shares of graduate researchers.

(FTEs); they exclude the time that many scientific staff spent on research not directly related to crop improvement.

First, consider the total time of scientific and technical staff combined. In 1976, roughly equal amounts of research staff were devoted to rice and beans, while there were about twice as many researchers dedicated to improving soybeans as for each of the other two crops. In 1998 the relative sizes of these three crop improvement programs in terms of the number of researchers (plus technical staff) was essentially unchanged although the size of all three programs had grown quite considerably (from a three-crop total of 18.1 FTE researchers in 1976 to 32.8 FTEs in 1998).

The composition of the crop-improvement staff has also varied among the crops, as well as over time for particular crops. In 1998, the ratio of support to research staff was higher (6.2 support staff for every scientific FTE) for rice than for beans (4.7) or soybeans (5.4 support staff per FTE researcher). The breeder versus nonbreeder composition of the scientific staff has also varied among crops and over time. In more recent years, the development of new crop varieties within Embrapa has involved a significantly higher ratio of breeders to other scientific and technical staff for soybeans and rice than for beans.

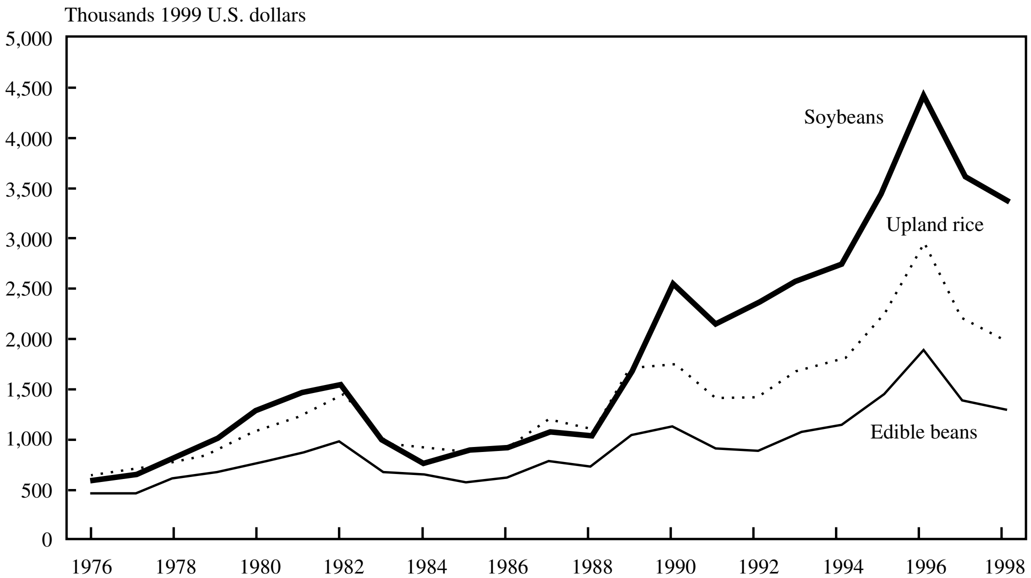
These differences in the relative amounts and composition of scientific and technical support staff may reflect substantive differences in the types of research required in developing new crop varieties. For example, compared with breeders, the numbers of agronomic, entomological, plant pathology, and other such scientific staff have been more important for edible beans than for upland rice and soybeans. These latter two crops use breeders more intensively in their crop improvement programs. Whatever the reasons for the differences, for management purposes it is surely worth more assessment, not least because these staffing differences result in significant differences in the costs of research.

Cost Streams

From 1976 to 1998 there was a general upward trend (with higher rates of growth for soybeans than for upland rice and edible beans), but with some variation around this trend. Moreover, investment in crop improvement research declined for all three crops after 1996. In present value terms, summing from 1976 to 1998, $61 million (1999 prices) was invested in varietal improvement research related to soybeans, about twice the present value of investment in the same research done for beans and substantially more than the $48.5 million invested in rice. This investment in crop-improvement represents about one quarter of the total research investment in edible beans and soybeans and more than one third of the total investment in rice-related research (Appendix A). Factoring in a share of the costs incurred by Sede (Embrapa headquarters) and CENARGEN as a kind of institutional overhead (see Chapter 3 for additional discussion) gives an augmented crop-improvement cost series that is 38 percent higher than the corresponding baseline costs (which only include costs managed directly by the respective Embrapa centers) for edible beans, 27 percent higher for upland rice, and about 36 percent higher in the case of soybeans.

The composition of crop-improvement expenditures varies among the crops and within a crop over time. Averaging over 1976–98, soybean research was more labor intensive (87 percent of total costs) than research on the other two crops (75 percent for edible beans and 83 percent for rice), although for all three crops there was a general tendency for the share of labor in total research costs to creep up over time. By construction the annualized series of user costs of capital created for this study is less volatile than the underlying outlays on capital items, and averages between 3 and 17 percent of total costs over 1976–98. A significant amount of year-on-year variability stems from fluctuations in operational costs, typically a cost category that is

Figure 4.1 Expenditures on crop improvement research, 1976–98



Source: Authors' calculations.

Note: Costs are specific to the respective centers (CNPAF for rice and edbible beans, CNPSo for soybeans) and do not include a prorated share of Sede and CENARGEN costs.

trimmed as budgets become tight and grows disproportionately when funds are more plentiful.

Estimating Research Benefits

Varietal Development Trends

To illustrate the role of Embrapa research in the context of varietal-improvement research more generally, we sought to compile data on *all* the varieties released since 1976 (from all sources, be that Embrapa or otherwise), but we were successful in doing so only for upland rice and soybeans. For edible beans we could compile these data only for varieties released since 1984.

Table 4.2 summarizes key elements of these data, which reveal significant differences among the crops we studied. The rate of varietal release was highest for soybeans (a total of 330 varieties from 1976 to 1998, averaging 13.8 varieties per year). A total of 75 new edible bean varieties were released in Brazil from 1984 to 1999 (an average of 4.7 varieties per year), and only 35 new upland rice varieties from 1976 to 1999 (an average of 1.5 varieties per year).

Embrapa varieties accounted for the lion's share (77 percent) of all upland rice varieties released in Brazil between 1976 and 1999 (Table 4.2 and Figure 4.2). Embrapa has played a less pivotal role in Brazil when it comes to edible bean and soybean releases. Less than 30 percent of the bean varieties came from Embrapa and only 37 percent of the soybeans. About one third of the bean varieties were released by other public research agencies, mostly state public institutions such as EMGOPA (Goiás) and EPAMIG (Minas Gerais), as well as research and extension agencies such as EMPAER (Mato Grosso and Mato Grosso do Sul). About one-quarter of the edible bean varieties were local releases of internationally developed varieties (principally bean varieties developed by CIAT, which is

Table 4.2 Summary of varieties released

Crop/Institution	Period	Number of varieties: Total	Number of varieties: Average per year	Share of total	1991–99 share of period total
		(count)		(percentage)	
Upland rice[a]	1976–99				
Embrapa (CNPAF)		27	1.13	77.1	55.6
Cooperative system		6	0.25	17.1	83.3
IAC[b]		2	0.08	5.7	0.0
Total		*35*	*1.46*	*100.0*	*57.1*
Edible beans[c]	1984–99				
Embrapa (CNPAF)		20	1.25	26.7	72.7
International Agencies		18	1.13	24.0	38.9
Other Public		27	1.69	36.0	60.0
University		3	0.19	4.0	66.7
Private		7	0.44	9.3	57.1
Total		*75*	*4.69*	*100.0*	*58.7*
Soybeans	1976–98				
Embrapa[d]		122	5.08	37.0	66.4
Other public		36	1.50	10.9	33.3
University		17	0.71	5.2	29.4
Private		152	6.33	46.1	56.6
Others		3	0.13	0.9	0.0
Total		*330*	*13.75*	*100.0*	*55.8*

Source: Authors' calculations based on own survey data and CNPAF (1974–93, 1994–2000), Embrapa and OCEPAR (not dated), Embrapa (various years), Embrapa (2000a–f), Martinez and Cuevas-Pérez (1995), Ministério da Agricultura e do Abastecimento (2001), and Voysest (2000).

[a] CNPAF produced the only upland rice variety released in Brazil in 2000.

[b] IAC indicates Agronomic Institute of Campinas.

[c] There were no edible bean varieties released in Brazil in 2000. Two new varieties were released in 2001, both developed by CNPAF.

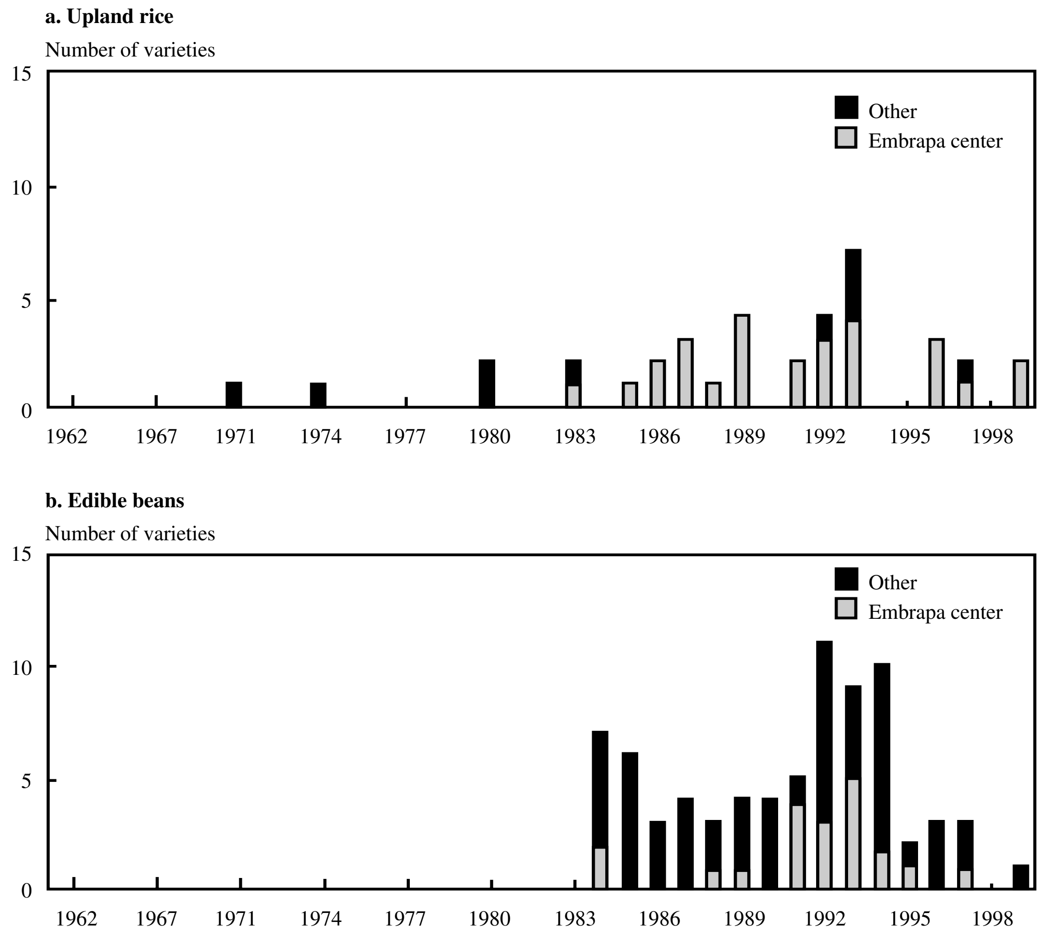
[d] Of the 122 varieties released by Embrapa, CNPSo released 121 varieties and CPAC only 1 variety.

based in Colombia but had a continuing research presence at CNPAF by way of an outposted crop breeder from 1982 to 1996, and continuing with the same breeder on a contract basis via CIAT since then).[26] Less than 10 percent of the bean releases came from the private sector. In contrast, private firms played a significant role in the development of soybean varieties. Nearly half the releases in Brazil from 1976 to 1999 came from the private sector, with a notable but more limited role played by other public agencies and, as for all the other crops in our study, a comparatively minor role for the universities.

Figure 4.2 illustrates the sizable year-to-year variation in the rate of varietal release and the changing institutional roles, under-

[26]The French agency Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) has also maintained a continuous presence in Brazil for the past 20 years or so, involving a number of scientists (but typically only one at any point in time) covering a range of scientific specialties related to rice research. At the time of this study, one economist from CIRAD was located at CNPAF in Goiânia.

Figure 4.2 Annual varietal releases in Brazil

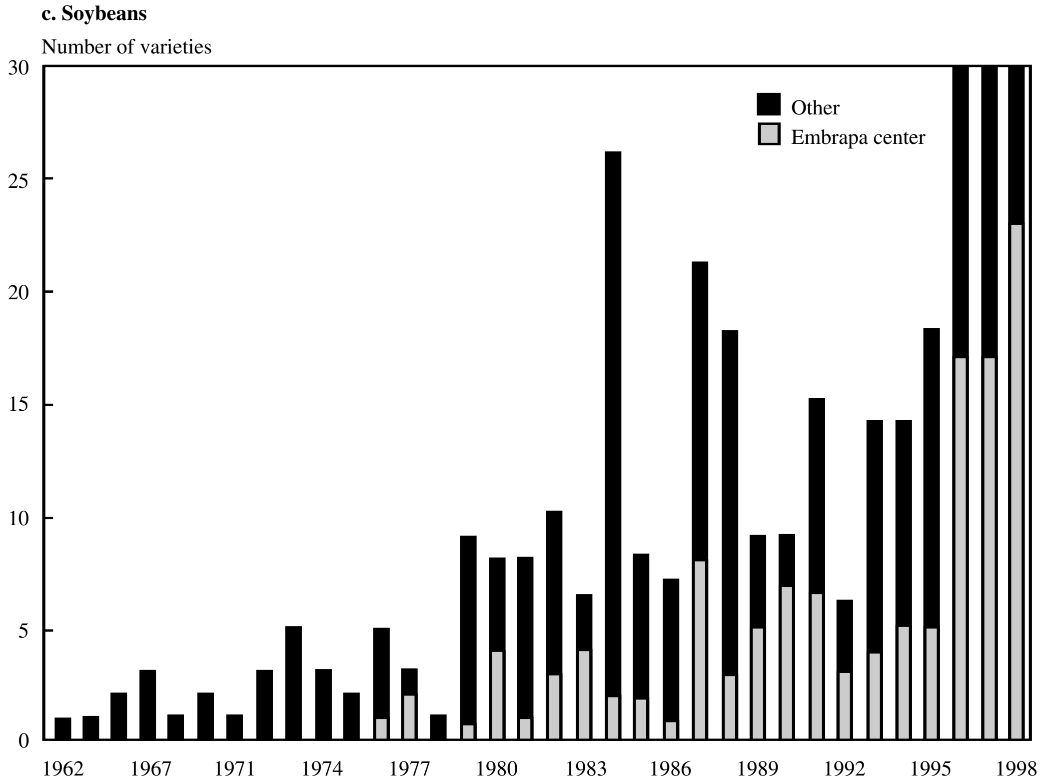


scoring the requirement for taking a longer-run perspective to understand these developments properly. For upland rice, edible beans, and soybeans, more than one half of the varieties in our totals were released during the 1990s. The general longer-run tendency has been for an increase in the annual rate of varietal release for upland rice, and especially soybeans, although the annual rates of release for both upland rice and edible beans declined in the past few years. The institutional shares of releases for any single year are not generally representative of any other period for any of the crops.

Varietal Adoption Patterns

Counts of varietal releases are a very tangible measure of research output, but give no real indication of economic impact. For a variety to have any economic consequences, it must be adopted either directly by farmers, or indirectly as an input into the development of commercially successful releases made by other agencies. The area sown to a particular variety in a particular year is a good measure of the rate of adoption by farmers, and a key element of our efforts to quantify the impacts of Embrapa research. Unfortunately, despite considerable effort, we had only partial success in compiling area-by-variety data for the three crops in this study. The area-by-variety adoption data we developed represent an improvement over previous efforts. Nevertheless the data are incomplete, and the questionable accuracy of

Figure 4.2—Continued



Source: Authors' calculations.
Note: For the sake of clarity, the vertical axis in panel c was truncated at 30 varieties. Number of soybean varieties released in 1996 was 31, 39 varieties in 1997, and 47 varieties in 1998.

some of the area-by-variety estimates remains a real constraint to the entire evaluation exercise.

Our objective was to estimate the area sown to each of the principal varieties of each crop in the main crop-producing states for the post-1975 period, recognizing that complete details would not be available on all varieties grown in every state in every year. Neither Embrapa nor any other federal or state agency in Brazil maintains a statistically sound series of data on area-by-variety. We used the available seed production data and our own recall surveys to compile such data, recognizing that each of these measurement methods has its own limitations.

Translating the amount of seed produced in each state in each year to an estimate of the area sown to a specific variety is fraught with problems. First and foremost, not all seed is grown commercially in the state in which it is produced—often seed is shipped in from other regions in Brazil or from other countries where it is produced off-season or in areas free from pests and diseases. In addition, using *average* seeding rates and seed production data to estimate the area sown to a particular variety abstracts from any variation in sowing rates among states as well as production systems within a state (for example, seeding rates may be higher for irrigated compared with rainfed agriculture). Another significant difficulty concerns the use of saved seed by farmers. For crops such as upland rice, edible beans, and soybeans, the use of saved seed can be significant and varies from season to season and across locations and production enterprises. Input-intensive commercial growers are more likely to change their seed stock frequently (perhaps annually) compared with subsistence or less input-intensive producers. Moreover, some traditional varieties have persisted in some locations for decades, and the use of these varieties would not be revealed when commercial seed production data are used to estimate the area sown to specific varieties.[27]

The limited availability of seed production data is another real constraint—for upland rice and edible beans it was typically available for only a few years in the late 1990s and for a few states, and for soybeans we could obtain sufficiently long time series of data only for two states (Rio Grande do Sul and Mato Grosso). For these reasons we opted to conduct our own survey. Variants of this survey form were used for each of the crops in our study. Survey forms were distributed to respondents deemed to be knowledgeable about varietal areas for a particular crop within a specific state, including Embrapa researchers as well as researchers from state agencies and universities and selected extension workers. With considerable help from colleagues at CNPAF we distributed about 30 rice surveys and 40 bean surveys, and in collaboration with colleagues at CNPSo 30 soybean surveys were mailed out. Despite extensive follow-up efforts, conducted intensively over a period of six months, we received only two replies for soybeans. A total of nine responses were obtained for beans and six for rice. Table 4.3 summarizes the sources and coverage of the area-by-variety data we compiled.

Figures 4.3 to 4.5 plot the area-by-variety for upland rice, edible beans, and soybeans for selected key varieties for the main states for which we have data. They reveal a complex, location-specific, and time-varying pattern, from which few generalizations are possible. In 1986, several varieties developed by Instituto Agronômico de Campinas, IAC[28] (specifically *IAC 25, 47, 164,* and *165*) were the among the most widely planted varieties in all eight states for which we have upland rice data; accounting for more than 40 percent (a total of 1.73 million hectares) of the area sown to upland rice in five of those states. By 1999, we estimate these rice varieties occupied only 50,780 hectares and were of commercial significance (that is, grown on at least 10 percent of the area under upland rice) in only two states. Interestingly, *IAC 47,* the most widely planted upland rice variety in five of the seven states in 1986, was released 15 years earlier, in 1971. *Caiapó,* the most widely planted variety in five of eight states in 1999, accounting for a total of nearly 234,000 hectares, was released only seven years earlier, in 1992.

As in the case of upland rice, it appears that only a few varieties of edible beans had wide appeal to farmers. In 1985, *Carioca* (a local variety of unknown origin that was purified and officially released by IAC in 1969) was the most widely planted variety in all nine states for which we have data, and continued to be the most widely (or sec-

[27]For example, traditional varieties such as *Lajedo* and *Palha Murcha* accounted for an estimated combined total of around 14 percent of the area sown to upland rice in Maranhão but were absent from the available seed production data. In addition, the rice variety *CIRAD 141* (developed by the French research agency CIRAD) was not registered as an officially released variety in Brazil and therefore does not appear in the official seed production statistics—although it was widely used (for example, according to our estimates occupying up to 60 percent of the upland rice area in Mato Grosso during the 1990s).

[28]IAC is a state public research agency located in Campinas, São Paulo that has been operating since June 1887.

Table 4.3 Area-by-variety data sources

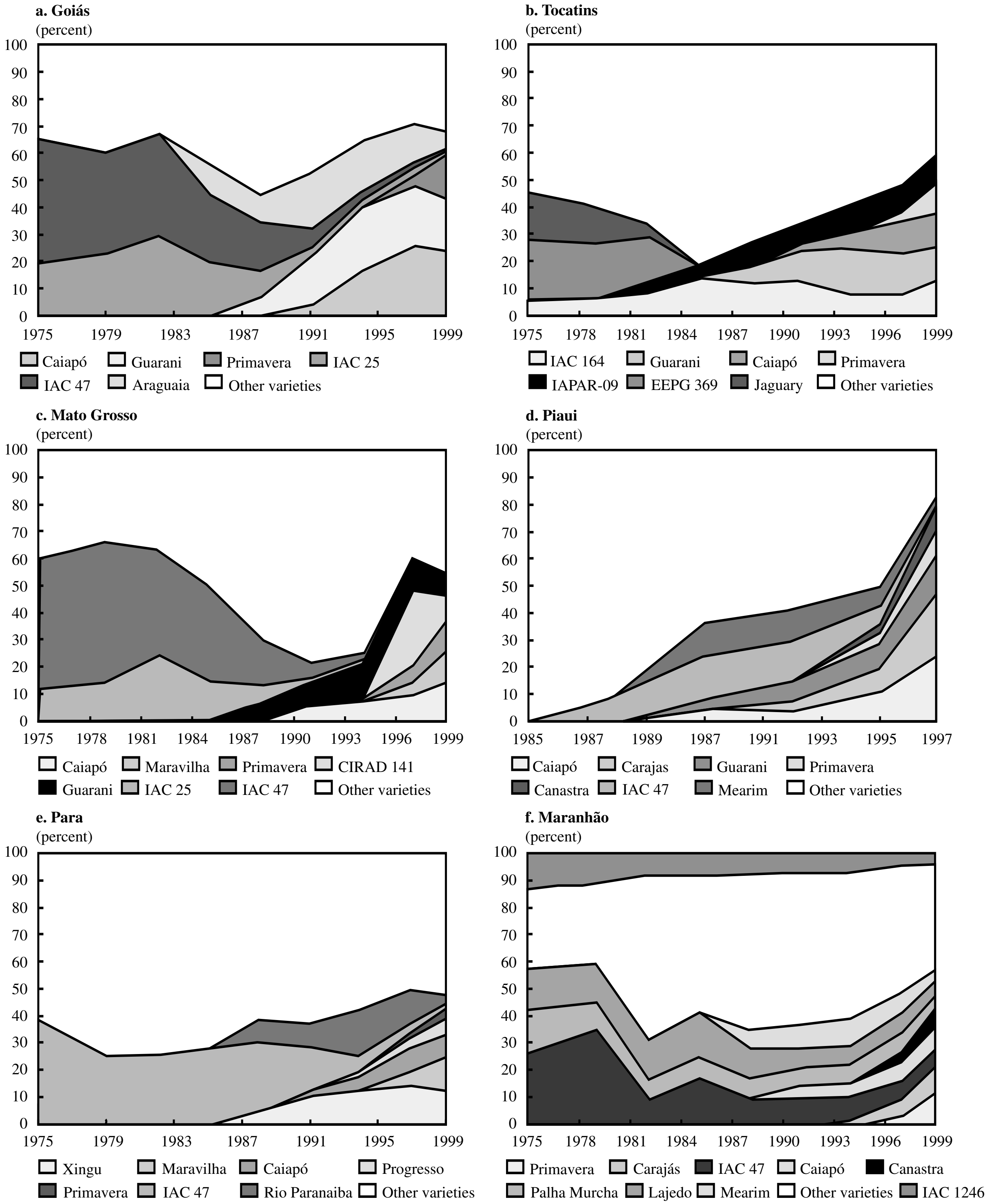
Commodity	States	Production share[a]	Years included	Notes
Upland rice	GO, MA, MT, MG, PA, PR, PI, RO, TO	82	Every two years, 1975–2000	All estimates are based on elicited survey returns obtained from knowledgeable scientists at Embrapa Rice and Bean (CNPAF) and from various other experts. A total of 6 individuals provided usable responses.
Edible beans	BA, DF, GO, MG, MT, PR, RO, SC, TO, SP	80	Every two years, 1975–2000	All estimates are based on elicited survey returns obtained from knowledgeable scientists at Embrapa Rice and Bean (CNPAF) and from various other experts. A total of 9 individuals provided usable responses.
Soybeans	PR, GO	34	Every year, 1975–1998	Estimates are based on elicited survey returns obtained from both knowledgeable scientists at Embrapa Soybean (CNPSo) and from various other experts. A total of two provided usable responses.
	MT, RS	44	Every year 1980–2000 (MT) 1973–2000 (RS)	Estimates based on seed production data provided by Embrapa Wheat (CNPT) for Rio Grande do Sul and by Embrapa Agriculture West (CPAO) for Mato Grosso.

Source: Compilation of survey returns and LSPA (2001).
[a] Indicates the share of 1998 national production represented by states for which area-by-variety data are available.

ond most widely) planted variety in seven states in 1999. The continuing dominance of a few key varieties throughout the latter half of the 1980s and the 1990s is a feature of both rice and beans (*Carioca* and *Pérola* for beans and *Caiapó* and *Guarani* for upland rice). However, farmers seem to use a greater mix of varieties for beans than for upland rice; perhaps this is a reflection of the greater total number of bean varieties released since the mid-1980s, combined with a persistence of traditional varieties in states such as Bahia (which accounted for 17 percent of total Brazilian area sown to edible beans in 1997), where such varieties still accounted for over 60 percent of the area under edible beans by the late 1990s.

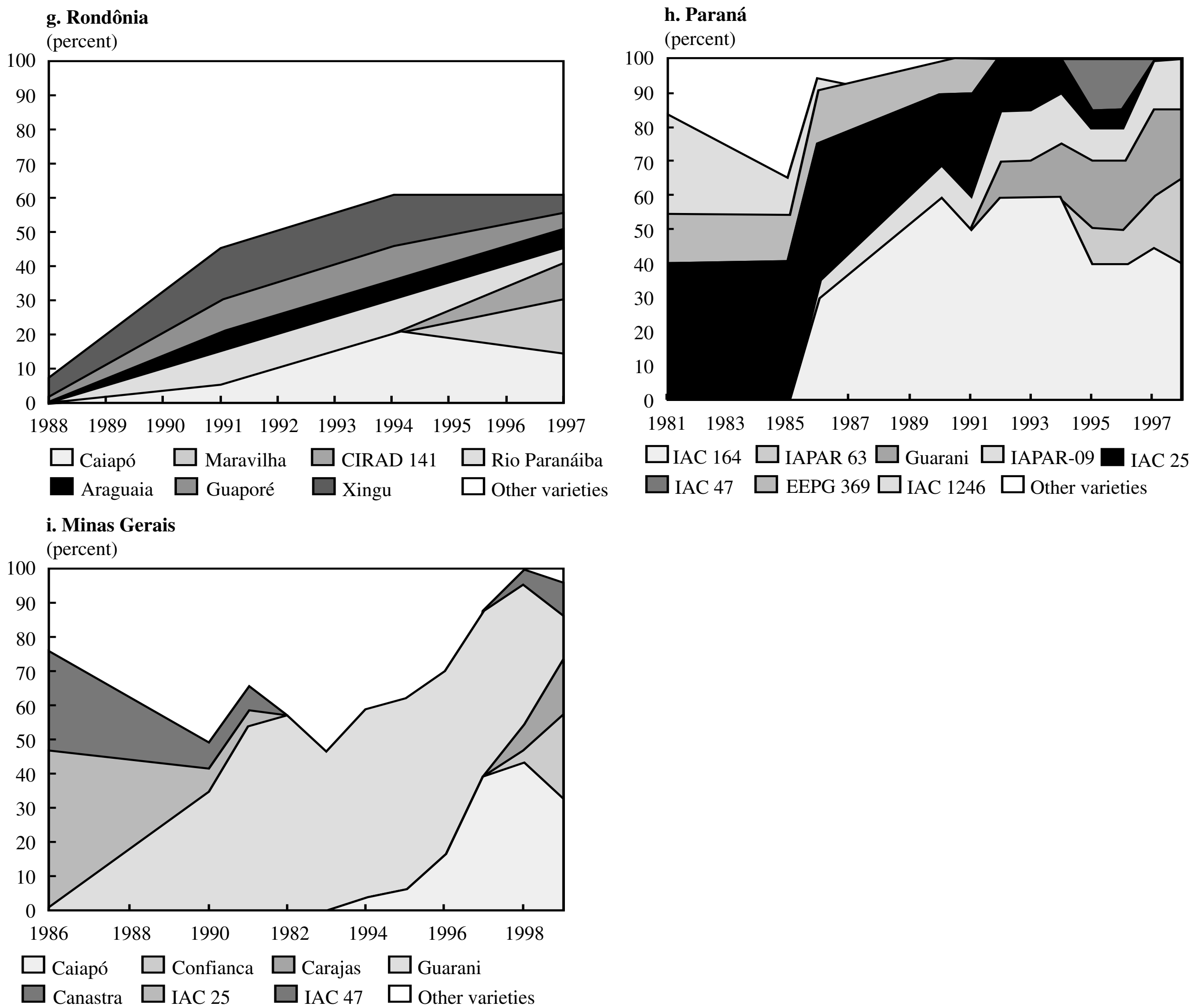
We developed area-by-variety estimates for four states that in 1998 accounted for a combined total of 76 percent of the 10.04 million hectares sown to soybeans throughout Brazil. About 94 percent of Brazil's 1960 soybean area was in the southern state of Rio Grande do Sul, but by 1998 this state accounted for only 24 percent of the total. The states of Goiás and Mato Grosso (both located in the Cerrados) and Paraná (another southern state) are now also important soybean producers, in 1998 accounting for a combined total of 51 percent of Brazilian soybean area. The pace of varietal turnover seems higher for soybeans than it was for either upland rice or edible beans. In Goiás, Paraná, and Mato Grosso, none of the

Figure 4.3 Varietal adoption patterns for upland rice, various states



Source: Authors' calculations based on area-by-variety estimates obtained from experts' elicitation questionnaires.

Figure 4.3—Continued



soybean varieties that predominated in the mid-to-late 1970s did so in 1998. In 1998, the top three varieties in Goiás and Mato Grosso were released only two or three years earlier, and in Paraná, the top three varieties were all released in the 1990s. Comparing rice and beans, we noted an apparent inverse relationship between the number of varieties released and the concentration of varietal use. The soybean data add support to this general notion—many more varieties were released for soybeans than for either edible beans or upland rice over the past few decades, and soybeans had a generally more diverse pattern of varietal use. In 1999, the top five soybean varieties accounted for only 62 percent of the area sown to soybeans in Goiás and 48 percent in Paraná, compared with generally higher degrees of varietal specialization within states for beans and rice.

Varietal Yield Performance

Our approach for developing an index of varietal improvement requires a complete set of observations on experimental yields

Figure 4.4 Varietal adoption patterns for edible beans, various states

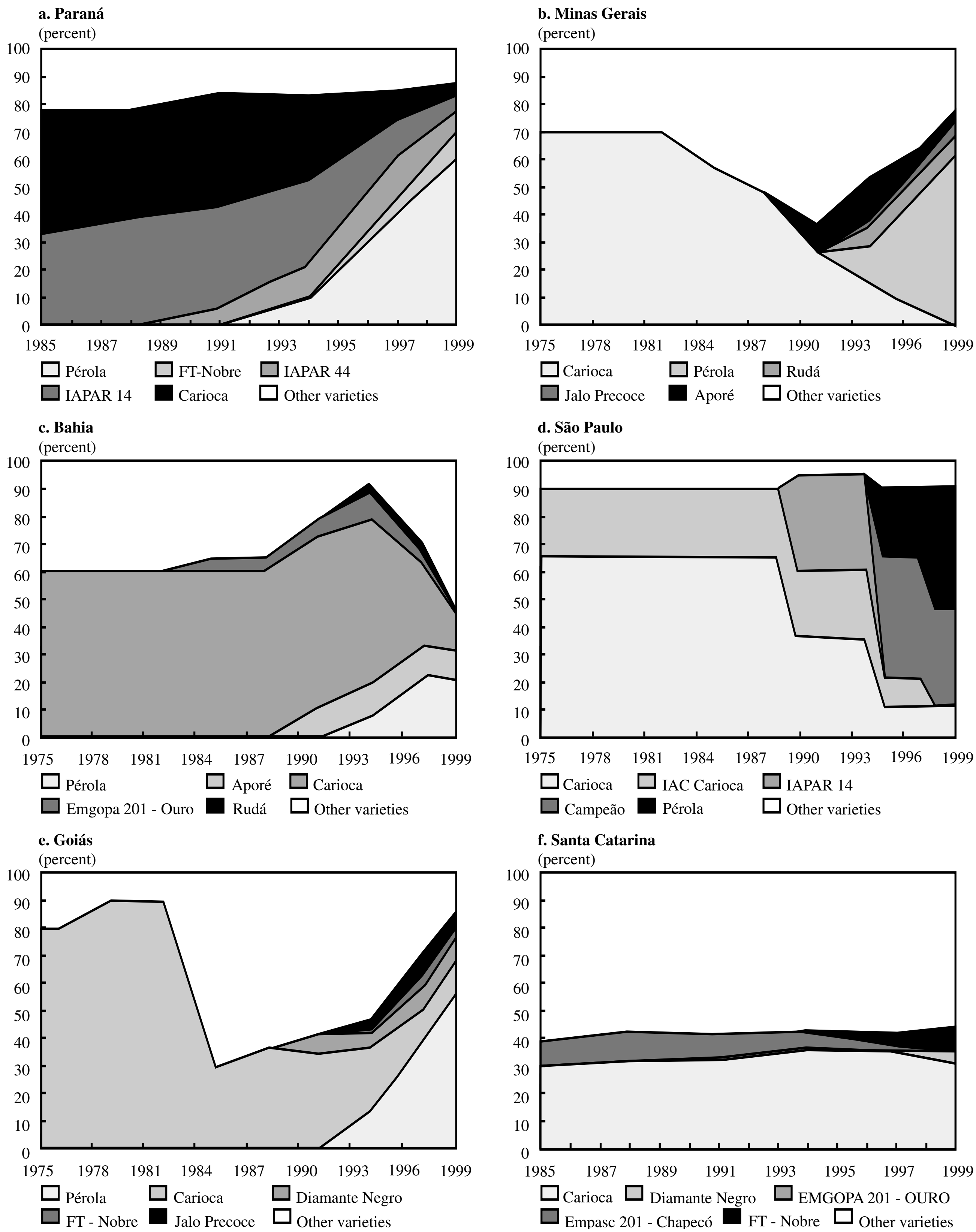
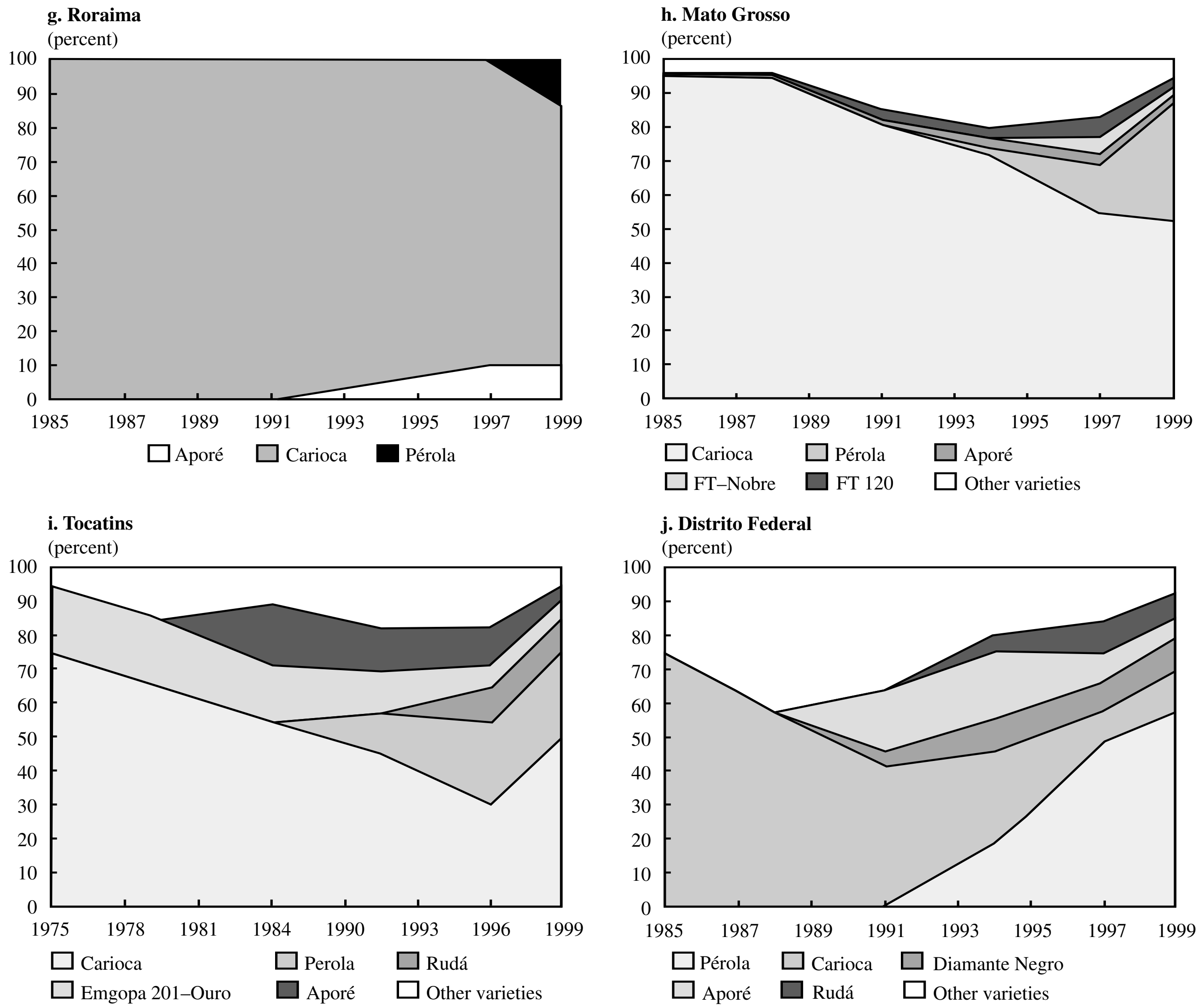


Figure 4.4—Continued



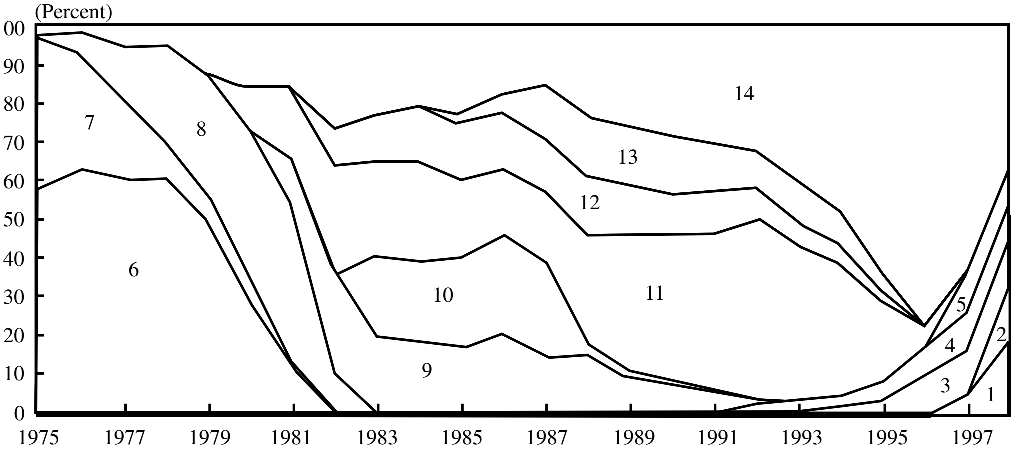
Source: Authors' calculations based on area-by-variety estimates obtained from experts' elicitation questionnaires.

for each of the years in which a variety was in commercial use. To take account of site-specific differences in varietal performance we conducted the analysis at the state level. Absent complete data on the experimental yields of every adopted variety for each state for each year, we used the regression model described by equation (6) to compute fitted values for the experimental yields of each adopted variety at each experimental site in each year, using equation (7). Then state-level fitted values were derived as an average of site-specific values across all the sites within each state.

Table 4.4 summarizes the data set used in our regression analysis. It details the years for which experimental yield data were observed, the year in which each variety in the sample was released (that is, the vintage year), the number of trial locations and varieties included, and the total number of observations in each regression

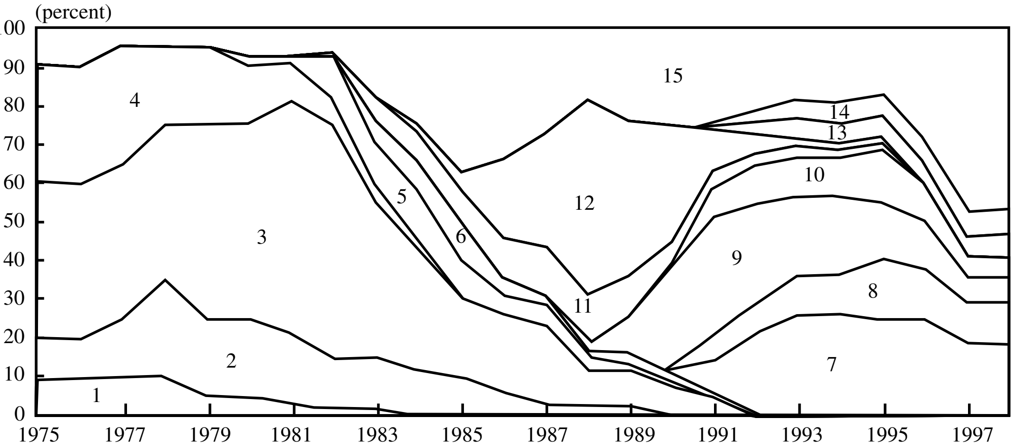
Figure 4.5 Varietal adoption patterns for soybeans, various states

a. Goiás
(Percent)



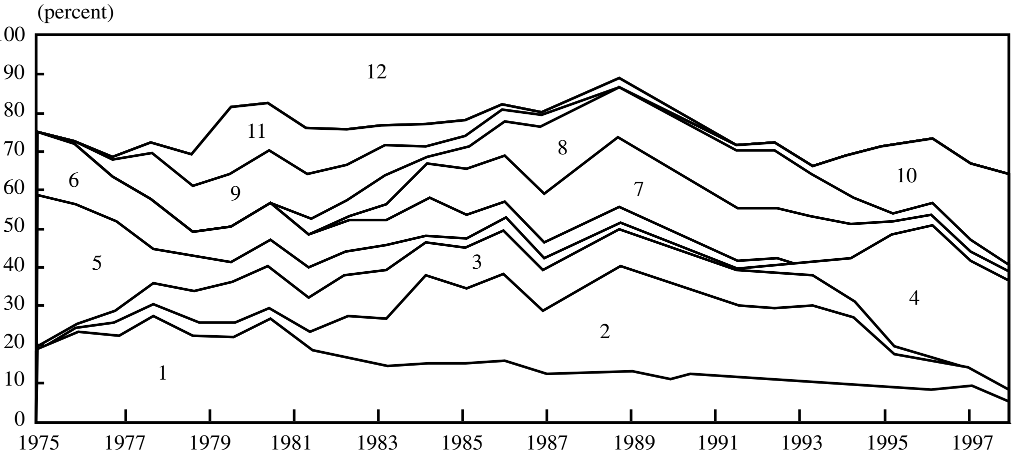
1. MG BR 46 (Conquista) 2. Emgopa-315 (rio Vermelho) 3. Emgopa-313 (Anhanguera) 4. Emgopa-302
5. Emgopa-314 6. IAC-2 7. Santa Rosa 8. UFV-1 9. Doko
10. Emgopa-301 11. FT-Cristalina 12. IAC-8 13. FT-11 (Alvorada) 14. Other varieties

b. Paraná
(percent)



1. Davis 2. IAS 5 3. Paraná 4. Santa Rosa 5. FT-1
6. Ocepar 2-lapo 7. BR-37 8. BR-38 9. BR-16 10. BR-36
11. BR-6 (Nova Bragg) 12. Ocepar 4-Iguaçu 13. Ocepar 14 14. Ocepar 13 15. Other varieties

c. Rio Grande do Sul
(percent)



1. Bragg 2. IAS 5 3. IAS 4 4. BR 16 5. Santa Rosa 6. Davis
7. BR 4 8. Cobb 9. FT Abyara 10. Bossier 11. Paraná 12. Other varieties

Source: Estimates for Paraná and Goiás are based on area-by-variety estimates obtained from experts' elicitation questionnaires. Estimates for Rio Grande do Sul are based on seed production data.

Table 4.4 Overview of data and goodness-of-fit for regression models

	Upland rice	Edible beans	Soybeans
Years of trials	1984–99	1985–89 1991–99	1976–78 1980–97 1999
Year of release	1971 1974 1983 1985–89 1991–93 1996–97 1999	1984–94 1996–97	1965–67 1969 1972–73 1976–77 1979–85 1987–93 1995–97
Number of trial locations	66	110	124
Number of varieties	29	73	72
Number of observations	1,680	2,281	1,673
Adjusted R^2	0.39	0.54	0.48
Joint tests of significance [*F* values (degrees of freedom)]			
Variety dummies (*DV*)[a]	1.53 (13, 1570)	1.66 (50, 2092)	2.10 (46, 1458)
Year-of-release dummies (*DA*)	1.04 (15, 1570)	2.00 (14, 2092)	4.77 (25, 1458)
Site dummies (*DS*)	11.46 65, 1570)	17.32 (108, 2092)	5.41 (122, 1458)
Trial year dummies (*DT*)	15.03 (15, 1570)	8.01 (13, 2092)	6.48 (20, 1458)

Source: Author's calculations.

Note: The figures in this table refer to estimation of the model represented by equation (6) in the text.

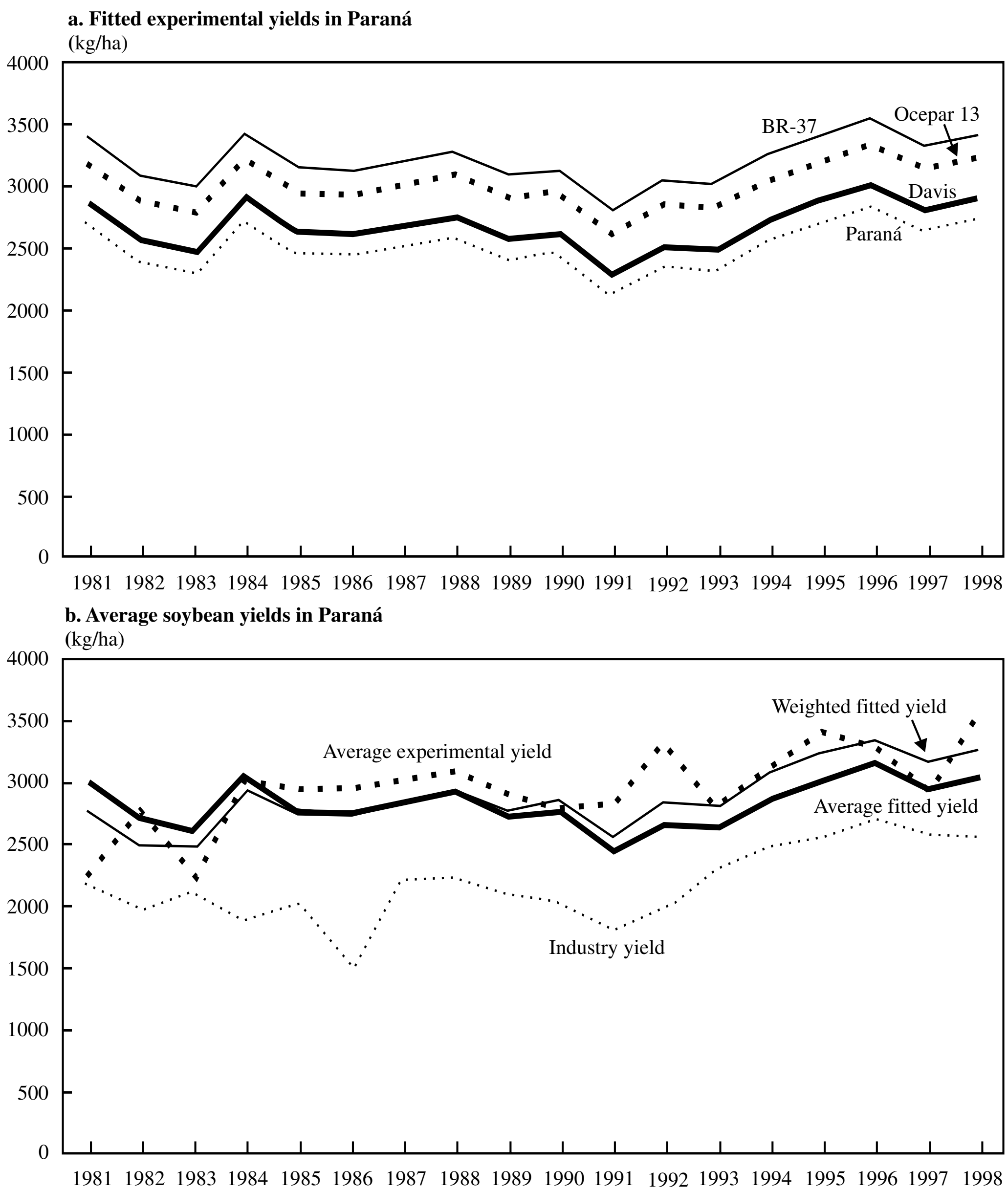
[a] Numerator degrees of freedom are less than numbers of released varieties, as some varieties were unavoidably omitted from the regression to avoid the dummy variable trap.

model. Dummy variables were created to represent effects for each variety, trial year, year of release (that is, vintage year), and experimental site. A continuous variable, commercial yield for each state in each year, was used to capture local weather effects. Separate experimental yield models were run for upland rice, edible beans, and soybeans, respectively. The fitted models accounted for a sizable share of the observed variation in experimental yields (the "goodness-of-fit" as indicated by the coefficient of determination, or R^2, adjusted for degrees of freedom was 0.39 for upland rice, 0.54 for edible beans, and 0.48 for soybeans). The low R^2 values may raise doubts about the precision of the estimates of benefits derived from the regression results. In the evaluation of benefits we are measuring the *difference* in yields between varieties, so the precision of the estimates of benefits is more dependent on the precision of the estimated varietal coefficients than on the overall goodness of fit. A series of *F*-tests revealed that the set of dummy variables for varieties jointly contributed significantly to the experimental regressions for soybeans and edible beans; similarly for year-of-release, site, and trial. For upland rice, varieties were jointly significant at the 10 percent level and year-of-release was not significant. In most cases the level of significance was 1 percent or better. Moreover, the *t*-values indicate that the relevant coefficients were estimated with reasonable precision.

Using the estimated parameters, the models were used to generate state-specific fitted values of experimental yields for each variety. Panel a in Figure 4.6 illustrates the profiles of fitted experimental yields for four of the most widely planted varieties of soybeans in the state of Paraná from 1981 to 1998. Panel b plots various state-level soybean yield estimates:

- Average industry yields obtained from the Brazilian statistical agency IBGE
- Average experimental yields, representing an arithmetic average of the experimental yields of 50 soybean varieties

Figure 4.6 Experimental yield estimates



Source: Authors' calculations.

for 22 trial locations in Paraná (noting that the number of trial sites varies from year to year, and typically is around 13 sites).

- Average fitted yields, representing a simple average of the fitted experimental yields for 50 soybean varieties in each of the 22 trial sites for each year
- Weighted average fitted yields, representing a weighted sum of the fitted experimental yields using the actual harvested area shares of each variety as the weights (that is, the *actual* yield performance, Y^a_{rt}, computed using equation [1] from Chapter 3).

As one would expect, the fitted experimental yields were higher than the corresponding commercial yields: fitted experimental yields averaged 709 kg per hectare more than industry yield from 1981 to 1998, with the difference being a little less in the 1990s (695 kilograms per hectare) than the 1980s (723 kilograms per hectare). There were also substantial differences in the rate of change in yields; industry yields grew by 1.68 percent per year from 1981 to 1998, compared with 1.22 percent per year for the weighted, fitted experimental yields. During the 1980s, industry yields grew by 1.06 percent per year while weighted, fitted experimental yields virtually stagnated. Industry yields continued to grow during the 1990s (at 2.75 percent per year), but weighted experimental yields grew even faster, albeit erratically, at an average rate of 4.76 percent per year for the period.

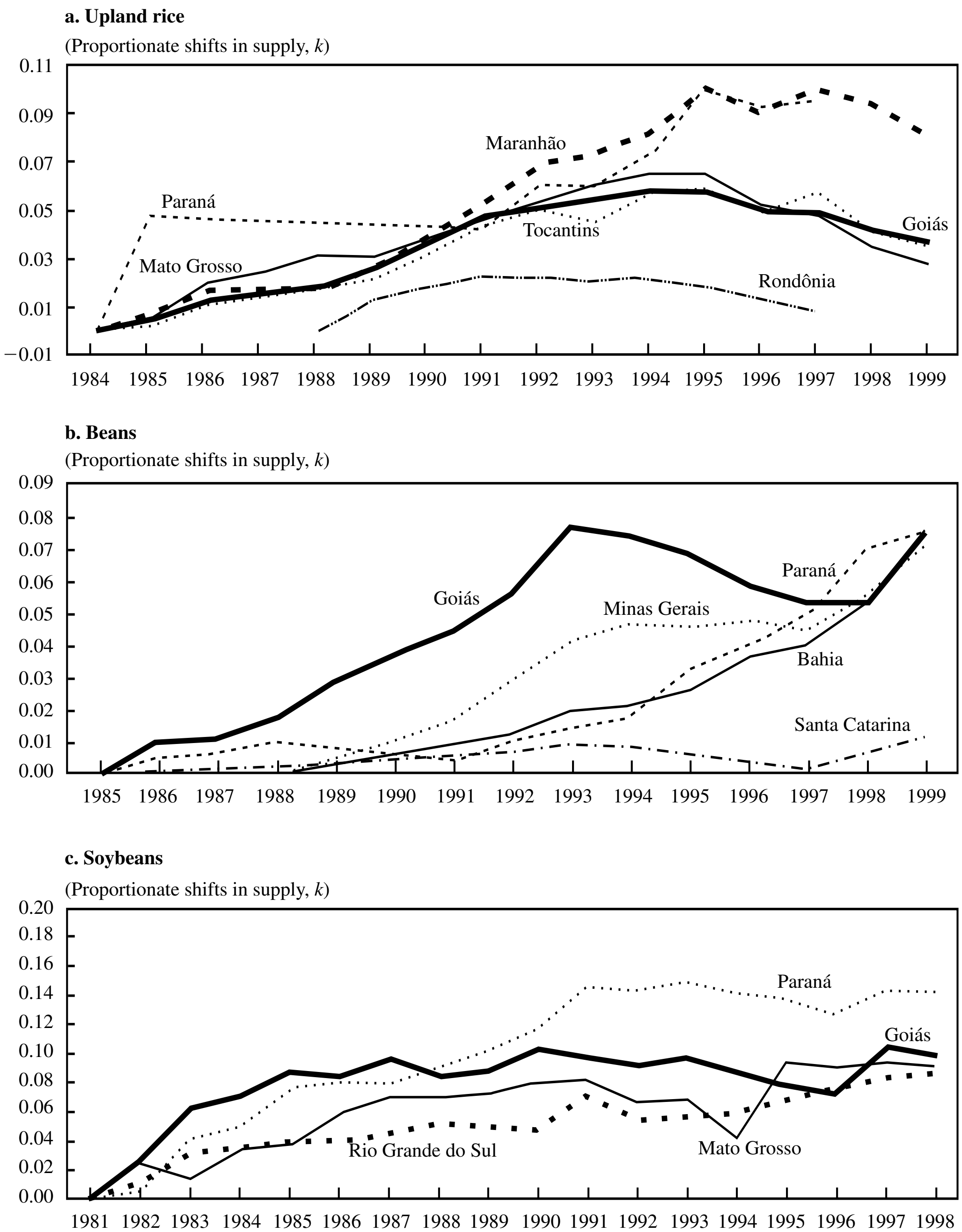
Differences in weighted-average, fitted experimental yields, with and without varietal change, provide the basis for estimating the benefits from varietal change. Panels a–c in Figure 4.7 plot estimates of the proportional shift in the industry supply of upland rice, edible beans, and soybeans, respectively. This supply shift was estimated using a counterfactual alternative of no varietal change since a reference or base year (which was 1985 for edible beans, 1984 for upland rice, and 1981 for soybeans), such that $k_{rt} = (Y^a_{rt} - Y^b_{rt}) / Y^a_{rt}$ based on the *counterfactual* index of experimental yields, Y^b_{rt} (that is, assuming the pattern of varietal use observed in the base year for each state remained unchanged over the subsequent years), and the *actual* index of experimental yields, Y^a_{rt} (that is, using the actual pattern of varietal use).

There are substantial differences among states in the patterns of supply curve shifts for each crop, reflecting local differences in the performance of each variety and the changing mix of varietal use over time. Clearly using a national average would not be representative of the pattern of change in any particular state. Looking in more detail at each crop, there is some similarity in the patterns of supply shifts for upland rice in the states of Goiás, Tocantins, and Mato Grosso, bounded by the states of Maranhão and Paraná with substantially larger reductions in unit costs, particularly during the 1990s, and Rondônia with a much lower rate of reduction in the unit cost of producing upland rice.

For edible beans, the shift to new varieties, compared with a counterfactual of no varietal change since 1985, resulted in similar unit cost reductions by the late 1990s in the states of Goiás, Paraná, Minas Gerais, and Bahia, although the pattern of cost reductions for the intervening years was quite different. The cost of producing edible beans in Santa Catarina has changed little over the years: reflecting the absence of much change in varietal use, *Carioca* remained the single most important variety, occupying about one third of the edible bean area for the entire period of our study.

The unit cost of producing soybeans generally declined faster as a result of varietal change than did the unit cost of producing upland rice and edible beans (k_{rt} values in the 8 to 14 percent range in 1998 for soybeans compared with 3 to 9 percent for upland rice, and only 1 to 7 percent for edible beans). Varietal changes had the biggest impact on production costs in Paraná, where they declined by an average of 12.3 percent

Figure 4.7 Proportionate shifts in supply *(k)* for various states and various crops



Source: Authors' calculations.

per year. Costs declined by 8.2 percent per year in Rio Grande do Sul, the state where 93 percent of Brazil's entire soybean crop was grown in 1960; 78 percent of total production in 1998.

Benefit Measures and Their Attribution

Supply shift estimates, k_{rt}, illustrated for selected states in Figure 4.7, in conjunction with world market prices for 1999 (expressed

Table 4.5 Present value of benefits from varietal improvement research in Brazil

	Total benefits from varietal change	All credit to last cross		Geometric rule	
		Not partitioned	Partitioned	Not partitioned	Partitioned
	(thousands 1999 U.S. dollars)				
Upland rice					
Enhancing yield	1,683,861	1,201,092	642,020	611,387	326,265
Improved grain quality	232,879				
Edible beans	677,538	328,443	212,634	221,232	144,172
Soybeans	12,473,825	5,022,045	4,472,371	2,901,042	2,626,328
All three crops	*14,835,224*	*6,551,580*	*5,327,026*	*3,733,661*	*3,096,765*

Source: Authors' calculations.
Note: Stream of benefits discounted using a 4 percent rate of interest. "Not Partitioned" indicates full credit was given to Embrapa for varieties it developed alone or jointly with others. "Partitioned" indicates Embrapa was given partial credit for varieties developed jointly with others. The present value of benefits from varietal change includes a stream of benefits from 1984 to 2003 for upland rice; 1985–2003 for beans; and 1981–2003 for soybeans.

in U.S. dollar terms) and the annual quantity produced of each crop in each state, Q_{rt}, were used to estimate a stream of total benefits from improved varieties. The benefit streams represent the additional value of production attributable to the release and adoption of any and all new varieties (such that $B_{rt} = k_{rt} P_t Q_{rt}$, where P is the price used to value the state specific-output, Q_r).

The left-hand column of data in Table 4.5 includes various summary estimates of the total national benefits for each crop.[29] The national total was formed by first summing the benefits across nine states for upland rice, representing 82 percent of Brazilian production in 1998; ten states for edible beans, accounting for 80 percent of output in 1998; and four states for soybeans, which produced 78 percent of Brazil's total output in 1998. Then, taking developments in these states to be representative of developments elsewhere in Brazil, the multistate totals were recalibrated on a year-by-year basis to generate a national total according to their corresponding share of Brazilian production.

We estimate the total benefit to Brazil from yield-improving varietal changes in upland rice from 1984 to 2003 was $1.68 billion, representing 3.8 percent of the present value of total production over the entire period, expressed in 1999 currency values.[30] The benefits attributable to improvements in the quality of upland rice were estimated to be $232 million. These both represent upper-bound estimates of the benefits attributable to Embrapa, some of which are attributable to the efforts of others. The total benefits from adopting new, higher yielding edible bean varieties is estimated to be $678 million (1.73 percent of the present value of production for the corresponding period) while the use of improved soybean varieties was worth an

[29]In this table, and others to follow, for didactic reasons benefit estimates have not been rounded, which is not meant to imply any false precision.

[30]Direct estimates of the benefits from varietal change in upland rice were estimated for the period 1984–99 (and from 1985 to 1998 for edible beans, and 1981–98 for soybeans). To obtain a better temporal match between the annual stream of research benefits and costs (which were from 1976 to 1998), benefits for 1998 were projected forward (unchanged) to 2003 in each instance.

estimated $12.8 billion to Brazil, which represents nearly 8 percent of the $159 billion present value of production.

Comparing Research Costs and Overall Benefits

These total benefit estimates do not take account of differences in the size of the research effort that helped bring them about. Three indicators that normalize benefit estimates in terms of the research resources giving rise to them are presented in Table 4.6. One divides the present value of benefits by the corresponding present value of the costs of varietal improvement research incurred by the rice and bean programs at CNPAF and the soybean program at CNPSo. These baseline costs include the costs of all the research and support staff involved in crop improvement research (that is, crop breeders as well as the appropriate shares of agronomy, plant pathology, entomology, and other scientific staff) and the associated capital and operational costs. However, because of budgeting and institutional divisions of responsibilities within Embrapa, the costs that show up in center budgets are not a full accounting of all the crop-improvement costs incurred by Embrapa. Some of the relevant costs are budgeted against Embrapa headquarters, Sede. In addition, some of the costs incurred by the prebreeding and other biotechnology activities undertaken by CENARGEN can be considered a form of "overhead" cost to be charged against the crop-improvement research undertaken at the respective centers. The augmented cost series includes center-specific costs to which have been added a suitable share of Sede and CENARGEN costs in an effort to match the benefit stream more closely to the total crop-improvement costs incurred by Embrapa.[31]

Although we sought to obtain benefit estimates that represented the gains attributable solely to varietal improvement research, this research is done in the context of a more comprehensive program of crop improvement R&D, the intent of which is to develop technologies such as improved methods of controlling pest and diseases, new fertilizer options, and various other crop management techniques that complement the breeding effort. Thus the varietal improvement research draws from and in turn affects the overall crop research agenda, and so a useful additional perspective is gained by normalizing the benefits arising from varietal change by the overall costs of research on each crop.

Typically, it is the time and skill of the senior scientific staff that constitute the most critical and binding constraints to research. To capture this aspect when comparing among programs of research we expressed the present value of benefits relative to the total number of full-time equivalent researchers engaged in crop-improvement research over the period 1979–98.

According to the benefit–cost criterion, an investment is profitable if its benefit–cost ratio is greater than 1. On this score all three crop-improvement programs have been remarkably profitable, whether one takes a narrow (that is, baseline) or broader (that is, augmented) measure of costs. For every dollar invested by Embrapa in developing new upland rice varieties, between 27 and 35 dollars of benefits have accrued to Brazil (left-hand data column, Table 4.6), and 149 to 204 dollars of benefits for every dollar invested in soybean research by Embrapa. Even edible bean research, the least profitable of the three programs evaluated in this study, generated between 15 and 21 dollars of benefits for every dollar invested by Embrapa in breeding new varieties for this crop.

The benefits arising solely from improved crop varieties were more than sufficient to offset the *entire* costs of each crop research program. Even after augmenting

[31]Chapter 3 and the earlier parts of Chapter 4 describe how we estimated these costs.

Table 4.6 Normalized research benefits

Indicators	Total benefits from varietal change	All credit to last cross		Geometric rule	
		Not partitioned	Partitioned	Not partitioned	Partitioned
	(benefit per unit cost)				
Benefits/crop improvement cost					
Upland rice					
Enhanced yield					
Baseline	34.7	24.8	13.2	12.6	6.7
Augmented	27.3	19.5	10.4	9.9	5.3
Improved grain quality					
Baseline	4.8				
Augmented	3.8				
Edible beans					
Baseline	20.8	10.1	6.5	6.8	4.4
Augmented	15.1	7.3	4.8	4.9	3.2
Soybeans					
Baseline	204.4	82.3	73.3	47.5	43.0
Augmented	149.3	60.1	53.5	34.7	31.4
All three crops					
Baseline	104.4	46.1	37.5	26.3	21.8
Augmented	78.1	34.5	28.0	19.7	16.3
Benefits/total crop research costs					
Upland rice					
Enhanced yield					
Baseline	12.6	9.0	4.8	4.6	2.4
Augmented	9.2	6.5	3.5	3.3	1.8
Improved grain quality					
Baseline	1.7				
Augmented	1.3				
Edible beans					
Baseline	5.1	2.5	1.6	1.7	1.1
Augmented	3.7	1.8	1.2	1.2	0.8
Soybeans					
Baseline	54.7	22.0	19.6	12.7	11.5
Augmented	39.6	16.0	14.2	9.2	8.3
All three crops					
Baseline	30.0	13.2	10.8	7.5	6.3
Augmented	21.8	9.6	7.8	5.5	4.5
	(thousands 1999 U.S. dollars)				
Benefits/FTE					
Upland rice					
Enhanced yield	11,230	8,011	4,282	4,078	2,176
Improved grain quality	1,553				
Edible beans	4,456	2,160	1,398	1,455	948
Soybeans	42,603	17,152	15,275	9,908	8,970
All three crops	24,942	11,015	8,956	6,277	5,206

Source: Authors' calculations.

Note: Stream of benefits discounted using a 4 percent rate of interest. FTE refers to the average annual Full Time Equivalent number of researchers between 1976 and 1998. "Not Partitioned" indicates full credit was given to Embrapa for varieties it developed alone or jointly with others. "Partitioned" indicates Embrapa was given partial credit for varieties developed jointly with others. The present value of benefits from varietal change includes a stream of benefits from 1984 to 2003 for upland rice; 1985–2003 for beans; and 1981–2003 for soybeans.

the overall cost of each of the crop programs with Sede and CENARGEN overhead costs, there was more than $9 of benefits from just the improvements in rice varieties alone for every dollar spent on the entire upland rice research program, nearly $4 of benefits for each dollar spent on edible beans research and $40 for soybeans.

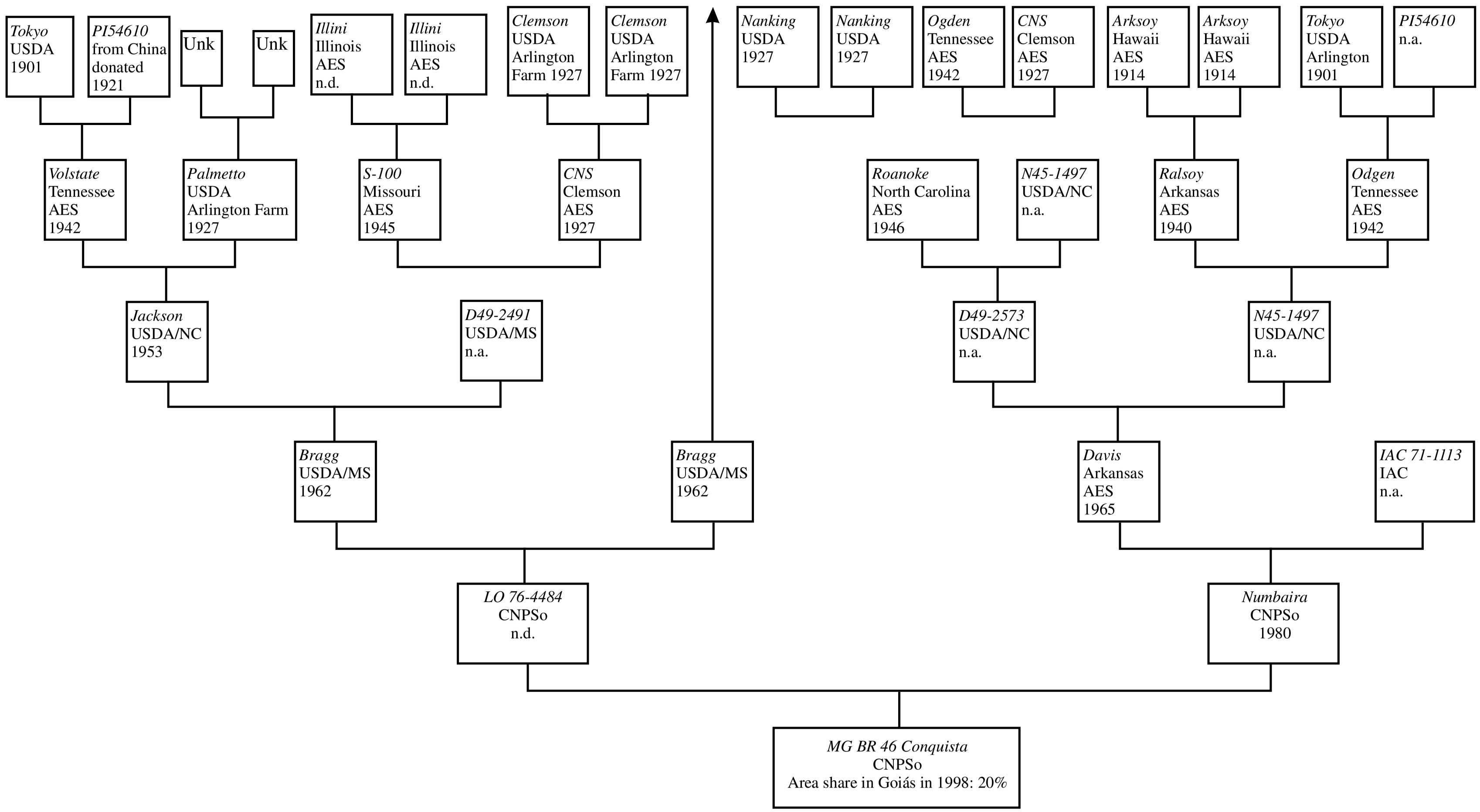
The figures on benefits per year of full-time equivalent (FTE) researchers presented in the bottom panel of Table 4.6 are also impressive. Since 1981, for every FTE researcher-year engaged in soybean improvement research at CNPSo, $42.6 million of total benefits resulted from varietal changes in soybeans. This compares with $11.2 million and $4.5 million of benefits per FTE researcher-year for upland rice and edible beans, respectively. These are a measure of the *average* total benefits per FTE researcher-year. They should not be interpreted as implying that the benefits were all attributable to the labor of researchers. Nor do they mean that an incremental researcher, with or without corresponding increases in other research inputs, would have generated a corresponding *marginal* benefit.

Attributing Benefits

Our task was to develop methods for meaningfully comparing the economic consequences of Embrapa's research programs, using the varietal improvement research conducted by the upland rice, edible bean, and soybean programs as a basis for pilot-testing this method. Having identified the total benefits attributable to the development and use of new varieties, in ways that abstract from all other changes that may affect industry yields, many of which are not related to research, and others not directly the consequence of varietal changes, is a major step in the right direction. Normalizing these total benefits for differences in the respective sizes of the crop-improvement programs provides an even better basis for comparison. However, as described in Chapter 2, Embrapa is but one of the myriad and changing sources of agricultural innovation in Brazil. A host of other research is done by state, university, and private agencies within Brazil and a good deal of technology stems from research done elsewhere in the world that spills in to Brazil.

The critical remaining task, therefore, is to estimate the share of *total* benefits from varietal improvement research attributable to the efforts of Embrapa versus the efforts of others. It would plainly be inappropriate to attribute the total benefits from varietal change to Embrapa alone, but what share of the total benefits is properly credited to Embrapa? As discussed in Chapter 3, and earlier in the present chapter, one way of attributing benefits among the agents of innovation is to give all the credit for a new variety to the agency (or individual researcher) that performed the last cross. But this gives an incomplete picture of the source of the benefits, given the cumulative nature of crop breeding. Figure 4.8, a partial pedigree for the variety *MG BR 46* (also known as *Conquista*), illustrates the issue. *Conquista* was released by CNPSo in 1995 and by 1998 accounted for one fifth of the soybean area in Goiás. Although CNPSo also developed both parents of this variety, virtually all the grandparents, great-grandparents, and great-great grandparents were developed in the United States. Beginning in the 1950s, a substantial amount of innovative breeding by USDA researchers located in Illinois, Mississippi, and several other southern U.S. states developed a number of commercially successful, day-length-insensitive soybean varieties (Warnken 1999). These varieties made it possible to grow soybeans successfully in tropical latitudes such as the Cerrados region in Brazil, which is located well to the north of the Tropic of Capricorn. During the 1960s and 1970s, the material emanating from this U.S. research was introduced and tested in Brazil under U.S. foreign assistance programs. As one consequence of this international technology transfer, we estimate that fully one half of the grandparents of all the commercially successful varieties grown in Brazil since

Figure 4.8 Partial pedigree for soybean variety *Conquista*



Source: Developed by authors based on information obtained from NGRP (2001) and provided by Embrapa scientists.

Note: Where available, nodes include information on name of variety or breeding line (in italics) and institution and year of release. "Unk" indicates unknown.

1981 came from the United States. Given the reliance of more-contemporary releases by CNPSo on material developed elsewhere, the question remains as to what share of the benefits attributable to varieties such as *Conquista* are attributable to the efforts of CNPSo, and what share should be attributed to the work done by other breeders, without which the Brazilian releases would not have been forthcoming.

Crop pedigrees not only illustrate the issue of attributing benefits but they also present a practical and transparent way to address the problem. However, one could use any of a large number of attribution rules, each of which gives a different perspective on the nature and sources of varietal innovations that may be useful for different purposes. Thus, the choice of rule to use is ad hoc, but not a matter of indifference. For example, the administrator of a research program that does lots of adaptive research (taking material from others and doing sets of simple crosses to produce finished lines) would opt for a "last-cross" rule. In contrast, some programs may have (recently) released few commercially successful varieties of their own but developed many earlier varieties or contemporary breeding lines that form parts of the releases made by others. A last-cross rule would attribute few of the total benefits to the efforts of such a program; administrators of these types of research programs would push to put more weight on varieties (or breeding lines) that typically show up further back in the pedigrees. Here we present the results of applying just two rules, one that gives all credit to the last cross, the other a geometric rule that gives declining weight to varieties from earlier generations in the pedigree back to the level of grandparents.

Using the last-cross rule, 40 percent of the total benefits from the use of improved soybeans (that is, \$5.0 billion of the total of \$12.5 billion) are attributed to Embrapa research (Table 4.5). Using the geometric rule that gives weight to prior research as well as the agency that released the variety, the Embrapa share drops to \$2.9 billion, or 23 percent of the total benefits, reflecting less "Embrapa-ness" in earlier generations.

The same general pattern—that is, a decline in the benefits attributable to Embrapa as one shifts from the last-cross rule to the geometric rule—is evident with both upland rice and edible beans. However, compared with soybeans, the share of total benefits attributable to non-Embrapa research is less for both upland rice and edible beans. For example, under the last-cross rule, Embrapa is assigned only 40 percent of the total benefits from the use of improved soybean varieties; Embrapa receives 71 percent of the upland rice benefits and 48 percent of the edible beans benefits. This reflects the much higher share of commercially successful soybean releases coming from agencies other than Embrapa compared with either upland rice or edible beans. Using the geometric rule, Embrapa's share of the total benefits from varietal change in soybeans drops to 23 percent, compared with 36 percent for upland rice and 33 percent for edible beans. This indicates that the development of commercially successful soybean varieties draws more intensively on genetic material developed by agencies other than Embrapa (at least back to the level of grandparents in each of the pedigrees) than does research aimed at breeding new varieties of the other two crops.

Research Partnerships

As discussed in general terms earlier, Embrapa engages a sizable number of partners in the conduct of its research. In some instances the partnering takes the form of joint breeding work, with breeders from collaborating institutions jointly designing and executing the breeding and varietal testing strategies. In other cases, one or more institutions take a lead role while the other cooperating agencies play a supporting role, hosting trial sites and such. To quantify these partnerships and their role in varietal improvement research we developed data on the number and type of cooperating institu-

Table 4.7 Partnerships involving CNPSo and CNPAF varietal improvement research

	Number of varieties			Share of varieties		
Number of partners per variety	Upland rice	Edible beans	Soybeans	Upland rice	Edible beans	Soybeans
		(count)			(percentage)	
0			44			36
1	15	3	60	56	15	50
2	7	9	8	26	45	7
3	3	2	7	11	10	6
4	1	2	2	4	10	2
5	1	1		4	5	
6						
7						
8		1			5	
9						
10						
11						
12		1			5	
13		1			5	
Total	27	20	121	100	100	100

Source: Authors' compilation based on survey returns and Guimarães (1997).

tions identified in the varietal lists obtained from CNPSo and CNPAF.

Table 4.7 summarizes the structure of research partnerships for all the varieties of upland rice and edible beans released by CNPAF and the soybean varieties released by CNPSo during the study period. Several aspects are noteworthy. All of the upland rice and edible bean varieties involved some research collaboration. More than one half the rice releases were developed jointly with one partner; one quarter of the varieties involved two partners. For edible beans, the tendency was to have even more partners—about 85 percent of the varieties involved two or more partners and some varieties involved as many as 12 or 13 partners. The propensity to partner was much lower in the development of new soybean varieties. CNPSo alone developed about one third of the Embrapa releases, and one half involved only a single collaborating institution.

A significant proportion of these partnerships were with other Embrapa centers. Of the 105 partnerships CNPSo formed in developing 121 soybean varieties from 1976 to 1999 (noting that 44 of the varieties were developed without partners), 19 percent of these partnerships involved other Embrapa centers. About 17 percent of the partnerships CNPAF formed to develop 27 rice varieties from 1976 to 1999 were with other Embrapa centers; 11 percent of the partners CNPAF worked with to produce 20 edible bean varieties were also from Embrapa. For rice and beans all the remaining collaborators were other public institutions, including other federal agencies and universities, but mainly state agencies. Soybean varieties developed by CNPSo involved less collaboration than the rice and beans research at CNPAF, but a greater diversity of collaborators. About 55 percent of the collaborators were other public agencies; and 26 percent of the partnerships involved private firms.

For each variety for each crop we elicited from the Embrapa scientific staff involved in breeding these crops their estimate of the contribution of each partnering agency to the development of each variety. The shares assigned CNPAF for rice varieties released by them ranged from 0 to 50 percent. Corresponding shares for beans ranged from 28 to 100 percent and for soybeans the range was 45 to 100 percent. These shares were used to partition further the benefits attributed to Embrapa, as designated by the "partitioned" columns in Tables 4.5 and 4.6.

Obviously, taking account of the role of research partners in the development of a particular variety (in addition to assigning part of the total benefits to the efforts of agencies not directly cooperating with Embrapa) reduces the total benefits attributable to Embrapa. In the case of upland rice, using the last-cross rule the benefits attributed to Embrapa drop by 47 percent if the role of research partners is taken into account (for example, comparing $1.2 million to $642,020 in Table 4.5) whereas for edible beans they were reduced by 35 percent (comparing $328,443 with $212,634). Nevertheless, the benefit–cost ratios remained substantially greater than 1:1, and the benefits per FTE remained large (Table 4.6, top and bottom panels). Embrapa's soybean breeders relied less on external partners, so factoring in their contribution did little to diminish the benefits attributable to Embrapa (for instance comparing $5.02 million to $4.47 million in Table 4.5).

The geometric rule gives more weight to earlier ancestors than the last-cross rule does. Because Embrapa releases feature more heavily in the more recent past of most varietal pedigrees, the geometric rule coupled with the partitioning procedure that attributes some of the benefit to Embrapa partners provides the smallest estimate of the benefits attributable to Embrapa (right-hand column of Tables 4.5 and 4.6).

Institutional origins of benefits. The data assembled for this study make it possible to delve deeper into the sources of benefits arising from varietal improvement research. Based on the two attribution rules used above, and in conjunction with data on the institutional origin of each variety (and the components of each pedigree back to the level of grandparents), we extended the attribution exercise beyond an Embrapa versus non-Embrapa split to give a more refined breakdown of the institutional origins of the non-Embrapa varieties. The results of this more refined attribution are presented in Table 4.8. They reinforce and shed more light on the results discussed above.

Here we highlight just a few key aspects. Using the last-cross rule, 59.7 percent of the total soybean benefits are attributed to non-Embrapa sources and most of that amount is attributed to domestic (and a few unknown) sources, including state-level public agencies and domestic private firms. Using the geometric rule, the non-Embrapa share increases to 76.7 percent of the total benefits, the domestic share remains about the same, and the share attributable to foreign (mainly U.S.) sources increases substantially from 4.2 to 21.7 percent. Drawing on all this evidence, we see that

- Since 1981, CNPSo accounts for a sizable but not dominant *share* of the benefits from improved soybean varieties.
- CNPSo's share of the benefits from more contemporary releases is higher than it was for earlier releases.[32]
- The genetic material underpinning Brazilian soybean varieties draws heavily from non-Embrapa (significantly U.S.) sources.

These results also indicate that the non-Embrapa content of upland rice varieties is much more reliant on domestic sources compared with soybeans, while edible bean varieties draw more heavily on foreign sources than either rice or soybeans (CIAT

[32]In 1981, varieties released by Embrapa accounted for only 10 percent of soybean total area; by 1998 this share increased to 50 percent.

Table 4.8 Institutional origins of research benefits

	Present value of benefits		Share of total benefits	
	All to last cross	Geometric	All to last cross	Geometric
	(thousands 1999 U.S. dollars)		(percentage)	
Upland rice				
Embrapa	1,201,092	611,387	71.3	36.3
Non-Embrapa	482,769	1,072,474	28.7	63.7
Foreign	0	105,654	0.0	6.3
Domestic[a]	482,769	444,183	28.7	26.4
Unknown	0	522,637	0.0	31.0
Total benefits	1,683,861	1,683,861	100.0	100.0
Edible beans				
Embrapa	328,443	221,232	48.5	32.7
Non-Embrapa	349,095	456,306	51.5	67.3
CIAT	83,169	49,075	12.3	7.2
Other Foreign	2,071	126,720	0.3	18.7
Domestic[a]	263,856	195,006	38.9	28.8
Unknown	0	85,505	0.0	12.6
Total benefits	677,538	677,538	100.0	100.0
Soybeans				
Embrapa	5,022,045	2,901,042	40.3	23.3
Non-Embrapa	7,451,780	9,572,783	59.7	76.7
United States	518,140	2,711,042	4.2	21.7
Other foreign	0	9,424	0.0	0.1
Domestic[a]	6,182,063	5,126,377	49.6	41.1
Unknown	751,577	1,725,940	6.0	13.8
Total benefits	12,473,825	12,473,825	100.0	100.0

Source: Authors' calculations.
Note: Stream of benefits discounted using a 4 percent rate of interest. The present value of benefits from varietal change includes a stream of benefits from 1984 to 2003 for upland rice; 1985–2003 for beans; and 1981–2003 for soybeans.
[a] Includes varietal selections made from local material, some of which originated elsewhere.

is a major source of the pedigree material used by CNPAF and other local breeders, and a nontrivial amount of varieties from foreign sources are directly used by Brazilian farmers).

Benefits from Improving the Quality of Upland Rice

The benefit estimates presented and discussed so far represent the value to Brazil from adopting higher-yielding varieties. As discussed in the section on varietal improvement research, beginning in the mid-1980s or thereabouts, the upland rice program refocused its breeding to emphasize improving grain quality. The effects of that shift were evident in the release and adoption of a series of upland varieties with *longo fino* characteristics (more typical of irrigated rice varieties with more desirable cooking qualities) as distinct from the "shorter and fuller" rainfed grain types that had hitherto been developed. We identified five varieties with this more desirable trait; *Maravilha* (released in 1996), *Confiança* (1996), *Canastra* (1996), *Primavera* (1997), and *Carisma* (1999), that had achieved some significant planted area. For example, in Minas Gerais, Maranhão, and Mato Grosso, these five varieties were planted on more than 30 percent of the upland rice area in 1999, and 29 percent of the area in Paraná.

Chapter 3 describes the methodology we used to estimate the additional benefits accruing to Brazil from adopting upland rice varieties with improved grain characteristics that commanded a price premium in the market.[33] The benefit estimates from quality-enhancing research are included in the left-hand column of data in Table 4.5. Adoption of varieties with *fino* traits increased the benefits for rice research by $232 million compared with the gains from yield-enhancing research alone (which were $1.68 billion). This represents a significant increase in the present value of the total benefits from upland rice research for the period 1984–2003 for a quality trait that only entered the market in 1996.

For research evaluation purposes we normalized the benefits from improved varieties against the varietal-improvement costs incurred by Embrapa. To gain some alternative perspectives on the worth of this research we also compare these benefits against alternative costs streams (for example, the total costs of Embrapa commodity research, the total costs incurred by each center conducting the varietal improvement research, and Embrapa's total crop-improvement costs and the overall costs of the agency).

Sensitivity Analysis

Even after apportioning varietal improvement benefits to the research efforts of various public and private agencies located within Brazil and elsewhere, and applying attribution rules that give more weight to distant past research compared with more recent times when Embrapa has been more prominent, the benefits attributed to Embrapa are large absolutely and relative to the crop-improvement costs incurred by Embrapa. Some might question the magnitude of these benefits and, implicitly, the measurement details that lay behind them. Here we explore the sensitivity of the benefit estimates to variations in some key parameters, specifically the interest rate used to calculate present values of the benefit and cost streams and the lag lengths chosen for the stream of benefits to be compared with a given stream of past R&D expenditures. We also investigate the implications of accounting for the full social costs of government spending, not simply the expenditures incurred by Embrapa.

Estimation Effects

The notion that estimates of the rates of return to agricultural research are implausibly high is not new (Pasour and Johnson 1982; Alston et al. 2000; Alston and Pardey 2001). Indeed authors of this study have given various reasons why upward biases are likely in many past rate-of-return estimates (Alston and Pardey 1996). Cognizant of these tendencies, we were duly diligent when estimating the costs and benefits of crop-improvement research, paying particular attention to those parts of the total benefits that are attributable to Embrapa research. Unavoidably there are still aspects of the analysis involving analytical judgments that have repercussions on the results. The significance of these analytical choices is the subject of this section.

Table 4.9 reports the present value of benefits and benefit–cost ratios for each crop using two discount rates (4 and 10 percent) and a longer (through to 2003) and shorter (through to 1998) lag length for the stream of benefits against which the 1976–98 cost streams are compared. As noted earlier, the lags between investing in R&D and reaping the full rewards of that

[33]CONAB (various years) reported a monthly producer price series from January 1970 to May 2000 for rice of different classes. We used the *longo* series for Goiás to represent the lower quality upland rice varieties and the *fino* series for Rio Grande do Sul to represent the premium quality grain type. (Unfortunately both *longo* and *fino* series were not reported for each state.) The monthly prices were averaged, and the price premium implied by comparing these annual averages was 6.6 percent in 1996, 8.2 percent in 1997, 15.3 percent in 1998, and 7.5 percent in 1999. The benefit estimate for 1999 was projected forward (unchanged) to 2003.

Table 4.9 Sensitivity analysis

	4 Percent		10 Percent	
	Longer	Shorter	Longer	Shorter
	(thousands 1999 U.S. dollars)			
Present value of research benefits				
Upland rice	326,265	252,093	426,195	352,023
Edible beans	144,172	80,971	164,205	92,055
Soybeans	2,626,328	1,569,043	3,335,390	2,217,108
	(benefit per unit cost)			
Benefit–cost ratios				
Upland rice	5.3	4.1	3.4	2.8
Edible beans	3.2	1.8	1.8	1.0
Soybeans	31.4	18.8	20.8	13.8
Benefit–cost ratios (with costs increased by 20 percent)				
Upland rice	4.4	3.4	2.8	2.3
Edible beans	2.7	1.5	1.5	0.8
Soybeans	26.2	15.6	17.3	11.5
	(percent per year)			
Internal rates of return[a]				
Upland rice			23.9	22.8
Edible beans			15.0	9.8
Soybeans			53.0	52.4
Internal rates of return (with costs increased by 20 percent)[a]				
Upland rice			21.9	20.7
Edible beans			13.4	7.9
Soybeans			49.5	48.9

Source: Authors' calculations.

Note: Benefits are those attributed to Embrapa using a geometric rule and partitioned among research partners. Stream of costs are augmented crop improvement cost from 1976 to 1998 expressed in 1999 present value terms. The "longer" stream of benefits is from 1984 to 2003 for upland rice, 1985–2003 for beans, and 1981–2003 for soybeans. The "shorter" stream of benefits is from 1984 to 1998 for upland rice, 1985–98 for beans, and 1981–98 for soybeans.

[a] Represents the rate of return that equates the present value of costs to the present value of benefits, with benefits running through to 2003 in the "longer" column, and, as described above regarding the benefit–cost ratios for the "shorter" column.

investment are very long, perhaps infinite, especially for crop improvement research. Thus any analysis that uses the evaluation techniques we employed, linking a stream of past research to a *finite* stream of research benefits, is bound to understate the total benefits attributable to that cost stream.[34] The magnitude of the bias is unknown, depending on the time path of the future benefits from research and the share of the benefits attributable to past research costs. To gain a sense of the biases, we truncated the stream of benefits attributable to Embrapa to 1998 (columns denoted "shorter" in Table 4.9), instead of 2003 reported elsewhere in this report, and denoted "longer"

[34]If econometric techniques are used instead of the economic surplus methods we employed here the likely bias is in the other direction, as Alston and Pardey (1996) described, and as borne out by the meta-analysis by Alston et al. (2000b).

in Table 4.9 (see also Appendixes F and I). Longer benefit streams naturally resulted in higher benefit–cost ratios: in this instance the increases were greatest for edible beans research and smallest for upland rice.

The appropriate interest rate for discounting streams of research costs and benefits is the social opportunity cost of public funds committed to long-term investments. Because our costs and benefits are in real (inflation adjusted) terms we opted for a real, risk-free, long-run rate of interest of 4 percent. It could be argued that a higher rate is warranted in developing economies where capital costs are typically higher than in comparable developed-country markets, so Table 4.9 also presents results for a 10 percent discount rate (see also Appendixes E, G, H, and J). For all three crops the higher rate of interest increases the total benefits (expressed in present value 1999 terms), with the smallest effect being for edible beans indicating that a comparatively higher proportion of the total benefits for this crop were realized in more recent years compared with the other crops. All the benefit–cost ratios were lower when the discount rate was increased from 4 to 10 percent, indicating a greater proportion of the overall costs than benefits occurred in earlier years. In all cases the total benefits and benefit–cost ratios were more sensitive to changes in lag length than changes in interest rates.

Table 4.9 reveals the sensitivity of the results when the full social costs of government funds used to conduct the Embrapa research are taken into account. The estimates presented earlier assume that the marginal opportunity cost of government spending is the amount spent. However, a more comprehensive assessment would include the deadweight costs of taxation in a more complete measure of the full social costs of government spending. The evidence presented and discussed by Browning (1987) and Fullerton (1991) suggests a social cost of U.S. government spending in the range of 1.07 to 1.24 times the amount spent.[35] In developing countries with less efficient taxation mechanisms the deadweight costs may be even higher. We took the social costs of Embrapa spending, which is mainly sourced from general government revenues, to be 1.20 times the amount spent, thereby raising the stream of relevant costs by 20 percent with a consequent reduction in the benefit–cost ratios (see the second and third blocks of data in Table 4.9).[36]

Finally, the bottom of Table 4.9 (fourth and fifth blocks of data) includes the real internal rates of return that correspond to the benefit–cost ratios—provided for purposes of comparison with other studies and noting that we favor the benefit–cost ratios as summary measures for this type of study (see Chapter 3).

Alterative Cost Attributions and Benefit Normalizations

Matching research costs to the relevant stream of research benefits is difficult. Even after a benefit stream attributable to Embrapa is identified, there remain some ambiguities in the span of Embrapa activities and costs associated with that benefit. For each crop we derived a stream of costs associated with crop-improvement research—a broader notion than costs incurred by crop breeders, incorporating the costs of other scientists such as plant pathologists and agronomists involved in crop-improvement research. These costs included a share of the administrative and support costs of each crop center plus some Embrapa-wide overhead costs. However, the cost attribution exercise is subject to error so that more, or less,

[35]Fox (1985) introduced this argument into the evaluation of agricultural research investments and Dalrymple (1990) summarized the relevant literature.

[36]Benefit–cost ratios that take account of these social costs are not directly comparable with those from other studies that do not.

Table 4.10 Benefits attributable to Embrapa compared with various Embrapa costs

	Present value of		Benefit–cost ratios				
	Benefits 1	Center crop improvement costs 2	Center crop improvement 3	Center total crop research 4	Total center 5	Embrapa crop improvement 6	Total Embrapa 7
	(thousands 1999 U.S. dollars)		(benefit per unit cost)				
Upland rice	326,265	61,623	5.29	1.78	0.89	0.05	0.03
Edible beans	144,172	44,727	3.22	0.79	0.39	0.02	0.01
Soybeans	2,626,328	83,572	31.43	8.34	7.57	0.42	0.26
Total all three crops	3,096,765	189,922	16.31	4.54	2.86	0.50	0.30

Source: Authors' calculations.

Note: Benefits are 1999 present values discounted using a 4 percent rate of interest and represent those attributed to Embrapa using a geometric rule and partitioned among research partners. The cost streams include the years 1976–88 while benefit streams include the years 1984–2003 for upland rice; 1985–2003 for edible beans; and 1981–2003 for soybeans. The crop improvement and total costs incurred by each center as well as Embrapa's overall crop-improvement costs were augmented to include a prorated share of Sede and CENARGEN costs. Center crop improvement costs include all the costs related to breeding a crop in a specific center; center total crop research includes total cost of research for each crop at each center; total center cost refers to total cost for research and nonresearch activities incurred by the rice and bean center and the soybean center, respectively; Embrapa crop-improvement costs refer to total crop-improvement research costs for Embrapa; and total Embrapa costs refer to total cost incurred by Embrapa for research and nonresearch activities.

of the total costs of Embrapa could arguably be charged against the estimated stream of benefits. Moreover, although every effort was made to include only the benefits derived from varietal change, abstracting from benefits attributable to improved crop management practices, including improved agronomic and pest and disease control methods, the reality is that some of the benefits from such sources is likely to be included.

Table 4.10 takes the Embrapa share of the benefit streams for each crop ending in 2003 estimated using a 4 percent discount rate, applying the geometric attribution rule and partitioning the benefit streams among Embrapa and its partners, and compares that with alternative streams of Embrapa costs. Working from left to right across the table, the cost–benefit ratios involve the augmented costs of crop-improvement research at each center, the overall cost of the respective crop research programs at each center, the total research costs of each center, the overall costs of crop-improvement research incurred by Embrapa, and finally, Embrapa total costs. The benefits attributable to Embrapa from adopting improved upland rice, edible bean and soybean varieties in Brazil was more than sufficient to offset the costs Embrapa incurred in developing these varieties (column 3, Table 4.10). The benefits were also sufficient to offset the respective total—not just crop-improvement—costs of the upland rice and soybean programs (column 4) as well as all the costs of the soybean research center (column 5). In fact the Embrapa-attributed benefits arising from these three crops alone were sufficient to cover one half the total crop improvement costs incurred by Embrapa since 1976 and almost one third of the agency's entire costs.

CHAPTER 5

Conclusion

As noted by Alston and Pardey (2001), attribution problems abound in the assessment of agricultural R&D. Although it seems clear that many studies of agricultural research benefits have not paid enough attention to attribution problems, the nature and importance of the consequences for biases in estimation and interpretation of the evidence is less clear. In this study we have emphasized the role of three types of attribution challenges in the context of an ex post evaluation of the returns to public varietal improvement research investments undertaken by Embrapa, in Brazil: (1) attribution among institutions that operate independently, taking account of spillovers of technologies both within and among countries; (2) attribution among institutes that collaborate in research, both within and among countries; and (3) attribution within an institution, taking account of the allocation of overhead costs both within centers and between centers and head office.

In the case of Embrapa's varietal improvement research, all of these elements of attribution played significant roles, varying in importance from one crop to another. If we had ignored these attribution issues, as many studies have done, and had given Embrapa credit for all of the benefits from improvement in Brazil's varieties of soybeans, edible beans, and upland rice over the past 30 years, we would have grossly overestimated the benefit–cost ratio for Embrapa's work. Even after we have taken account of the international and intranational institutional spillovers of research results, which are especially important for soybeans, the rate of return to Embrapa's research remains high, particularly for soybeans.

This study has revealed the importance of taking greater care in the attribution of benefits and costs of research in a context in which the attribution problems are made more transparent through the availability of information on the genetic history of crop varieties—information on which institution released a particular variety and its parents. Nevertheless, implementation of the methods used in this study requires a great deal of information on the experimental and commercial performance and adoption rates of individual varieties, and such information is often not readily available. In many cases the results from experimental trials are not kept in an appropriate form, if they are kept at all for the longer time periods required for this kind of work, and information on adoption is often sketchy at best. Even with good information on genetic histories, performance, and adoption patterns, we are obliged to use arbitrary but nonetheless transparent procedures to apportion credit among institutions. Other types of (nonvarietal) technologies may pose different, and in some senses even greater, challenges both in terms of conceptualizing how to address them and in obtaining data; especially, perhaps, privately produced technologies. However, if our results are any guide it will be important to give greater attention to attribution issues in studies of research benefits of all types.

Any evaluation of research benefits, or for that matter any benefit–cost analysis, involves a host of implicit or explicit decisions about models, data, procedures, and so on—decisions that may have major or minor consequences for the results and their interpretation. Many of these decisions are arbitrary, and often they are left implicit. In this report we have focused on the issue of the attribution of research benefits among multiple sources. In addressing that question, as well as the measurement of the total benefits, we have attempted to make our key analytical and measurement choices transparent and explicitly clear. We have provided a detailed report of the complicated journey one must travel and the arbitrary choices one must make in producing estimates of returns to research, even when unusually detailed data and information are available. By reporting all of these details, and examining the consequences of alternative choices in those cases where there is little or no empirical basis for a particular choice, we hope to have added to the value of our estimates, in terms of a greater understanding of where they come from and what they mean. In addition, we hope this study may serve as a guide for future research evaluations, and as a set of cautions to be kept in mind when interpreting the work from other studies.

The payoffs to past investments made in Embrapa's upland rice, edible bean, and soybean improvement research have been substantial, even after careful accounting of the contributions made by other agencies in Brazil and the spillin of new crop varieties from agencies elsewhere in the world. This ex post benefit–cost analysis provides some support for strategic decisions about the total budget for crop improvement research in Embrapa, suggesting it should be greater, and its allocation, suggesting that, everything else equal, a higher share should be allocated to the comparatively much higher payoff, soybean program. However, the benefit–cost ratios cannot be used directly to answer the related questions concerning how much additional funding in total and how best to allocate that funding among programs of research. To do this would require ex ante (forward looking) estimates of the likely benefits from such investments, as distinct from the ex post evidence developed for this study, and a measure of the sensitivity of the benefits to marginal changes in funding, as distinct from the average type of evidence implicit in the benefit–cost ratios reported here, which are more helpful in decisions on whether or not to continue with a program of research.

APPENDIX A

Research Cost Profiles

	Total commodity			Augmented total commodity			Crop improvement			Augmented crop improvement		
	Rice	Beans	Soybeans	Rice	Beans	Soybeans	Rice	Beans	Soybeans	Rice	Beans	Soybeans
	(1999 thousands U.S. dollars)											
Annual expenditures												
1976	2,065	2,065	4,020	2,908	2,908	5,660	629	465	577	821	655	812
1977	2,205	2,205	3,752	3,501	3,501	5,957	682	482	640	969	766	1,017
1978	2,182	2,182	5,181	3,183	3,183	7,559	789	587	821	1,062	856	1,197
1979	2,662	2,662	5,422	4,513	4,513	9,192	880	673	1,000	1,353	1,140	1,695
1980	4,650	4,650	7,462	6,213	6,213	9,970	1,081	761	1,287	1,344	1,017	1,720
1981	4,304	4,304	5,463	5,789	5,789	7,347	1,234	853	1,447	1,545	1,148	1,946
1982	4,048	4,048	5,996	5,835	5,835	8,643	1,436	981	1,550	1,884	1,414	2,234
1983	2417	2,417	3,568	3,305	3,305	4,878	986	683	1,005	1,246	934	1,374
1984	2,292	2,292	2,846	3,031	3,031	3,765	909	668	768	1,132	884	1,016
1985	1,935	1,935	3,543	2,850	2,850	5,217	871	593	896	1,162	873	1,320
1986	2,202	2,202	5,649	2,745	2,745	7,042	949	644	914	1,120	803	1,139
1987	3,015	3,015	4,303	3,960	3,960	5,651	1,216	792	1,080	1,487	1,040	1,419
1988	2,965	2,965	4,502	3,653	3,653	5,547	1,107	735	1,051	1,303	905	1,295
1989	3,901	3,901	6,962	4,862	4,862	8,677	1,709	1,056	1,721	2,009	1,316	2,145
1990	4,449	4,449	6,963	5,627	5,627	8,805	1,779	1,150	2,582	2,123	1,455	3,265
1991	3,585	3,585	5,878	5,086	5,086	8,340	1,444	919	2,178	1,859	1,303	3,090
1992	3,570	3,570	6,236	4,174	4,174	7,293	1,433	899	2,370	1,621	1,052	2,771

1993	4,416	4,416	7,173	5,661	5,661	9,194	1,703	1,084	2,617	2,053	1,390	3,354
1994	4,827	4,827	7,833	6,597	6,597	10,705	1,850	1,178	2,786	2,333	1,610	3,807
1995	6,034	6,034	11,317	7,886	7,886	14,791	2,268	1,478	3,524	2,789	1,932	4,606
1996	8,032	8,032	13,683	11,206	11,206	19,091	2,947	1,883	4,486	3,795	2,627	6,259
1997	5,834	5,834	11,246	8,660	8,660	16,694	2,245	1,429	3,662	3,010	2,121	5,437
1998	5,106	5,106	9,693	7,311	7,311	13,880	2,023	1,321	3,406	2,647	1,892	4,878
Sum	86,696	86,696	148,691	118,556	118,556	203,898	32,170	21,314	42,368	40,667	29,133	57,796
Present value (4%)	133,470	133,470	228,074	183,554	183,554	314,738	48,521	32,536	61,040	61,623	44,727	83,572
Present value (6%)	168,902	168,902	288,474	233,147	233,147	399,729	60,705	40,964	74,675	77,337	56,530	102,541
Annual growth rates						(percentages)						
1976–1979	7.80	7.80	12.98	13.02	13.02	18.45	12.24	13.92	20.92	17.25	19.43	26.77
1980–1989	–3.64	–3.64	–1.23	–4.73	–4.73	–2.34	1.45	0.32	–0.94	0.58	–0.81	–2.06
1990–1998	6.80	6.80	9.23	8.60	8.60	11.08	6.12	6.30	7.33	7.50	8.10	9.14
1976–1998	4.34	4.34	4.37	3.88	3.88	3.91	5.58	4.78	8.40	5.17	4.32	7.92

Source: Authors' calculations.

Note: Growth rates are compound annual growth rates. Commodity costs refer to total research cost for each commodity for Embrapa; crop improvement costs include all costs related to crop improvement research activities. Augmented costs include a prorated share of Sede and CENARGEN costs.

APPENDIX B

Sources of Commercially Significant Upland Rice Germplasm

Institution of release	Agency type	Pedigree source				
		Cultivar	Father	Mother	Grandparents	Total
Brazil						
CNPAF	Embrapa	23			2	25
IAC	Public	5	8	16	30	59
IAPAR	Public	2				2
IPEAS	Public	1				1
Traditional	Other	3		5		8
National Rice Research Project, RS Brazil	Other				1	1
Brazil total		*34*	*8*	*21*	*33*	*96*
International						
CIAT	International			1	3	4
IITA	International		2		3	5
IRAT	International				5	5
IRRI	International		1		2	3
International total		*0*	*3*	*1*	*13*	*17*
France						
CIRAD	Public	1				1
IRAT	Public		10	5		15
France total		*1*	*10*	*5*	*0*	*16*
Traditional or local varieties						
Traditional	Other		2	4	44	26
Total traditional or local varieties		*0*	*2*	*4*	*44*	*26*
Other						
Cameroon	Other				1	1
China	Other				1	1
Colombia	Other				1	1
China	Other				1	1
Philippines	Other				1	1
Côte d'Ivoire	Other				11	11
Mexico	Other		1			1
Taiwan	Other				1	1
West Africa	Other		4		5	9
Zaire	Other				10	10
Unknown cross	Other		3	4	2	9
Unknown	Other		4		16	20
Total other		*0*	*12*	*4*	*50*	*66*
Total		**35**	**35**	**35**	**140**	**245**

Source: Authors' calculations.

Note: Unknown cross means that one of the nodes in the pedigree was a cross for which it was not possible to identify the institution that did the cross.

APPENDIX C

Sources of Commercially Significant Edible Beans Germplasm

		Pedigree source				
Institution of release	Type	Cultivar	Father	Mother	Grandparents	Total
Brazil						
Embrapa	Embrapa	9	2	2	2	15
FT	Private	4	1	4	2	11
CEFET-PR	Public	1	1			
EEP	Public	1	1	2		
EPABA	Public	1	1			
IAC	Public	8	7	8	10	33
IAPAR	Public	4	1	2	4	11
IPA	Public	2	2	4		
IPEACO/EEP/MG	Public	1	1			
PESAGRO	Public	1	1			
ESAL	University	3	3			
UFV	University	1	1			
Brazil total		*31*	*13*	*18*	*22*	*84*
Traditional						
Traditional variety		3	6	6	36	51
Traditional total		*3*	*6*	*6*	*36*	*51*
International						
CIAT	International	5	13	7	30	55
International total		*5*	*13*	*7*	*30*	*55*
Other countries						
INIA (Uruguay)	Public	1	1			
ICA (Colombia)	Public	1	1	5	7	
CATIE (Costa Rica)	University	1	1			
Other (Costa Rica)		2	11	13		
EAP (Honduras)	University	2	2			
Cornell University (U.S.)	University	1	1			
Un. of Nebraska (U.S.)	University	1	1			
Other (Venezuela)		2	2			
CIA (Venezuela)	Public	1	1	2		
Other countries total		*1*	*3*	*2*	*24*	*30*
Unknown or unspecified		0	5	7	48	60
Total		**40**	**40**	**40**	**160**	**280**

Source: Authors' calculations.

APPENDIX D

Sources of Commercially Significant Soybean Germplasm

Institution of release	Type	Pedigree source: Cultivar	Father	Mother	Grandparents	Total
Brazil						
CNPSo	Embrapa	36	8	12	7	63
CPAC	Embrapa	1	2		2	5
CAC	Private	1				1
CEP/FECOTRIGO	Private		2	5	7	14
CEP/FEPAGRO	Private	1				1
COODETEC	Private	15	2	2		19
FECOTRIGO	Private	1	3			4
FEPAGRO	Private	3	1		1	5
FT	Private	21	16	10	24	71
INDUSEM	Private			2		2
OCEPAR	Private		2	1	4	7
EMGOPA	Public	10	3	3	1	17
EPAMIG	Public			1		1
Ex-DNPEA/IPEAME	Public	1		1		2
Ex-IPEAME	Public	2	11	10	23	46
Ex-IPEAS	Public	2	3	1	7	13
IAC	Public	8	5	6	14	33
UFV	University	1	2	1	9	13
UREMG/ESA	University		1	1	6	8
Total Brazil		*103*	*61*	*56*	*105*	*325*
United States						
Arkansas, Hale Seeds Farms	Private				1	1
Coker Pedigree Seed Co., South Carolina	Private		7	2	8	17
Nickerson American Plant Breeders/Northrup King	Private	1	2		2	5
USDA	Public	1	1	1	4	7
USDA Arlington Farm	Public			1	6	7
USDA Florida	Public	2	4	2	9	17
USDA Mississippi	Public		13	12	104	129
USDA North Carolina	Public		1	2	19	22
Arkansas AES	University	1	5	4	10	20
Florida AES	University	1				1
Louisiana AES	University	1	1	1	5	8
North Carolina AES	University				12	12
North Carolina AES/Tennessee AES	University				3	3
Tennessee AES	University			1	7	8
University of Tennessee	University			1	3	4
Missouri AES	University				3	3
Illinois AES and USDA	University/Public			1		1

Institution of release	Type	Pedigree source				
		Cultivar	**Father**	**Mother**	**Grandparents**	**Total**
Hawaii AES/USDA Arkansas	University/Public		1		3	4
Louisiana AES and USDA	University/Public	1	2			3
University of Tennessee/USDA Arlington Farm	University/Public				1	1
Clemson AES and USDA	University/Public				4	4
Illinois AES and USDA	University/Public			1	1	2
Virginia AES and USDA	University/Public				2	2
From U.S. Germplasm Bank				1		1
Total United States		*8*	*37*	*30*	*207*	*282*
Other countries						
Jilin, China					2	2
South Africa or Zimbabwe					1	1
Philippines					2	2
Total other countries		*0*	*0*	*0*	*5*	*5*
Unknown		1	14	26	131	172
Total		**112**	**112**	**112**	**448**	**784**

Source: Authors' calculations.

APPENDIX E

Present Value of Research Benefits with a 10 Percent Discount Rate and a Stream of Benefits Ending in 2003

	Total benefits from varietal change	All credit to last cross		Geometric rule	
		Not partitioned	Partitioned	Not partitioned	Partitioned
			(thousands 1999 U.S. dollars)		
Upland rice					
Enhanced yields	2,354,440	1,578,900	840,157	802,031	426,195
Improved grain quality	238,251				
Edible beans	818,914	376,631	244,431	251,527	164,205
Soybeans	17,399,184	6,361,626	5,770,837	3,630,603	3,335,390
All three crops	20,572,538	8,317,157	6,855,426	4,684,161	3,925,790

Source: Authors' calculations.

Note: "Not Partitioned" indicates that full credit was given to Embrapa for varieties it developed alone or jointly with others. "Partitioned" indicates that Embrapa was given partial credit for varieties developed jointly with others. The present value of benefits from varietal change includes a stream of benefits from 1984 to 2003 for upland rice; 1985–2003 for edible beans; and 1981–2003 for soybeans.

APPENDIX F

Present Value of Research Benefits with a 4 Percent Discount Rate and a Stream of Benefits Ending in 1998

		All credit to last cross		Geometric rule	
	Total benefits from varietal change	Not partitioned	Partitioned	Not partitioned	Partitioned
			(thousands 1999 U.S. dollars)		
Upland rice					
Enhanced yields	1,390,400	936,925	497,858	474,909	252,093
Improved grain quality	55,482				
Edible beans	431,666	177,763	116,812	122,760	8,971
Soybeans	8,423,551	2,945,227	2,777,079	1,652,994	1,569,043
All three crops	10,245,617	4,059,915	3,391,749	2,250,663	1,902,107

Source: Authors' calculations.

Note: "Not Partitioned" indicates that full credit was given to Embrapa for varieties it developed alone or jointly with others. "Partitioned" indicates that Embrapa was given partial credit for varieties developed jointly with others. The present value of benefits from varietal change includes a stream of benefits from 1984 to 1998 for upland rice; 1985–98 for edible beans; and 1981–98 for soybeans.

APPENDIX G

Present Value of Research Benefits with a 10 Percent Discount Rate and a Stream of Benefits Ending in 1998

	Total benefits from varietal change	All credit to last cross		Geometric rule	
		Not partitioned	Partitioned	Not partitioned	Partitioned
		(thousands 1999 U.S. dollars)			
Upland rice					
Enhanced yields	2,060,980	1,314,733	695,995	665,553	352,023
Improved grain quality	60,855				
Edible beans	558,857	217,258	143,081	139,407	92,055
Soybeans	13,115,240	4,164,992	3,977,740	2,310,552	2,217,108
All three crops	15,735,077	5,696,983	4,816,816	3,115,512	2,661,186

Source: Authors' calculations.

Note: "Not Partitioned" indicates that full credit was given to Embrapa for varieties it developed alone or jointly with others. "Partitioned" indicates that Embrapa was given partial credit for varieties developed jointly with others. The present value of benefits from varietal change includes a stream of benefits from 1984 to 1998 for upland rice; 1985–98 for edible beans; and 1981–98 for soybeans.

APPENDIX H

Normalized Research Benefits with a 10 Percent Discount Rate and a Stream of Benefits Ending in 2003

Indicators	Total benefits from varietal change	All credit to last cross		Geometric rule	
		Not partitioned	Partitioned	Not partitioned	Partitioned
	(benefit per unit cost)				
Benefits/crop improvement cost					
Upland rice					
Enhanced yield					
Baseline	24.0	16.1	8.6	8.2	4.3
Augmented	18.7	12.5	6.7	6.4	3.4
Improved grain quality					
Baseline	2.4				
Augmented	1.9				
Edible beans					
Baseline	12.2	5.6	3.6	3.7	2.4
Augmented	8.8	4.0	2.6	2.7	1.8
Soybeans					
Baseline	150.0	54.9	49.8	31.3	28.8
Augmented	108.4	39.6	36.0	22.6	20.8
All three crops					
Baseline	73.1	29.6	24.4	16.6	14.0
Augmented	54.1	21.9	18.0	12.3	0.3
Benefits/total crop research costs					
Upland rice					
Enhanced yield					
Baseline	8.4	5.6	3.0	2.9	1.5
Augmented	6.0	4.1	2.2	2.1	1.1
Improved grain quality					
Baseline	0.9				
Augmented	0.6				
Edible beans					
Baseline	2.9	1.3	0.9	0.9	0.6
Augmented	2.1	1.0	0.6	0.6	0.4
Soybeans					
Baseline	36.3	13.3	12.1	7.6	7.0
Augmented	26.0	9.5	8.6	5.4	5.0

(continued)

Indicators	Total benefits to varietal change	All credit to last cross		Geometric rule	
		Not partitioned	Partitioned	Not partitioned	Partitioned
		(benefit per unit cost)			
All three crops					
Baseline	19.8	8.0	6.6	4.5	3.8
Augmented	14.2	5.7	4.7	3.2	2.7
		(thousands 1999 U.S. dollars)			
Benefits/FTE					
Upland rice					
Enhanced yield	15,703	10,530	5,603	5,349	2,842
Improved grain quality	1,589				
Edible beans	5,386	2,477	1,607	1,654	1,080
Soybeans	59,425	21,727	19,709	12,400	11,392
All three crops	34,588	13,983	11,526	7,875	6,600

Source: Authors' calculations.

Note: FTE refers to the average annual full-time equivalent of researchers between 1976 and 1998. "Not Partitioned" indicates that full credit was given to Embrapa for varieties it developed alone or jointly with others. "Partitioned" indicates that Embrapa was given partial credit for varieties developed jointly with others. The present value of benefits from varietal change includes a stream of benefits from 1984 to 2003 for upland rice; 1985–2003 for edible beans; and 1981–2003 for soybeans.

APPENDIX I

Normalized Research Benefits with a 4 Percent Discount Rate and a Stream of Benefits Ending in 1998

Indicators	Total benefits from varietal change	All credit to last cross: Not partitioned	All credit to last cross: Partitioned	Geometric rule: Not partitioned	Geometric rule: Partitioned
		(benefit per unit cost)			
Benefits/crop improvement cost					
Upland rice					
Enhanced yield					
Baseline	28.7	19.3	10.3	9.8	5.2
Augmented	22.6	15.2	8.1	7.7	4.1
Improved grain quality					
Baseline	1.1				
Augmented	0.9				
Edible beans					
Baseline	13.3	5.5	3.6	3.8	2.5
Augmented	9.7	4.0	2.6	2.7	1.8
Soybeans					
Baseline	138.0	48.3	45.5	27.1	25.7
Augmented	100.8	35.2	33.2	19.8	18.8
All three crops					
Baseline	72.1	28.6	23.9	15.8	13.4
Augmented	53.9	21.4	17.9	11.9	10.0
Benefits/total crop research costs					
Upland rice					
Enhanced yield					
Baseline	10.4	7.0	3.7	3.6	1.9
Augmented	7.6	5.1	2.7	2.6	1.4
Improved grain quality					
Baseline	0.4				
Augmented	0.3				
Edible beans					
Baseline	3.2	1.3	0.9	0.9	0.6
Augmented	2.4	1.0	0.6	0.7	0.4
Soybeans					
Baseline	36.9	12.9	12.2	7.2	6.9
Augmented	26.8	9.4	8.8	5.3	5.0
All three crops					
Baseline	20.7	8.2	6.9	4.5	3.8
Augmented	15.0	6.0	5.0	3.3	2.8

(continued)

Indicators	Total benefits to varietal change	All credit to last cross		Geometric rule	
		Not partitioned	Partitioned	Not partitioned	Partitioned
		(thousands 1999 U.S. dollars)			
Benefits/FTE					
Upland rice					
Enhanced yield	9,273	6,249	3,320	3,167	1,681
Improved grain quality	370				
Edible beans	2,839	1,169	768	807	533
Soybeans	28,769	10,059	9,485	5,646	5,359
All three crops	17,226	6,826	5,702	3,784	3,198

Source: Authors' calculations.

Note: FTE refers to the average annual full-time equivalent of researchers between 1976 and 1998. "Not Partitioned" indicates that full credit was given to Embrapa for varieties it developed alone or jointly with others. "Partitioned" indicates that Embrapa was given partial credit for varieties developed jointly with others. The present value of benefits from varietal change includes a stream of benefits from 1984 to 1998 for Upland rice; 1985–1998 for edible beans; and 1981–1998 for soybeans.

APPENDIX J

Normalized Research Benefits with a 10 Percent Discount Rate and a Stream of Benefits Ending in 1998

Indicators	Total benefits from varietal change	All credit to last cross: Not partitioned	All credit to last cross: Partitioned	Geometric rule: Not partitioned	Geometric rule: Partitioned
		(benefit per unit cost)			
Benefits/crop improvement cost					
Upland rice					
Enhanced yield					
Baseline	21.0	13.4	7.1	6.8	3.6
Augmented	16.3	10.4	5.5	5.3	2.8
Improved grain quality					
Baseline	0.6	0.0	0.0	0.0	0.0
Augmented	0.5	0.0	0.0	0.0	0.0
Edible beans					
Baseline	8.3	3.2	2.1	2.1	1.4
Augmented	6.0	2.3	1.5	1.5	1.0
Soybeans					
Baseline	113.1	35.9	34.3	19.9	19.1
Augmented	81.7	26.0	24.8	14.4	13.8
All three crops					
Baseline	55.9	20.2	17.1	11.1	9.5
Augmented	41.4	15.0	12.7	8.2	7.0
Benefits/total crop research costs					
Upland rice					
Enhanced yield					
Baseline	7.4	4.7	2.5	2.4	1.3
Augmented	5.3	3.4	1.8	1.7	0.9
Improved grain quality					
Baseline	0.2				
Augmented	0.2				
Edible beans					
Baseline	2.0	0.8	0.5	0.5	0.3
Augmented	1.4	0.6	0.4	0.4	0.2
Soybeans					
Baseline	27.4	8.7	8.3	4.8	4.6
Augmented	19.6	6.2	5.9	3.5	3.3

(continued)

Indicators	Total benefits to varietal change	All credit to last cross		Geometric rule	
		Not partitioned	Partitioned	Not partitioned	Partitioned
		(benefit per unit cost)			
All three crops					
Baseline	15.1	5.5	4.6	3.0	2.6
Augmented	10.9	3.9	3.3	2.2	1.8
		(thousands 1999 U.S. dollars)			
Benefits/FTE					
Upland rice					
Enhanced yield	13,745	8,768	4,642	4,439	2,348
Improved grain quality	406				
Edible beans	3,675	1,429	941	917	605
Soybeans	44,793	14,225	13,585	7,891	7,572
All three crops	26,455	9,578	8,098	5,238	4,474

Source: Authors' calculations.

Note: FTE refers to the average annual full-time equivalent of researchers between 1976 and 1998. "Not Partitioned" indicates that full credit was given to Embrapa for varieties it developed alone or jointly with others. "Partitioned" indicates that Embrapa was given partial credit for varieties developed jointly with others. The present value of benefits from varietal change includes a stream of benefits from 1984 to 1998 for Upland rice; 1985–1998 for edible beans; and 1981–1998 for soybeans.

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