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Philip G. Pardey, Julian M. Alston, Connie Chan-Kang,
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International and Institutional R&D Spillovers: Attribution of Benefits Among Sources for Brazil's New Crop Varieties

July 19, 2002

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Abstract

In general, reported rates of return to agricultural R&D are high, but questions have been raised about upward biases in the evidence. Among the reasons for this bias, insufficient attention to attribution aspects—matching of research benefits and costs—is a pervasive problem, the magnitude of which is illustrated here with new evidence for Brazil. Over the period 1981 to 2003, varietal improvements in upland rice, edible beans, and soybeans yielded benefits attributable to research of $14.8 billion in present value (1999 prices) terms; 6.1 percent of the corresponding value of crop output. If all of those benefits 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. If 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. The sources of these gains vary markedly among crops and over time, making it hard to generalize about the international and institutional origins of varietal innovations in Brazilian agriculture during the past several decades.

Keywords: Brazil, agricultural R&D, attribution, soybeans, rice, beans, benefit-cost ratios

The returns-to-research literature has contributed to a widespread agreement among agricultural economists and other agricultural scientists that the payoffs to agricultural R&D have been high (Alston et al. 2000). Much of this literature has dealt with varietal-improvement research. Nevertheless, relatively little is known about the precise origins of the relevant R&D or sources of many of the varietal innovations that gave rise to the historically unprecedented growth in yields of particular crops in particular countries during the last half of the 20th century, nor how the sources of innovation may have changed over time.[1] Are the gains largely attributable to home-grown technologies or spillins of results developed elsewhere, what shares of the gains are attributable to efforts by farmers or public versus private research, or research done by particular agencies, and do these dimensions remain stable over time or vary among crops?

Here we deal with how to attribute 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 (in this case, upland rice, edible beans, and soybeans). It is more difficult to measure the benefits attributable to any one agency such as Embrapa—the primary agricultural research agency 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 institutional dimension of 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

[1] The more-general literature contains several excellent general treatments of elements of the topic. Smith (1998) describes the origins of plant and animal domestication, and Diamond (1997) analyzes their subsequent spread worldwide. Evans (1993) deals mainly with the scientific underpinnings of the growth in crop yields, while Olmstead and Rhode (2002) using the example of wheat, re-examine the timing and magnitude of the effects of biological innovations in U.S. agriculture. And there are a small number of specific exceptions, such as Griliches' (1958) pioneering study of hybrid corn in the United States.

attributable to those varieties. Further challenges arise in defining the relevant counterfactual—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.

In dealing with these generally neglected attribution problems, we show they have substantial implications for the reported returns to research while also substantially enriching our understanding of the international and institutional sources of crop varietal change in Brazil. To do this we use an entirely new, detailed set of data compiled specifically for the purpose.

Economic Effects of New Varieties

For an imported good (such as edible beans or rice in the Brazilian economy) or an exported good (such as soybeans in the Brazilian economy) it is necessary to allow explicitly for international trade when computing the price and welfare effects of a given innovation. It is also necessary to allow for technology spillovers (i.e., when other countries adopt the results from domestic R&D or vice versa) in order to obtain correct measures of the domestic effects of domestic research. 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.

Figure 1 represents the adoption of higher-yielding crop varieties in the case of a large-country exporter. In this model S represents Brazil's supply, D_T represents the total demand (the sum of domestic and export demand) and D_d represents domestic demand. When supply shifts down by R per unit through competitive responses to the lower cost of production, adoption of the new variety leads to an increase in production and consumption from Q_0 to Q_1, and the world market price falls from P_0 to P_1.

[Figure 1: *Benefits from adopting a high yielding variety in a large exporting country*]

Although they receive a lower price per unit, producers are better off, because their unit costs have fallen by an amount, R per unit, that is more than the change in price, $\Delta P = P_1 - P_0$.[2] Producer profits per unit rise by $R+\Delta P$ (where ΔP is a negative number in the case of a research-induced fall in price). Hence producer benefits are approximately equal to quantity produced times the benefit per unit—i.e., $Q\times(R+\Delta P)$. Consumers benefit from the lower price by an amount approximately equal to their cost-saving on the total quantity consumed—i.e., $-\Delta P\times Q$. Total benefits are obtained as the sum of producer and consumer benefits.

As an approximation, the cost-saving per unit multiplied by the total quantity is often used as the measure of *gross annual research benefits*—i.e., $GARB = R\times Q$.[3] Some of the consumer benefits, however, accrue to foreign "consumers." Here, the benefits can be approximated as:[4]

[2] For reasonably small price changes (say, less than 10 percent) we can use the approximation: $\Delta P = -R/(\varepsilon+\eta)$, where ε is the elasticity of supply and η is the absolute value of the elasticity of demand. Similarly, we can approximate the change in quantity using $\Delta Q = (Q/P)(\eta R)/(\varepsilon+\eta)$. For traded goods the relevant elasticities of demand are those facing suppliers of the domestic product, after allowing for the demand for exports or the supply of imports as well as the domestic demand.

[3] Martin and Alston (1997) showed that this same approximation to producer surplus would be an *exact* measure of the change in producer profit under the functional forms and other assumptions that often underpin the producer surplus estimation.

[4] The conventional measures include the triangles as well as the rectangles of producer and consumer surplus trapezoids. Hence, a slightly better approximation to the conventional measures of benefits is given

domestic consumer benefit:

$$\text{Ä}CS_d = -\, C \times \text{Ä}P \quad (1a)$$

foreign "consumer" benefit:

$$\text{Ä}CS_f = (C\text{-}Q) \times \text{Ä}P \quad (1b)$$

domestic producer benefit:

$$\text{Ä}PS = Q \times (R + \text{Ä}P) \quad (1c)$$

total domestic benefit:

$$\text{Ä}NS = Q \times R - (C\text{-}Q) \times \text{Ä}P \quad (1d)$$

global benefit:

$$\text{Ä}WS = Q \times R \quad (1e)$$

The total domestic benefit depends on the change in the world price. Hence, if the technological change leads to significant changes in the world price, we have to measure this price change, and pay attention to the difference between quantities produced and consumed, in order to measure the total domestic benefits. In the present context, 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. However, 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. Even though we might safely assume away technology spillout

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by replacing the relevant initial quantity, C_0 or Q_0, with the average of the corresponding pre- and post-research quantities.

effects, we cannot assume that world prices are unaffected by the adoption of Embrapa crop varieties in Brazil, at least in the case of soybeans.[5]

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. Experimental data have the advantage 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, and past studies have shown that the correspondence between experimental yields and industry yields is poor.[6] Here we apply an index of proportional growth of experimental yields to industry output.

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 want a "with-and-without" measure of the effect

[5] 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 η = -0.5, then the short-run 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 short-run elasticity because it does not allow for any supply response in other countries. Such elasticities 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 benefits. 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.

[6] 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. Alston, Norton, and Pardey (1995, pp. 338-340), and the references cited therein, discuss these issues in more detail. There may be grounds for scaling down experimental yield gains to better reflect yield gains on-farm—but it would probably be an over-correction to scale down the gains in proportion to the usual differences between experimental and industry yields.

of varietal change. That is, we want 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 we want to have information on the adoption of varieties over time (and, for question (b), whether they were Embrapa releases), and measures of varietal performance.

A measure of *actual* experimental yield performance in region r in year t, given the actual adoption pattern and the observed experimental yields can be defined as

$$Y_{rt}^{a} = \sum_{i=1}^{n} Y_{irt}\pi_{irt} \text{ where } \pi_{irt} = \frac{A_{irt}}{A_{rt}} \text{ where } A_{rt} = \sum_{i=1}^{n} A_{irt} \quad (2)$$

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 index of *counterfactual* 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 (i.e., 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)

$$Y_{rt}^{b} = \sum_{i=1}^{n} Y_{irt} p_{irb} \; . \quad (3)$$

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 yield attributable to varietal improvement, for each region is given by:

$$k_{rt} = \left(\frac{Y_{rt}^{a} - Y_{rt}^{b}}{Y_{rt}^{a}} \right), \tag{4}$$

where, as defined above, Y_{rt}^{b} denotes an index of experimental yield computed using the base-year area weights (i.e., in the absence of varietal innovation), and Y_{rt}^{a} denotes an index of experimental yield computed using the actual area weights (i.e., 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), as follows.

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:

$$Y_{ist} = \sum_{i=1}^{I} \alpha_i DV_i + \sum_{v=1}^{t} \beta_v V_i + \sum_{t=1}^{T} \gamma_t DT_t + \sum_{s=1}^{S} \delta_s DS_s + \phi_r W_{r(s)t} + e_{ist} \tag{5}$$

where the variables in the regression are defined as follows: Y_{ist} is the experimental yield of variety i at site s in year t; 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; V_i is the year of release of variety i, which must fall before the year of the trial; 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; 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; $W_{r(s)t}$ is an index of weather in region r (that contains site s) in year t (or it could be a vector of such indexes); and e_{ist} is the residual from the model.

Then, taking the estimated parameters of the model (denoted by the "hats") we can compute fitted values (also denoted by "hats") for the experimental yields of each variety included in the sample, for every year and every region as follows:

$$\hat{Y}_{irt} = \sum_{i=1}^{I} \hat{\alpha}_i DV_i + \sum_{v=1}^{t} \hat{\beta}_v V_i + \sum_{t=1}^{T} \hat{\gamma}_t DT_t + \hat{\delta}_s DS_{s(r)} + \hat{\phi}_r W_{rt} \tag{5}$$

where $DS_{s(r)}$ is the site-dummy for the site, $s(r)$, that is selected to represent region r. These fitted values can then play the role of data in the indexes, above.

The k factor (equation 4) can be used as a measure of the proportional shift in supply, as a result of the actual varietal adoption pattern relative to the counterfactual alternative scenario of no varietal change.[7] 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:

$$B_{rt} = k_{rt} P_t Q_{rt}. \tag{7}$$

Attribution of Credit

Embrapa's varietal improvement research is not done in isolation from the research that preceded it, nor from the contemporary research done by others. Some of Embrapa's

[7] 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 (such as dysfunctional seed markets), 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 as their resistance to evolving populations of pests and disease deteriorates, or decline relative to the yields of newly released varieties with superior yield prospects (or at least farmers perceive relative yields in this way, as they typically do not observe the comparative yields of base-year and new varieties in each year). 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.

research draws on this contemporary research in an arms-length fashion; some is done as joint research. If 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

$$B_{rt}^{E} = B_{rt} \sum_{i=1}^{n} E_i \pi_{irt} . \tag{8}$$

Here we consider two options for estimating attribution weights (i.e., the E_is) that reflect these other participants. 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.[8] 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 "Embrapaness" 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, none to its parents that still exist as varieties in their own right. This is a 0 or 1 index, which is 1 for varieties (or breeding lines) released by the program and 0 for all others.

[8] A multiplicity of rules has been used in the past to attribute benefits from varietal improvement across stages of varietal development (Pardey et al. 1996). In essence, these rules vary in terms of the benefits they ascribe on the basis of breeders' efforts (i.e., using crosses as the basis of attribution) and on the basis of various views on genetic content (i.e., using 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. Brennan and Fox, 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 a parent bred by CIMMYT, an international research center located in Mexico, 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. See Brennan (1986, 1989) and Byerlee and Moya for other examples.

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. When the allocation stops at generation G, $1/2^{(2G)}$ of the benefits are 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).

Another, sometimes complementary, approach is to attribute benefits on an *institutional* basis, recognizing the contemporary role of other state agencies and universities (and even some private firms) in the conduct of Embrapa research. One simple option is to prorate the benefits on the basis of the number of partners. 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 it may be more appropriate to take account of these unequal contributions. For each of the new varieties included in this study, we elicited a set of weights from scientific staff at CNPAF (Embrapa's upland rice and bean center) and CNPSo (Embrapa's soybean research center) 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 here.[9]

[9] 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.

Varietal Research, Releases, Uptake, and Yield Consequences

Embrapa, a public corporation established by the Brazilian federal government in 1972, accounts for more than one quarter of the total agricultural research spending in Latin America and is the country's dominant research agency with about 57 percent of total agricultural research spending in 1996, the latest year for which national totals are available (Beintema, Avila and Pardey 2001). About one-half of Embrapa's research is concerned with crops and over one-third of that research deals directly with crop genetic improvement (i.e., breeding and related research). Embrapa's Upland Rice and Bean Research Center (CNPAF) is headquartered in Goiânia, Goiás and was formally established in 1974. The agency's Soybean Research Center (CNPSo) began operations in 1975 and is headquartered in Londrina, Paraná.

We used a combination of survey and secondary data sources to develop research cost data, for the period 1975-1998, for each crop varietal improvement program within Embrapa, for the respective Embrapa center conducting the varietal-improvement research, and for Embrapa's overall program of research (see Pardey et al. 2002 for details). A set of baseline costs include the costs of all the research and support staff involved in crop improvement research (i.e., crop breeders as well as the appropriate shares of agronomy, plant pathology, entomology and other scientific staff) and associated capital and operational costs incurred at the centers. Center budgets do not account for all of 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 pre-breeding and other biotechnology activities undertaken by CENARGEN (Embrapa's genetic resources and biotechnology center) 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 reported in this paper includes center-specific costs to which have been added a suitable share of Sede and CENARGEN costs in order to match the benefit stream more closely to the total crop-improvement costs incurred by Embrapa.

From 1976 to 1998, investments in crop-improvement research for all three crops trended upward in real terms, with higher rates of growth for soybeans (7.92 percent per year) than for upland rice (5.16 percent) and edible beans (4.32 percent) and some variation around this trend. In present value terms, compounding forward from 1976 to 1998 using a real discount rate of 4 percent per annum, $83.6 million (1999 prices) was invested in varietal improvement research related to soybeans (including prorated CENARGEN and Sede costs), nearly twice the $44.7 million present value of investment in varietal improvement research for beans, and substantially more than the $61.6 million invested in rice. The crop-specific 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. Factoring in a share of the costs incurred by Sede (Embrapa headquarters) and CENARGEN as a kind of institutional overhead 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.

Among the three crops 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 (Table 1). Embrapa accounted for the lion's share (77 percent) of all upland rice varieties released in Brazil between 1976 and 1999, but contributed a smaller share of the country's 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 like 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 the international research center CIAT, which is based in Colombia, but had a continuing research presence at CNPAF by way of an out-posted crop breeder from 1982 to 1996, who continued to contribute from CIAT on a contract basis since then).[10] Less than 10 percent of the bean releases came from the private sector while nearly half the soybean releases from 1976 to 1999 were by private firms, with a notable but more limited role played by other public agencies. For all three crops in our study comparatively few of the releases came from universities.

[Table 1: *Summary of Varieties Released*]

The area-by-variety data we compiled for upland rice, edible beans, and soybeans reveal a complex, location-specific, and time-varying pattern, from which few generalizations are possible.[11] In 1986, several varieties developed by Instituto Agronômico de Campinas, IAC,[12] (specifically *IAC 25*, *47*, *164*, and *165*) were 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 acreage 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 (i.e., grown on at least 10

[10] 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. Presently one economist from CIRAD is located at CNPAF in Goiânia.

[11] We used unpublished seed production data obtained from Embrapa and returns from our own recall survey of breeders and those knowledgeable about the respective crop industries to construct area-by-variety estimates for each of the major crop producing states, mindful of the pitfalls in translating seed production to sown area estimates.

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

percent of the area under upland rice) in only two states. *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 with 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 second-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). Farmers appear to use a greater mix of varieties for beans than for upland rice. This is perhaps a reflection of the greater total number of bean varieties released since the mid-1980s, combined with a persistence of traditional varieties in states like Bahia (which accounted for 17 percent of the 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 to have been higher for soybeans than it was for either upland rice or edible beans. In Goiás, Paraná, and Mato Grosso, none of the 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.

We worked closely with Embrapa breeders to compile over 1,600 trial results for upland rice and soybeans (and more than 2,000 observations for edible beans) of the experimental yield performance of particular varieties, in particular locations, in particular years. Table 2 summarizes these data, which we used in our regression analysis to compute fitted values for the experimental yields of each adopted variety at each experimental site in each year. The fitted models accounted for a substantial share of the observed variation in experimental yields with R^2 adjusted for degrees of freedom of 0.39 for upland rice and 0.48 for both edible beans and soybeans.

[Table 2: *Overview of Data and Goodness of Fit of Regression Models*]

Figure 2 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 for 22 trial locations in Paraná[13] (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 average of the fitted experimental yields using the actual harvested area shares of each variety as the weights (i.e., the *actual* yield performance, Y_{rt}^{a}, computed using equation 2).

[Figure 2: *Various soybean yield estimates for the state of Paraná*]

[13] With 21.9 percent of the country' soybean production in 2001, Paraná was second to Mato Grosso, which had 26.8 percent of total output.

The fitted experimental soybean yields were higher than the corresponding commercial yields: fitted experimental yields averaged 709 kg per hectare (33 percent) more than industry yield from 1981 to 1998, with the difference being a little less in the 1990s (695 kg per hectare, 30 percent) than the 1980s (723 kg per hectare, 36 percent). 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 average of the fitted experimental yields. During the 1980s, industry yields grew by 1.06 percent per year while the weighted average of the fitted experimental yields virtually stagnated. Industry yields continued to grow during the 1990s (at 2.75 percent per year), but experimental yields grew even faster, albeit erratically, at an average rate of 4.76 percent per year for the period.

Differences in the weighted-average of the fitted experimental yields, with and without varietal change, provide the basis for estimating the benefits from varietal change. Panels a, b, and c in figure 3 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 $k_{rt} = 1 - I_{rt}$, where I_{rt} is the ratio given by the *counterfactual* index of experimental yields, Y_{rt}^{b} (i.e., assuming the pattern of varietal use observed in the base year for each state remained unchanged over the subsequent years), divided by the *actual* index of experimental yields, Y_{rt}^{a} (i.e., 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, a national average would not represent the pattern of change in any particular state.

[Figure 3: *Proportionate shifts in supply (k) for various states and various crops*]

Benefit Measures and Their Attribution

Supply shift estimates, k_{rt}, illustrated for selected states in figure 3, in conjunction with world market prices for 1999 (expressed 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.[14]

We estimate the present value of total benefits to Brazil from yield-improving varietal changes in upland rice from 1984 to 2003 was $1.68 billion (1999 prices) or 3.8 percent of the present value of total production over the entire period (table 3, top half). The total present value of benefits from adopting improved edible bean varieties is estimated to be $678 million (1.73 percent of the corresponding value of production) while the use of improved soybean varieties was worth an estimated $12.5 billion to Brazil (nearly 8 percent of the $159 billion present value of production). These estimates represent upper bound estimates of the benefits attributable to Embrapa, since some of the benefits are attributable to the efforts of others.

[Table 3: *Present Value of Research Benefits*]

If, in spite of this fact, we attribute all of the benefits to Embrapa, the benefit-cost comparison is very favorable. For every dollar invested by Embrapa in developing new upland rice varieties, about 27 dollars of benefits accrued to Brazil (left-hand data

[14] National totals were 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 (that 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 multi-state totals were recalibrated on a year-by-year basis to generate a national total according to their corresponding share of Brazilian production.

column, bottom half of table 3), and 149 dollars of benefits for every dollar invested in soybean research. Even edible bean research, the least profitable of the three programs evaluated in this study, generated 15 dollars of benefits for every dollar invested by Embrapa in breeding new varieties for this crop.

Genetic History and International-cum-Institutional Attribution of Benefits

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).[15] These varieties made it possible to grow soybeans successfully in tropical latitudes like the Cerrados region in Brazil, which sits well to the north of the Tropic of Capricorn. During the 1960s and 1970s, U.S. varieties and breeding lines were introduced and tested in Brazil, with support from 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 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 specific varieties 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.

Using the last-cross rule, 40 percent of the total benefits from the use of improved soybeans (i.e., $5.0 billion of the total of $12.5 billion) are attributed to Embrapa research (table 3). Using the geometric rule that gives weight to prior research as well as the

[15] Breeding soybeans suitable for the tropics requires modifying the plant's juvenile period. Day-length insensitive varieties were developed in the southern United States from research dating back to the 1930s. Research 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 varieties that resist a range of pests and diseases.

agency that released the variety, the Embrapa share drops to $2.9 billion, or 23 percent of the total benefits, reflecting less "Embrapaness" in earlier generations.[16]

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 for 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 gets 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) then does research aimed at breeding new varieties of the other two crops.

Attribution among Collaborators

All of the upland rice and edible bean varieties involved some research collaboration. Over 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

[16] Ayres estimated the benefits from Brazilian soybean research conducted between 1955 and 1983 using supply shift parameters based on estimated production and industry yield functions that included research stock measures as estimators. Research stocks were formed using comparatively short lag lengths (ranging from 9 to 15 years) and an estimate of the total Brazilian investment in soybean research, but omitting investments made outside Brazil. All of the gains were attributed to Brazilian research investments. The reported marginal internal rates of return ranged from 40 to 49 percent and, for selected states within Brazil, from 21 to 74 percent.

partners—nearly 70 percent of the varieties involved two or more partners and some varieties involved as many as 11 or 12 partners. The propensity to work with partners was much lower for soybean research. CNPSo alone developed about one-third of the Embrapa releases, and one-half of the releases involved only a single collaborating institution.

A significant proportion of these partnerships were with other Embrapa centers. Of the 104 partnerships CNPSo formed in developing 122 soybean varieties from 1976 to 1999 (noting that an additional 44 varieties were developed without partners), 19 percent of these partnerships involved other Embrapa centers. About 9 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 22 edible bean varieties were also from Embrapa. For rice and beans all the remaining collaborators were other public institutions (mainly state agencies).[17] Soybean varieties developed by CNPSo involved less collaboration than the rice and beans research at CNPAF, but a greater diversity of collaborators. Only 39 percent of the collaborators were other public agencies, about 16 percent of the partnerships involved private firms.

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 with $642,020 in table 3) 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. 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 with $4.47 million in table 3).

[17] Public institutions include other federal and state agencies and universities.

The geometric rule gives more weight to earlier ancestors than the last-cross rule. 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 table 3).

Synthesis of Elements of Attribution

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 (table 4).

[Table 4: *Institutional Origins of Research Benefits*]

Using the last-cross rule, 59.7 percent of the total soybean benefits are attributed to non-Embrapa sources and most of that benefit 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 United States) sources increases substantially from 4.2 to 21.7 percent. Drawing on all this evidence, we see that since 1981, CNPSo accounted 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[18]; and the genetic material underpinning Brazilian soybean varieties has drawn heavily from non-Embrapa (significantly United States) sources. The non-Embrapa content of upland

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

rice varieties has been much more reliant on domestic sources compared with soybeans, while edible bean varieties have drawn more heavily on foreign sources than either rice or soybeans (CIAT is a major source of the pedigree material used by CNPAF and other local breeders, and a nontrivial amount of foreign-sourced varieties are used directly by Brazilian farmers).

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 lie behind them. Here we evaluate 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.

Table 5 reports the present value of benefits and benefit-cost ratios for each crop using two discount rates (4 and 6 percent) and a longer (through to 2003) and shorter (through to 1998) lag length for the stream of benefits against which the 1976-1998 cost streams are compared. It typically takes 7-10 years of directed breeding to develop a new crop variety, but the cumulative nature of innovation means the lag between investing in R&D and reaping the full rewards of that investment are very long, perhaps infinite

(Alston, Craig, and Pardey 1998). This is especially true of crop improvement research where breeding lines and varieties developed in the distant past form parts of the pedigrees of contemporary varietal releases. 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.[19] 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 5), instead of 2003 reported elsewhere in this paper (and denoted “longer” in table 5). 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.

[Table 5: *Sensitivity Analysis*]

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. Since 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 5 also presents results for a 6 percent discount rate. 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

[19] 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. (2000).

the discount rate was increased from 4 to 6 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.

Comparing the second and third tiers of table 5 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 above 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 Fullerton (1991) suggests a social cost of U.S. government spending in the range of 1.07 to 1.24 times the amount spent.[20] 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 as revealed by a comparison of the middle and bottom blocks of data in table 5.[21]

Conclusion

As pointed out by Alston and Pardey (2001), attribution problems abound in the assessment of agricultural R&D. While 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

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

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

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 (2) 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 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 (non-varietal) 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), but 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.

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Table 1: *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		2	0.08	5.7	0.0
Total		*35*	*1.46*	*100*	*57.1*
Edible beans[b]	1984-99				
Embrapa (CNPAF)		22	1.38	29.3	72.7
International Agencies		18	1.13	24.0	38.9
Other Public		25	1.56	33.3	60.0
University		3	0.19	4.0	66.7
Private		7	0.44	9.3	57.1
Total		*75*	*4.69*	*100*	*58.7*
Soybeans	1976-98				
Embrapa (CNPSo)		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*	*55.8*

Source: Authors' calculations based on own survey data and CNPAF (1974-1993, 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] There were no edible bean varieties released in Brazil in 2000. Two new varieties were released in 2001, both developed by CNPAF.

Table 2: *Overview of Data and Goodness of Fit of Regression Models*

	Years of Trials	Year of release	Number of trial locations	Number of varieties	Number of observations	Adjusted R^2
Upland rice	1984-99	1971, 1974, 1983 1985-89, 1991-93, 1996-97, 1999	66	29	1,680	0.39
Edible beans	1985-89 1991-99	1984-94, 1996-97	110	73	2,281	0.48
Soybeans	1976-78, 1980-97, 1999	1965-67, 1969, 1972-73, 1976-77, 1979-85, 1987-93, 1995-97	124	72	1,673	0.48

Table 3: *Present Value of Research Benefits*

	Total benefits from varietal change	All credit to last cross		Geometric rule	
		Not partitioned	Partitioned	Not partitioned	Partitioned
		(thousands 1999 U.S. dollars)			
Present value of benefits					
Upland rice	1,683,861	1,201,092	642,020	611,387	326,265
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*
Benefit-cost ratios with augmented costs					
Upland rice	27	20	10	10	5
Edible beans	15	7	5	5	3
Soybeans	149	60	54	35	31
	78	*35*	*28*	*20*	*16*

Source: Authors' calculations using data from CONAB (1970-2000), Embrapa (2000a – f), Embrapa-DAP (2000), FVG (various years), IBGE (various years), LSPA and IBGE (2001), and Martinez and Cuevas-Pérez (1995).

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. Direct estimates of the benefits from varietal change in upland rice were for the period 1984 to 1999 (and from 1985 to 1998 for edible beans, and 1981 to 1998 for soybeans). To get 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 for each year) to 2003 in each instance.

Table 4: *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*	*100*
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*	*100*
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*	*100*

Source: Authors' calculations as well as Martinez and Cuevas-Pérez (1995), NGRP (2001), USDA-ARS (2001a and b), and Voysest (2000).

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.

Table 5: *Sensitivity Analysis*

	4 percent		6 percent	
	Longer	Shorter	Longer	Shorter
	(thousands 1999 U.S. dollars)			
Present value of research benefits				
Upland rice	326,265	252,093	355,634	296,296
Edible beans	144,172	80,971	150,497	80,971
Soybeans	2,626,328	1,569,043	2,831,584	1,753,966
	(1999 U.S. dollars)			
Benefit-cost ratios				
Upland rice	5.3	4.1	4.6	3.8
Edible beans	3.2	1.8	2.7	1.4
Soybeans	31.4	18.8	27.6	17.1
Benefit-cost ratios (with costs increased by 20 percent)				
Upland rice	4.4	3.4	3.8	3.2
Edible beans	2.7	1.5	2.2	1.2
Soybeans	26.2	15.6	23.0	14.3

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, 1985-1998 for beans, and 1981-1998 for soybeans.

Figure 1: *Benefits from adopting a high yielding variety in a large exporting country*

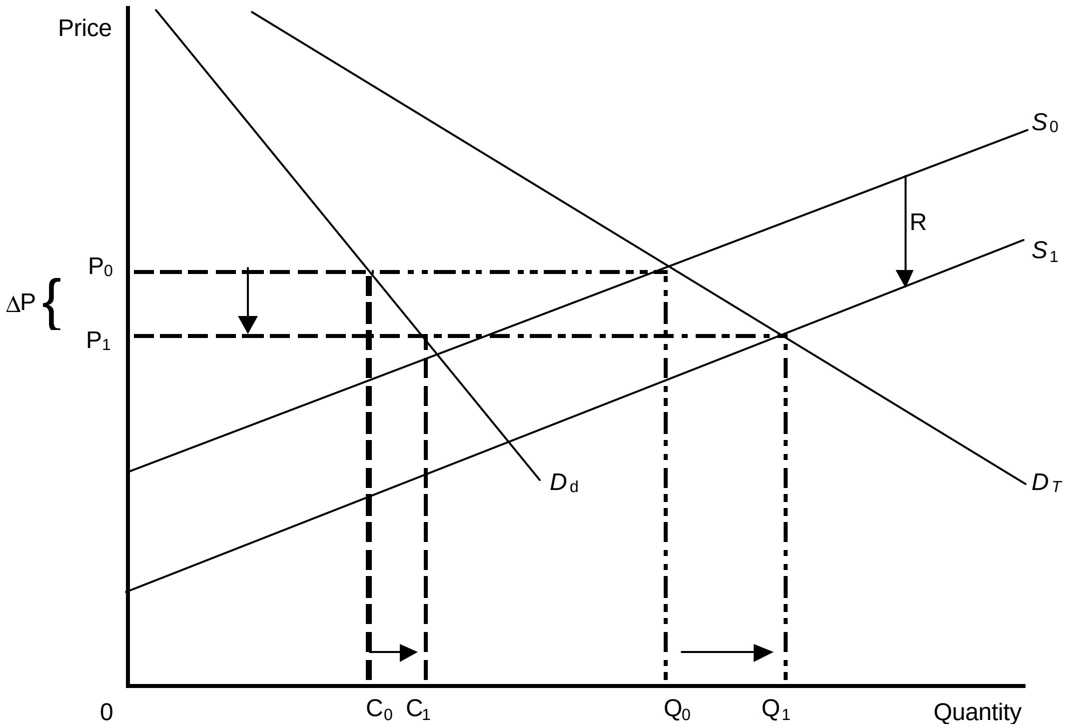
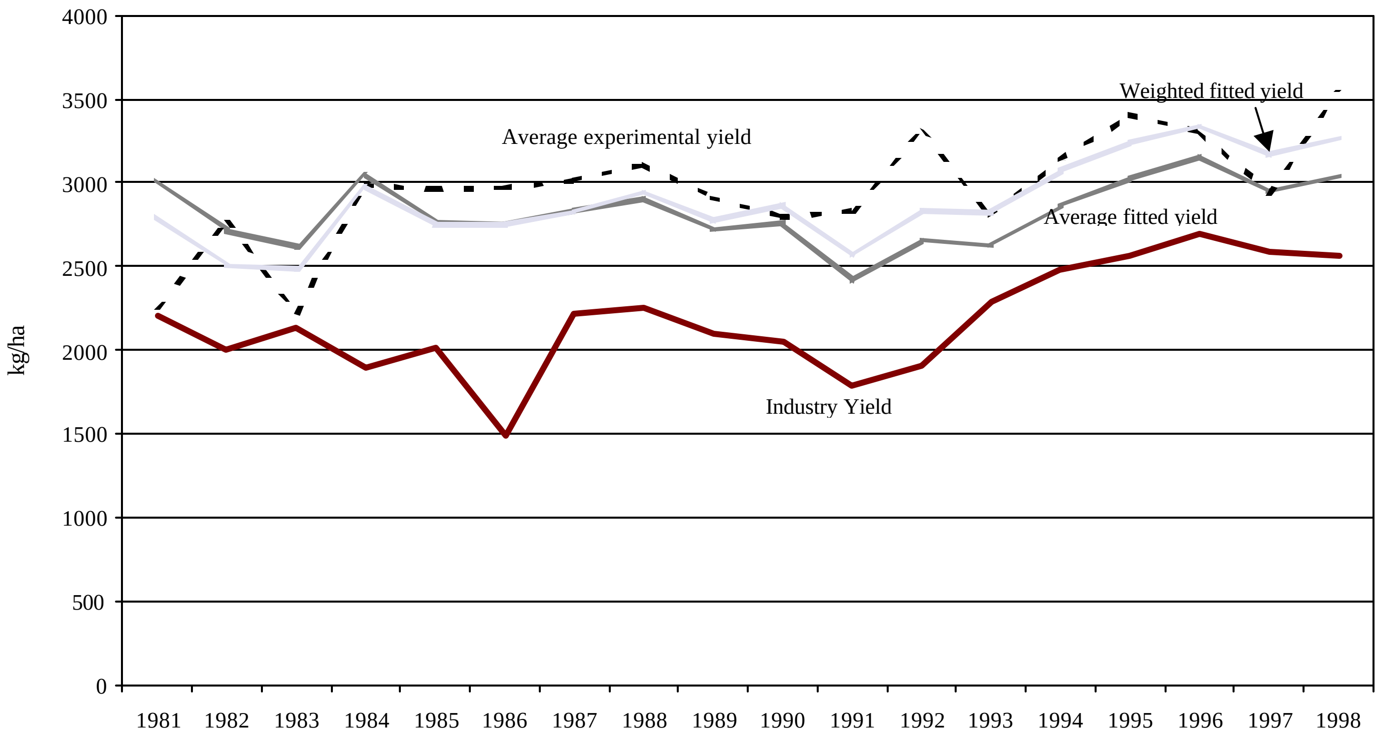
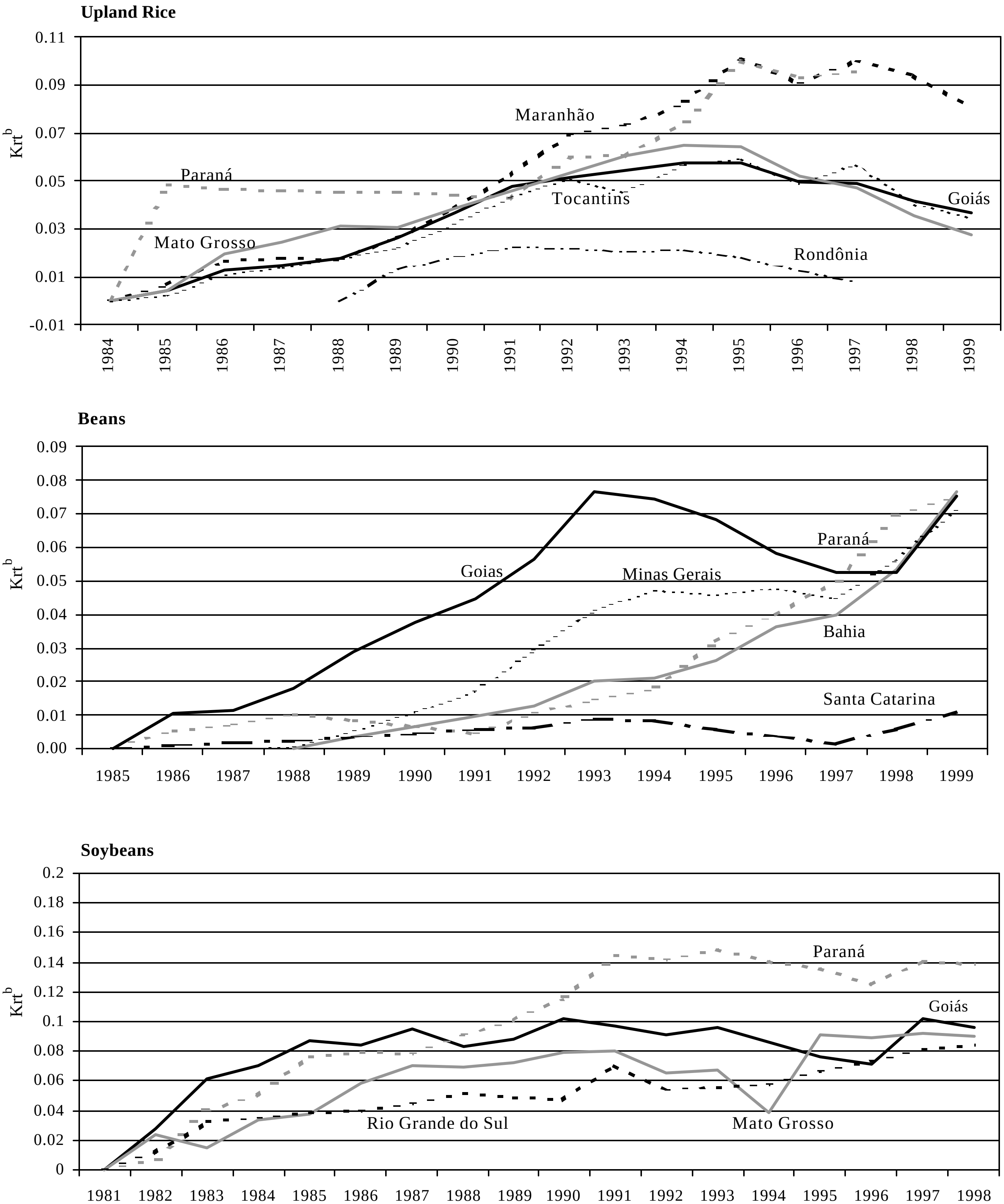


Figure 2: *Various soybean yield estimates for the state of Paraná*



Source: Authors' calculations.

Figure 3: *Proportionate shifts in supply (k) for various states and various crops*



Source: Authors' calculations.