Technological spillovers in Southern Cone agriculture

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ABSTRACT

The PROCISUR program, which was set up in several Latin American countries in 1988, is designed to facilitate the exchange of scientific agricultural findings between member countries. This paper reports on a statistical evaluation of the program's economic impact. The model utilized specifies that the "spill-in" of technology from one country to another is enhanced by the program. Statistical estimates confirm that the program enhanced spill-in of technology in all three commodity programs evaluated (corn, wheat, and soybeans). The economic return to program investment, calculated from the estimates, was extraordinarily high, thus indicating that programs of this type can be quite effective.

Key words: agriculture, technology, spillovers.

RESUMO

O programa PROCISUR, estabelecido em vários países latino-americanos em 1988, foi concebido para facilitar a troca de resultados científicos sobre a agricultura entre os países membros. Este trabalho descreve os resultados de uma avaliação estatística dos impactos do programa. O modelo utilizado especifica que o *spill-in* de tecnologia de um país para outro é melhorado pelo programa. As estimativas estatísticas confirmam que o programa de fato melhora o *spill-in* de tecnologia nos três produtos avaliados (milho, trigo e soja). O retorno econômico do investimento no programa, calculado a partir das estimativas, foi extraordinariamente alto, indicando que programas desse tipo são bastante eficazes.

Palavras-chave: agricultura, tecnologia, *spillovers*.

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1 Introduction

The PROCISUR (Programa Cooperativo de Investigación Agrícola del Cono Sur) program agreement was signed in 1978 by Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay. Funding for the program was provided by the Inter-American Development Bank (IADB), the Inter-American Institute for Cooperation in Agriculture (IICA), and the participating countries. The purposes of PROCISUR were as follows:

- the strengthening and consolidation of creative research;
- cooperation in technology transfer from other countries and international agricultural research centers;
- support for adaptive research efforts;
- intensification of the interchange of knowledge, experience and information between the participating countries;
- cooperation in the search for solutions to common problems.

The administration of the program was the responsibility of IICA and the implementation of the program was assigned to the following agencies in each country:

INTA - Instituto Nacional de Tecnología Agropecuaria — Argentina
IBTA - Instituto Boliviano de Tecnología Agropecuaria — Bolivia.
EMBRAPA - Empresa Brasileira de Pesquisa Agropecuaria — Brazil
INIA - Instituto de Investigaciones Agropecuarias — Chile
DIEAF - Dirección de invest. y Extension Agrop. y Florestal — Paraguay
CIAAB - Centro Invest. Agrícolas Alberto Boerger — Uruguay

The implementation of the program started in 1980, with emphasis on research cooperation for corn, wheat, soybeans and beef cattle. A second stage of PROCISUR, (IICA/BID/PROCISUR), which emphasized training activities and reciprocal cooperation arrangements and included winter cereals, summer cereals, oilseeds, and cattle as program areas, started in 1984.

PROCISUR is thus a scientific exchange program between member countries. It supports observation visits, scientific consultancy, participation in scientific meetings and post-graduate training. it has also facilitates the exchange of genetic materials. Its role is primarily to help the national agricultural research programs in member countries to facilitate the "spill-in" of research contributions from other countries. It is not intended to be an independent research program. This "spill-in" enhancement effect on national programs will differ according to the relative strength of the national research programs in member countries.

In this paper we develop an evaluation of the PROCISUR program as it has affected change in productivity in wheat, maize, and soybean production in the member countries since the beginning of the program in 1978.[1] We also make an economic analysis of the benefits of the PROCISUR program and compare this analysis with other studies in Latin America.

Our analysis requires the development of a statistical model designed to capture the enhancement features of the PROCISUR program and to account for the simultaneity of PROCISUR investment decisions with productivity change and national research programs strengths in the respective countries.[2] An application of the model for the three major commodity programs in PROCISUR: wheat, maize and soybeans, is developed and reported.

Section 2 of this report summarizes PROCISUR activities relevant to the three commodities. Section 3 presents the methodology utilized and makes a summary of the data. Section 4 presents a summary of the estimates of model parameters. The concluding section interprets the estimates in terms of returns on investments.

2 PROCISUR activities: a summary

Most PROCISUR activities can be associated with a receiving and a sending country. They can further be classified according to whether they are oriented toward wheat, maize, soybeans, or to general support activities.

The following describes the distinction between sending and receiving countries or regions for ten types of activities supported by PROCISUR:

1 A preview study by Evenson and da Cruz (1989) made an earlier analysis of PROCISUR data. The PROCISUR evaluation project also included national studies for Brazil, Paraguay, Bolivia, Uruguay, Argentina, and Chile.

2 A central feature of our analysis is that we do not treat PROCISUR investments as exogenously determined. We specifically model the determinants of this investment and treat PROCISUR investments as an endogenous variable in our estimates.

1. Support for scientific observation visits from country A to country B. (A is the receiving country, B the sending country).

2. Support for participation in congresses and seminars by scientists from country A but hosted by country B. (A is the receiving country.) All countries are sending countries if it is an international seminar. (B is the sending country if it is a national seminar).

3. Support for administrative and technical assistance by scientists from country A in country B. (A is the sending country, B the receiving country).

4. Support for administrative and technical assistance and support by scientists from non-member countries and international centers in country A. (A is the receiving country).

5. Support for postgraduate courses by researchers from country A in country B or a non-member country. (A is the receiving country).

6. Support for scientific consultants from country A to work in country B. (B is the receiving country).

7. Support for scientific consultants from non-member countries to work in country A. (A is the receiving country).

8. Support for scientific consultants from International Agricultural Research Centers to work in country A. (A is the receiving country).

9. Support for attendance and participation in technical meetings held in country A. (B is the receiving country).

10. Support for attendance in technical courses in country A by researchers from country B. (B is the receiving country).

Program expenditure data show that each member country is a significant recipient of PROCISUR activities (da Cruz and Evenson, 1989). Only Brazil sends more than it receives. Bolivia and Paraguay are significant recipients of activities but are not sending countries. International sources (primarily CIMMYT and CIAT) constitute 31 percent of all sources. Brazil accounts for 33 percent of all sources (and 22 percent of all recipients). Thus the program has an "equalizing" effect in that the smaller countries with the least developed national research systems are significant recipient countries even though they are not sending countries.

3 Methods and data

3.1 Methods

The methods utilized in this study require an extension of standard productivity decomposition methods in two dimensions. Firstly, the PROCISUR investments must be modeled as being responsive to conditions in both sending and receiving regions and are thus simultaneously determined with productivity growth. Secondly, the PROCISUR activities must be modeled as *enhancing* national research programs.

Let us consider the basic productivity decomposition model:

$$P_{it} = F(R_{it}^{N}, R_{it}^{S}, H_{it}, W_{it}, I_{it}, e_{it})$$

where P_{it} is an index of productivity. This may be an index of output per unit of total input. (i.e., "Total Factor Productivity" index) or an index of output per hectare (a "Partial Factor productivity" index). It is measured for region i and for different time periods.

R_{it}^{N} is a research "stock" variable constructed from past expenditure on research directed toward improving P_{it} for the region for which P_{it} is measured N (i.e., region i). Timing weights are used in the construction of R_{it}^{N} [3]

R_{it}^{S} is a similar research "stock" variable constructed from past expenditure on research directed toward improving in other regions but where those improvements may potentially "spill-in" to region i.

H_{it} is (are) a measure(s) of the human capital skills of farmers in region i. This may also include measures of extension services.

W_{it} is a weather index measuring weather effects in region i, time t.

I_{it} is a measure(s) of public sector infrastructure investments in region i, time t.

e_{it} is an error term.

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3 See Evenson (1982) and Hoffman and Evenson (1989) for a fuller development.

Equation (1) is often estimated in logarithmic form with cross-section and time series data.

The most critical specification issue for the PROCISUR analysis is the specification of the spill-in variables) R_{it}^{S} The spill-in of technology is relevant to regions even where a local research program exists. It is also relevant when the receiving region is in a different country from the region of origin. Indeed it is this spill-in that the PROCISUR program seeks to facilitate.

Spil-in of technology can be considered to be of two basic types:

Direct - as when the technology originating in region A is directly adopted in region B.

Indirect (or Germplasmic) - as when the research and technical discoveries originating in region A enhance and stimulate the technological research undertaken in region B. This can be thought of as "germplasm" spill-in when the term germplasm is broadly defined to include biological, mechanical and intellectual materials that serve as parents for the further development of materials.

The PROCISUR program does not support the development of the origin technology or germplasm but is designed to facilitate and enhance more international spill-in, chiefly of the indirect type. Thus, if we are to measure its impact, we require international data and an interaction specification to test for a PROCISUR impact. We have the further econometric problem that the PROCISUR activities might be responsive to productivity changes and thus be endogenous in the model. Simultaneous equations estimates will be required to deal with this problem. Finally, we also have to deal with the fact that geo-climate factors affect spill-in (and spill-out), and these must be taken into account.

Our procedure entails defining three research variables: R_{it}^{N}, R_{it}^{S} as discussed above and an additional PROCISUR enhancement variable, R_{it}^{SP}

The first variable, R_{it}^{N} is the research stock variable where the research activities are directed toward improving productivity in region *i*:

$$R_{it}^{N} = \sum_{l} W_{t-l} \; r_{i,t-l}$$

Where the W_{t-l} are time weights reflecting the time relationship between research expenditure, $r_{i,t-l}$ and productivity. Research conducted in time *t* will typically not have an immediate impact on productivity. Many research projects do not have impacts for several years (some never do). These timing weights have been estimated in other studies (e.g., da Cruz and Evenson, 1989). Based on these other estimates they are taken to be:

0 for l = 0, 1
.2 for l = 2
.4 for l = 3
.6 for l = 4
.8 for l = 5
1 for l = 6 and higher

This procedure effectively creates a research stock where the service flow creating productivity gains from that stock may be considered to be constant over time.

The second variable, R_{it}^{S}, is the basic spill-in variable. It is defined as:

$$R_{it}^{S} = \sum_{j} G_{ij}^{\alpha} R_{jt}^{N}$$

where the R_{jt}^{N} are research stocks (defined as in (2)) directed toward region *j*, but which can potentially spill-in to region *i*. The G_{ij}^{α} are geo-climate spill-in weights measuring the proportionate value of research in region *j* to productivity enhancement in region *i* via direct, semi-direct and indirect spill-in. These weights are estimated in three steps (see below). They are designed to adjust for geo-climate impediments to technology spill-in.

The third variable is the PROCISUR enhancement variable. It is defined as:

$$R_{it}^{SP} = \sum_{j} G_{ij}^{\alpha} R_{jt}^{N} PR_{ijt}$$

where the G_{ij}^{α} and R_{jt}^{N} are defined above. The PR_{ijt} are the cumulative (to time *t*) expenditures PROCISUR activities where *i* is the receiving region and *j* is the sending region. Thus R_{it}^{SP} is an interaction variable designed to test whether PROCISUR activities increase or enhance the value of spill-in research. It is defined with respect to sending and receiving regions. (See below for a further discussion.) (Note that since the R_{it}^{S} variable is also included in the regression, this variable picks up the PROCISUR enhancement effect.)

It can be reasonably argued that the time lag inherent in the W_{t-l} weights effectively creates a "recursive" structure between the research spending variables and productivity change. Since it takes time before research affects productivity, the current research stock is unlikely to be influenced by current productivity change. It cannot be argued, however, that the PROCISUR activities do not respond to the perceived *opportunities* for research enhancement. We would expect that PROCISUR activities, PR_{ij}, would respond positively to the past productivity performance in region *j* and negatively to the current research capacity in region *i*. Accordingly, the R_{it}^{SP} variable it should be treated as an endogenous variable in a simultaneous system with equation (1). We thus have the following two equation system that we will estimate using Zellner's SUR procedure:

$$P_{it} = f(R_{it}^{N}, R_{it}^{S}, R_{it}^{SP}, W_{it}, I_{it})$$

where P_{it}^{*} is defined as $\Sigma_j G_{ij} P_{ij}$ (* indicates lagged values).

3.2 Data and variable definitions

Data were gathered from a number of sources for 14 regions for the 1966-87 period. The regions included six states in Brazil (Mato Grosso, Minas Gerais, Paraná, São Paulo, Santa Catarina and Rio Grande do Sul), four states in Argentina (Buenos Aires, La Pampa, Córdoba and Santa Fé), Bolivia, Chile, Paraguay and Uruguay. Table 1 reports variable definitions. Note that we have used a logarithmic specification.

Table 2 reports comparative mean values for the key research and extension variables for alternative groupings of states (regions). These data show that PROCISUR impacts have been highest for other countries and lowest for Brazil. (This is defined as the ratio R_{it}^{SP}/R_{it}^{S}.)

3.3 Estimation of the G_{ij}^{α} spill-in weights

The estimation of the G_{ij}^{α} weights actually entailed 3 steps:

Step 1 [Establishing Geo-climate Region Relationships]. Appendix 1 describes geo-climate classification based on Papadakis (1975). This classification is the most detailed available with international coverage. The relevant geo-climate regions for the PROCISUR states include 1.2, 1.4, 1.9, 2.4, 4.1, 4.3, 3.8, 5.7, 5.1, 7.1, 5.3, 6.2, and 6.3. A ratio of relative productivity between each pair of regions was constructed based on the geo-climate "distance" between the regions. For example, between regions 1.2 and 1.4 the ratio was .9, between 1.2 and 2.4 it was judged to be .8, between 1.2 and 6.2 it was judged to be only .1. These relative ratios were thus constructed for all geo-climate region pairs.

Step 2 [Conversion to State G_{ij} Ratios]. For each commodity the distribution of acreage within a state was determined. The proportions were then used as weights in state i to determine the relative spill-in potential weight G_{ij} from state j.

Step 3 [Estimating α]. This entailed a simple iteration where α was alternatively set equal to 1, 2 and 3. Table 3 reports R^2 values for the first equation and for the SUR system for alternative α's. For all three commodities the $\alpha = 1$ weights were estimated to be the appropriate weights. These estimated G_{ij}^{α} weights between regions for maize are reported in Table 4.[4]

4 Maximizing R^2 over α is equivalent to minimizing the sum of squared errors in the equation. This is effectively a nonlinear least squares procedure for estimates α .The estimated weights for soybeans and for wheat differed only slightly from those for maize.

4 Model Estimates

Table 5 summarizes estimates of the key parameters of the model for the third stage simultaneous equations estimates for pooled data for all fourteen states and for the six Brazilian states. Appendix 2 gives the full set of regressions on which the summary is based.

Table 5 does not report estimates for the second equation in the system. Reference to Appendix 2, however, will show that in all cases the expected relationship between PROCISUR inputs and the key predicting variables is borne out. The sign on the lagged state research variable, LSTRESA, is always negative. The sign of the lagged productivity variable, LNYIELDA, is always positive. All coefficients are statistically significant. This indicates that, as expected, PROCISUR activities respond positively to spill-in potential as measured by the productivity performance of spill-in geo-climate neighbors. These activities also respond positively to low research capacity in the recipient state. These results support the general validity of the model and give credibility to the PROCISUR enhancement estimates reported in Table 5.

The estimates reported in Table 5 are reported for Brazil states and for the aggregate of all states. We expect the aggregate results to generally be the most reliable because they capture the international effect of PROCISUR through cross-section variation. It would be much more difficult to measure a PROCISUR effect for a country with only a single time series (e.g., Paraguay) because of the limited number of observations. Nevertheless, it is of interest to disaggregate the data to some extent to investigate whether there are significant differences between groups of states.

We have provided computed marginal productivity elasticities and marginal products to enable the reader to interpret the net impacts of the research variable. The marginal elasticity for state research is computed as:

$$d\ln(Y)/d\ln(R^N) + d\ln(Y)/d\ln(R^S)$$

where the interacting variables entering into these derivatives are evaluated at mean levels in the relevant data set. Thus the fact that for maize and soybeans the interaction terms (LSRNR) between state and spill-in research are negative (indicating that spill-in research is a substitute for state research) does not mean that the marginal product of research is negative. The negative term is more than offset by other positive terms.

The results are generally as expected for the agricultural research variable in all three commodities. Spill-in research is highly significant in all commodities for Brazil and for all states combined. Spill-in research is a substitute for state research in maize and soybeans. State research is also significantly positive in maize and wheat. The combined effects of state research plus spill-in are significantly positive for all commodities in all regional groupings.

The results for extension are much weaker. Few significant extension coefficients are estimated.

Our chief interest is in the PROCISUR enhancement variable, LPRNGHI. If PROCISUR has had an impact, we firstly expect that spill-in research is a significant determinant of productivity, and secondly that it has a higher impact when enhanced by PROCISUR activity. The estimates show significant PROCISUR enhancement effects for all 3 commodities for both data sets. This can be regarded to be a important result given the data and consistency of the results of the second equation. The findings that PROCISUR impacts were of roughly similar size in each commodity and data set give further credibility to the results.

5 Economic Implications

Table 5 reports the calculated estimated marginal productivity elasticities for the state research programs and for PROCISUR. These are computed as the logarithmic derivatives of the estimated equations. Where a variable is involved in the calculation it is set to its mean value in the relevant data set. These elasticities are approximately comparable to those obtained in other studies of this nature (see Evenson, 1988, for a review).

It is possible to compute the marginal products from the elasticities by making use of the relationship:

$$MP = \text{Elasticity} \times \text{AverageProduct}$$

This is the general formula for the marginal product of the research stock. The average product must thus be computed as the ratio of the cumulated stock to the value of agricultural product. The average stock is approximately 5 times the average investment level in the PROCISUR data since research spending is rising. Data for Brazil and other PROCISUR countries indicate that the research expenditure relative to commodity value was approximately

.003 for maize and soybeans and .0035 for wheat. PROCISUR spending is actually only one percent of national research expenditure in recent years.

These factors are then used to convert the elasticity estimates into marginal product estimates in Table 5. These marginal products are to be interpreted as the annual benefit stream (adjusted for time weights) from a single one dollar investment in time "*t*" Thus a one dollar investment in maize research in time "*t*" will produce an income stream of .8 dollars that will be realized in future periods according to the time weights. They indicate that nothing will be realized in year *t*+l, .16 in year *t*+2 (.2×8), .32 in year *t*+3 (4×8), .48 in year *t*+4 (.6×8), .64 in year *t*+5 (.8×8), and .8 thereafter (.8×l). This can then be treated in an investment context and an internal rate of return on investment calculated. (See Table 5)[5]

In the case of maize research, a one dollar investment in time *t* will yield an internal rate of return on investment of 26 percent. The comparable internal rate of return for wheat in all PROCISUR regions is a very high 78 percent. The internal rate of return for soybeans is 41 percent.

For Brazilian research the comparable internal rates of return are 36 percent for maize, 39 percent for wheat and 50 percent for soybeans. These returns (except for wheat) are somewhat lower than estimated in other studies but nevertheless represent high returns on investment. (See Evenson, 1989, for a review)

The returns on PROCISUR research can also be computed. Note that the marginal products are extraordinarily high for PROCISUR impacts. Since PROCISUR enhances national research programs and there is a lag between PROCISUR spending and enhancement, the time lags are somewhat longer than for national research spending. Taking these time lags to be double those of national research spending, we find internal rates of return to PROCISUR of 191 percent for maize, 110 percent for wheat and 179 percent for soybeans. (The comparable figures for the six Brazilian states are 115 percent for maize, 110 percent for wheat, and 148 percent for soybeans) These are extraordinarily high rates of return. Even if they are overestimated by a factor of 4, they are still extraordinarily high. They are higher than the rates of return of International Agricultural Research Centers (IARCs). For the case of IARC investment in maize, millets and sorghum in Latin America, Evenson (1988) found rates of return above 80 percent.

5 The internal rate of return is the discount interest rate at which the discounted benefits over future periods is equal to one in period *t*.

It would seem reasonable to conclude that the marginal returns for PROCISUR appear to be extremely high. They indicate that the PROCISUR program, which is actually a relatively small program (only one percent of national research spending), has had an extraordinarily high "leverage" factor, giving it very high returns. The program has clearly been effective and has yielded large benefits. The signs presented by this study indicate that it can fruitfully be continued and expanded.

The relevance of PROCISUR type programs to other regions and countries will depend on the willingness of the research units to cooperate in the program. Cooperation in the PROCISUR program appears to have been very good and the program seems to have been effectively administered.

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Table 1
Variable Definitions: PROCISUR Analysis

I. Endogenous Variables

LIYIELD: Natural logarithm of the commodity yield index. For each region or state and commodity this index was constructed as the ratio of yield in year t to the 1966-70 average yield. Thus regional differences in the 1966-70 average yields are not incorporated in this index.

LPRNGHI: Natural logarithm of the PROCISUR spill-in research stock (see equation (4)). This is the PROCISUR enhancement variable (see below for estimation of the G_{ij} weights). PROCISUR data include the cumulated commodity data plus the general data.

II. Exogenous Variables (1 indicates that the variable is included in LIYIELD equation (2) that it is included in the LPRNGHI equation)

(1) LCRESEXP: Natural logarithm of the states research stock, R_{it}^{N} (see equation (2)). This variable is constructed from research expenditure in the state.

(1) LRNGHI: Natural logarithm of the spill-in research stock, R_{it}^{S} (see equation (3)). This is the basic spill-in research stock (see below for estimation of the G_{ij} weights.

(1) LSRNR: LCRESEXP times R_{it}^{S} the spill-in research stock.

(1) LEXTA: Natural logarithm of field extension staff (for all crops) per hectare of cultivated land. The time weights are .25 for l - 0, .5 for l 1, .25 for l 2, 0 for l greater than 2).

(1) LRESEX: LCRESEXP times the extension stock.

(2) LSTRESA: The average of LCRESEXP for periods t - 1, t - 2, t - 3, and t - 4.

(2) LNYIELDA: Natural logarithm of the spill-in in weighted yield index averaged for periods t 1, t - 2, t - 3, and t - 4. Defined as:

$$\sum_{j} G_{ij}^{\alpha} Y_{jt}^{*}$$

(2) YEAR: A time variable, 1966, 1964 etc.

(1) GOOD, POOR, BAD: Dummy variables for weather effects: GOOD = 1 if yields are more than 1-1/2 standard deviations above trend. POOR = 1 if yields are from 1-1/2 to 2 standard deviations below trend. BAD = 1 if yields are more than 2 standard deviations below trend.

(1, 2) BRMT, BRMG - Bolivia: Dummy variables for states.

Table 2
Comparative Means: PROCISUR Data

	Brazil	Argentina	Others	All
I. Maize				
State Research Stock	702	1,995	7,445	2,257
Neighbors' Research Stock	15,249	8,905	11,150	12,452
State Extension	.0009	.029	.37	.070
PROCISUR	392	513	933	523
II. Wheat	1,550	2,633	5,911	3,105
State Research Stock	23,239	15,543	17,249	19,329
Neighbors' Research Stock	.0009	.03	.32	.10
State Extension	782	1,059	1,586	1,091
PROCISUR				
III. Soybeans				
State Research Stock	1,825	2,202	5,093	2,736
Neighbors' Research Stock	19,339	11,493	16,166	16,584
State Extension	.0009	.03	.25	.070
PROCISUR	294	1,856	1,435	970

Table 3
Parameter Estimates

	Maize		Wheat		Soybeans	
α	$R^2(1)$	$R^2(2)$	$R^2(1)$	$R^2(2)$	$R^2(1)$	$R^2(2)$
$\alpha = 1$	.5987	.7374	.7215	.6910	.7438	.7098
$\alpha = 2$	.5015	.7238	.7012	.6922	.7429	.7202
$\alpha = 3$	.4377	.7044	.6735	.6878	.7351	.7177

Notes: $R^2(1)$ is the R^2 for equation (1) and $R^2(2)$ is the R^2 for the system.

Table 4

Interregional G_{is} Weights (Maize)

Receiving Region	Sending Region													
	Brazil						Argentina				Bolivia	Chile	Paraguay	Uraguay
	Mato Grosso	Minas Gerais	Paraná	São Paulo	Santa Catarina	Rio Grande de Sul	Buenos Aires	La Pampa	Córdoba	Santa Fé				
Brazil														
Mato Grosso	1.0													
Minas Gerais	.8	1.0												
Paraná	.5	.5	1.0											
São Paulo	.55	.5	.55	1.0										
Santa Catarina	.6	.8	.8	.7	1.0									
Rio Grande do Sul	.6	.8	.8	.7	1.0	1.0								
Argentina														
Buenos Aires	.2	.2	.3	.25	.3	.3	1.0							
La Pampa	.1	.2	.2	.15	.3	.3	.6	1.0						
Córdoba	.2	.4	.3	.35	.6	.6	.8	.8	1.0					
Santa Fé	.3	.3	.4	.3	.5	.5	.6	.6	.7	1.0				
Bolivia	1.0	.8	.5	.85	.6	.6	.2	.1	.2	.3	1.0			
Chile	.2	.3	.4	.25	.4	.4	.2	.4	.4	.4	.2	1.0		
Paraguay	.8	.4	.4	.6	.7	.7	.4	.4	.4	.2	.8	.7	1.0	
Uruguay	.6	.8	.8	.7	1.0	.3	.3	.6	.5	.6	.4	.7	1.0	

Table 5
Third Stage Estimates of Key Parameters: PROCISUR Analysis

	Six Brazil States			All PROCISUR States		
	Maize	Wheat	Soybeans	Maize	Wheat	Soybeans
I. Parameter Estimates						
LN (State Research) LCRESEXP	–.0111**	–.0049	–.0021	.0135**	.0058*	–.0003
LN (State Research)×Spill-in Research LSRNR	–7.613 (12)	6.831 (10)	–2.375** (10)	–3.455 (10)	1.103 (10)	–2.741*** (10)
LN (State Research)×Extension	6.064**	9.006**	4.028	.0002	–.0007	–.0065**
LN (Spill-in Research) LRNGHI	.0254**	.0061	.0773***	.0321**	.0502***	.0669***
PROCISUR Enhancement LPRNGHI	.0061**	.0065**	.0104***	.0165***	.0067***	.0145**
LN (Extension) LEXTA	.0131	–.054*	–.045	–.061**	–.083	–.044
Wtd. R^2 for System	.825	.835	.815	.750	.720	.784
II. Computed Marginal Elasticity						
State Research	.0188	.0258	.0343	.0096	.0886	.0238
PROCISUR	.0061	.0065	.0104	.0165	.0067	.0145
III. Computed Marginal Products						
State Research	1.3	1.5	2.3	.8	5.9	1.6
PROCISUR	12	11	20	33	11	29
IV Computed Marginal Internal Rates of Return						
State Research	36	39	50	26	78	41
PROCISUR	115	110	148	191	110	179

Notes: Appendix 2 provides full regression estimates. Numbers in parentheses are *E* (-*N*) indicators, i.e., the decimal point is moved *n* places to the left.
* indicates "*t*" ratio between 1.5 and 2.0.
** indicates "*t*" ratio between 2.0 and 3.0.
*** indicates "*t*" ratio greater than 3.0.

Elasticities are evaluated at mean levels of interacted variables. State Research includes spill-in.

Appendix 1 - Geo-Climate Class (Papadakis, 1975)

1. Tropical		2. Tierra Fria		3. Desert	
1.1	Semi-hot equatorial. Ex. Jakarta, Indonesia	2.1	Semi-tropical tierra fria. Ex. Bulawayo, Rhodesia	3.1	Hot tropical desert. Ex. Massawa, Ethiopia
1.2	Semi-hot tropical. Ex. Rio de Janeiro, Brasil	2.2	Low tierra fria. Ex. Tananarive, Madagascar	3.2	Hot subtropical desert. Ex. Cairo, U.A.R.
1.3	Dry semi-hot tropical. Ex. Accra, Ghana	2.3	Medium tierra fria. Ex. Mexico City, Mexico	3.3	Semi-hot or cool tropical desert. Ex. Lima, Peru
1.4	Hot tropical. Ex. Madras, India	2.4	High tierra fria. Ex. La Paz, Bolivia	3.4	Cool subtropical desert. Ex. Walwis Bay, S.W. Africa
1.5	Semi-arid tropical. Ex. Niamey, Niger	2.5	Low andine. Ex. Puno, Peru	3.5	Tropical highland desert. Ex. Las Anod, Somalia
1.6	Cool tropical. Ex. Hamilton, Bermuda	2.6	High andine. Ex. Cerro de Pasco, Peru	3.7	Continental desert. Ex. Kashgar, China
1.7	Humid tierra templada. Ex. San Jose, Costa Rica	2.7	Andine mist forest. Ex. Pangerango, Indonesia	3.8	Pampean desert. Ex. Mendoza, Argentina
1.8	Dry tierra templada. Ex. Tabora, Tanzania	2.8	Andine tundra	3.9	Patagonian desert. Ex. Col. Sarmiento, Argentina
1.9	Cool winter hot tropical. Ex. Calcutta, India	2.9	Andine sub-glacial desert		

4. Subtropical		5. Pampean		6. Mediterranean	
4.1	Humid subtropical. Ex. Porto Alegre, Brasil	5.1	Typical pampean. Ex. Nueve de Julio, Argentina	6.1	Subtropical mediterranean. Ex. Sevilla, Spain
4.2	Monsoon subtropical. Ex. Lahore, Pakistan	5.2	Highland pampean. Ex. Pigué, Argentina	6.2	Marine mediterranean. Ex. San Francsico, CA, USA
4.3	Hot semi-tropical. Ex. Asuncion, Paraguay	5.3	Subtropical pampean. Ex. Houston, TX, USA	6.3	Cool marine mediterranean. Ex. Seattle, WA, USA
4.4	Semi-hot semi-tropical. Ex. Miami, FL, USA	5.4	Marine pampean. Ex. Christchurch, New Zealand	6.4	Tropical mediterranean. Ex. Funchal, Madeira
4.5	Semi-mediterranean subtropical. Ex. Cherat, Pakistan	5.6	Monsoon peri-pampean. Ex. Córdoba, Argentina	6.5	Temperate mediterranean. Ex. Marseille, France
		5.7	Semiarid peri-pampean. Ex. San Angelo, TX, USA	6.6	Cold temperate mediterranean. Ex. Erzurum, Turkey
		5.8	Patagonian grassland. Ex. Fairlie, New Zealand	6.7	Continental mediterranean. Ex. Thessaloniki, Greece
		5.9	Semi-arid patagonian. Ex. Lago Argentino, Argentina	6.8	Subtropical semiarid mediterranean. Ex. Murcia, Spain
				6.9	Continental semiarid mediterranean. Ex. Teheran, Iran

Appendix 1 - Geo-Climate Class (Papadakis, 1975) - *continued*

7 Marine	
7.1	Warm marine. Ex. Auckland, New Zealand
7.2	Cool marine, Ex. London, UK
7.3	Cold marine. Ex. Sitka, AL, USA
7.4	Polar marine. Ex. Heard Island
7.5	Warm temperate. Ex. Bordeaux, France
7.6	Cool temperate. Ex. Berlin, Germany
7.7	Cold temperate. Ex. Helsinki, Finland
7.8	Humid patagonian. Ex. Ushuaia, Argentina

Appendix 2 - Regression Estimates

Appendix Tables 2.1, 2.2, and 2.3 report third stage (least squares) SUR estimates for maize, wheat, and soybeans for all regions. Note that regional dummy variables are not included.

Appendix Tables 2.4, 2.5, and 2.6 report comparable estimates for Brazil.

Appendix 2 - Third Stage Estimates (SUR System)

Equation (1) Estimates: All PROCISUR Regions

Dependent Variable LIYIELD (t-ratio in parenthesis)

	Maize		Wheat		Soybean	
INTERCEPT	–1.1024	(3.22)	–1.5161	(4.37)	–1.1684	(3.07)
BRMT	.1173	(2.13)	.0733	(1.14)	–.3700	(5.01)
BRMG	.0994	(1.50)	.1856	(3.21)	.2840	(4.03)
BRSP	.1321	(2.13)	.1906	(3.54)	–.0064	(.10)
BRBR	.0097	(.19)	–.1150	(2.66)	.0631	(1.31)
BRSC	.1155	(1.93)	.2033	(3.89)	–.1103	(1.76)
SANTA FE	.5231	(3.16)	.8728	(5.82)	.3419	(1.67)
CORDOBA	.5395	(3.07)	.7849	(4.82)	.3184	(1.50)
BUENOS	.4892	(2.96)	.6171	(4.02)	.2546	(1.27)
LA PAMPA	.9117	(5.35)	.7534	(4.88	—	
URUGUAY	—		–.1652	(1.71)	–.4790	(3.44)
PARAGUAY	.5725	(2.35)	.7362	(3.25)	.3848	(1.32)
BOLIVIA	–.0836	(1.39)	.1776	(3.34)	–.0265	(.41)
CHILE	—		.7440	(3.26)	—	
LCRESEXP	.0135	(3.81)	.0058	(1.85)	–.00003	(.01)
LRNGH1	.0321	(2.55)	.0502	(3.85)	.069	(5.23)
B1.LPRNGH1	.0165	(5.36)	.0067	(3.09)	.0145	(5.65)
LRESEX	.0002	(.13)	–.0008	(.52)	–.0066	(3.89)
LSRNR	$-3.4558E^{-10}$	(2.50)	$1.1033E^{-11}$	(.16)	$-2.7447E^{-10}$	(3.06)
LEXTA	–.0649	(2.39)	–.0829	(3.24)	–.0441	(1.31)
GOOD	.1009	(1.71)	.2106	(4.39)	.2034	(4.02)
POOR	–.1469	(6.04)	–.2137	(9.97)	–.1904	(7.64)
BAD	–.3389	(7.84)	–.6269	(13.11)	–.3916	(10.76)

Equation (2) Estimates: All PROCISUR Regions
Dependent Variable LPRNGH1

	Maize		Wheat		Soybean	
INTERCEPT	–2496.04	(6.84)	–23.02.56	(7.21)	–2617.11	(7.24)
BRMT	–4.1182	(1.87)	–3.9881	(1.74)	–.8110	(.28)
BRMG	–.4090	(.20)	.4062	(.19)	.4314	(.20)
BRSP	.1399	(.07)	.3474	(.16)	.7983	(.37)
BRBR	.2865	(.14)	.5535	(.26)	.3664	(.17)
BRSC	.0431	(.02)	–.1521	(.07)	.0343	(.02)
SANTA FE	–3.5668	(1.73)	.5790	(.27)	–.9392	(.42)
CORDOBA	–2.8410	(1.40)	.9381	(.44)	.4886	(.20)
BUENOS	–3.3527	(1.64)	.4680	(.22)	.5878	(.27)
LA PAMPA	–7.1711	(3.12)	–4.2235	(1.76)	—	
URUGUAY	—		–1.3384	(.62)	–1.8412	(.63)
PARAGUAY	–.5578	(.28)	1.5486	(.71)	2.5250	(1.14)
BOLIVIA	.3294	(.16)	1.6691	(.77)	2.7908	(1.26)
CHILE	—		–.2815	(.12)	—	
LSTRESA	–.5767	(3.68)	1.5486	(.71)	2.5250	(1.14)
LNYIELDA	17.5862	(2.89)	20.8993	(4.99)	19.0251	(3.21)
YEAR	1.2707	(6.86)	1.1727	(7.23)	1.3343	(7.28)

Appendix 2, *continued*

Equation (1) Estimates: Brazil
Dependent Variable LIYIELD

	Maize		Wheat		Soybean	
INTERCEPT	–.0762	(.23)	–.5037	(1.28)	–1.3156	(2.56)
BRMT	–.0608	(1.70)	–.0726	(1.06)	–.3964	(5.80)
BRMG	–.0929	(1.81)	–.0389	(.53)	.2306	(2.35)
BRSP	–.0077	(.18)	.0372	(.69)	–.0436	(.54)
BRSC	–.0211	(.87)	–.1406	(4.81)	.0499	(1.12)
LCRESEXP	–.0398	(.96)	.0852	(1.69)	–.1520	(2.05)
LRNGH1	–.0111	(2.62)	–.0049	(1.03)	–.0022	(.57)
B1.LPRNGH1	.0061	(3.42)	.0065	(3.12)	.0104	(2.72)
LRESEX	6.0638	(2.21)	9.0066	(2.53)	4.0287	(.74)
LSRNR	$-7.6127E^{-12}$	(.10)	$6.8345E^{-11}$	(1.29)	$-2.3750E^{-10}$	(2.13)
LEXTA	.0131	(.55)	–.0548	(2.08)	–.0451	(.99)
GOOD	.1120	(3.12)	.1244	(2.82)	.1975	(2.27)
POOR	–.1349	(8.44)	–.1321	(5.64)	–.1760	(5.14)
BAD	–.3526	(12.48)	–1.7381	(20.32)	–.4103	(11.96)

Appendix 2, *continued*

Equation (2) Estimates: Brazil
Dependent Variable LPRNGH1

	Maize		Wheat		Soybean	
INTERCEPT	–2369.53	(4.42)	–2019.44	(3.98)	–1875.94	(3.61)
BRMT	–4.0639	(1.58)	–5.429	(2.19)	–1.7266	(.55)
BRMG	–.2692	(.14)	.5458	(.24)	.9843	(.44)
BRSP	.2069	(.11)	.5887	(.26)	1.6545	(.73)
BRPR	.3898	(.21)	.7673	(.33)	.8614	(.38)
BRSC	.0550	(.03)	–.2047	(.09)	.0707	(.03)
LSTRESA	–.5337	(1.68)	–.8490	(2.92)	–1.9589	(4.38)
LNYIELDA	22.4091	(2.44)	28.1169	(3.43)	39.2495	(3.63)
YEAR	1.2063	(4.43)	1.0311	(4.01)	.9652	(3.67)