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EMPLOYMENT AND CAPITAL-LABOR SUBSTITUTION IN SOUTH BRAZILIAN AGRICULTURE

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Inderjit Singh and Choong Yong Ahn

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This paper analyzes the capital-labor utilization and substitution patterns for the wheat region of Rio Grande do Sul in Southern Brazil. By using parametric programming it displays short-run capital labor substitution relations as they were estimated for 1960, 1965 and 1970 from a dynamic regional model used to simulate the agricultural transformation in the region. The results include estimates of land use, employment, capital utilization, factor proportions and productivity in the long-run and comparative static short-run estimates for the marginal efficiency of capital, the derived demand for labor and non-farm capital goods, capital-labor and machine-power substitution and the demand for debt, for the region and ~~decomposed~~ by farm size, for small, medium and large farms. The paper reports on a study commissioned by the Development Research Center, I.B.R.D.

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By
Inderjit Singh and Cheong Yong Ahn

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EMPLOYMENT AND CAPITAL LABOUR SUBSTITUTION IN SOUTH BRAZILIAN AGRICULTURE

by

INDERJIT SINGH and CHOONG YONG AHN *

I. INTRODUCTION

The main purpose and the methodology of this study is similar to the previous study on capital - labour utilization and substitution in the Punjab.[1/] It differs in two respects: firstly it describes the process of capital - labour substitution as it occurred during the period 1960 - 1970 in the wheat growing regions of Southern Brazil and secondly it attempts to extend the methodology of the Punjab study by incorporating differences in farm size using the decomposition framework of linear programming. Let us briefly elaborate on these regional and methodological differences.

The setting for this study are the adjacent regions called Planalto Medio (plateau region) and Missoes (a lowland region) in the state of Rio Grande do Sul in Southern Brazil. These regions, fairly homogeneous with regard to climate and agricultural practices, covering some 5.7 million hectares of land under cultivation, account for over 90 percent of the total wheat production in Brazil. In the recent decade the wheat region of Southern Brazil has played a crucial role in bringing about one of the highest rates of agricultural growth in

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1/ The present paper is written as a comparison piece to the Punjab study paper by I. J. Singh and Richard H. Day [10] and constantly refers to it.

the world; a rate of growth of total output in excess of 8 percent per annum. This rapid rate of growth has been accompanied by rapid mechanization and vast changes in the cropping patterns and the increased use of commercialized inputs such as seeds, fertilizers and credit. This performance has been closely associated with two policy instruments: 1) price supports for wheat at twice the level of the international price and 2) a subsidized credit program with low nominal and negative real rates of interest tied with the purchase of commercial inputs, which have transformed the regions agricultural economy from predominantly livestock production on natural pastures to the production of wheat (double cropped with soybeans), for which these policies were specifically intended. The accompanying sixfold increase in wheat production and ninefold increase in area cultivated to wheat between 1962-63 to 1970-71 [2/] changed the entire structure of the agricultural economy. This changing structure included changes in the composition of both inputs and outputs, changes in regional employment, as well as a large increase in mechanized crop farming.

The agricultural transformations in Punjab and Brazil though they have many characteristics in common - a high rate of growth of output, changing composition of inputs and outputs, rapid mechanization and structural changes in the demand for labour - also have much that distinguishes them. Most specifically are the vastly different factor endowments (with a relatively very high land and labour ratio in Brazil compared to the Punjab); the fact that in Brazil the main technological changes have been mechanical while the biological changes have lagged

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[2/] See Engler and Singh [5], pg. 4.

behind with little increases in physical productivity per cropped hectare[3/]; and the large policy efforts that have introduced very specific product and factor price "distortions" in the Brazilian case.[4/] These differences alone present enough of a contrast to make this second comparitive study interesting and important.

Another difference of major consequence between the regions are the differences in farm size. Whereas the Central Punjab by and large has farms fairly homogeneous in size, ranging between 5-30 hectares, farms in Southern Brazil are characterized by great differences with the size of the operational unit varying from 10 hectares to over 10,000 hectares. These large differences imply differences in resource endowments and consequently different response to regional economic opportunities. Besides differences in factor proportions, especially the land-labour ratio, farm size differences also imply different access to markets, different cash flows, economies of scale in choice of equipment, differences in degrees of subsistence and commercialization and differential rates of adoption and adjustment to new technologies given different degrees of risk aversion and risk assimilation capacities. These and other factors make it essential that farm size differences be treated explicitly in order to capture structural and behavioural differences which regional aggregation over a homogeneous

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3/ Value productivity per hectare has increased both as a result of increased intensity in land use (double cropping) and increased value per unit of output.

4/ Somewhat similar price distortions existed in the Punjab, but they were less crop specific, smaller in size and not applied in a concerted or systematic manner in a short period of time, with a view to bringing about any specific change as was the intent and purpose of Brazilian price and credit policies.

farm size would totally obfuscate.

In order to take account of these differences, the Brazilian study extends the methodology of the Punjab model to include three different farm size groups - small farms (0-50 hectares), medium farms (51-300 hectares) and large farms (300+ hectares) - each with its own separable optimizing function, technical, behavioural and financial constraints. In order to do this use is made of the decomposition principle in linear programming, wherein the objective functions become additive, and the technology matrix is represented by non-empty sub-matrices along the diagonal and by null matrices in the off-diagonal zones. In addition, in order to represent competition among farm groups for regional resources, the diagonal sub-matrices are bordered at the bottom by an array of non-empty matrices to represent this regional competition. 5/ Such a linear programming structure consists of a set of almost separable sub-problems, one for each farm size group, but linked together by several common resource constraints. Operationally, the regional objective function is the summation of the three separable objective functions; the production, consumption and investment decisions of each homogeneous farm group are constrained by on-farm resources and behavioural criteria, while financial resources can be augmented by regional credit agencies. But regional credit, wage labor and non-farm quasi-fixed capital resources are competed for by all farm size groups, through regional coupling constraints. In addition the following simplifying assumptions have been made in the model:

5/ In this study, the decomposition principle is used in structuring the model, not as a computational device for a large system. The use and implications of the decomposition principle, related computer algorithms, and other empirical applications can be found in Dantzig (3), Baumol and Fabian (2), Simmonard (8), and Hillier and Lieberman (6) among others. For a comprehensive treatment of the principle, see Lasdon (7).

1) All farm size groups have identical input-output coefficients except where economies of scale accrue to machine operations;[6/]

2) All farms face identical input and output prices;

3) Different farm size groups have different on-farm resource endowments, but each farm within the group has similar resource endowments enabling regional aggregation for each group;

4) All farm groups compete for regional credit and wage labour resources.

Besides this major extension to include farm groups of varying size, the Brazilian model follows essentially the same principles and adopts similar estimation procedures as the Punjab study. Because the inclusion of the different farm sizes enlarged the size of the problem considerably, fewer details of technology were incorporated in the Brazilian study.[7/] Otherwise, however, the model includes the same features as the Punjab model with alternative production, consumption, sales and investment activities. Intermediate activities are included to allow alternative mechanical (animal draft and power) technologies for various tasks and biological technologies to include traditional and modern crop practices, expected yields and use of modern inputs. Financial activities allow saving, short term borrowing, debt repayment and cash purchases of non-farm durable and non-durable

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6/ Economies of scale are allowed in the land preparation and harvesting tasks specifically.

7/ Thus for example only land preparation and harvesting tasks were analyzed in detail and only two yield technologies - traditional and modern - were considered. For model details see Aim (1), and appendix.

consumer goods and services. Investment activities replace worn out machines and depreciated animal draft and add to available machine and draft capacities.

Farmers' choice of activity levels are constrained by resource, financial and behavioural limitations represented by a set of inequalities for each year. Resource constraints include regional availabilities by farm size of family labour, animal draft, tractor and combine capacities by seasons and fixed regional resources of winter and summer arable lands, and regional resources of credit and wage labour. Financial constraints restrict cash availability by farm size group to previous years gross sales plus previous savings if any with accrued interest and non-farm incomes less cash outlays for production inputs, cash consumption expenditures and debt repayment of previous years borrowings. Short term borrowings are constrained on a regional basis by a proportion of the total regional farm sales in the previous year at a 10% nominal rate of interest. Behavioural constraints reflecting, adoption and adjustment behaviour include upper bounds on new technologies defining S - shaped diffusion paths and upper and lower crop flexibility bounds on individual crop acreages in any given year to reflect "safety first" criteria in response to risk and uncertainty.[8/]

The additive objective function is maximized each period where the current parameters of the linear programming problem depend upon solutions of the previous linear programs in the sequence and on various exogenous data which include regional supplies of land, and family labour

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8/ See Day and Singh (4) for a detailed exposition of how behavioural constraints are used to handle learning, cautious adoption and response to uncertainty in r.l.p. models.

by farm size and input and output prices. Detailed data on physical input-output coefficients were constructed from a random sample of some 430 crop and livestock farms in the region of study supplemented by information obtained from field surveys. The sample also provided data for on-farm resources by farm size which was supplemented by data on regional resources from the Brazilian census, and other published sources.[9/]

The model was used to estimate resource use, production patterns, technological change and investment patterns by farm size for the years 1960 - 1970. Estimates of employment and capital utilization were obtained from the results. Detailed short run capital labour substitution relations were analyzed as they existed for the years 1960, 1965, and 1970 in a comparitive static framework. The next section gives briefly the results of the model for the years 1960, 1965 and 1970; section III provides the results of the comparative static analyses while our conclusions are given in the last section.

9/ These include the Conjuctura Economica, Annuario Estatistico do Brazil, Trigo-Estudo do Custo de Producao among others. For details ses Ahn (1).

2. EMPLOYMENT, CAPITAL UTILIZATION AND RESOURCE USE (1960-1970)

2.1. Land Use

Table 1 gives the estimated resource use in Southern Brazil for the years 1960, 1965 and 1970 which were selected for further comparative static analysis. The substantial changes in land use patterns between 1960 and 1970 can be seen in the declining area devoted to natural pasture (used for range livestock production) and the increasing area devoted to field crops such as wheat, soybeans, corn and improved pastures. The area sown to wheat increased nearly sevenfold while total cropped area more than doubled. This changing pattern was accelerated after 1963 when the wheat price and credit policies came into effect as evidenced by the fact that cropped area increased only slightly between 1960 and 1965 but more than doubled between 1965 and 1970. This acceleration was mainly due to a 3.5 fold increase in area devoted to wheat double cropped with soybeans which rapidly transformed natural livestock pastures to crop production. After 1963 livestock production on improved pasture also accelerated as production on natural pastures became less profitable.

2.2. Employment

The changing pattern of production and land use towards crop farming increased the demand for labor substantially over the period with a 3.9 percent per annum increase in total on-farm employment, which increased from 101 to 140.4 million man hours annually. This increased demand was accompanied by a structural change in the demand for labor

with employment increasing at 7.3 percent per annum during the months of May to mid-November when winter wheats are harvested and soybeans planted, but increasing at a much slower rate of 1.7 percent per annum during the months of mid-November to April, the season for corn and soybeans. There is a seasonal scarcity of family labor during the months of November to April but only on large farms which employed approximately 4 million man hours of wage labor. The regional demand for wage labor declined nearly 50 percent between 1960-65, but increased again between 1965-70, mainly on large farms, until by 1970 3.4 million man hours of wage labor was employed. The share of wage labor to total employment consequently has fallen moderately from 3.9 percent in 1960 to 2.4 percent by 1970. This decline can be mainly attributed to the long run substitution of labor intensive by machine intensive technologies, especially on large farms. 9a/

To summarize, the long run estimates show that total regional employment has been increasing at about 4 percent per annum mainly due to a change in the patterns of land use from range livestock to double crop farming. A certain amount of change has also occurred in the seasonal demand for labor with labor scarcity especially on large farms, and most critically in the month of November when winter wheat is harvested and land prepared for soybeans. The demand for wage labor, however, has declined only slowly, for as harvesting and land preparation tasks have been rapidly mechanized, replacing labor, increases in total output have offset this diminished demand.

9a/ It should be recalled that the supply of family labor is increasing at 2% annually on all farms, so that a falling demand for wage labor on large farms indicates that total demand has been increasing at a rate of less than 2% annually.

2.3. Power Use

Total animal draft power use increased nearly threefold in the decade, but this increase was confined mainly to small farms which continue to use traditional animal draft-labor intensive technologies. Medium and large farms, however, are rapidly mechanizing as is evident from the use of tractors and combines in the region. Total tractor use increased nearly threefold from 1.9 million hours to 6.4 million hours, while total combine hours used increased nearly fivefold. Total machine use estimated in B.H.P. units increased over four times from 103 million to 446.8 million hours. Thus there has been a rapid displacement of animal draft by machine power in the region, the displacement being confined mainly to larger farms, with the consequent displacement of labor. The decline in the demand for labor as a result of this, however, has been offset by an overall increase in demand due to changes in cropping patterns. The displacement of wage labor on large farms has, however, been the direct consequence of the mechanization process which as in the case of the Punjab is also seen to be task specific, being most rapid for the harvesting and land preparation tasks. 10/

10/ The task specific nature in the adoption of mechanical technologies is closely related to seasonal labor scarcities though not wholly due to them. See Singh and Day (10).

TABLE 1. ESTIMATED RESOURCE USE IN SOUTHERN BRAZIL: 1960, 1965 and 1970.

Resources		1960	1965	1970
A. Land Use (1000 Hectares)				
1. Total Land Use:	SF	1,068.15	1,090.83	1,136.56
	MF	1,500.72	1,513.27	1,559.78
	LF	1,989.95	2,007.70	2,075.55
	Regional	4,558.82	4,611.90	4,771.89
2. Natural Pasture:	SF	940.00	887.70	728.12
	MF	1,352.00	1,326.63	1,213.46
	LF	1,789.00	1,738.15	1,358.53
	Regional	4,081.00	3,952.48	3,300.11
3. Improved Pasture:	SF	22.15	30.36	1.95
	MF	23.22	52.41	128.54
	LF	30.95	91.04	276.74
	Regional	76.32	173.81	407.23
4. Area Cropped:	SF	106.00	172.77	406.39
	MF	125.50	134.23	217.78
	LF	170.00	178.61	440.28
	Regional	401.50	485.61	1,064.45
5. Area Sown to Wheat:	SF	20.00	74.26	262.17
	MF	29.50	41.89	87.80
	LF	40.00	58.00	271.17
	Regional	39.50	174.15	621.14

(SF: Small Farms, MF: Medium Farms, LF: Large Farms)

TABLE 1. ESTIMATED RESOURCE USE IN SOUTHERN BRAZIL: 1960, 1965 and 1970. (cont.)

Resources		1960	1965	1970
B. Labor Use (Million Man Hours)				
1. Total Annual:	SF	56.763	65.419	87.854
	MF	28.98	31.996	35.326
	LF	15.348	14.905	17.299
	Regional	101.091	112.32	140.41
2. May - Mid November:	SF	40.616	39.311	44.804
(Season I)	MF	14.49	15.998	17.663
	LF	5.848	6.282	8.523
	Regional	60.954	61.591	70.99
3. Mid November-April:	SF	16.147	26.108	43.05
(Season II)	MF	14.49	16.0	17.663
	LF	9.50	8.623	8.706
	Regional	40.136	50.731	69.42
4. Total Hired Labor:	Season I	0.158	0.0	1.587
	Season II	3.81	2.341	1.771
	Annual	3.968	2.341	3.358
C. Draft Animal Use (Million Hours)				
1. Annual Use:	SF	795.56	1,266.37	2,786.23
	MF	242.96	288.81	321.51
	LF	0.0	0.0	0.0
	Regional	1,038.62	1,533.81	3,107.74

(SF: Small Farms, MF: Medium Farms, LF: Large Farms)

TABLE 1. ESTIMATED RESOURCE USE IN SOUTHERN BRAZIL: 1960, 1965 and 1970. (cont.)

Resources		1960	1965	1970
D. Mechanical Power				
1. Tractors:	SF	0.0	0.0	0.0
(1000 Hours)	MF	716.0	947.36	1,917.41
	LF	1,241.4	1,655.54	4,469.98
	Regional	1,957.4	2,602.9	6,387.39
2. Combines:	SF	0.0	0.0	0.0
(1000 Hours)	MF	25.49	38.18	126.92
	LF	76.0	110.21	376.88
	Regional	101.49	148.99	503.8
3. Total Machine Use:	SF	0.0	0.0	0.0
(Million B.H.P.)	MF	37.075	49.307	102.216
	LF	65.87	82.29	344.56
	Regional	102.945	137.537	446.776
E. Nutrient Use:	SF	20.415	32.937	77.089
	MF	22.897	25.927	43.24
	LF	31.095	36.126	104.173
	Regional	74.407	94.99	224.507

(SF: Small Farms, MF: Medium Farms, LF: Large Farms)

2.4 Capital Utilization

Capital utilization took two forms: 1) outlays on variable farm and non-farm produced inputs such as fuel, fertilizers, seeds and wage labor and 2) outlays on durable farm assets mainly animal and mechanical power sources such as tractors and combines. Table 2 shows that total capital utilization and outlays on variable inputs (at constant prices) more than doubled, while outlays on durable assets nearly doubled in the decade between 1960 and 1970. More than four fifths of these outlays were on variable inputs whose proportion of total outlays increased from 82.5 percent in 1960 to 93.1 percent by 1965 and subsequently declined to 85 percent by 1970. The most important variable input are chemical nutrients which account for 15-20 percent of total capital outlays and whose use has more than tripled in the ten year period. 11/ The differences among farms in these regards are not large, and the increases have been fairly evenly spread although among small farms variable outlays account for over 98 percent of all outlays.

The most important feature of capital utilization in the region is the increased reliance on credit to finance farm operations after the wheat pricing and credit subsidy programs came into effect in 1963-64. Whereas working capital borrowed declined somewhat between 1960 to 1965 from 2.5 to 2.2 million Cr.$, and borrowing as a percentage of total outlays declined from 44 to 37.6 percent, the period between 1965 and 1970 saw total borrowings increase over fourfold to 9.4 million Cr.$ and borrowing as a percentage

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11/ The increased nutrient use is associated with the shift from natural pasture to improved pasture and double cropping since these latter activities require some nutrient application while the former does not require any. The increased nutrient use is not yet associated with shifts along a higher point on the nutrient yield function with higher yield levels.

TABLE 2: ESTIMATED CAPITAL UTILIZATION IN SOUTHERN BRAZIL: 1960, 1965, 1970

Capital Items (At 1960 Constant Prices in 1000 Cr.$)		1960	1965	1970
1. Total Outlays:	SF	1,015.23	1,352.89	2,362.45
	MF	1,763.69	1,733.26	3,043.06
	LF	2,998.82	2,884.52	6,364.38
	Regional	5,777.74	5,970.67	11,769.89
2. Outlays on Variable Inputs:	SF	1,014.07	1,322.37	2,316.28
	MF	1,501.33	1,677.19	2,516.12
	LF	2,250.19	2,547.13	5,170.76
	Regional	4,765.59	5,556.69	10,003.16
Percentage of Total	(Regional)	(82.5)	(93.1)	(85.0)
3. Outlays on Nutrients:	SF	224.57	362.31	847.98
	MF	251.87	285.2	475.64
	LF	342.05	397.39	1,145.96
	Regional	818.49	1,044.90	2,469.58
Percentage of Total	(Regional)	(14.2)	(17.5)	(21.0)
4. Outlays on Non-Farm Investment Goods:	SF	1.16	20.52	46.17
	MF	262.36	56.07	526.94
	LF	748.63	337.39	1,193.62
	Regional	1,012.15	413.98	1,766.73
Percentage of Total	(Regional)	(17.5)	(6.9)	(15.0)
5. Working Capital Borrowed:	SF	358.22	342.87	776.3
	MF	751.69	321.31	2,219.84
	LF	1,432.82	1,561.87	6,364.38
	Regional	2,542.73	2,246.05	9,360.52

(SF: Small Farms, MF: Medium Farms, LF: Large Farms)

TABLE 2: ESTIMATED CAPITAL UTILIZATION IN SOUTHERN BRAZIL: 1960, 1965, 1970 (cont.)

Capital Items (At 1960 Constant Prices in 1000 Cr.$)		1960	1965	1970
6. Borrowing As a Percentage of Total Outlays:	SF	35.3	26.8	32.9
	MF	42.6	18.5	72.9
	LF	47.8	54.1	100.0
	Regional	44.0	37.6	79.5

(SF: Small Farms, MF: Medium Farms, LF: Large Farms)

of total outlays increased over twofold to 79.5 percent. More than half of the twofold increase in capitalization in the region was due to the availability of external funds at negative real interest rates.

In a later section (4.6), we will examine the sensitivity of borrowing to changes in the interest rate, but here we point to the substantial differences in both the growth of credit use and increased reliance on it. Borrowings on small farms increased very slightly between 1960 and 1965 while borrowing as a percentage of total outlays actually declined from 35.3 to 26.8 percent. Between 1960 and 1970 small farm borrowings more than doubled from 0.36 to 0.78 million Cr.$ but borrowings as a percentage of total outlays declined to 32.9 percent. Thus small farms, although they have nearly doubled their credit use, their reliance on credit has not increased.

The results on medium and large farms present a different picture. Between 1960 and 1965 borrowings declined by more than half on medium farms and increased by some 16 percent on large farms. Borrowing as a percentage of total capital use decreased from 42.6 to 18.5 percent on medium farms and increased from 47.8 to 54.1 percent on large farms. Between 1960 and 1970 as credit use increased more than threefold on medium farms and nearly fourfold on large farms, borrowings as a percentage of total capital use increased to 73 and 100 percent respectively for medium and large farms. This increased dependence on credit to finance farm operations on medium and large farms is directly related to credit policies which have enabled

the purchase of both variable and quasi-fixed inputs with credit at nominal rates of interest far below the rate of inflation. 12/

2.5 Productivity and Factor Proportions.

The resource utilization patterns have substantially altered the aggregate factor proportions which provide a clue to the changing factor productivity and substitution in the long run. These are reported in Table 3.

Total output increased only slowly between 1960 and 1965 at about 2.5 percent per annum, but after 1965 it accelerated, increasing at the rate of 7.5 percent per annum. There were farm size differences in the latter period in the rate of growth with medium farms increasing their output at about 5 percent per annum and large farms at about 10 percent per annum with small farm output growing at about 6.3 percent per annum.12a/

Average labor and land productivity have also increased, the greatest increase coming after 1965. Labor productivity increases with an increase in farm size being ten times greater on large than on small farms in 1970, but land productivity on small farms is higher than on medium farms but lower than on large farms, the lower productivity on medium farms being a consequence of a higher proportion of land being devoted to natural pasture. Capital productivity measured on both a gross and net basis increased slightly between 1960 and 1965 as capital utilization declined, but declined substantially after that as easy credit increased the supply of credit in the region. Capital productivity generally declines with an increase in

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12/ Thus after 1964, modern variable inputs such as seeds, nutrients and pesticides could be purchased 100 percent on credit, while farmers can obtain long term, low interest financing for agricultural machinery with a 25 percent down payment at a 7 percent rate of interest, during a period when the rate of inflation has been in excess of 35 percent.

12a/ This is partly explained by the fact that both small and large farms specialize in their choice of technologies, while medium farms which have a mixed pattern of technological adoption follow a less efficient expansion path.

TABLE 3. ESTIMATED OUTPUT, FACTOR PRODUCTIVITIES AND FACTOR PROPORTIONS: 1960, 1965, 1970

Item		1960	1965	1970
(In 1000 Cr.$ at 1960 prices)				
A. Total Output:	SF	6,021.6	7,143.2	9,420.1
	MF	8,500.8	9,263.7	11,597.5
	LF	11,333.4	12,714.3	19,053.2
	Regional	25,855.4	29,121.2	40,070.8
B. Factor Productivity (At constant 1960 prices)				
1. Labor (Cr.$/Hr.):	SF	0.106	0.109	0.107
	MF	0.293	0.289	0.328
	LF	0.738	0.853	1.101
	Regional	0.256	0.259	0.285
2. Land (Cr.$/Hectare):	SF	5.64	6.55	8.29
	MF	5.66	6.12	7.44
	LF	5.69	6.33	9.18
	Regional	5.67	6.31	8.40
3. Capital (Cr.$/Cr.$): (Net Revenue/Total Outlays)	SF	4.93	4.28	2.99
	MF	3.82	4.34	2.81
	LF	2.78	3.41	1.99
	Regional	3.48	3.88	2.40
4. Capital (Cr.$/Cr.$): (Gross Revenue/Total Outlays)	SF	5.93	5.28	3.99
	MF	4.82	5.34	3.81
	LF	3.78	4.41	2.99
	Regional	4.48	4.88	3.41

(SF: Small Farms, MF: Medium Farms, LF: Large Farms)

TABLE 3. ESTIMATED OUTPUT, FACTOR PRODUCTIVITIES AND FACTOR PROPORTIONS: 1960, 1965, 1970 (cont.)

Item		1960	1965	1970
C. Inputs Per Hectare				
1. Labor (Hours)	SF	53.14	59.97	77.3
	MF	19.30	21.14	22.65
	LF	7.71	7.42	8.33
	Regional	22.17	24.35	29.42
2. Animal Draft (Hours):	SF	0.74	1.16	2.45
	MF	0.16	0.19	0.21
	LF	0.0	0.0	0.0
	Regional	0.23	0.34	0.65
3. Mechanical Power: (BHP Hours)	SF	0.0	0.0	0.0
	MF	24.7	32.6	65.5
	LF	33.1	58.3	166.0
	Regional	22.6	29.8	93.6
4. Working Capital: (Constant 1960 Cr.$)	SF	0.95	1.22	2.04
	MF	1.00	1.11	1.61
	LF	1.13	1.27	2.49
	Regional	1.04	1.20	2.10
D. Inputs Per Unit of Labor (Per Hour)				
1. Animal Draft (Hours):	SF	0.1402	0.0194	0.0317
	MF	0.0084	0.0090	0.0091
	LF	0.0	0.0	0.0
	Regional	0.0103	0.0138	0.0221

(SF: Small Farms, MF: Medium Farms, LF: Large Farms)

TABLE 3. ESTIMATED OUTPUT, FACTOR PRODUCTIVITIES AND FACTOR PROPORTIONS: 1960, 1965, 1970 (cont.)

Item		1960	1965	1970
2. Mechanical Power: (BHP Hours)	SF	0.0	0.0	0.0
	MF	1.279	1.541	2.894
	LF	4.292	5.923	19.918
	Regional	1.018	1.225	3.182
3. Land (Total Hectares):	SF	0.0188	0.0167	0.0129
	MF	0.0518	0.0473	0.0442
	LF	0.1297	0.1347	0.1200
	Regional	0.0451	0.0411	0.0340
4. Working Capital: (Cr.$) (Constant 1960 prices)	SF	0.0179	0.0204	0.0264
	MF	0.0152	0.0524	0.0712
	LF	0.1466	0.1709	0.2989
	Regional	0.0471	0.0495	0.7124
E. Total Capital Use (In Constant 1960 Cr.$)				
1. Per Hectare:	SF	0.9505	1.2402	2.0788
	MF	1.1746	1.1454	1.951
	LF	1.5069	1.4367	3.0664
	Regional	1.2674	1.2946	2.4666
2. Per Man Hour:	SF	0.1789	0.0207	0.0269
	MF	0.0609	0.0542	0.0861
	LF	0.1954	0.1935	0.3679
	Regional	0.0571	0.0532	0.0838

(SF: Small Farms, MF: Medium Farms, LF: Large Farms)

TABLE 3. ESTIMATED OUTPUT, FACTOR PRODUCTIVITIES AND FACTOR PROPORTIONS: 1960, 1965, 1970 (cont.)

Item		1960	1965	1970
3. Per Unit of Output:	SF	0.1686	0.1839	0.2508
	MF	0.2075	0.1871	0.2624
	LF	0.2646	0.2269	0.3340
	Regional	0.2235	0.2050	0.2937

(SF: Small Farms, MF: Medium Farms, LF: Large Farms)

farm size with small farms showing a 33 percent higher gross and 50 percent higher net capital productivity than large farms in 1970.

Changes in factor proportions in the long run have included higher labor, animal draft, mechanical power and capital use per hectare indicating an increase in the intensity of land use. Labor use per hectare has increased on all farms, but increased the most on small farms, while capital use per hectare has increased on all farms also but most on large farms. The animal draft to labor ratio on small farms and the mechanical power to labor ratio on medium and large farms have increased nearly threefold since 1965 reflecting the increased demand for power associated with increased intensity of land use. The increase in capital utilization is reflected in the increased capital use per unit of output, per hectare and per man hour between 1965 and 1970.

Thus there has been substantial substitution of capital in the form of mechanical power and variable inputs for both labor and land with a consequent decline in capital productivity. An increase in the demand for labor as a result of increased intensity of land use has been only partially offset by increased mechanization. Thus although the machine-labor ratio has increased, the land-labor ratio has continued to decline. Capital-labor substitution is also reflected in the fact that in the aggregate, the machine-animal draft use ratio has increased.

In summary, the model shows the process of long run transformation in agriculture in Southern Brazil which has involved 1) a change in the cropping pattern from extensive livestock to intensive crop and livestock farming, brought about 2) by substantial changes in pricing and credit policies in the region especially after 1965 that have 3) substantially increased mechanization, labor and capital use in the region bringing about 4) an increase in labor and land productivity and 5) an increase

in the capital-labor and capital-land and a decrease in the land-labor ratios through time.

3. COMPARATIVE STATIC ANALYSES FOR 1960, 1965, 1970.

The analysis in the preceeding section has focused on the long run transformation of the agricultural sector in Southern Brazil wherein we have shown that the substantive changes in the output mix as a result of deliberate price and credit policies have brought about increases in employment and capital use with increased land and labor productivity and changing factor proportions in favor of increased labor, mechanical power and capital use per hectare. In this section, we turn our attention to an analysis of the short-run possibilities for resource substitution and allocation in response to independently varied parameters. Six individual comparative static analyses have been performed for the years 1960, 1965, and 1970 using as a base in each case the situation estimated by the dynamic model for the given year, the results of which were discussed in the previous section. The analyses involved parametric changes in the supply of 1) working capital, 2) labor and 3) non-farm investment goods and the "cost" of 4) labor, 5) mechanical power sources and 6) credit. The results and their implications for short-run capital-labor adjustments are discussed below. 13/

3.1 The Marginal Efficiency of Capital.

The comparative static results obtained by varying the supply of working capital are graphically displayed in figure 1. They show the impact of changing working capital availability on the weighted shadow price of the cash constraint, thus tracing out the marginal efficiency of capital

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13/ The discussion follows the outline of the Punjab study in order to enable comparative analysis.

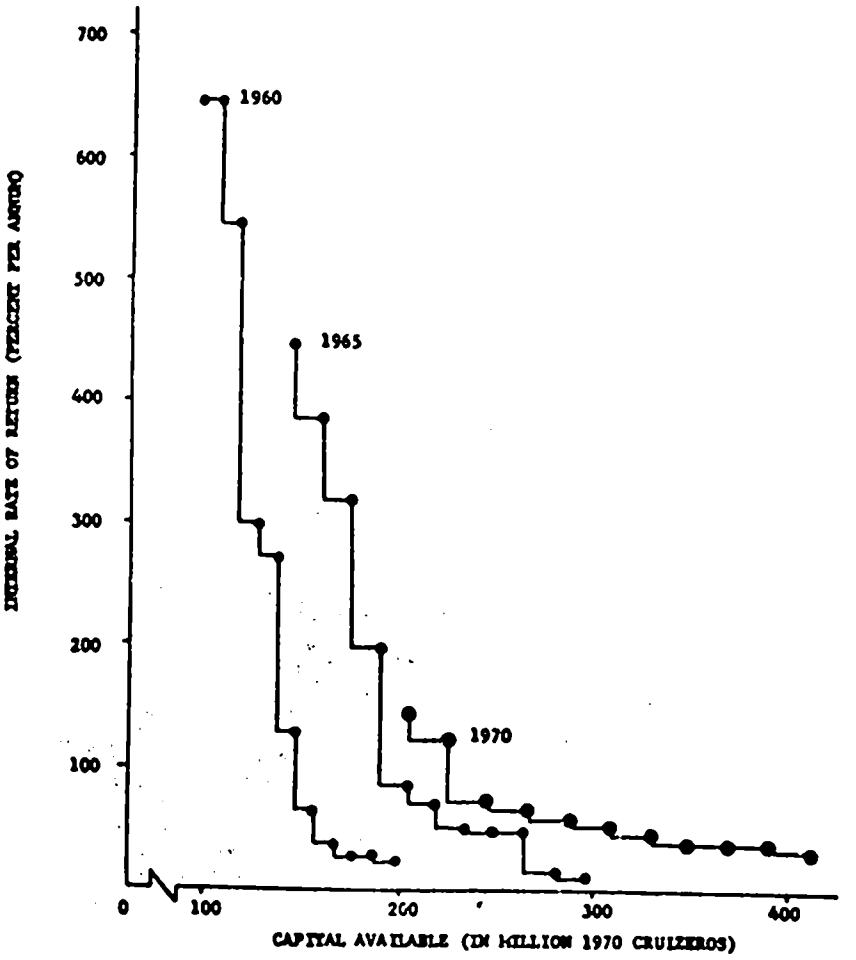

FIGURE 1. THE MARGINAL EFFICIENCY OF CAPITAL

at various levels of capital supply (internal and external) available in each year. 14/

The results show a substantial shift in the derived demand for capital over time and an increase in its elasticity especially between 1965 and 1970. The increased demand is the result of an increasing use of commercial inputs (seeds, fertilizers, pesticides, fuels and wage labor) in the resource mix occasioned by the dramatic shift from range livestock to crop production in the region. The changing elasticity of demand for capital over time is due partly to shifts in the cropping patterns and partly due to the nature of technological change in the region. A shift into crop intensive farming increases the range of cash using enterprises allowing a greater range of substitution in the output mix and hence a greater sensitivity to changes in the capital endowments of the farming enterprise. At the same time most of the technological change in Brazil has been labor rather than land saving bringing about a comparative saturation as far as non-farm invetment goods are concerned, leaving only those possibilities for further capital absorbtion associated with enterprise changes in favor of intensive cropping. 15/ The rates of return at the initial margin are relatively low ranging between 10-30 percent for internal and external capital funds in the aggregate. However, if

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14/ Since each farm size group has its own working capital constraint and hence associated shadow prices, these are weighted by the total cash outlays in each farm size group to obtain the regional internal rate of return.

15/ Thus compared with the Punjab where changes in the elasticity of the demand for capital took a much longer period of 20-25 years to become evident. The difference arises due to the fact that the Punjab experienced changes in biological and mechanical components of technology jointly over the same period, whereas in Brazil only the mechanical changes in technology are as yet evident.

we keep in mind that loose credit policies have saturated the sector with credit at low and even negative real rates of interest, meeting a large portion of the capital requirements, it is evident that working capital would have had a much higher marginal efficiency in the absence of such policies. The increased reliance on external funding (borrowing) to finance production and investment, where not only interest rate but allocation distortions were introduced implies that capital has not been efficiently allocated in the region. In the absence of these distortions introduced on the supply side by external finance the path of regional development may have been substantially different. 16/

The future productivity of capital in the region will depend upon two inter-related factors: 1) the rate at which new biological technologies are introduced and adopted in the region, thus shifting the marginal efficiency schedule outwards and making it less elastic and 2) the extent to which these new technologies are also externally financed and allocated according to institutional criteria at low or negative rates of interest, continuing the current regime of distortions which effectively veils differences in the real rates of return in the region to different farm enterprises.

In the absence of new biological technologies, it can be said that the rates of return to capital in agricultural production will continue

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16/ Allocation distortions are most evident in the policy where maximum credit limits are set at some proportion of gross revenues for all farm enterprises as in Brazil in this period. Thus a larger proportion of the credit per hectare has gone to large farms where capital productivity is lower than on small farms, which have as a consequence been starved. Small farms consistently show a shadow price for capital several times larger than do large farms in the parametric results.

to decline far enough (except on small farms) to warrant tighter regional credit policies, and to call a halt to the expansion of credit in this sector. The obvious exception are small farms which have been starved of credit in the past and where marginal rates of returns will continue to be high to warrant further credit expansion.

3.2 The Derived Demand for Non-Farm Capital Goods.

The possibility that investments in mechanical power and machinery may have been especially influenced by factor price distortions in favor of capital inputs was analyzed by varying the annual investment charge or depreciation allowance. The result is the derived demand curve for each capital good in each farm size group. These have been aggregated using 1970 prices and trace out the aggregate derived demand curves for non-farm capital goods in each year which are shown in figure 2.

The results illustrate two very interesting features about the derived demand for non-farm capital goods: 1) its shift over time and 2) its sensitivity to changes in farm machinery prices. Thus, we see for example that annual investments stood at about 2.8 million Cr.$ in 1960 (at constant 1970 prices) but declined to half that amount between 1960 and 1965. However, with the introduction of the new wheat price and credit policies annual investments increased fourfold between 1965 and 1970. These investments were confined largely to increasing tractor and harvesting combine capacity mainly on medium and large farms. This large increase in the demand for machine capacity was the direct result

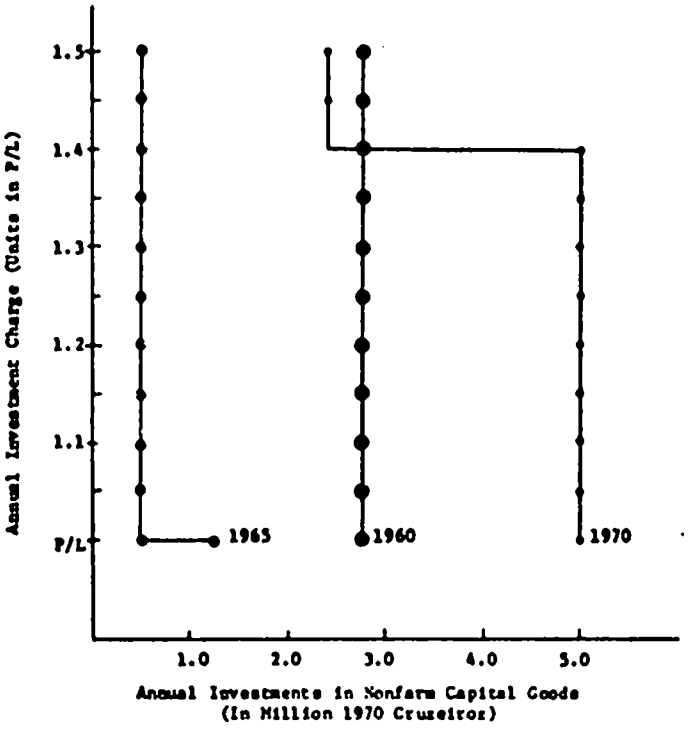

FIGURE 2. DERIVED AGGREGATE DEMAND FOR NONFARM CAPITAL GOODS

of price and credit policies since wheat support prices made the increased production of wheat possible, bringing about an increase in the potential demand for land preparation and harvesting equipment especially during periods of labor shortage on large and medium farms, while the availability of credit at negative real rates made the expansion of such capacities profitable over this period.

Just how critical, cheap and plentiful credit was to this process of capacity expansion can be seen in the large drop in annual investments in 1965 and 1970 when the investment charge is increased. Whereas in 1960 the investment schedule is perfectly inelastic over a range where farm machinery prices are increased by 50 percent, in 1965 a mere 5 percent increase in these prices causes annual investments to decline by 59 percent and in 1970 a 45 percent increase in prices brings about a 53 percent decline in total investments. Besides the price elasticity of the investment schedules in 1965 and 1970 the results show that the decline in annual investments was confined to large farms where in 1965 annual investments in combines declined by 98 percent while that in tractor by 42 percent. The figures for 1970 were 82 percent and 50 percent respectively. Thus, it is the investments on large farms that are price elastic and investments in combine capacity that are most sensitive to changes in the investment charge. We can infer from this that the greatest impact of subsidized capital and loose credit policies in the region has been to encourage mechanization on large farms, especially in the purchase of combines, at a rate far in excess of what would have been justified

either by profitability, even given the labor shortages on large farms. A certain amount of mechanization would have occurred on large farms as hired labor was replaced to relieve seasonal labor shortages, but by reducing the effective cost of capital, credit policies have increased the rate of mechanization far above that justified by the capital productivity of power sources and brought about a misallocation of investible funds in the region.

3.3 Substitution Between Animal and Mechanical Sources of Power.

In the performance of agricultural tasks, a choice of various power sources is available. Although we often think of capital-labor substitution possibilities in the range of available choice, the real choice is often between mechanical and animal power sources with labor being a complementary input to several available alternatives. 17/ However, labor also provides motive power and can be directly substituted for by both animal and mechanical power sources, thus reducing the labor input per task unit in the process. In the aggregate where all three power sources, human, animal and mechanical are in use, we can analyze both the substitution between animal and mechanical power sources and between labor and machine or animal draft use. Since generally tasks performed with the help of animal power require a relatively larger complement of labor and tasks performed with mechanical power relatively larger outlays of capital (variable and fixed), we can refer to the

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17/ The only case where labor is not a complement is where we have total automation of a task.

replacement of animal by mechanical power as a substitution between labor intensive and capital intensive power.

In order to analyze these substitution effects in the short-run, the "adjustment constraints" on investments in tractors and combines were varied parametrically in a way that would account for a decrease in the supply of machines and/or a decline in the willingness of farmers to adjust in the short run to profitable opportunities. The results shown in figure 3 indicate the range of substitution possibilities between labor intensive animal power and capital intensive machine power given fixed supplies of labor.

The range of substitution possibilities is very limited in any year. Over time the substitution possibilities become more inelastic so that by 1970 even very large increases (decreases) in mechanical power availability bring about only small decreases (increases) in the use of animal draft power. The short-run rigidity in the substitution possibilities are mainly due to the fact that most of animal draft use is confined to small farms, which given their factor proportions are not likely to adopt mechanical power, while the reduction in available mechanical power on medium and large farms does not allow them to increase the use of animal draft given labor shortages and fixed labor supplies. Since more labor would be required on medium and large farms if they were to replace capital intensive by labor intensive power use, they are unable to do so in the face of seasonal labor scarcity.

This rigidity is, however, removed quickly if we relax the assumption of fixed labor supplies and allow them to increase as we reduce the

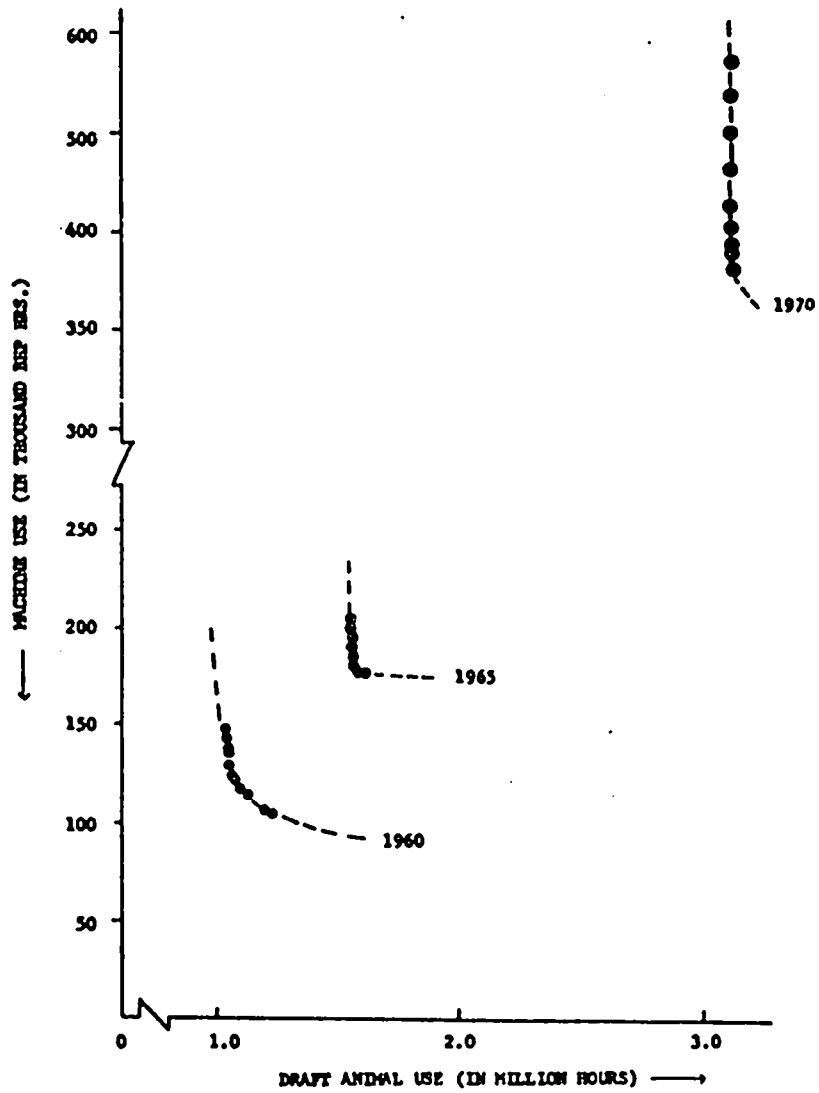

FIGURE 3. SHORT RUN SUBSTITUTION OF POWER SOURCES GIVEN FIXED LABOR SUPPLIES

supply of capital goods. These results are shown in figure 4 and indicate a substantial range of substitution possibilities since medium and large farms can obtain the additional labor needed to adopt labor intensive power sources. This, however, does not imply that labor intensive power sources are profitable, only that if the supply of non-farm capital goods was decreased and regional supplies of labor augmented substitution over a wide range would be possible.

For purposes of policy, these results suggest that attempts to increase regional employment by substituting labor intensive for capital intensive technologies are likely to succeed only if regional wage labor supplies are increased by in-migration and the cost of capital is raised in order to make capital-intensive technologies less profitable. Without these combined measures, increased employment will be associated, as in the past, with further increases in crop farming which also entail increased capital outlays so that the capital-labor ratio will most likely continue to increase.

3.4 The Derived Demand For Labor

Between 96-98 percent of the total employment in the region is accounted for by the use of family labor with wage labor use being confined to medium and large farms and that, too, in peak periods. Changes in the derived demand for labor therefore depend largely on the opportunity cost assigned to the use of family labor.

The results in the tables in section 2 are based on the assumption that family labor is a fixed farm resource in the short run and therefore has a zero opportunity cost to the farmers. The fixed costs of maintaining

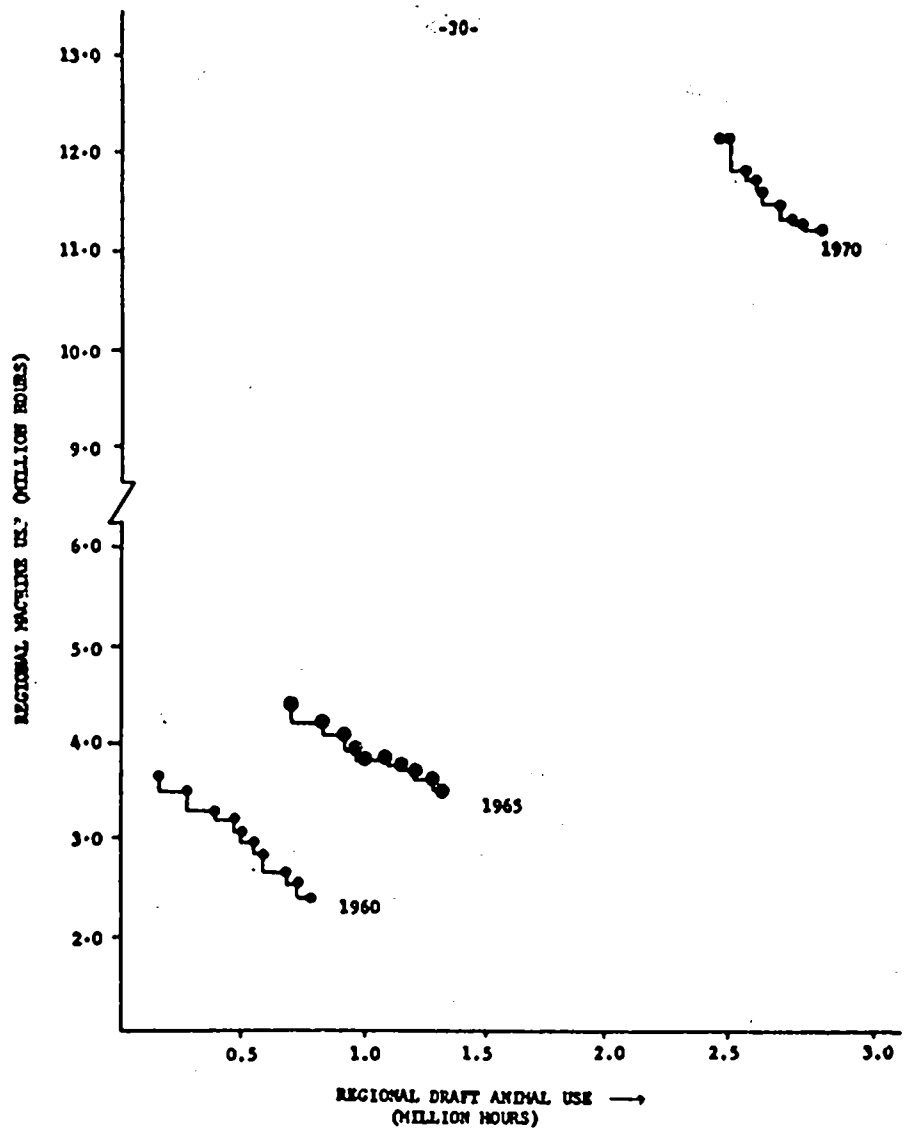

FIGURE 4. SHORT-RUN SUBSTITUTION BETWEEN ANIMAL DRAFT AND MACHINE USE

the family labor force are accounted for by explicitly subtracting consumption requirements from the available cash flows when the working capital constraint is calculated each. 18/ On the basis of a zero opportunity cost for family labor, with wage labor at the going agricultural wage rate the model estimated annual regional farm employment of 101, 112 and 140 million man hours respectively for 1960, 1965 and 1970.

In order to examine the impact of increasing the opportunity cost of family labor and hired labor as well, we give family labor a wage equal to half the going market wage rate and then vary the wage rates for both family and hired labor continuously. The parametric results then trace out the derived demand curves for labor for each year which are graphed in figure 5.

The impact of raising the opportunity cost of labor from zero to fifty percent of the market wage was to substantially reduce employment in 1960 and 1965 but not in 1970. Total employment fell to 65.4, 80.1 and 139.9 million respectively, a decline of 35.3 and 28.6 percent in 1960 and 1965 but of only 0.4 percent in 1970. There has been an increase in the derived demand for labor as indicated by shift in the curves to the right, the greatest shift being between 1965 and 1970 a period associated with changes from livestock to crop farming.

The demand for labor is fairly inelastic for all the three years. The arc elasticity measured over the range where all wages are increased by 50 percent is 0.51, 0.35 and 0.32 respectively for 1960, 1965 and 1970 showing

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18/ Thus cash available on the farm firm is the value of the marketable surplus after internal consumption and living expenditures are met, less debt repayment plus previous savings, if any, with accrued interest.

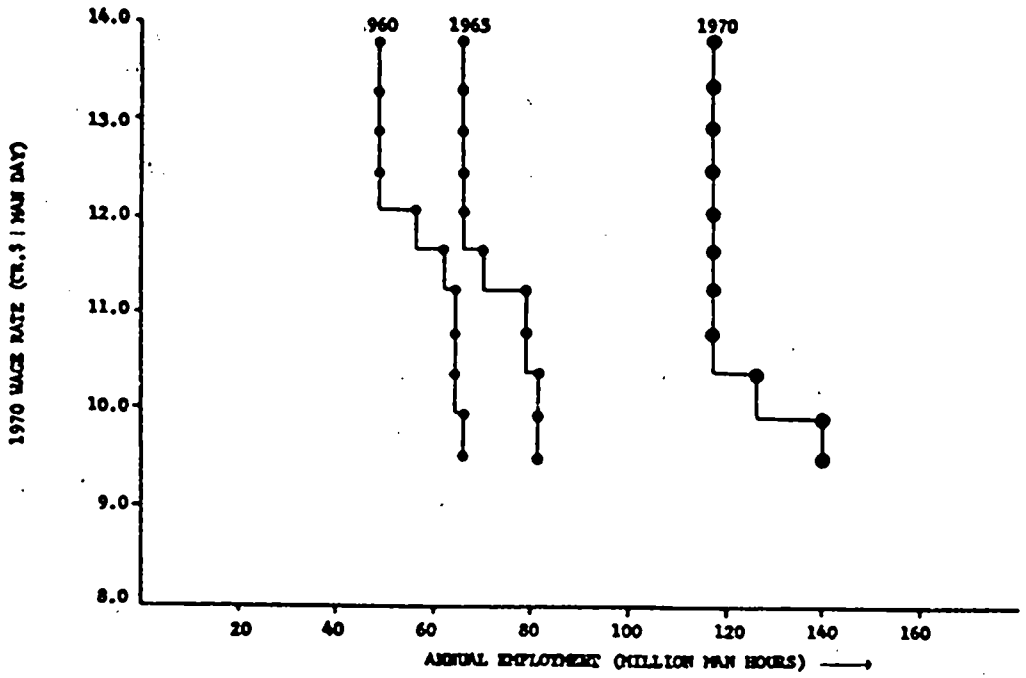

FIGURE 5. DERIVED DEMAND FOR LABOR.

an increasing inelasticity over time. This is due in part to the fact that as mechanization in the region has progressed, an increasingly smaller margin for labor displacement has remained, without further changes in the cropping patterns. The relative wage inelasticity of labor demand in the region suggest that small changes in wage rates are unlikely to change regional employment and that only a more drastic shift in labor costs are likely to bring about substitution, between capital and labor intensive technologies.

3.5 Capital-Labor Substitution.

The short run substitution possibilities between labor and capital vary depending upon whether or not labor supply, a scarce resource on medium and large farms, is held constant or not. In order to examine these possibilities in greater detail, we present the results of varying the supply of labor (both family and hired) over a range from one-half to two folds of the actual regional availability. The schedules shown in figure 6 display the short-run substitution between the flow of machine services measured in brake horsepower (BHP) hours and employment.

The results show that the elasticity of substitution of labor for machine use is relatively high, so that as labor supply is increased, labor is quickly substituted for machine use with the elasticity of substitution increasing between 1960 and 1965, and declining by 1970. Thus over the range of analysis, a decline of a million hours in machine use is associated with an increase of 37.4, 75.1 and 31.8 million hours of employment in 1960, 1965 and 1970 respectively.

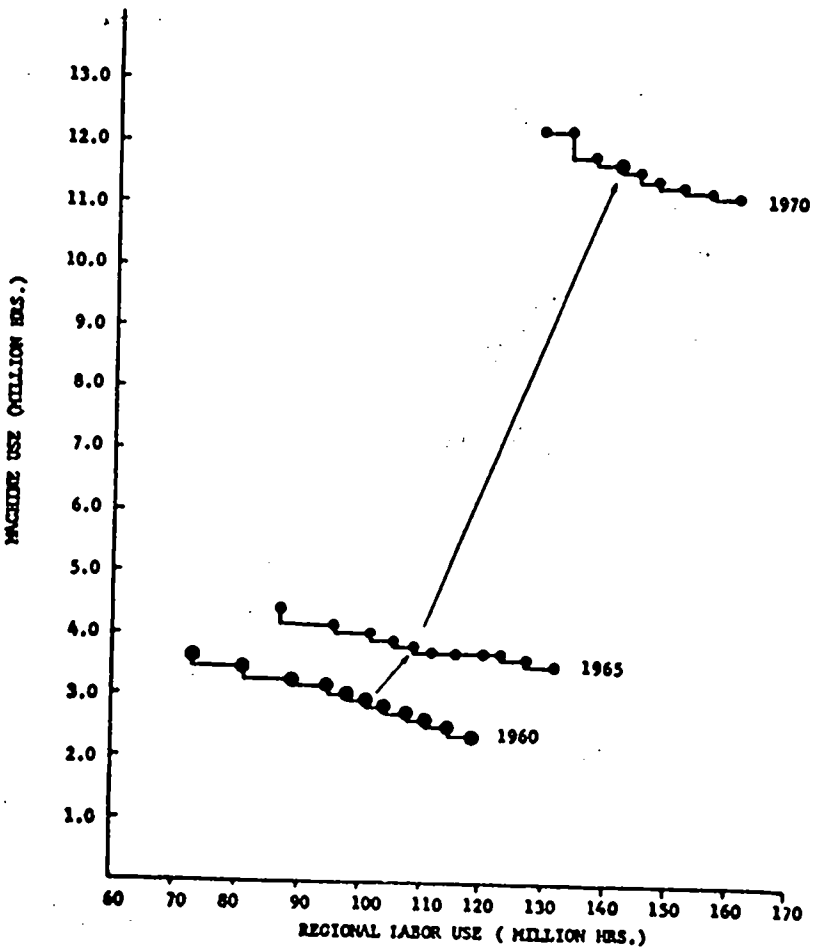

FIGURE 6. SHORT-RUN MACHINE POWER - LABOR SUBSTITUTION

These results, combined with those of sections 3.2 and 3.4, bear out the fact that capital-intensive technologies are only marginally profitable, this profitability being due mainly to the relatively low capital costs, and that the adoption of capital intensive technologies is due mainly to seasonal family labor shortages on medium and large farms. This considerable flexibility in the short-run substitution process suggests that migration that increases the supply of labor in the region, would slow the pace of mechanization considerably, though the evidence is not conclusive since the additional cost associated with hiring labor could also be partly responsible for the current rate of mechanization, given the currently low cost of capital. 19/

In the long-run opportunities for increasing employment are likely to come from increased land use intensity as the transformation from a land extensive livestock agriculture to a land intensive livestock and double crop agriculture continues resulting in increased employment and mechanization. 20/ Thus even though short-run capital-labor substitution possibilities exist, dynamically over time, the short-run substitution possibilities are likely to be swamped by the long run impact of growth on both employment and capital use until this transformation is completed.

19/ An increase in the supply of family labor would slow the pace of mechanization only if capital intensive technologies were to become relatively unprofitable. Increased supplies of family labor can occur either through an increase in population leading to a division of family holdings, or where the law of primogeniture applies through a drastic land reform that changes land ownership patterns by giving land to the landless, thus converting hired wage labor into peasant proprietors. Both these changes are unlikely in the short-run.

20/ As indicated by the arrows showing the expansion of employment and machine use for actual labor supply conditions.

3.6 Demand for Debt.

As pointed out earlier, not only is debt an important source for financing farm expenditures but its importance has increased substantially. Since in our treatment all debt is short-term and assumed to be financed each year, the total borrowings in each year reflect the total demand for debt under existing economic conditions. The importance of low nominal interest rates in increasing the level of indebtedness in the region has been mentioned throughout. In order to see how important this is, we have varied the nominal interest rates, increasing them from the average 10 percent nominal rate which has been effective, and have traced out the demand for loanable funds. The results are shown in figure 7 for each year by farm size at current prices and for the regional aggregate for all three years at constant 1960 prices. The results are revealing.

First looking at the regional aggregate demand for debt at constant 1960 prices, 21/ we note that the demand increased from 1.58 to 1.73 million Cr.$ between 1960-65 and to 7.8 million Cr.$ by 1970. Secondly, we see that as the estimated real rate of interest is increased to 10 percent, borrowings in 1965 are reduced by 65 percent, and in 1970 by about 45 percent, while in 1965 borrowings drop to zero! In the positive range for the real rate of interest, the demand for debt was inelastic for 1960, while in 1970 a

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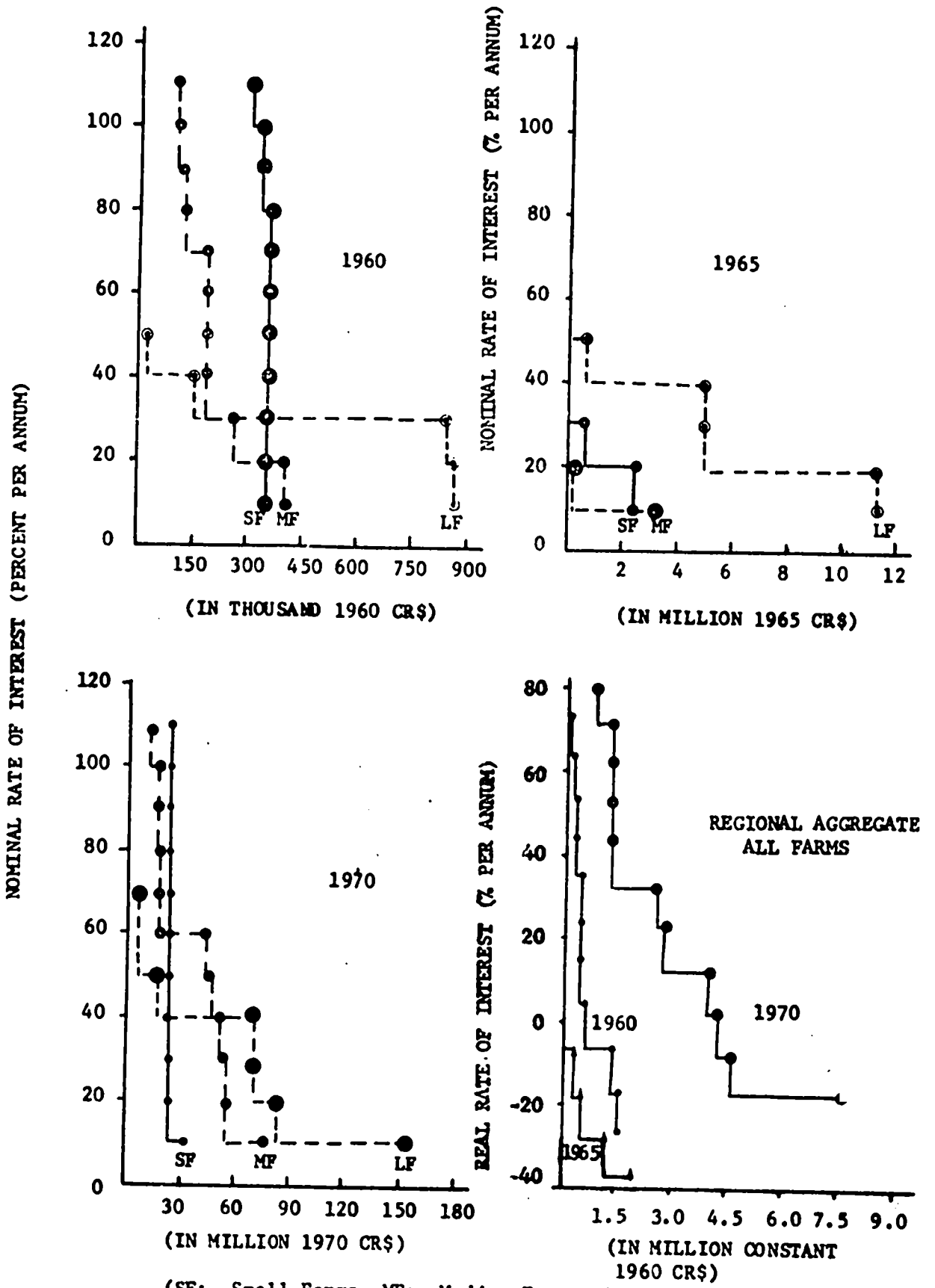
21/ In order to compare the three years, each with a different rate of inflation (the wholesale agricultural price index increased by 36.3%, 47.1% and 27.2% respectively between 1960-61, 1964-65 and 1970-71 respectively) we have plotted the estimated real rate of interest on the y-axis. The real rate = Nominal rate - percentage change in the price index.



(SF: Small Farms, MF: Medium Farms, LF: Large Farms)

FIGURE 7. DEMAND FOR DEBT

further increase of interest rates to 40 percent brings an additional 53 percent decline in borrowings. Thus in 1965 and 1970 if "realistic" rather than the negative real rates of interest had been changed, borrowings would have declined very substantially.

Because of inflation and substantial differences in response to interest rates by farm size, we have also presented the results for each of the years separately. In 1960, we see that the regional inelasticity of the demand for debt is due in large part to the inelasticity on small farms. The demand for debt on medium farms is more elastic while that on large farms extremely elastic. If we consider the fact that the increase in the wholesale agricultural price index between 1960 and 1961 was 36.3 percent, in order to measure the demand for debt at a 10 percent real rate of interest, we have to look at a 46.3 percent nominal rate. At this rate, large farm borrowings decline to zero, medium farm borrowings drop by 53 percent, while borrowings on small farms do not change at all.

Even more dramatic results are obtained for 1965 for with a 47 percent increase in the price index between 1964-65, there are no borrowings at all at a 50 percent nominal or 3 percent real rate of interest! Inded if positive rates of interest had been charged (47+ percent nominal interest rates) there would have been no borrowings at all even on large farms!

By 1970, not only has the demand for debt increased sixfold but it has become less elastic. The debt schedule for small farms depicts an extremely inelastic demand, while demand on medium and large farms continues to be fairly elastic. Again with a 27 percent increase in the wholesale agricultural price index between 1969-70, the demand at 40 percent nominal interest rates (13 percent real rate of interest) declined by 65 percent on large farms and 32 percent on medium farms.

There are several important implications of these results. First, the demand for debt is elastic and generally more elastic on medium than on small farms and on large farms than on medium farms. Second, the relative inelasticity of demand on small farms reflects the higher productivity of capital as well as a shortage of capital on small farms which have to augment their own funds with credit to finance production, even though the internal funds provide over two-thirds of their capital needs. Third, if interest rates were raised to realistic levels from the current negative levels (a 10-12 percent real rate corresponding to approximately 45-50 percent nominal rate over the period) small farm credit use would not have declined. On the other hand, charging a realistic positive rate of interest would have in 1970 (where demand is least elastic) resulted in a 32 and 65 percent decline in the demand on medium and large farms respectively. Since these accounted for 32.5 and 62.7 percent of the total borrowing respectively (98.2 percent jointly), charging realistic rates would have caused a 40 percent contraction in regional debt, leaving borrowings at only two-thirds their current levels. Thus over 30 percent of the debt on medium farms and over 65 percent on large farms is due to low and uncompetitive rates of interest being extended beyond the levels justified by capital productivity on these farms.

These results, along with the earlier results on the demand for non-farm capital goods and capital productivity on various farms, show how factor price distortions (in favor of capital) have seriously affected factor proportions (increased substantially the capital-labor and capital

land ratios) and distorted the flow of credit in favor of and increased the rate of capitalization on medium and large farms, resulting in a substantial misallocation of capital both within the sector and vis-a-vis other sectors.

4. CONCLUSIONS.

An analysis of both the short run and long-run factor substitution in the region allows us to conclude with the following points of summary:

1) The long run transformation from range livestock to intensive livestock and crop farming has brought both increased employment and capital utilization to the region increasing both labor and capital use per hectare;

2) This transformation has been definitely accelerated by government price and credit policies, wherein product prices have been "distorted" in favor of crop farming (especially wheat) and factor prices "distorted" in favor of capital leading to increased mechanization, use of modern variable inputs and reliance on debt to finance farm operations.

3) Short run and long run evidence on relative factor productivities and substitution, and their differences among farm size groups point towards a misallocation of capital both within the sector and vis-a-vis other sectors. Especially the extreme sensitivity of farm investments to capital charges and demand for debt to interest rates, most specifically on large farms, indicate that credit policies have encouraged capitalization and reliance on debt on large farms far in excess of what would have occurred in the absence of such policies;

4) Although the demand for labor is fairly inelastic, reflecting in part seasonal shortages and in part the unrealistically low capital costs facing farms, the substitution between capital and labor is high though somewhat limited in the short run by the supply of labor;

5) The long-run changes in the future are likely to remain the same unless price and credit policies are changed, since low capital relative to wage costs have encouraged mechanization and increased the capital-labor and capital output ratio;

6) Perhaps the single most effective measure that will substantially change these trends is the raising of the nominal interest rates from their current negative real levels to around 45-50 percent to reflect the real opportunity cost of capital. This is perhaps the best means of correcting the large distortions government policies have introduced in the region. The impact of such a change in policy should be an area for further research. They are, however, beyond the scope of the present paper.

Balance Equation Constraints

(5) $\Sigma_q \Sigma_{j \varepsilon p} a_{ij} X_j(t) + \Sigma_q \Sigma_{j \varepsilon v} a_{ij} X_j(t) \leq B_i(t) \quad , \quad i \varepsilon E$

which allow the production of intermediate outputs and their transfer for use in final production, sales or investment;

Behavioural Constraints and Dynamic Feedback

These restrictions describe the recursive nature of the model and include:

a) Flexibility Constraints

(6) $$\left.\begin{aligned} -X_i(t) &\leq -(1 + \underline{\beta}_i)\, X_i^*(t-1) \\ X_i(t) &\leq (1 + \bar{\beta}_i)\, X_i^*(t-1) \end{aligned}\right\} \quad i \varepsilon D$$

which describe the restrictions placed on the response of the activity set to changes in short run profitability due to uncertainty and safety first criteria;

b) Adoption Constraints

(7) $$K_2(t) \leq \min \left\{\begin{aligned} &(1 + \rho)^n K_i(t-n) \\ &\alpha(\bar{K}_i(t) - K_i(t-1)) + K_i(t-1) \end{aligned}\right\} \quad i \varepsilon D$$

which describe an S-shaped time path to the adoption of new activities and new technologies in the region and by farm size;

c) Quasi-Fixed and Variable Resources Feedback

(8) $B_i(t) = (1 - \lambda)\, B_i(t-1) + \delta\, X_i^*(t-1) \quad , \quad i \varepsilon K$

which allows the augmentation and depreciation of quasi-fixed capacities and the growth in the labour force through time by farm size:

d) Financial Feedback

(9) $B_i(t) = f(\text{Gross Revenue}^*(t-1), \text{Borrowing}^*(t-1), \text{Saving}^*(t-1)), \quad i \varepsilon F$

which determines the availability of working capital for each farm size group.

where: q = subscript for farm size groups

j = subscript for farm activities

i = subscript for Regional Resources

t = time subscript

X = Decision Variable

B = Resource availability

G = Gross revenue of given activity

H = Total cost of given activity

p = subset for production activities

c = subset for purchasing activities

F = subset for financial activities

V = subset for investment activities

L = Land and labor resources

K = Quasi-fixed capacities and variable inputs

E = Intermediate outputs for balance equation

R = Regional binding (common) resources

D = subset for behavioral constraint

X^* = Ex-ante Optimal planning value

$\overline{\beta}$ = Upper bound of flexibility constraint

$\underline{\beta}$ = Lower bound of flexibility constraint

ρ = Adoption coefficient

Mathematical Appendix

The regional recursive programming model can be very briefly summarized as follows:[1]

The regional objective function is:

$$\text{Maximize} \quad [\ \Sigma_q \Sigma_j G_{qj}(t) X_{qj}(t) - \Sigma_q \Sigma_j H_{qj}(t) X_{qj}(t)\ ]$$

$$t = 1, \ldots \theta$$

Subject to:

Land and Labor Constraints

$$(1) \quad \Sigma_q \Sigma_{j \varepsilon p} a_{ij} X_j(t) + \Sigma_q \Sigma_{j \varepsilon c} a_{ij} X_j(t) \leq B_i(t) \ , \quad i \varepsilon L$$

which include land and family labour restrictions by season and farm size;

Quasi-Fixed Capacities and Variable input Constraints

$$(2) \quad \Sigma_q \Sigma_{j \varepsilon p} a_{ij} X_j(t) - \Sigma_q \Sigma_{j \varepsilon v} a_{ij} X_j(t) \leq B_i(t) \ , \quad i \varepsilon K$$

including seasonal machine and animal draft capacities and annual restrictions of seeds and fertilizers by farm size;

Financial Constraints

$$(3) \quad \Sigma_q \Sigma_{j \varepsilon p} a_{ij} X_j(t) + \Sigma_q \Sigma_{j \varepsilon v} a_{ij} X_j(t) + \Sigma_{j \varepsilon F} a_{ij} X_j(t) \leq B_i(t) \ , \quad i \varepsilon F$$

which include a constraint on working capital by farm size;

Regional Coupling Constraints

$$(4) \quad \Sigma_q \Sigma_{j \varepsilon c} a_{ij} X_j(t) + \Sigma_q \Sigma_{j \varepsilon v} a_{ij} X_j(t) + \Sigma_q \Sigma_{j \varepsilon T} a_{ij} X_j(t) \ , \quad i \varepsilon R$$

which incorporate inter-farm competition for regional resources including wage labour restrictions by seasons and regional credit and non-farm quasi-fixed capital supplies;

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[1] For detailed model description see C. Y. Ahn (1).

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