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THE RETURNS TO RESEARCH AND EXTENSION SERVICES IN REGIONS AND ZONES OF SOUTH AUSTRALIAN BROADACRE AGRICULTURE: A COMPARISON OF TWO TOTAL FACTOR PRODUCTIVITY DECOMPOSITION MODELS

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ABSTRACT: This paper reports total factor productivity decomposition modelling results of the returns to research and extension in zones and constituent regions of broadacre agriculture in SA, with the ultimate objective of providing policy advice on future research and extension (R&E) resource allocation. A traditional TFP decomposition modelling approach provided unacceptable results at the smaller region level, but acceptable results at the larger zone level. Utilising systematic techniques to accommodate volatility in the raw statistics caused by seasonal rainfall and small sample sizes, it was possible to demonstrate that regional differences in productivity growth were due to differences in the level of research and extension resources applied and not differences in seasonal rainfall. When modelling regional activity, the results support the use of systematic techniques to counter data problems related to large inter-year fluctuations that are associated with exogenous factors and small sample sizes.

1. INTRODUCTION

Agricultural research and extension (R&E) covers activities that lead to improvements in farming productivity and profitability. Broadacre agricultural research that results in new crop and pasture varieties and improved livestock types is well known but it also includes activities that, for example, result in improved fertilizer and weed control recommendations for crops and pasture, more efficient agricultural machinery (tractors, tillage equipment, crop harvesters) and improved crop sowing recommendations related to opening season rains and/or stored soil moisture. Extension refers to activities that deliver new information to primary producers, drawing on the fruits of research as well as district best practice. The range of public and private organizations that deliver agricultural research includes universities, CSIRO and state government based institutions in the public sector and agrichemical, fertiliser and agricultural machinery companies in the private sector. Extension is also delivered from a mixture of public and private sources, including extension officers employed by state government organizations and private consultants.

There is an extensive literature on international and within-country inter-regional comparisons of agricultural productivity. Recent studies include Ha and Chapman (2000), Suhariyanto and Thirtle (2001) and Acquaye, Alston and

Pardey (2003). However, there are fewer studies comparing a measure that can be derived from productivity estimations in a next step - rates of return to agricultural research and extension (R&E) - between countries and between regions within a country. Thirtle et al. (1995) compared rates of return in the US and European countries but reported an enormous variation between countries. From the smaller literature on inter-regional rates of return to R&E within a country, Lyu, White and Lu (1984) estimated returns in 10 USA regions ranging from 30 to 150 percent. They suggested the high rate of return figures in the Northern Plains and Mountain regions were an over-estimate of the effects of the low research intensity in these regions and that estimates would have been reduced if R&E spill-ins from other regions had been accounted for. Evenson (1992, p. 39) found that research productivity for US agriculture is enhanced by branch station activity within a state, and this enhancement is "more effective the more complex and heterogenous are geo-climate conditions in the state".

The relatively smaller literature on small area studies of R&E relative to national level studies may be due a combination of a paucity of historical series of reliable statistics at the sub-national level and a lack of development of modelling techniques to address problems at the small area level. This deficiency may hamper economists in providing policy makers with assessments of the effectiveness of R&E between small regions at a sub-national level and hence advice on the future allocation of R&E resources between regions. This paper reports econometric analysis of R&E returns to regions of broadacre agriculture in SA, with the ultimate objective of providing policy advice on future R&E resource allocation. While focused on R&E in agriculture, the methodology employed for small area modelling is considered to have application to other matters of regional research interest where data limitations are encountered.

Over the past few decades in SA, several regional agricultural research centres have closed or been reduced to minimal staffing levels. Research has contracted to a few larger centres. While much of this behaviour is a result of budget constraints and concerns for a concentration of a critical mass of scientists at remaining research centres, it is perhaps also symptomatic of an expectation that research results are generally applicable with little adaptation across areas that differ widely in terms of rainfall and edaphic features. SA broadacre agriculture has exhibited variation in the rate of crop yield increase and livestock production between zones (Black 1998, 1999). Whilst the variation appears closely linked to average seasonal rainfall, SA has also experienced a variation in the level of research and extension applied to regions in a similar pattern to rainfall variation. The question arises as to whether the variation in growth of output productivity is related to rainfall variation or related to variation in the level of applicable R&E. The research outlined in this paper proceeded from the null hypothesis that there were no differences in the effectiveness of applicable research and extension between SA regions and zones of broadacre agriculture.

Given the relatively small size and varied nature of the regions involved, the second objective for this study was the evaluation of alternative modelling approaches to small area studies. This was driven strongly by concerns about very large inter-year fluctuations in the raw statistics at the small regional (sub-state) level. Preliminary data analysis and modelling showed that these concerns were well-founded – large perturbations in the raw statistics significantly distorted the results from conventional TFP decomposition modelling. For outputs, these perturbations were related to the amount and timing of growing season rainfall and for inputs they were related to small sample sizes. We addressed these concerns by employing perturbation reduction techniques on the raw statistics.

2. DERIVATION OF REGIONS AND ZONES

Broadacre agriculture in SA is defined to include closer settled areas of dryland agriculture where farms predominantly produce grain, wool, and sheep and beef meat (i.e. the pastoral zone of SA is specifically excluded). The genesis of the mixed crop/livestock regions and zones is described in Black (1998). In summary, the rate of cereal crop yield increase showed a divide between regions of higher rainfall and those of lower rainfall. These regions, as defined approximately by above and below the 1600 mm annual rainfall isohyet, were formed into two zones. An additional higher rainfall predominantly livestock zone with 3 regions as defined in Black (1999) was added. The 11 regions, grouped into 3 zones, are shown in Figure 1. Hundreds are the smallest areal statistical unit in SA and formed the foundational statistical data on which this study was based, and contiguous aggregation of Hundreds is the basis of the regions. The period under study was 1977-96. ABS ceased publication of “Hundreds” data after 1996 when they terminated annual censuses of agriculture.

3. METHODOLOGY

3.1 Choice of models

There exists a range of analytical techniques available for assessing the impact of research and extension on production systems. Models that find significant support in the literature include production, cost, profit, supply, non-parametric and total factor productivity decomposition. The TFP decomposition model was adopted as it dominates the econometric literature for analysing the impact of R&E (Alston et al. 2000).

3.2 TFP Decomposition Model Specifications

After Alston, Norton and Pardey (1995), a measure of total factor productivity is defined in (1) and the specification for the TFP regression used by Mullen and Cox (1995), was initially adopted for this work:

$$TFP = \frac{\mathbf{Q}}{\mathbf{X}} = f\left(REL, \left[EDU\right], TOT, WTHR\right) \tag{1}$$

where:

$\mathbf{Q}$ is a vector of outputs,

$\mathbf{X}$ is a vector of inputs,

REL is real research and extension expenditure lagged L years according to the chosen profile,
EDU is an education variable (dropped from the final version of our model),
TOT is a terms of trade index, and
WTHR is a rainfall variable.

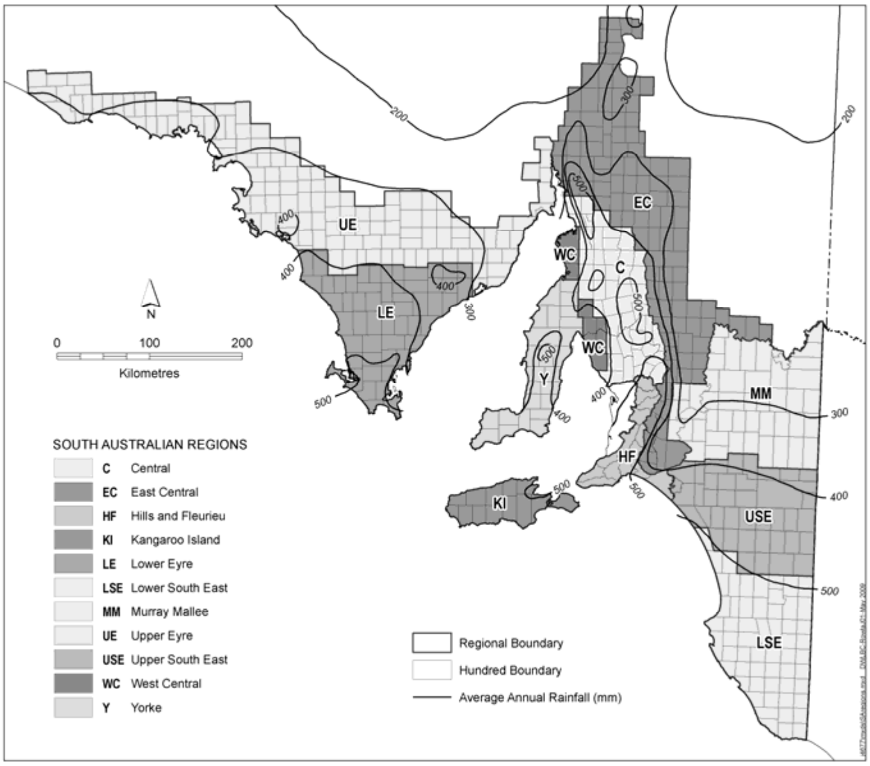

Figure 1. Map of the closer settled area of South Australia, showing boundaries of Hundreds and the regions of this study, as well as annual rainfall isohyets. UE, EC, MM form the low rainfall mixed crop/livestock zone, LE, Y, EC, C, USE form the high rainfall mixed crop/livestock zone and HF, KI, LSE form the high rainfall predominantly livestock zone.

Preliminary analysis showed that the EDU variable, a measure of school enrolments compared to the population of school age children as used in Mullen and Cox's (1995) work, was statistically insignificant and hence it was dropped. EDU may suffer from inadequate measurement in the context of Australian agriculture, and is therefore less likely to be able to contribute meaningfully to R&E impact models. The contribution of EDU was variable in Mullen and

Cox's (1995) work. Despite the EDU term being dropped, the model proved unsatisfactory for our purpose of accurately measuring TFP in small regions of broadacre agriculture. The first reason was large fluctuations in outputs, **Q**, (grain, wool and sheep and beef meat production – derived from ABS data) caused by variations in seasonal rainfall particularly in the lower rainfall regions and mostly, but not exclusively, related to grain production. Secondly there were unrealistic fluctuations in the inputs, **X**, derived from ABARE data - due to the small sample sizes in the relatively small regions that were our focus.

Given these unacceptably large fluctuations in the data, we therefore employed a second model, shown in (2):

$$TFP_{PR} = \frac{\mathbf{Q}_{PR}}{\mathbf{X}_{PR}} = f\left(REL, TOT\right) \qquad (2)$$

where $\mathbf{Q}_{\mathrm{PR}}$ and $\mathbf{X}_{\mathrm{PR}}$ are perturbation reduced measures of **Q** and **X** respectively.

In (2) EDU has been dropped (as in the final version of (1)) and WTHR has also been dropped. WTHR can be dropped because **Q** was regressed against seasonal rainfall in the region and the results used to form $\mathbf{Q}_{\mathrm{PR}}$. Greene (1997, p. 696) discusses the approach with reference to the Berndt and Wood (1975) study that regressed US manufacturing data against 10 exogenous macroeconomic variables and then used the fitted values in their final model.

The Tornqvist-Theil procedure was used to derive the TFP indexes. Linear indexes with 1977=100 were used for all variables. This implies that the individual regional and zone TFP analyses were not scaled relative to each other.

The objective of the modelling was to obtain marginal coefficients, elasticities and internal rates of return (IRR) for the REL variable. The IRR measures are calculated from the elasticities according to the 20-year asymmetric inverted V lag structure used to characterise the influence of REL on TFP. The reported IRRs are based on the projected returns that the estimated model would generate from a 1-year investment in R&E equal to the mean level of R&E and TFP for that zone or region, for a 20 year distributed lag structure (3).

$$0 = -REm + \frac{\Delta TFPt}{1+r} + \ldots + \frac{\Delta TFPt}{1+r} \qquad \text{(for t = 1 to 20)}$$

and (3)

$$\Delta TFPt = \varepsilon(\Delta TFPt.wt).\frac{TFPm}{REm} \qquad \text{(for t = 1 to 20)}$$

where:

REm	is the mean level of R&E,
$\Delta TFPt$	is the change in total factor productivity in year t,
r	is the internal rate of return,
ε	is elasticity of TFP to REL,
wt	is the distributed lag weight for year t, and
TFPm	is the mean level of TFP.

Estimations were conducted using the SHAZAM Version 8.0 econometrics program with its OLS or, where necessary, its AUTO estimation command. Generally, correction for first order autocorrelation was sufficient. However, for some regions, second order autocorrelation correction was necessary.

3.3 Data Sources and derivation of perturbation reduced variables.

A detailed explanation of the derivation of model variables (***Q*, *X*,** *REL, TOT*) and the perturbation reduction techniques applied is given in Black (2004, pp 59-79). A summary of data sources and methods applied is provided in Table 1.

3.4 Comparison of Conventional and Perturbation Reduced TFP Decomposition Variables

The most notable feature of the results shown in Table 2 is the difference in values for the conventional quantity measure, **Q**, and the perturbation reduced quantity measure, $\mathbf{Q}_{\mathrm{PR}}$, in both mixed crop-livestock production regions, but in regions 1-4 in particular (region 4, although low rainfall, has been grouped with the higher rainfall regions because its seasons are much more reliable than regions 1-3, it has higher rainfall regions on both its Eastern and Western sides and proportional cereal yield increases have kept pace with its higher rainfall neighbours). There was a very large increase in grain output particularly in the low rainfall regions (1-4) in 1978 which was an above average seasonal rainfall year, compared to the drought year of 1977. This contrast is incorporated in the Divisia index and hence biases the average rate of increase upwards. The French-Schultz model provides an insight into the biological basis for the result. The basis of the French-Schultz model is removal of a base level of growing season rainfall for evaporation and leaching losses before the remaining rainfall is multiplied by 20 kg/ha to produce a yield at 100 percent water use efficiency. In general, therefore, the closer average growing season rainfall is to the threshold, the greater the change in grain production with changes in seasonal rainfall. The change in grain production is particularly marked when a wet season follows a dry season in these low rainfall regions. This was the case in the growing seasons of 1977 and 1978, 1982 and 1983, 1988 and 1989, and 1994 and 1995 on the Upper Eyre. The increase in grain output in the second year of these pairs was 605, 410, 375 and 130 percent respectively. The large difference in the raw output results between the Upper Eyre and the other low rainfall regions (2, 3 & 4) can be mostly explained by the fact that Upper Eyre had an additional drought year (1988) in the data series. The unrealistically large differences between **Q** and $\mathbf{Q}_{\mathrm{PR}}$, particularly in the lower rainfall regions (1-4) and most particularly in Region 1 resulting in distorted TFP measures compared to $\mathrm{TFP}_{\mathrm{PR}}$, is in itself sufficient reason to reject the conventional TFP decomposition modelling approach for the small regions under study here. Both the rainfall modified output measure ($\mathbf{Q}_{\mathrm{PR}}$) and rolling mean modified input measure ($\mathbf{X}_{\mathrm{PR}}$) considerably reduce the range of region results compared to the unmodified measures of **X** and **Q**. This results in more conservative and consistent measures of total factor productivity, $\mathrm{TFP}_{\mathrm{PR}}$, compared to the conventional TFP measure.

Table 1. Data Sources and Perturbation Reduction Methods

<table>
<tr><td><i>Outputs:</i> Q
Source: ABS 7000 series (various dates) “Hundreds” annual data
<u>Grain production data</u> - area (ha) & production (t)
• <i>Major source of inter-year variation: Growing season rainfall</i></td><td>$\mathbf{Q}_{PR}$
Remove the influence of growing season rainfall by:
• use of the French-Schultz model (French and Schultz 1984) to provide seasonal rainfall dependent potential annual yields;
• fit resulting yearly water use efficiencies (WUEs), from actual annual yields divided by potential annual yields, over the time domain;
• reconvert WUEs to annual yields;
• multiply by ha sown (which then becomes the source of inter-year variation)</td></tr>
<tr><td><u>Livestock data</u> – numbers of sheep & beef animals, wool produced (kg)
• Convert to dry sheep equivalents (White and Bowman 1985, allowing for the large frame of the SA merino), adjusted for changing carcase weight and wool produced per sheep over the time domain.
• <i>Major source of inter-year variation: Annual rainfall</i></td><td>Remove the influence of annual rainfall by:
• estimating ha of each Hundred grazed (Black 1998) on an annual basis and combine with Hundreds DSE populations to provide a stocking rate per ha;
• use of the model published in Court (1998), modified to encompass the range of farm environments in the settled areas of SA, to provide annual rainfall dependent potential stocking rates per ha;
• fit resulting animal production efficiencies, from actual annual stocking rate divided by potential annual stocking rate, over the time domain;
• multiply by ha of Hundred grazed (which then becomes the source of inter-year variation)</td></tr>
<tr><td><i>Inputs:</i> X
Source: ABARE (2000a,b) annual data
• Use a Divisia indexing procedure to convert these data into variable inputs, plant and machinery, owner/manager and family labour; land area.
• <i>Major source of inter year variation: small sampling sizes (caused in part by use of ABARE survey data for regions that are smaller than what the survey was designed for)</i></td><td>$\mathbf{X}_{PR}$
Reduce inter-year variation by use of:
• 3-year rolling means for variable inputs;
• 5-year rolling means for plant and machinery;
• a curve fitting procedure for land price, indexed to 1998/99, over the time domain.
The rolling mean procedure was not necessary for owner/manager and family labour.</td></tr>
<tr><td colspan="2"><i>Lagged research and extension: REL</i>
Sources: Mullen, Lee and Wrigley (1996) for SA Department of Agriculture; University of Adelaide, CSIRO (pro rata); OECD (2003) for appropriate percentages of fertiliser, agricultural and veterinary chemicals, and machinery sales.
• Allow for obvious spill-ins (University of Adelaide livestock research deficient) and spill-outs (University of Adelaide preponderance of cereals research) (ABS 8109.0); otherwise assume spill-ins equals spill-outs.
• Partition this annual R&E quantum into high and low rainfall zones, making due allowance for spill-ins from the high rainfall zones into the low rainfall zone.
• Disaggregate each annual R&E quantum according to the 20 year inverted V chosen profile and then aggregate as annual REL.
<i>Terms of trade: TOT</i>
Source: ABARE (1999): “Farmer’s terms of trade”)</td></tr>
</table>

Table 2. Comparison Rates of Increase in Q, Q_{PR}, X, X_{PR}, TFP and TFP_{PR}

	Inputs and Outputs				TFP	
Model:					1	2
Average annual growth in: Region	X	Q	X_{PR}	Q_{PR}	TFP	TFP_{PRQX}
Low Rainfall Mixed Crop/livestock Zone:						
Upper Eyre	-2.11	9.05	-1.10	2.01	11.16	3.11
Murray-Mallee	0.62	5.55	-0.09	2.07	4.93	2.16
East Central	0.74	5.12	0.03	3.26	4.38	3.23
High Rainfall Mixed Crop/livestock Zone:						
West Central	2.18	7.53	0.70	4.62	5.35	3.92
Central	1.39	4.79	0.14	3.98	3.40	3.84
Yorke	0.52	6.21	0.44	4.02	5.69	3.58
Lower Eyre	-3.56	4.96	-1.48	4.04	8.52	5.52
Upper South-East	2.03	2.26	-0.62	2.12	0.23	2.74
High Rainfall Predominantly Livestock Zone:						
Lower South-East	-1.90	0.48	-0.77	1.32	2.38	2.09
Kangaroo Island	0.16	1.55	0.43	2.36	1.39	1.93
Hills and Fleurieu	-0.93	0.27	-0.65	0.44	1.20	1.09
Mean	-0.06	4.34	-0.27	2.75	4.42	3.02
Range (max. - min.)	5.81	8.78	2.18	3.60	10.93	4.43
Zone:						
Low Rainfall Mixed	0.48	6.47	-0.34	2.85	5.60	3.19
High Rainfall Mixed	0.95	4.78	-0.08	3.66	3.83	3.74
High Rainfall Livestock	-1.50	0.78	-0.28	1.44	2.28	1.72
Mean	-0.02	4.01	-0.23	2.62	3.90	2.88
Range (max. - min.)	2.45	5.69	0.26	2.22	3.32	2.02

Notes: The zone results refer to separate analyses, not to the means of constituent regions.

4. RESULTS

4.1 Estimation results for TFP (1) and TFP_{PR} (2) Models

Given the satisfactory nature of the results obtained by Mullen and Cox (1995), where weather was used as an explanatory variable, in their assessment of the impact of R&D at national level, our equivalent model (1) results are disappointing at the regional level as can be seen in Table 3. In only 5 of the 11 regions are the REL coefficients significant. Rainfall (WTHR) is significant in 6 of the regions and terms of trade (TOT) significant in 4 regions. The R^2 measure is poor in 3 regions and only moderate in 4 others. Rainfall (WTHR) was significant in all 4 of the low rainfall regions as would be expected, given that changes in rainfall between growing seasons is likely to have a greater impact on production in lower rainfall areas (see discussion in previous section).

The region results for Model (2) show improved measures of statistical fit, with higher R^2 values and, more importantly, no sign problems and considerably reduced, sensible variability in the REL coefficient estimates across regions. All REL coefficients are highly significant. These results support the assertion that the perturbation reduction model is a superior approach.

Table 3. Estimation results

Model	(1) *TFP = f(REL,TOT,WTHR)*					(2) *TFP$_{PR}$ =f(REL,TOT)*			
Regions:	Constant	REL	TOT	WTHR	R^2	Constant	REL	TOT	R^2
Low Rainfall Mixed Crop /Livestock Zone									
Upper Eyre	149.71	-0.183	-0.927	0.794	0.93	41.45	0.755	-0.113	0.91
	(2.81^b)	(-0.60)	(-2.75^b)	(7.09^a)		(1.39)	(5.20^a)	(-0.69)	
Murray-Mallee	25.20	0.412	0.081	0.364	0.52	74.02	0. 364	-0.071	0.84
	(0.37)	(1.54)	(0.19)	(3.32^a)		(2.84^b)	(4.14^a)	(-0.42)	
East Central	49.35	0.537	-0.245	0.180	0.58	21.62	0.737	0.075	0.96
	(0.76)	(2.11^c)	(-0.63)	(1.86^c)		(0.83)	(7.24^a)	(0.46)	
Means		0.26	-0.36	0.45	0.68		0.75	-0.04	0.90
High Rainfall Mixed Crop/ Livestock Zone									
West Central	-47.23	0.509	0.368	0.656	0.53	33.52	0.693	0.021	0.95
	(-0.34)	(1.32)	(0.39)	(3.96^a)		(1.25)	(9.34^a)	(1.12)	
Central	-0.444	0.490	0.240	0.337	0.53	0.210	1.466	-0.006	0.98
	(-0.01)	(2.20^b)	(0.42)	(3.14^a)		(1.14)	(15.85^a)	(-0.05)	
Yorke	31.83	0.413	0.165	0.258	0.37	35.99	0.665	-0.008	0.98
	(0.32^c)	(1.56)	(0.24)	(1.58)		(2.35^b)	(14.97^a)	(-0.08)	
Lower Eyre	-51.12	1.139	-0.015	0.378	0.86	13.72	1.029	-0.171	0.99
	(-0.66)	(5.66^a)	(-0.03)	(3.58^a)		(0.85)	(24.36^a)	(-1.56)	
Upper South-East	241.82	-0.120	-1.372	-0.092	0.71	97.70	0.355	-0.348	0.91
	(2.90^b)	(-0.49)	(-2.28^b)	(-1.09)		(3.11^a)	(2.56^b)	(-1.95^c)	
Means		0.64	-0.12	0.31	0.60		0.84	-0.10	0.96
High Rainfall Predominantly Livestock Zone									
Lower South-East	160.33	0.476	-1.035	-0.126	0.94	76.23	0.396	-0.221	0.98
	(2.90^b)	(3.23^a)	(-2.74^b)	(-1.62)		(5.14^a)	(8.50^a)	(-2.19^b)	
Kangaroo Island	135.01	0.158	-0.294	-0.174	0.38	62.01	0. 319	-0.004	0.92
	(2.15^b)	(0.92)	(-0.73)	(-1.39)		(2.16^b)	(2.10^b)	(-0.03)	
Hills and Fleurieu	10.40	-0.324	-0.922	-0.007	0.36	51.73	0.214	0.210	0.77
	(4.14^a)	(-1.60)	(-2.76^b)	(-0.05)		(2.05^b)	(3.48^a)	(1.20)	
Means		0.10	-0.75	-0.10	0.56		0.31	-0.005	0.89
Zones:									

Low Rainfall Mixed	14.84	0.722	-0.144	0.358	0.77	37.77	0.697	-0.036	0.96
	(0.27)	(3.57^a)	(-0.44)	(4.84^a)		(1.74)	(8.46^a)	(-0.26)	
High Rainfall Mixed	75.31	0.448	-0.419	0.177	0.76	50.41	0.634	-0.133	0.98
	(1.07)	(2.54^b)	(-0.86)	(1.88^c)		(3.37^a)	(15.72^a)	(-1.31)	
High Rainfall Livestock	154.67	0.338	-0.986	0.017	0.92	79.41	0.280	-0.121	0.95
	(3.546^a)	(2.86^b)	(-3.33^a)	(0.28)		(4.65^a)	(3.37^b)	(-1.34)	
Means		0.50	-0.52	0.18	0.82		0.54	-0.10	0.96

Notes:
The zone results refer to separate analyses, not to the means of constituent regions.
^{c}, ^{b}, ^{a}: t values in brackets significant at P < 0.10, P < 0.05 and P < 0.01, respectively.

For consolidated data sets, in our case for the zones, the TFP model (1) produces acceptable results. The result confirms the validity of the modelling approach described in (1) for broadacre data sets at the state or national level, for example the data sets employed by Mullen and Cox (1995). The statistical reason for this greater coherence in zone results is that a coalescence of the data results in a standard error of the mean of data points that is less than the standard deviation of an individual datum. The coefficient estimates for the explanatory variables therefore have reduced standard errors and hence are more likely to yield significant estimates. In terms of the explanatory variables, the reason for the significance of rainfall is that in zones where cropping is important, growing season (April-October) rainfall has a marked influence on productivity because of its very large influence on crop yields, particularly in the low rainfall zone.

Overall, it appears that terms of trade are important to productivity increases in regions where livestock production is important, supporting the results of Beck et al. (1985). There is a negative sign on these significant elasticities indicating that improving terms of trade reduces the rate of productivity increase in these regions. This result is also found for the Upper Southeast, a region in the high rainfall mixed zone but where livestock production is much more important than the other regions in that zone. It also included the Upper Eyre, a region where livestock production became relatively more important in the second half of the review period, in contrast to the other mixed regions.

4.2 REL coefficient, elasticity and IRR results for TFP$_{PR}$ Model (2)

Table 4 shows results from the preferred model (2) that are necessary for policy conclusions.

The results from all three measures for individual regions are consistent. This is as expected given that the IRR results are dependent on research intensity at the mean (RELm/TFPm) and elasticity values (3). However there are notable differences in results across regions within particular zones and across zones. A key factor in explaining these differences is the presence of a considerably higher level of research intensity applied to the high rainfall zones (both mixed and livestock) relative to that for the low rainfall zone.

Table 4. REL results for Model (2)

Regions:	REL	E_{REL}	IRR
Low Rainfall Mixed Crop/Livestock Zone			
Upper Eyre	0.755	0.77	44.70
Murray-Mallee	0.364	0.44	31.60
East Central	0.737	0.79	45.50
Means	0.494	0.67	40.60
High Rainfall Mixed Crop/Livestock Zone			
West Central	0.693	0.75	31.60
Central	1.466	0.85	34.30
Yorke	0.665	0.75	31.60
Lower Eyre	1.029	1.01	38.40
Upper South-East	0.355	0.47	22.80
Means	0.842	0.77	31.74
High Rainfall Predominantly Livestock Zone			
Lower South-East	0.396	0.53	24.90
Kangaroo Island	0. 319	0.46	22.40
Hills and Fleurieu	0.214	0.32	16.80
Means	0.310	0.44	21.37
Zones:			
Low Rainfall Mixed	0.697	0.74	43.60
High Rainfall Mixed	0.634	0.72	30.80
High Rainfall Livestock	0.280	0.40	19.80
Means	0.540	0.62	31.40

Notes: The zone results refer to separate analyses, not to the means of constituent regions.

4.3 Region results

The null hypothesis, that there was no difference in the effectiveness of REL between regions, appears to hold for the majority of regions in the two mixed crop-livestock zones when evaluated by the coefficient and elasticity estimates. However given the difference in research intensity, this translates to a higher rate of return for the low rainfall mixed zone compared to the high rainfall mixed zone as evaluated by the IRR measure. With the exception of the Murray-Mallee region in the Low Rainfall Mixed zone and Upper South-East and Lower Eyre in the High Rainfall Mixed zone, the coefficient and elasticity estimates for the other five regions are very similar. Special factors may be impacting on the outlier regions. The increase in crop yields was relatively poor in the Murray-Mallee region. Although this was the also the case in the Upper Eyre, lower crop yields in the Murray-Mallee were not compensated for by R&E generating greater cost reductions, as was evident in Upper Eyre (Table 2, $\mathbf{X}_{\mathrm{PR}}$). In the high rainfall mixed crop-livestock zone the Upper South-East result is lower than the average for the zone, and this is probably due to the much higher livestock component in the production system of the region – overall, improved productivity in livestock production systems has not matched that in crop production systems. In addition this region suffers from soil constraints that impede productivity and are difficult to rectify: non-wetting sands across much of the area and the onset of toxic levels of soil salinity due to raised saline water tables over large areas. The Lower Eyre result is higher than the high rainfall mixed crop-livestock zone average and is probably due to a large expansion of cereal cropping in the production system. Cereal crop yields have increased at a greater rate than grain legumes and oilseeds, which form a higher component of crop production in the other four regions in this zone.

Given the lower rate of TFP increase (3.19 percent) in the low rainfall mixed zone, and under the assumption that the previous performance of R&E provides a good indication of future performance, a policy implication is that an increase in the level of R&E resources applied to this zone, will generate an increase in the productivity of the low rainfall mixed regions to a level comparable to that achieved in the high rainfall mixed zone (3.74 percent) (Table 2). The IRR results reflect the fact that this increase in resources will generate a higher rate of return (40.6 percent) compared to the high rainfall mixed zone (30.8 percent), until research intensity becomes similar (Table 4).

However the null hypothesis, of no difference in effectiveness of REL, was not maintained for regions in the high rainfall, predominantly livestock zone. The Kangaroo Island and Hills and Fleurieu results were the poorest for all regions. The generally lower R&E elasticity in these two regions is assumed to be due to the lack of impact of crop production research and extension in the high rainfall predominantly livestock zone. Cropping is a relatively small component of the production system for all three regions in the High Rainfall Livestock zone, and improved productivity in livestock systems in the zone as a whole has not matched those in cropping systems, although it is known that livestock systems R&E, particularly pasture improvement, has had positive impact in the Upper South-East and Kangaroo Island. Ha and Chapmen (2000) and Knopke, O'Donnell and Shepherd (2000) provide Australia-wide and region rate of productivity improvement results comparing cropping and livestock enterprises that also demonstrate this difference.

A policy implication of findings showing regional differences in REL elasticities within zones is that applied R&E which is specifically tailored to meet the needs of individual regions is important. Some of the low elasticity results in particular regions are likely to be due to the inapplicability of new technologies to specific environments and circumstances in each region. This consideration has to be balanced against budget constraints and concerns for a concentration of a critical mass of scientists at research centres.

4.4 Zone results

If R&E resources are limited, and maximising the State return on R&E is the priority, then the REL and IRR results in Table 4 provide support for the policy conclusion that R&E should be directed away from the high rainfall livestock zone to the low rainfall mixed zone. Given the low productivity growth inherent in the broadacre livestock industries (Ha and Chapmen, 2000 and Knopke, O'Donnell and Shepherd 2000) research should be concentrated on cropping systems. As cropping continues to expand and becomes an increasing component of the high rainfall livestock zone's production system, productivity is likely to improve somewhat in this zone as well.

If zone welfare over-rides maximising R&E rate of return (Table 4), and given that animal production will still be dominant within the high rainfall livestock zone, the result should not be used as an argument to reduce livestock research and extension. This would have the effect of further disadvantaging this zone in terms of rate of productivity improvement. Another consideration for retaining the current level of livestock production research is that the total benefits of such research will be relatively greater, compared to grains, than those captured in the farm level econometric models used here. Because the bulk of grain produced in SA is exported, grain prices are generally set internationally. Hence most of the benefits of research accrue to SA farmers whereas livestock production has a greater influence on domestic prices (Mullen, Alston and Wohlgenant 1989) and hence the benefit is spread across producers and consumers. Some adjustment in cropping research and extension to focus on cropping in higher rainfall areas in unusual environments might be beneficial.

Overall, the size of the IRR figures is as expected. Given the high aggregate level of R&E (it represents all formal R&E impacting on a zone, with allowances for spillovers) an average model figure of 31.3 percent return on investment accords with prior expectations for a 20 year lag structure. In their global sample of agricultural R&E rates of return studies, Alston, Chan-Kang et al. (2000) found that, compared to the sample mean IRR of 65 percent, a) econometric derivation, b) inclusion of both R and E (versus either alone), c) program (versus a single project), d) multi-institutional, and e) long-lag length (greater than 15 years) estimations all significantly reduced the IRR. The estimations in this work combine all these characteristics. In particular, because all formal R&E is measured, it is expected that the lagged R&E intensity is high compared to most other studies (due to factors b and d).

5. CONCLUDING REMARKS AND POLICY IMPLICATIONS

The aim of the work described in this paper was firstly to test the effectiveness of alternative approaches to total factor productivity (TFP) modelling in a study of the impact of research and development across 11 regions of South Australian broadacre agriculture. The results confirmed a substantial variation in comparable results. The perturbation-reduced measure of total factor productivity, TFP_{PR}, provided more consistent and stable results for TFP across the multiple small regions studied.

We conclude that in studies where exogenous factors, such as weather variability, have a significant influence on TFP, a perturbation reduction approach such as that applied in this study may be the superior approach to adopt. Similarly, where data deficiencies are anticipated to have an adverse impact on model results (such as in small area studies) the perturbation reduction measures outlined in this paper may provide a superior approach to conventional TFP decomposition modelling of broadacre agriculture, both with respect to superior estimation results and consistency.

The more consistent and stable results from the TFP_{PR} model translated into more consistent and stable results from the REL elasticity measure in the TFP decomposition modelling. This provided confidence that the significant differences between regions and between zones were real and therefore the results were translated into agricultural R&E policy recommendations for small regions.

At the zone level, the model that included rainfall as an explanatory variable (1) provided satisfactory results, comparable to the zone perturbation reduction model results (2). This supports the conclusion that at this, and higher aggregate levels (state, national), the traditional TFP decomposition modelling approach to measuring the effect of R&E is adequate.

The policy recommendation at zone level arising from this work depends on the R&E resource available and the socioeconomic goal to be achieved. If R&E resources are limited, and maximising the State return on R&E is the priority, then the results provide support for the policy conclusion that R&E should be directed away from the high rainfall livestock zone to the low rainfall mixed zone. If zone welfare over-rides maximising R&E rate of return, and given that animal production will still be dominant within the high rainfall livestock zone, the result should not be used as an argument to reduce livestock research and extension. This would have the effect of further disadvantaging this zone in terms of rate of productivity improvement.

While focused on R&E in agriculture, the methodology employed for small area modelling is considered to have application to other matters of regional research interest where data limitations, related to large inter-year fluctuations due to small sample sizes or exogenous factors, are encountered.

REFERENCES

ABARE (1999) *Australian Commodity Statistics – 1999.* Australian Bureau of Agricultural and Resource Economics: Canberra.

ABARE (2000a) *AgAccess. Electronic data base.* Australian Bureau of Agricultural and Resource Economics: Canberra.

ABARE (2000b) A*SPIRE-AAGIS. Electronic data base.* Australian Bureau of Agricultural and Resource Economics: Canberra

ABS (various dates) 7000 series (Agriculture), 1301.4 (South Australian Yearbook), 8109.0 (Research and Experimental Development: General Government and Private Non-Profit Organisations, Australia) and 6306.0 (Employee Earnings and Hours, Australia). Australian Bureau of Statistics: Canberra.

Acquaye, A.K.A., Alston, J.M. and Pardey P.G. (2003) Post-war productivity patterns in U.S. agriculture: influences of aggregation procedures in a state level analysis. *American Journal of Agricultural Economics,* 85, pp. 59-80.

Alston, J.M., Chan-Kang, C., Marra, M.C., Pardey P.G. and Wyatt,T. J. (2000) A Meta-Analysis of Rates of return to Agricultural R&D: Ex Pede Herculem? *IFPRI Research Report No. 113.* International Food Policy Research Institute: Washington, DC.

Alston, J.M., Norton, G.W. and Pardey (1995) *Science Under Scarcity: Principles and Practice for Agricultural Research and Priority Setting.* Cornell University Press: Ithaca and London.

Beck, T., Moir, B., Fraser, L. and Paul, P. (1985) Productivity Change in the Australian Sheep Industry. Paper prepared for the 55th ANZAAS Congress, Monash University, 28th August.

Berndt, E. and Wood, D .(1975) Technology, prices and the derived demand for energy. *Review of Economics and Statistics,* 57, pp.376-384.

Black, I.D. (1998) A Review of the Impact of Public Sector Applied Research and development for the South Australian Wheat Industry. *SARDI Research Report Series No. 21.* South Australian Research and Development Institute: Adelaide.

Black, I.D. (1999) A Review of the Impact of Farm-Level Research and Development for the South Australian Sheep Industry. *SARDI Research Report Series No. 44.* South Australian Research and Development Institute: Adelaide.

Black, I.D. (2004) The regional Impact of Research and Extension in Increasing the Productivity of South Australian Broadacre Agriculture: Results and Recommendations from Econometric Analyses. *SARDI Research Report Series No. 61.* South Australian Research and Development Institute: Adelaide

Court, J. (Ed.) (1998) *Grasslands Productivity Program Final Report to Members.* Grassland Society of Victoria: Melbourne.

Evenson, R.E. (1992) Two blades of grass: Research for U.S. agriculture. Economic Growth Centre, *Yale University. Centre Discussion Paper No. 653.*

French, R..J. and Schultz, J.E. (1984) Water use efficiency of wheat in a Mediterranean type environment. I The relationship between yield, water use and climate. *Australian Journal of Agricultural Research*, 35, pp. 743-764.

Greene, W.H. (1997) Econometric Analysis (Third International Edition). Prentice Hall: New Jersey.

Ha, A. and Chapman, L. (2000) Productivity growth trends across Australian broadacre industries. *Australian Commodities,* 7, pp. 334-340.

Knopke, P., O'Donnell, V. and Shepherd, A. (2000) Productivity Growth in the Australian Grains Industry. *ABARE Research Report 2000.1.* Australian Bureau of Agricultural and Resource Economics: Canberra.

Lyu, S.J., White, F.C, and Lu, Y.C. (1984) Estimating effects of agricultural research and extension expenditures on productivity: a translog production function approach. *Southern Journal of Agricultural Economics*, 16, pp. 1-8.

Mullen, J.D., Alston, J.M. and Wohlgenant, M.K. (1989) The Impact of Farm and Processing Research on the Australian Wool Industry. *Australian Journal of Agricultural Economics*, 33, pp. 32-47.

Mullen, J.D. and Cox, T.L. (1995) The returns from research in Australian broadacre agriculture. *Australian Journal of Agricultural Economics*, 39, pp.105-128.

Mullen, J., Lee, K. and Wrigley (1996) Agricultural Research Expenditure in Australia: 1953-1994. A*gricultural Economics bulletin No. 14.* Industry Economics Unit, NSW Agriculture.

SHAZAM Version 8.0 (1997). *Users's reference Manual.* Vancouver.

Suhariyanto, K. and Thirtle, C. (2001) Asian agricultural productivity and convergence. *Journal of Agricultural Economics*, 52, pp. 96-110.

Thirtle, C.G., Ball, V.E., Bureau, J-C., Townsend,R., Peters, G.H. and Hedley D.D. (1995) Accounting for productivity differences in European agriculture: Co-integration, multilateral TFPs and R&D spillovers. In Peters, G.H. and Hedley, D.D. (Eds.) *Agricultural Competitiveness: Market Forces and Policy Choice.* Proceedings of the Twenty-Second International Conference of Agricultural Economists, Harare, Zimbabwe. Aldershot, UK; Dartmouth.