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Research Facility

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Nazrul Islam

Department of Agriculture and Food, WA & Curtin University

nazrul.islam@outlook.com.au

Vilaphonh Xayavong

Department of Agriculture and Food, WA

vila.xayavong@agric.wa.gov.au

Ross Kingwell

Australian Export Grains Innovation Centre & University of Western Australia

rkingwell@aegic.org.au

Lucy Anderton

Department of Agriculture and Food, WA

lucy.anderton@agric.wa.gov.au

David Feldman

Department of Agriculture and Food, WA

dfeldman2@optusnet.com.au

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Farm productivity in an Australian region affected by a changing climate

Nazrul Islam^{1,3}, Vilaphonh Xayavong², Ross Kingwell^{1,2,4},
Lucy Anderton^{2,4} and David Feldman¹

¹*Australian Export Grains Innovation Centre*

²*Department of Agriculture and Food, Government of Western Australia*

³*Curtin University, Western Australia*

⁴*University of Western Australia*

ABSTRACT

Since the mid-1970s the south-west of Australia has displayed a warming and drying trend in its climate. Using parametric and non-parametric methods this paper provides a decadal assessment of the profitability, productivity and productivity components of over 250 farms in the region. The farm panel data are detailed descriptions of the physical and financial characteristics of each farm business from 2002/3 to 2011/12, a period of challenging weather-years. This study yields insights about farm characteristics and management strategies that have weakened or strengthened farm viability over the decade. In spite of the climate challenges experienced in the region during that decade, a majority of farm businesses improved their productivity and profitability.

Keywords: Agriculture, Climate change,
Productivity, Profitability, Farm management

1. Introduction

It is often argued that in order to remain internationally competitive Australian farming needs ongoing gains in productivity. Given limitations to Australia's agricultural resources of arable land and water, the future growth in agricultural production seems destined to depend largely on increases in productivity (Zhao *et al.* 2008; Nossal and Sheng 2010). Of encouragement are empirical findings that Australia's largest agricultural sector, known as broadacre agriculture, has achieved in recent decades reasonably high rates of productivity gain; with total factor productivity (TFP) growth averaging 1.4 percent per annum from 1977-8 to 2007-8 (Nossal and Sheng 2010). However, of some concern is the suggestion that this productivity growth has slowed recently. Nossal and Sheng (2010) report that between 1977-78 and 2000-01, broadacre productivity grew at 2 per cent per annum, but since 2000-01 up until 2007-8 growth averaged -1 per cent per annum. This slowdown is largely attributed to drought effects (Sheng *et al.* 2010).

Whether these drought conditions are part of underlying climate variability or a portent of unfolding climate change is not clear (CSIRO 2007). With some regional and seasonal variations, the annual average temperature across Australia has increased and average rainfall has decreased. There are however different opinions over whether these changes are weather variability rather than climate change (Nicholls *et al.* 2003; Van Ittersum *et al.* 2003). Either way, their impact on productivity and farm production has been large, further complicating the management of already complex broadacre farm businesses (Kingwell 2006) and exacerbating the risks associated with farming (Quiggin *et al.* 2010). If projected climate change does unfold, then in some regions farm profitability and viability are likely to be threatened (John *et al.* 2005; Kingwell 2006; Garnaut 2010; Quiggin *et al.* 2010).

The physical operating environment for broadacre farm businesses in southern Australia is widely acknowledged to have been challenging since the late 1990s (Howden and Hayman, 2005; Garnaut, 2011; Stretch *et al.*, 2012). Many scientists consider the future environment will remain challenging due to continuing climate variability and long-term climate change (Sietchiping, 2007; Kingwell and Pannell, 2005; Kingwell, 2006; Gunasekera *et al.*, 2007; Garnaut, 2011; Addai, 2013). Warming and drying trends, complemented by increasing atmospheric concentrations of carbon dioxide (CO₂) have been observed in southern Australia (Frederiksen *et al.*, 2011; Cai *et al.*, 2012; Asseng and Pannell, 2012; Addai, 2013).

Contemporaneous with the unfolding recent apparent change in climate (Kingwell *et al.*, 2013) has been a period of marked price volatility for many farm and food commodities since the late 1990s (Kingwell, 2012, Martin, 2013). Against this backdrop of price volatility and climate challenge, farm businesses in Australia have also needed to cope with the business pressures arising from a strong Australian dollar, scarce skilled farm labour and an ageing farm workforce; all factors adding to the challenge and complexity of broadacre farming (Kingwell, 2011).

The variable nature of the farm operating environment over the last decade or so would have affected farm productivity and profitability. This paper examines how the productivity and productivity components of 250 broadacre farms in south-western Australia has changed over the years 2002 to 2011. The rest of the paper includes four sections. Section 2 is an overview of the study location and its farming system. The farm data and analytical methods are described in Section 3. Then results are presented and discussed in Section 4. Lastly concluding comments are presented in Section 5

2. The Study Region

The study region of south-western Australia (Figure 1) has a Mediterranean climate and is characterised by long, hot and dry summers and cool, wet winters. In the northern and central parts of the study region around three-quarters of the average annual rainfall is received between April and October. Summer rainfall is highly variable, and is more common along the south coast parts of the study region.

The region's farming systems are mixed grain and livestock, predominantly sheep enterprises. The grains grown are wheat, barley, canola, and lupins, although the area of lupins has decreased substantially in more recent years due to poor yields and low profitability and the canola area has increased.

Sheep are run on annual pastures during winter and spring. In summer months, livestock feed is mainly pasture residues and crop stubbles. In late summer through to early winter there is often a feed gap and supplements of lupins or feed barley are fed to maintain animal welfare. The quantity and quality of pasture produced is mainly influenced by the timing of the first winter rains, farm soil type, rotation sequences, early spring rainfall and sheep and weed management. The sheep systems mainly involve Merinos and include both wool and meat dominant systems.

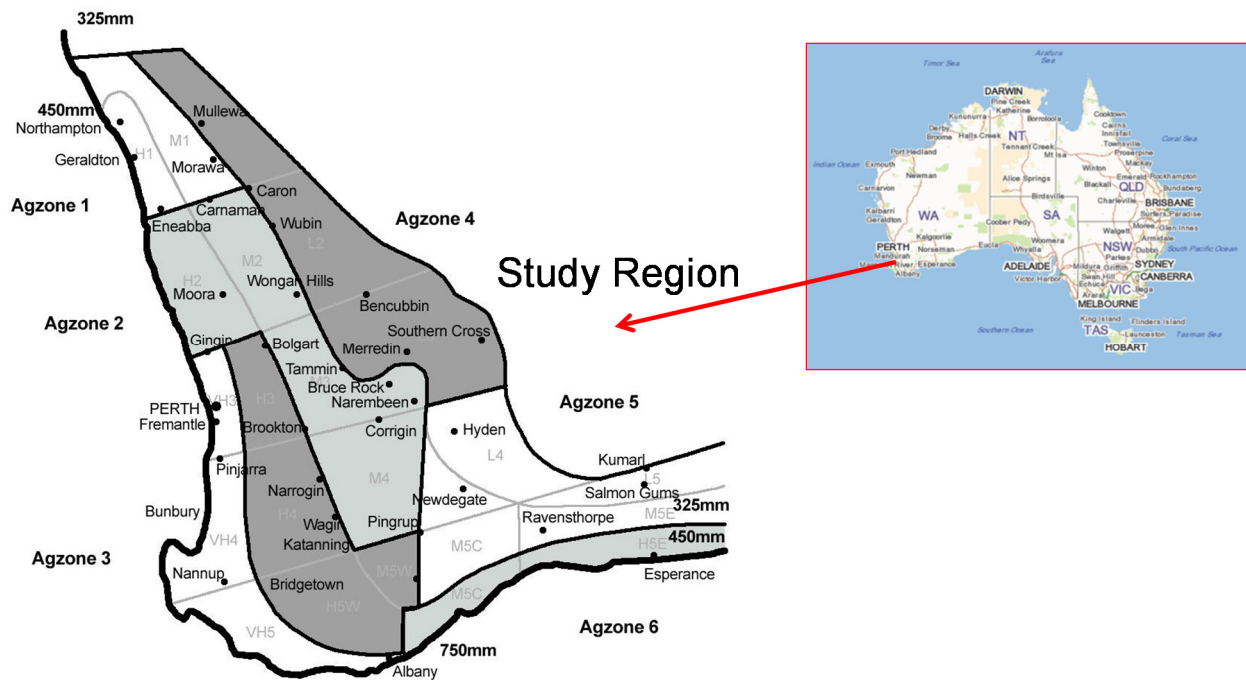


Figure 1. The study region of south-western Australia.

During the study period (2002 to 2011) sheep numbers in Western Australia decreased from 24 million to less than 15 million, mostly in response to the decreasing relative profitability of sheep production. The highest reduction in sheep numbers occurred in the low rainfall areas (Agzones 4 and 5 in Figure 1) where stocking rates and profitability in the last ten years were low compared to the potential profitability of cropping enterprises. However, despite the high relative

profitability of cropping many farmers have continued to maintain mixed enterprise farms. In the study sample, farms were segregated into three farm types:

1. Crop specialists with more than 80% of the farm used for cropping,
2. Mixed enterprise 40 to 80% of farm used for cropping, and
3. Livestock specialists with less than 40% of farm used for crop.

Figure 2 shows that the majority (72%) of the sample farms had a mixed farming enterprise system.

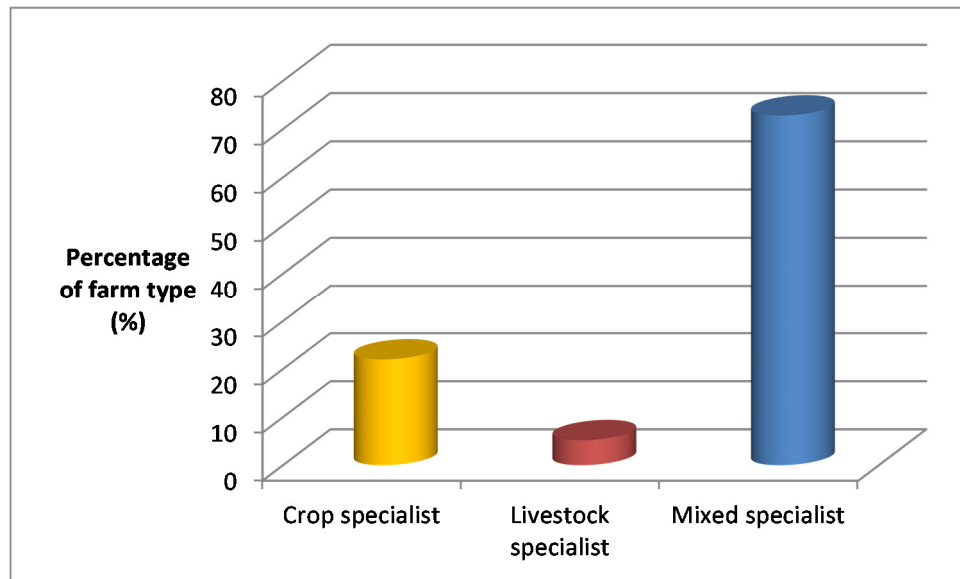


Figure 2. Proportion of farms by farming enterprise type.

3. Data and Methodology

Data describing the farm businesses in the study region were supplied by three agricultural consulting firms with farm business clients in the region. Initially farm business records of 275 farms were obtained for the period 2002 to 2011, with farms being selected from a majority of the zones shown in Figure 1. Zones H2, H3 and L4 were not represented. The longitudinal datasets describe the farm production and financial records of each farm over the decade. Because each consultancy firm provided different sets of physical and financial variables, and some variables are measured differently by each firm, care was taken to form a consistent unified dataset and therefore data from 250 farms were used for productivity trajectories. The sample size in the main zones represents around 15 percent of the farm population in those zones¹.

¹ However, since the data come from farms sufficiently viable to afford agricultural consultants, they may not necessarily be truly representative of the wider farming community in each zone. The data may be upwardly biased if only above average farmers use consulting firms.

Farm Productivity Measures

Farm productivity variations in agricultural production exist as farms face different production opportunities due to differences in factors such as: (i) physical resource endowments (e.g. quality of soils and climate), (ii) technology, capital and infrastructure and (iii) levels of costs and prices (Hayami 1969; Hayami and Ruttan 1971; Lau and Yotopoulos 1989; Battese et al. 2004). On the other hand, efficiency variations exist as a result of management decisions where farmers under-utilise certain inputs or misallocate inputs or select an inappropriate mix of enterprises or choose a crop type or crop variety that performs poorly. In this context measurement of efficiency has been a controversial analytical tool as it is a residual measure and thus is likely to involve measurement errors when functional forms or distributions are mis-specified. There is substantial evidence in the literature however, that inefficiency does exist and that it can be measured effectively using either data envelopment analysis or parametric methods (O'Donnell et al. 2008; O'Donnell 2010a).

To measure farm productivity and efficiency, increasingly sophisticated methodologies have been developed to deal with issues such as data discrepancies, functional forms and behavioural assumption restrictions, *inter alia*. Ozkan et al. (2009) have reviewed literature on measuring efficiency in agricultural production. Existing approaches can be classified as parametric or non-parametric. The modified least-squares econometric production and stochastic frontier production function models (a maximum likelihood procedure based on a non-linear model) are examples of the first and the traditional Tornqvist-Theil or Christensen and Jorgenson total factor productivity index and data envelopment analysis are examples of the second. Detailed reviews of the productivity estimation methods can be found in Van Beveren (2010) and Van Biesebroeck (2007). Most of these studies deal with productivity and efficiency issues - not with profitability to which farm business viability is closely linked (Lovell 2001). Productivity and profitability, however, are related in the sense that a more productive business typically is also more profitable, and a faster growth in productivity often translates into faster growth in profitability, *ceteris paribus* (O'Donnell 2010a).

Economists have used a number of methods to demonstrate a relationship between profitability and productivity changes. According to O'Donnell (2010a), the sources of profitability change can be decomposed into three stages provided that: (a) the output and input quantity aggregates are associated with input and output price aggregates; (b) the quantity and price aggregates are non-negative and linear homogeneous in prices; and (c) any quantity-price aggregator function pair satisfy the product rules. The formulae for decomposing these profitability and productivity drivers are presented in simplified forms in Equations (1) to (6).

Firstly, the profitability index change ($dPROF$) between firms or periods, 0 and t , can be decomposed into the indexes of changes in the terms of trade (dTT) and total factor productivity ($dTFP$):

$$dPROF = dTT * dTFP \tag{1}$$

Following O'Donnell (2010a) we used a multiplicatively complete Färe-Primont index number. We computed the change of index numbers in Equations (1) to (6) between firms for periods 0 to t , using firm or period 0 as a base. For example, the change in profitability ($dPROF$) in Equation (1) can be computed as the ratio of profitability in time t over profitability in time 0 for firm n . This can be expressed as: $dPROF = PROF_{nt} / PROF_{n0}$ where,

$PROF_{nt} = P_{nt}Q_{nt} / W_{nt}X_{nt}$; $PROF_{n0} = P_{n0}Q_{n0} / W_{n0}X_{n0}$; P and Q are the price and quantity of outputs; and W and X are the price and quantity of inputs.

Similarly, the change in terms of trade (dTT) and the change in total factor productivity ($dTFP$) in Equation (1) can be expressed respectively as: $TT_{n0,nt} = P_{n0,nt} / W_{n0,nt}$ and $TFP_{n0,nt} = Q_{n0,nt} / X_{n0,nt}$.

Secondly, the total factor productivity change ($dTFP$) index in Equation (1) can be further decomposed into the indexes of technical change ($dTECH$) and technical efficiency change ($dEFF$):

$$dTFP = dTECH * dEFF \quad (2)$$

Where, $dTFP = TFP_{n0,nt} = \frac{TFP_{nt}}{TFP_{n0}}$ or $dTFP = TFP_{n0,nt} = \left(\frac{TFP_t^*}{TFP_0^*} \right) \times \left(\frac{EFF_t^*}{EFF_0^*} \right)$. The term $\left(\frac{TFP_t^*}{TFP_0^*} \right)$ is the $dTECH$ which measures the difference between the maximum TFP that is possible using the technology available in period t and the maximum TFP that is possible using the technology available in period 0 and the term $\left(\frac{EFF_t^*}{EFF_0^*} \right)$ is the $dEFF$ which measures technical efficiency change in period t compared to period 0 .

Finally, the index of efficiency change ($dEFF$) can be decomposed into various indexes of efficiency change components as specified in Equations (3) to (6) (for simplicity, the subscripts are omitted):

$$dEff = dOTE * dOME * dROSE \quad (3)$$

$$dEff = dOTE * dOSE * dRME \quad (4)$$

$$dEff = dITE * dIME * dRISE \quad (5)$$

$$dEff = dITE * dISE * dRME \quad (6)$$

The above indexes are briefly defined below.

- OTE (ITE) is output-oriented (input-oriented) technical efficiency that captures the potential change in TFP output (input) level by best practice use of existing technology. It is measured by the difference between observed TFP and the maximum TFP possible with existing technology, while holding the output (input) mix fixed and the input (output) level fixed.
- OSE (ISE) is output-oriented (input-oriented) scale efficiency that captures the potential change in TFP, if output (input) level is changed to achieve the maximum TFP with existing

technology. It is measured by the difference between TFP at a technically-efficient point and the maximum TFP based on existing technology, while holding the input and output mixes fixed but allowing the levels to vary.

- OME (IME) is output-oriented (input-oriented) mix efficiency that captures the potential change in TFP if output (input) level is changed by altering the mix of enterprises in such a way that output is increased for a given set of inputs (output). It is measured by the difference between TFP at a technically-efficient point for use of existing technology or enterprise mix and the TFP that is possible holding the input (output) level fixed but allowing the output (input) level and mix to vary.
- ROSE (RISE) is residual output-oriented (input-oriented) scale efficiency that measures the difference between TFP at a technically and mix efficient point and the maximum TFP that is possible through altering both input and output with existing technology.
- RME is residual mix efficiency that measures the difference between TFP at a technically and scale efficient point and the maximum TFP that is possible through altering input and output mixes with existing technology.

More detail about the definitions and graphic illustrations of the index numbers specified in Equations (1) to (6) can be found in O'Donnell (2010a and 2011).

Variables and index construction

We followed the approach used by Islam *et al.* (2014) in measuring variables and indexes. The following is a list of key variables used in this study's productivity analyses.

Crop output (q1) was constructed as the sum of production (tonnes) of all crops (wheat, barley, oats, lupin, canola and other) for each farm, noting that cereals (wheat in particular) were by far the dominant crop type.

Animal output (q2) was generated by dividing the sum of all revenue from cattle, sheep and wool sales by animal price index (p2).

Land input (x1) was effective land area utilized for crop and animal production (in hectares).

Labour input (x2) was in person weeks and was constructed as the annual sum of family, managerial and hired labour.

Capital input (x3) was constructed using asset values (livestock, machinery and equipment) divided by their average prices index series from ABARES (2011) using capital value share as a weighted.

Fertilizers (x4) was constructed by dividing fertilizer expense by its price index.

Materials and services (M&S) inputs (x5) was constructed by summing annual farm expenditures over five input categories: chemicals, livestock materials, fuel and lubricants, and repairs and maintenance and dividing each item by the relevant price index from ABARE (2011).

Growing Season Rainfall (GSR) input (x6) was actual rainfall recorded in millimetres for each farm in each growing season of the data period.

4. Results and discussion

Profitability and productivity decomposition

The indexes of profitability ($dPROF$), total factor productivity ($dTFP$) and their components are presented in Appendix Table A.1. These measures were recorded as geometric means for average farms all the farms for each data period using 2002 as the base year. The $dPROF$, terms of trade (dTT) and other indexes were computed directly by the DPIN 3.0 program using both quantity and price data for the selected variables as specified in Section 3. The first three columns of the Table A.1 show the changes in profitability ($dPROF$), terms of trade (dTT) and total factor productivity ($dTFP$) of average farms. These results are illustrated in Figure 2.

The components of profitability and productivity are measured for each sample farms in each year of the study period. In Figure 2, their averaged changes in profitability, productivity and terms of trade are for average farm productivity measures. As mentioned above, the measure of change in farm profitability ($dPROF$) is the ratio of revenue to cost in each year compared to a previous year and this measure of change in profitability can also be decomposed into its components of change in the terms of trade (dTT), where the terms of trade is the ratio of prices received to prices paid, and change in total factor productivity ($dTFP$) (see equations (1) and (2)).

The results in Figure 3 show that when the change in total factor productivity among farms is decomposed into technical change and technical efficiency components, then the increase in farm productivity is almost solely attributable to increases in technical efficiency. Although the index of technical change ($dTECH$) is slightly positive, the greater contribution to change in productivity ($dTFP$) is via change in technical efficiency ($dEFF$). The practical implication of this finding is that throughout the study period farms have improved their productivity, not so much by investing in new technologies that may have shifted outwards their production possibilities, but rather through better use of existing technologies, including some technologies that offer scale economies.

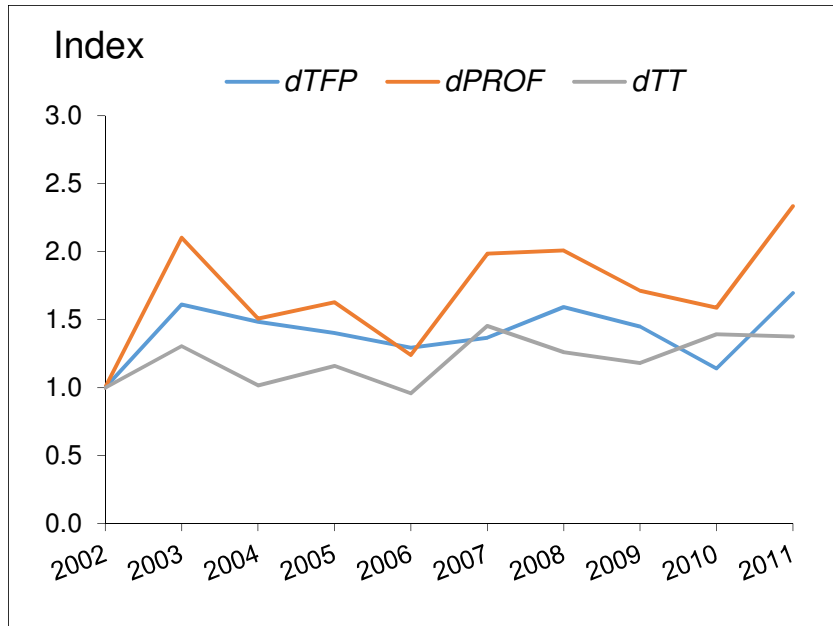


Figure 2. Changes in farm profitability, productivity and terms of trade.

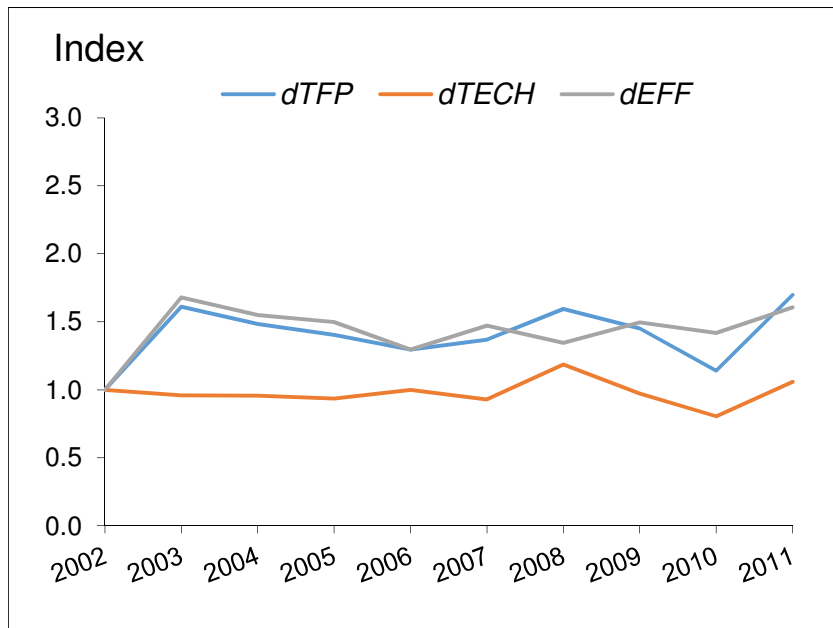


Figure 3. The technical change and technical efficiency components of farm productivity

As outlined earlier, the change in efficiency ($dEFF$) also can be decomposed into various indexes of efficiency change components. How all these components of the change in efficiency ($dEFF$) alter over the study period is shown in Figure 6. The results indicate that changes in output oriented technical efficiency ($dOTE$) that involve best practice use of existing technology and scale

efficiency ($dROSE$) are the dominant causes for the improved changes in efficiency ($dEFF$) and changes in total factor productivity ($dTFP$).

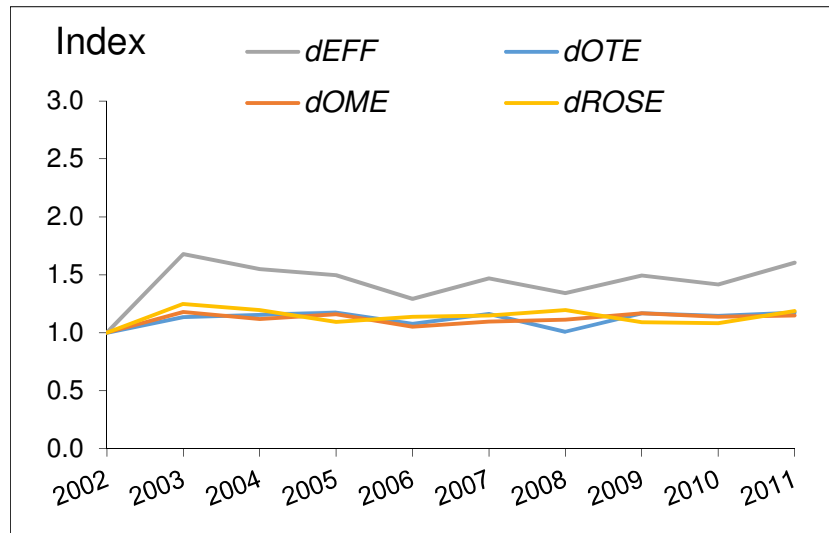


Figure 4. Components of the change in efficiency

The output- and input-oriented efficiencies measured in levels, presented in Figure 5 reaffirm that output-oriented scale and mix efficiencies are major contributing factors.

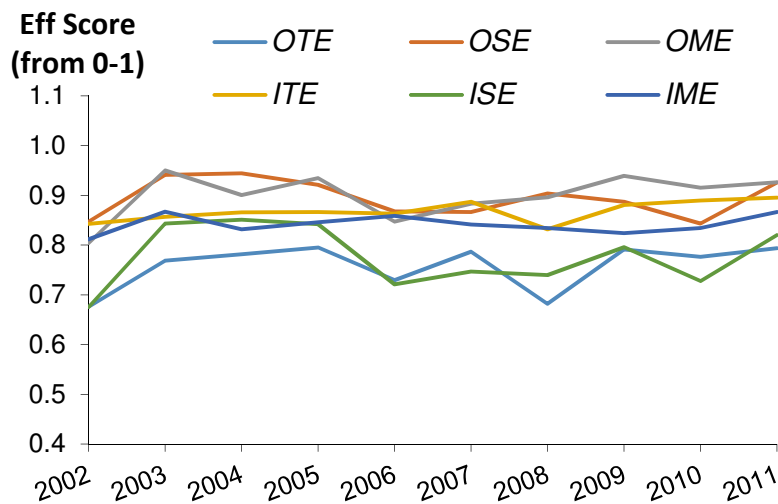


Figure 5. Output- and input-oriented efficiency scores of farms

The improvement in total factor productivity among broadacre farmers (see Figure 2) is not a new finding. Productivity growth has been a key factor driving agricultural output in Australia. Mullen and Crean (2007) identify that more than two-thirds of the current real value of Australian

agricultural output can be attributed to productivity growth that has occurred since the early 1950s. These authors and Sheng et al. (2010) argue that an important source of productivity growth has been new technology from investment in research.

Sheng et al. (2011) point out however, that agricultural productivity growth in Australia, as in some other developed countries, has been slowing. These authors suggest that a significant structural change, or turning point, occurred in the total factor productivity in Australia in the mid-1990s. They argue that the slowdown has been attributable to a combination of adverse seasonal conditions and stagnant public research and development expenditure since the late 1970s.

More particularly, Hughes et al. (2011) observe that a significant slowdown in productivity growth was observed over the past decade, even after controlling for deteriorating climate conditions. For cropping specialists across Australia they found that climate adjusted productivity growth averaged 1.06 per cent a year post 2000, in comparison to 2.15 per cent pre 2000. Importantly, Hughes et al. (2011) concluded that technical change was the key contributor to long-run productivity growth. They also found that growth in technical change was offset by a small decline in technical efficiency, where declining technical efficiency implied that the gap between the most efficient farms and the less efficient farms had widened. However, when the spatial details of Hughes et al.'s findings are examined it is clear that different results apply to farmers in Australia's south west.

Table 1 presents a sub-set of results from Table 6 in Hughes et al. (2011). What is interesting about the results is how different are the productivity change components in the western region (i.e. south-western Australia) compared to the southern region (i.e. southern and south-eastern Australia). In the western region the principal component of growth in climate-adjusted TFP for all farm types is scale mix efficiency which refers to changes in farm scale and input mix that influence productivity, typically in response to prevailing input and output prices. Importantly, in the western region for cropping specialists, technical change exerted a strong negative influence over climate-adjusted TFP during the years 1999/2000 to 2007/8, whilst technical efficiency exerted a small negative influence.

Table 1. Average annual growth in productivity components for ABARES surveyed farms in the GRDC southern and western regions in 1999/2000 to 2007/8.

Farming type and TFP components		GRDC Southern region	GRDC Western region
Cropping specialists and mixed enterprise farms	Technical change (dTECH)	0.45	0.37
	Technical efficiency change (dTEFF)	-0.35	-0.34
	Scale mix efficiency change (dSE)	-0.26	1.30
	Climate-adjusted TFP change	-0.16	1.32
Cropping specialists only	Technical change (dTECH)	1.00	-0.42
	Technical efficiency change (dTEFF)	-0.36	-0.09
	Scale mix efficiency change (dSE)	0.79	1.56
	Climate-adjusted TFP change	1.43	1.04

Source: Abstracted from Hughes et al. (2011)

The important role played by scale efficiency ($dROSE$) has previously been reported for studies of Australian broadacre agriculture (O'Donnell, 2010a). He found that during periods of significant declines in the terms of trade that scale (and mix) efficiency increased. In this current study of broadacre farming in south-western Australia, during a period of a slight reduction in the terms of trade, we also have found that scale efficiency and technical efficiency have played important roles in boosting change in total factor productivity ($dTFP$).

Hughes et al. (2011) and the current study both find that scale efficiency and technical efficiency, rather than technical change, have played important roles in generating productivity gain, particularly for crop farms in south-western Australia. The business and adaptation strategy that many farms have employed is to increase farm size and/or the size of cropping programs, and thereby reap the benefits of scale economies. In undertaking this often successful expansion strategy, farms have tended to rely on existing technologies and to improve their use of best practice methods. Underpinning this strategy has been often a greater reliance on wheat production, and wheat growing has supported the growth and resilience of many farm businesses during the study period.

The current reliance on wheat production may also be a useful on-going farm business strategy. Support for this assertion comes from wheat yield modelling under future climate scenarios by Asseng and Pannell (2012), Potgeiter et al. (2012) and Addai (2013). These authors point to little decline in wheat yields over the next couple of decades, due to beneficial CO_2 fertilisation effects.

Asseng and Pannell (2012) recognise farmers' current sound use of best practice methods, yet they argue for the need to develop technologies that will boost technical change ($dTECH$). It is true that future productivity enhancement cannot solely rely on improvements in technical efficiency ($dEFF$). Rather technical change is also essential so that at some stage farmers' production frontiers can move outwards. Hence, the call by Asseng and Pannell for further research and development that offers farmers beneficial technical change is a sound conclusion.

Other evidence that supports the greater dependence on cropping comes from Deards et al. (2012). Drawing on ABARES farm survey data they found that between 1977–78 and 2009–10, cropping specialists achieved average annual total factor productivity growth of 1.6%, compared with the broadacre industry average of 1.2% per cent. The greater productivity growth of cropping specialists would have supported the growth in their farm profitability.

Productivity trajectories and farm characteristics

How profitability and productivity are affected by the variable nature of farm operating environments and characteristics are examining the relationship between the mean and standard deviation of farms' total factor productivity ($dTFP$) by using the annual data.

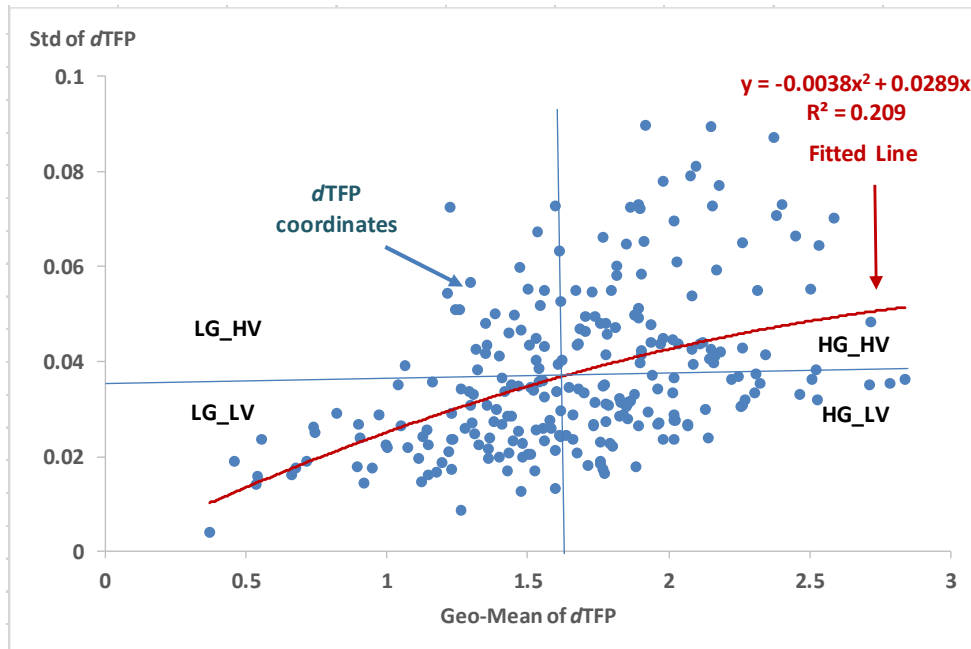


Figure 6. The mean and standard deviation of farms' total factor productivity ($dTFP$) growth.

It is possible to overlay on Figure 6 a simple grouping of farms by the mean and standard deviation of each individual farm's total factor productivity ($dTFP$) growth over the study period. The solid vertical and horizontal lines in Figure 6 split the farm sample into 4 categories: (i) high growth in $dTFP$ and high volatility in $dTFP$ (top right quadrant, HG_HV), (ii) high growth in $dTFP$ and low volatility in $dTFP$ (bottom right quadrant, HG_LV), (iii) low growth in $dTFP$ and high volatility in $dTFP$ (top left quadrant, LG_HV) and, (iv) low growth in $dTFP$ and low volatility in $dTFP$ (bottom left quadrant, LG_LV). The point of splitting is the overall mean values of the mean and standard deviation of farms' total factor productivity ($dTFP$) growth.

The data in Figure 6 show the heteroskedastic response of increasing variance in $dTFP$ as the mean of $dTFP$ increases. In practice this means that the group of farms that recorded a high mean in $dTFP$ over the study period also displayed a large range in the variance of their $dTFP$ over that same period.

Farm businesses in each quadrant can be compared to generate insights about what sorts of farm characteristics are associated with that quadrant of $dTFP$ performance. Comparative data on the productivity and profitability components are presented in Table 2 and on the farms' physical and financial characteristics are listed in Table 3.

Table 2. Profitability and productivity components farms in the four quadrants of total factor productivity (*dTFP*) performance during 2002 to 2011 (mean values).

Variable	Unit	HG_HV	HG_LV	LG_HV	LG_LV
<i>dTFP</i>	index	1.98	1.97	1.38	1.19
<i>dPROF</i>	index	2.10	2.08	1.37	1.20
<i>dTT</i>	index	1.06	1.05	1.00	1.00
<i>dTECH</i>	index	1.00	1.00	1.00	1.00
<i>dEFF</i>	index	1.97	1.96	1.37	1.19
<i>dOTE</i>	index	1.73	1.68	1.62	1.50
<i>dOSE</i>	index	0.94	0.96	0.84	0.87
<i>dOME</i>	index	1.25	1.24	1.22	1.20
<i>dROSE</i>	index	0.91	0.95	0.70	0.66
<i>dOSME</i>	index	1.14	1.17	0.85	0.80
<i>dITE</i>	index	1.33	1.29	1.34	1.28
<i>dISE</i>	index	1.22	1.25	1.01	1.01
<i>dIME</i>	index	1.03	1.06	0.99	1.01
<i>dRISE</i>	index	1.44	1.43	1.04	0.92
<i>dISME</i>	index	1.48	1.52	1.02	0.93
<i>dRME</i>	index	1.21	1.21	1.01	0.92

Also it is possible to use other farm characteristics data (see Table 4) to reveal more information about the nature of farms that fall into each of the productivity quadrants

Most farms fall into the quadrant with high mean and high variance of *dTFP* (31% of all farms) or the quadrant with low mean and low variance of *dTFP* (31% of all farms). Drawing on the data in Tables 3 and 4 reveals that farms in the HG_HV quadrant, relative to those in the LG_LV quadrant are:

- larger in size; 4822 hectares versus 2257 hectares,
- recipients of less growing season rainfall; 231 mm versus 273 mm, and are more likely to be in a low rainfall region,
- more crop dominant, with 84% of farm income coming from crop revenues versus 69%,
- similar in farm equity - around 80%,
- more profitable, \$259K of farm profit versus \$26K,
- able to generate more crop yield per 100mm of growing season rainfall, 0.77 versus 0.70 tonnes per 100mm per hectare,
- more lucrative in terms of return on equity, 4% versus 1%

Table 3. Physical and financial characteristics of farms in the four quadrants of total factor productivity ($dTFP$) performance during 2002 to 2011 (mean values).

Variable	Unit	HG_HV	HG_LV	LG_HV	LG_LV
Gross farm income (GFI)	\$	1,819,730	1,453,523	868,373	806,243
Operating costs (OC)	\$	1,178,295	945,512	591,638	560,019
Operating surplus	\$	641,435	508,011	276,735	246,224
Profit	\$	259,092	187,324	41,726	25,534
Personal expenses	\$	127,314	115,352	82,470	79,034
Interest payments	\$	114,378	93,967	79,248	79,783
Machinery replacement	\$	140,651	111,368	73,291	61,622
Debt to Income	Ratio	1.0	1.1	1.3	1.3
Share of OC to GFI	%	72	68	80	78
Land owned	Ha	4,882	3,613	3,351	2,317
Land used	Ha	4,822	3,664 ^a	3,302	2,257
Land value	\$	5,415,875	4,898,827	2,685,354	3,273,108
Equity	%	82	79	78	80
Cropped area	Ha	3,561	2,608	2,201	1,325
Pasture area	Ha	1,263	1,056	1,100	933
Crop income share	%	84	80	79	69
Crop Income	\$/Ha	433	463	343	440
Livestock income	\$/Ha	219	306	163	263
Farm asset	\$/Ha	1,633	1,916	1,414	2,258
Business asset	\$/Ha	1,831	2,118	1,598	2,465
Debts	\$/Ha	342	433	361	485
Equity	\$/Ha	1,529	1,686	1,224	1,950
Return on capital (ROC)	%	10.6	9.7	12.5	7.2
Return on equity (ROE)	%	3.8	3.7	1.4	0.9
Growing season rainfall (GSR)	mm	231	241	227	273
Crop income efficiency	\$/Ha/100mm	188	192	151	161
Livestock income efficiency	\$/Ha/100mm	95	127	72	96
Livestock expenses	\$/Ha	58	58	37	40
Profit	\$/Ha/100mm	23	21	6	4

^a “Land used” could be higher than “Land owned” because of additional land leasing.

- mostly crop specialists and mixed enterprise farms versus livestock specialists and mixed enterprise farms,
- less exposed to debt as indicated by the debt to income ratio, 1.0 versus 1.3 and the debt burden, \$342 per hectare versus \$485 per hectare,
- able to generate more livestock income per mm of growing season rainfall, \$2.03 versus \$1.36 per mm per hectare,
- more likely to be a growing farm,
- less likely to be a less secure farm (see Appendix Two for definitions of these farm types).

Table 4. Percent of sample farms by additional characteristics in each quadrant of farm total factor productivity ($dTFP$) performance during 2002 to 2011.

Additional Farm Characteristics	HG_HV	HG_LV	LG_HV	LG_LV
All Sample farms	77	48	48	77
Crop Specialist farms	28	9	11	7
Mixed Enterprise farms	48	39	34	61
Livestock Specialist farms	1	0	3	9
Farms receiving GSR >325mm	3	1	6	13
Farms receiving GSR >275 and <325mm	11	5	3	19
Farms receiving GSR <275mm	63	42	39	45
Farms with 'Growing' business ¹	43	22	11	23
Farms with 'Strong' business ¹	18	12	10	19
Farms with 'Secure' business ¹	12	11	15	14
Farms with 'Less-Secure' business ¹	4	3	12	21

¹ The financial performance of farms was assessed over the period 2002 to 2011 and then farms were classed as being growing, strong, secure or less secure. The methodology for this classification is provided in Appendix Two and is also described in Kingwell et al (2013).

Appendix Two outlines the financial methodology for classifying farms as growing, strong, secure or less secure. Most 'growing' farms are characterised as having a HG-HV trajectory in $dTFP$ whilst most 'less secure' farms have a LG-LV trajectory (see Figure 7).

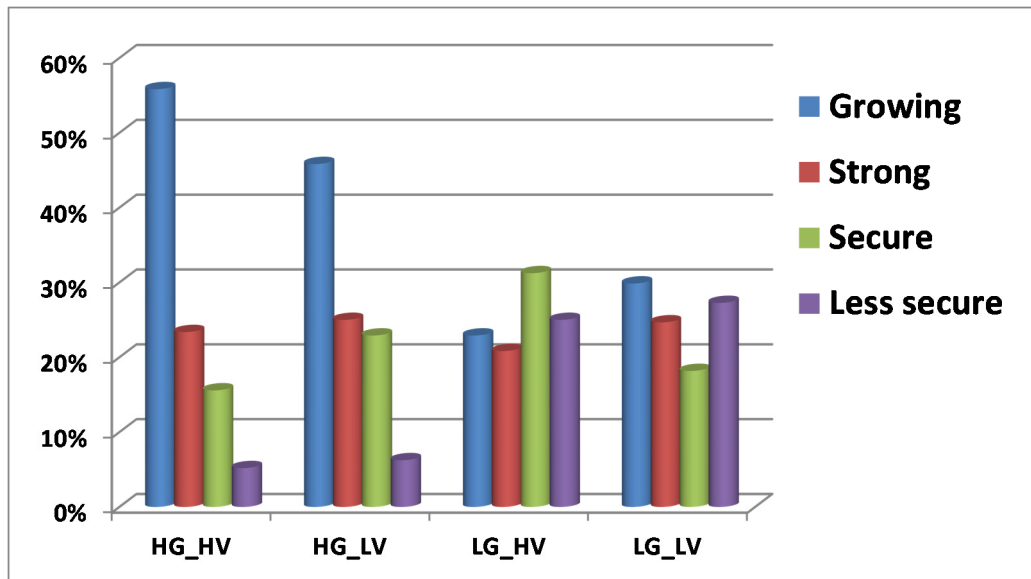


Figure 7. The commercial characteristics of farms within each category of $dTFP$ trajectory.

Similarly the proportions of categories of $dTFP$ trajectory for each commercial grouping of farms are shown in Figure 8.

Most growing farms have a HG_HV trajectory of $dTFP$, although just over a quarter of these farms express a LG-LV trajectory. By contrast, almost 75% of all less secure farms express a low growth trajectory in $dTFP$, with the majority displaying a LG_LV trajectory.

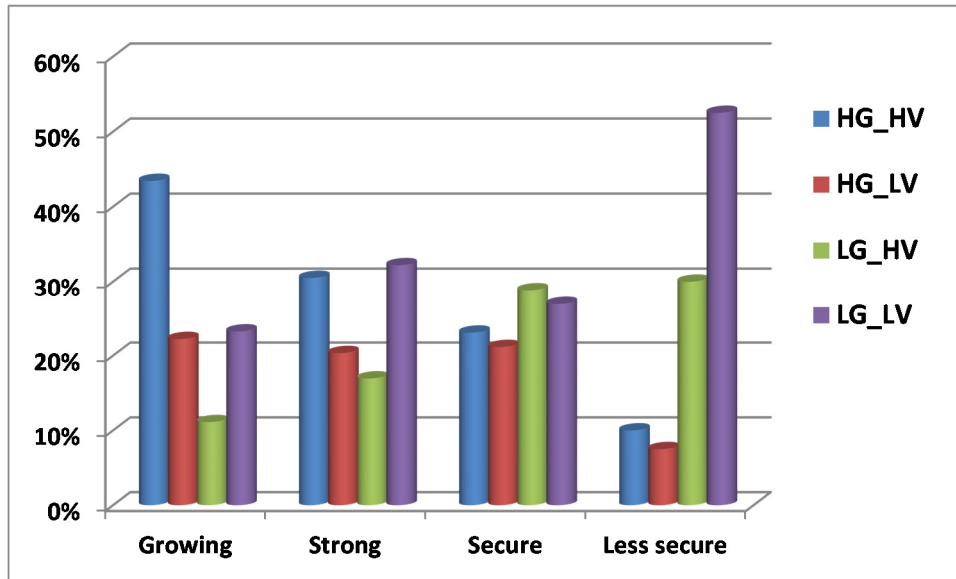


Figure 8. The proportions of categories of $dTFP$ trajectory for each commercial grouping of farms.

Farms in the LG_LV quadrant were principally livestock specialist farms and mixed enterprise farms, mostly operating in higher and moderate southern rainfall zones (M4, M5 and H5 in Figure 1). The positive terms of trade effect, principally due to increased livestock and wool prices during the study period, was associated, as expected, with a decline in $dTFP$. By contrast, the slight decline in terms of trade for farms in the HG_HV quadrant, principally due to farm-gate crop prices trending slightly downwards in real terms, was linked to an increase in $dTFP$. In practice this meant that the large crop dominant farms in the low and moderate rainfall northern regions (L1, M1 and M2 in Figure 1) greatly capitalised on the reasonable number of favourable weather years during the study period and curtailed their losses in the very poor years, often by restricting crop area and input use.

Applying equation (1) to the four quadrants of productivity performance shows the different trajectories for $dTFP$, $dTECH$ and $dEFF$. Especially for groups displaying high growth in $dTFP$, $dEFF$ rather than $dTECH$ is the principal source of growth in $dTFP$ (see Figure 9). The practical implication of these findings is that farms that have experienced higher growth in their $dTFP$ have done so by ensuring they use commonly available technologies consistently in the best possible way. Moreover, the crop dominance of these farms, when combined with their experience of a reasonable frequency of favourable seasons, has allowed these farms, on average, to lift their total factor productivity.

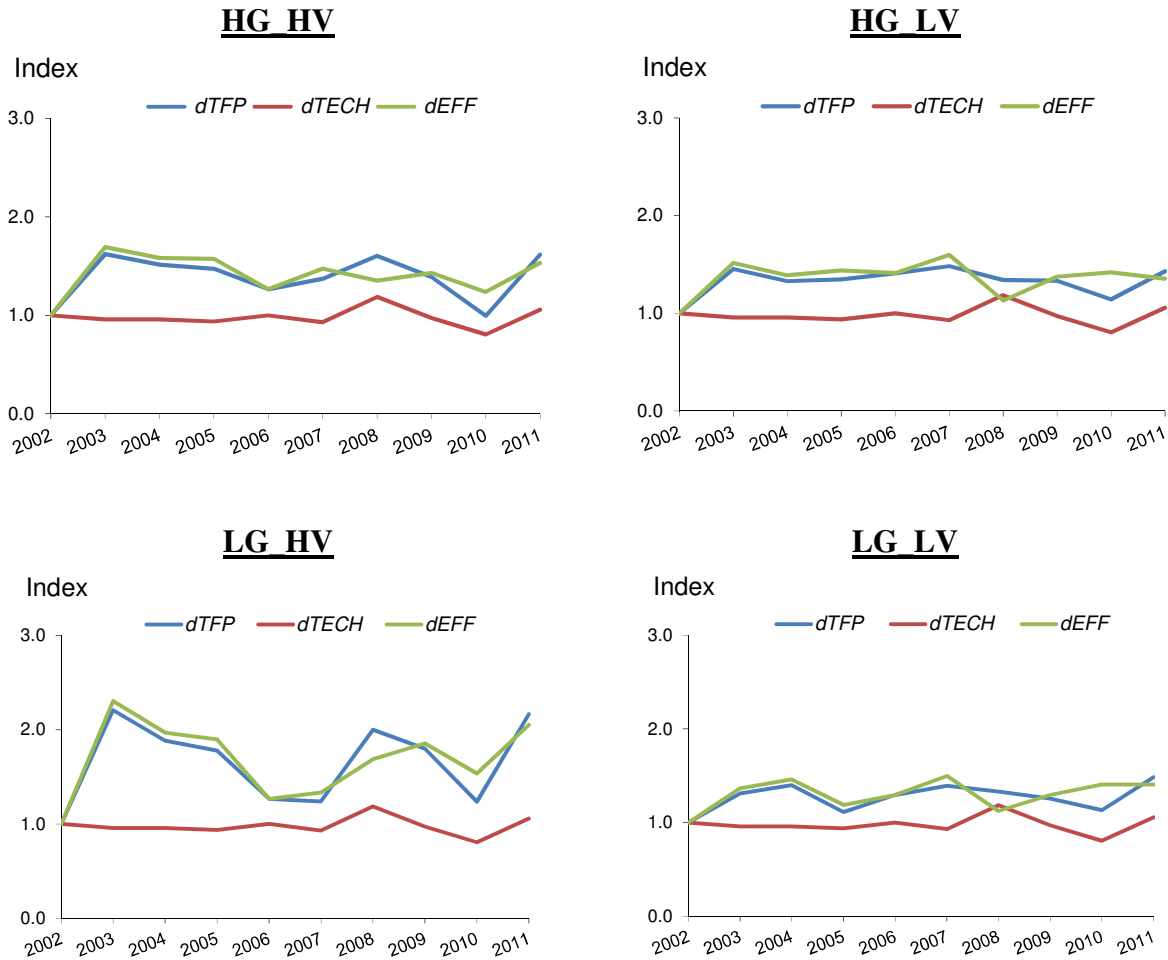
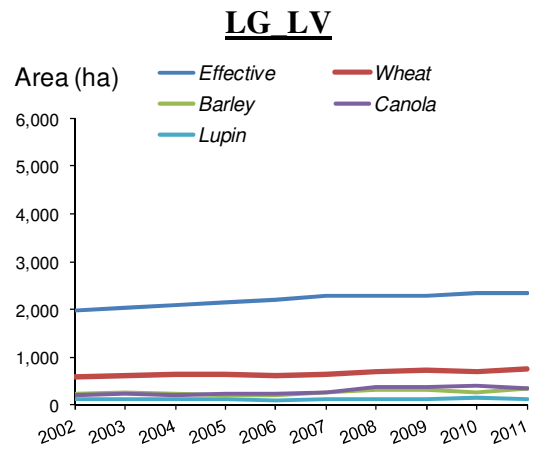
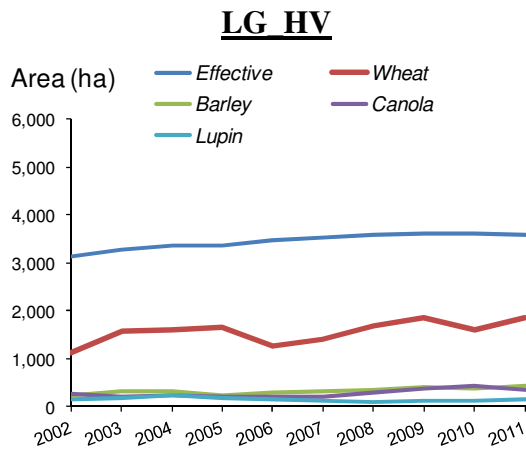
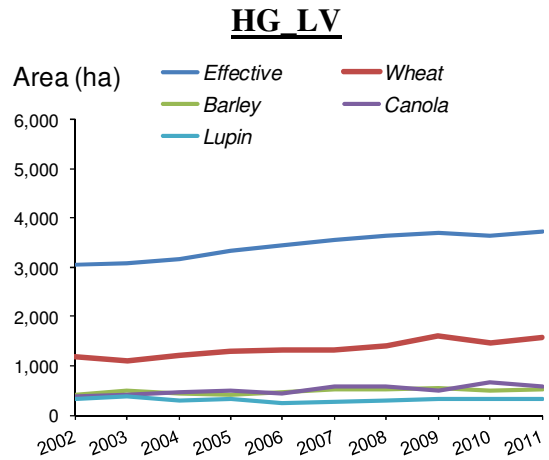
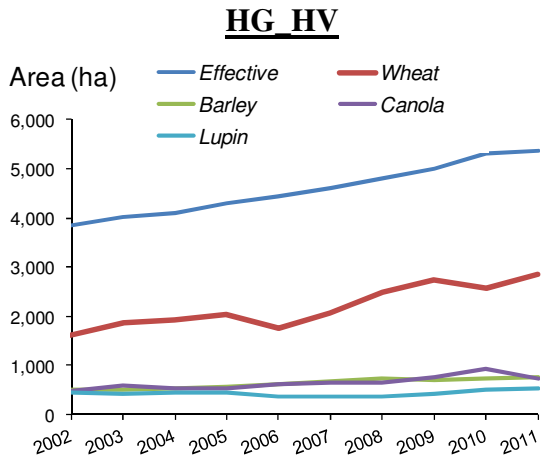


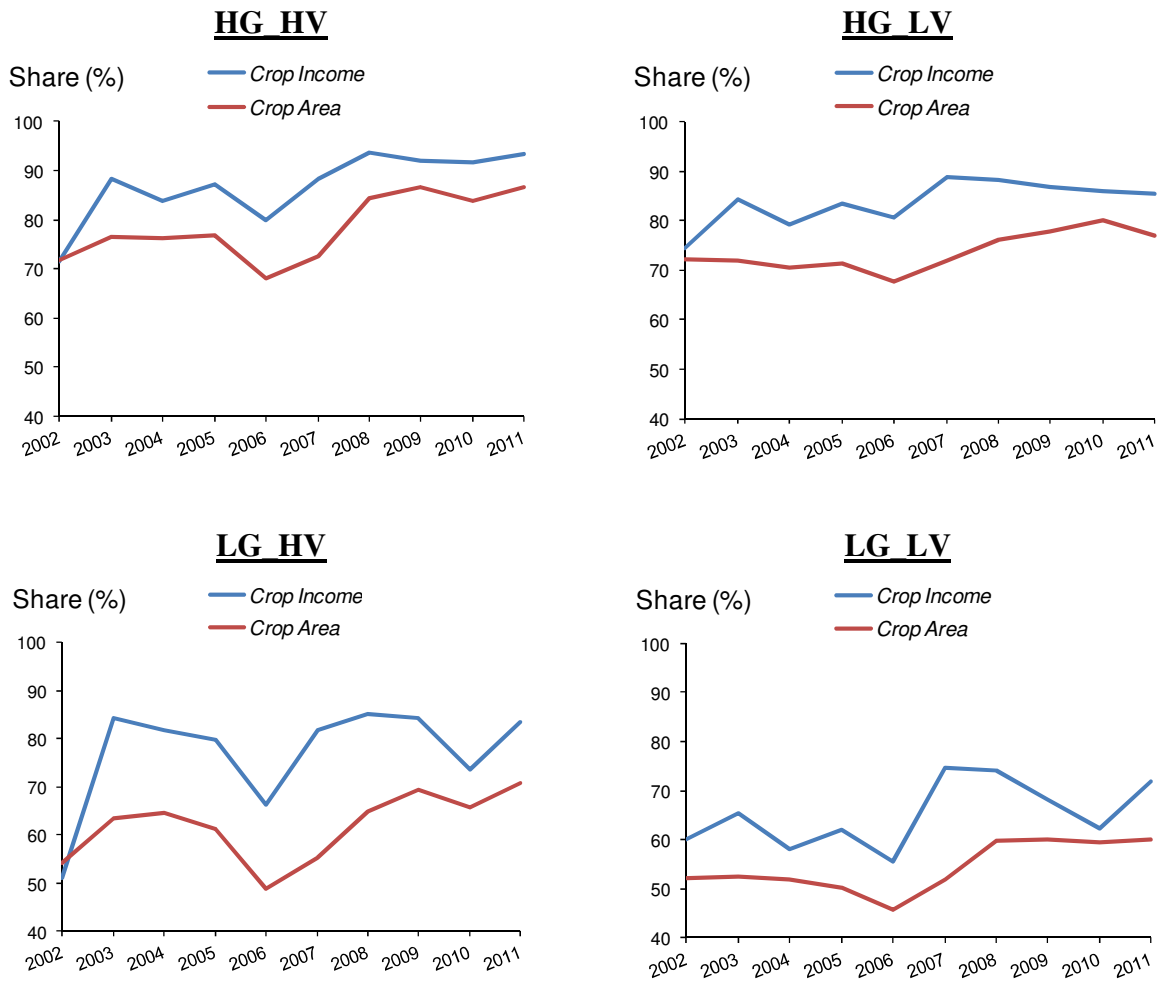
Figure 9. Trajectories of mean *dTFP*, *dTECH* and *dEFF* for farms in each quadrant of productivity performance.

Interestingly, yet of some concern, is the finding that *dTECH* has played a relatively minor role in boosting farms' total factor productivity. The implication is that farmers have either not adopted new technologies or these technologies have not been available or have not delivered the anticipated outcomes. Either way technical change has not been the pathway for lifting total factor productivity. Rather, mostly it is farmers' improved use of existing technologies that has lifted their productivity performance, with reliance on scale economies playing an additional but far less important role.



A. Average farm size and crop plated areas

Figure 10. Trajectories of key farm characteristics in each quadrant of productivity performance (cont'd on next page).



B. Share crops in farm income and farm area

Figure 10. (Cont'd from previous page).

The route to lifting growth in $dTFP$ is often larger farm size, increased plantings of wheat and greater crop dominance, especially in terms of the proportion of farm income stemming from crop revenue (see panels A and B in Figure 10).

5. Conclusion

Australia's broadacre agriculture sector relies on productivity gain to support and lift its profitability. This paper estimates the annual productivity of the same group of 250 farms over the period 2002 to 2011. Farms are classed according to the geometric mean of their total factor productivity and the variance of this productivity. The sample population of farms displays convexity in this relationship; high growth in productivity is associated with greater volatility in productivity.

Most farms either experienced high growth and high variability in productivity or low growth and low variability in productivity. The decomposition of productivity change reveals that efficiency gain rather than technical change is the principal source of improvement in total factor productivity. The practical implication of this finding is that farms that have experienced higher growth in their total factor productivity have done so by ensuring they use of commonly available technologies consistently in the best possible way. Interestingly, yet of some concern, is the finding that technical change has played a minor role in boosting farms' total factor productivity.

The characteristics of farm businesses that have experienced highest growth in their total factor productivity typically appear to have employed a range of business strategies and tactics. Relative to farms that by contrast have achieved low growth in productivity, the high growth farms have increased their farm size, become more crop dominant, have often operated farms in lower rainfall regions, have generated more profit and are less exposed to debt. They generate more crop yield per 100mm of growing season rainfall, yet also generate more livestock income per mm of growing season rainfall. High growth farms are often crop specialists or mixed enterprise farms rather than livestock specialists.

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Appendix One

Table A.1. Indexes of changes in productivity and profitability components

Year	dPROF	dTT	dTFP	dTECH	dEFF	dOTE	dOSE	dOME	dROSE	dOSME
2002	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2003	2.10	1.31	1.61	0.96	1.68	1.14	1.11	1.18	1.25	1.48
2004	1.51	1.02	1.48	0.96	1.55	1.16	1.11	1.12	1.20	1.34
2005	1.63	1.16	1.40	0.94	1.50	1.18	1.09	1.16	1.10	1.27
2006	1.24	0.96	1.29	1.00	1.29	1.08	1.02	1.05	1.14	1.20
2007	1.99	1.45	1.37	0.93	1.47	1.16	1.02	1.10	1.15	1.26
2008	2.01	1.26	1.59	1.19	1.34	1.01	1.07	1.11	1.20	1.33
2009	1.71	1.18	1.45	0.97	1.49	1.17	1.05	1.17	1.09	1.28
2010	1.59	1.39	1.14	0.80	1.42	1.15	1.00	1.14	1.08	1.24
2011	2.34	1.38	1.70	1.06	1.61	1.17	1.09	1.15	1.19	1.37
Geo-Mean	1.66	1.20	1.39	0.98	1.42	1.12	1.05	1.12	1.14	1.27

Appendix Two

Five categories of farm business performance were derived, based on Blackburn and Ashby (1995), causing farms to be classed as growing, strong, secure, less secure and non-viable. The derivation of these categories is shown in Table A.1. The operating surplus/deficit is calculated as gross farm income (GFI) minus variable costs and fixed costs. Profit for each year is calculated by subtracting the cost of finance (interest), personal expenses of the business and depreciation (calculated as 10% of total machinery value for the year), from the operating surplus.

The change in equity was calculated as the difference between value of net assets in 2002 versus their value in 2011, using constant land values based on the values in the first year, 2002. A business which achieved a profit at least seven years in ten and showed an increase in equity from 2002 to 2011 was classified as a growing business. The distinction between a growing and strong business was that the strong business only maintained equity and achieved a profit in six of the ten years. Secure businesses could pay for their personal expenses, finance costs and depreciation but they made minimal profit and their equity was either maintained at a constant level or decreased over the period. Less secure businesses failed to achieve a profit after allowing for their finance cost, depreciation and unpaid family labour; and their equity declined as a consequence.

Table A.2. Categories of farm performance

	Growing	Strong	Secure	Less Secure	Non viable
Operating surplus	✓	✓	✓	✓	
MINUS					
Finance (interest)	✓	✓	✓	✓	
Personal expenses	✓	✓	✓	✓	
Depreciation	✓	✓	✓		
EQUALS Profit	+ve	+ve	-ve	-ve	-ve
EQUITY	Increasing	Maintaining	Maintaining or Declining	Declining	Declining