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How drought affects the financial characteristics of Australian farm businesses

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The financial performance of 240 farms in a drought-affected agricultural region of Australia is analysed. The decadal study period included some years of widespread drought, as well as years with only subregional droughts or no drought. Some droughts created larger adverse financial impacts than others. Mostly, the more droughts farms experienced, the worse was their financial performance relative to farms within the same quantile of farm performance. Despite the incidence of drought, by the end of the decade, almost all the farm businesses were wealthier from increasing their farm size and becoming more crop dominant. Unexpectedly, consecutive years of drought had a significant positive effect on the operating profit per hectare and retained profit per hectare of farms in a majority of their respective quantiles. Many farms that experienced consecutive drought were forced to make structural changes, shifting away from livestock production towards additional cropping. These structural changes boosted farm performance over the decade. The incidence of drought affected some measures of farm performance differently whilst others were affected similarly. Understanding these metrics of farm performance and the structural changes underway in an agricultural region helps form a more complete view of drought impacts.

Key words: drought, farm businesses, farm performance, quantile regression.

1. Introduction

Drought is a commonly acknowledged climatic feature of rain-fed Australian agriculture. Australia's main grain crop, wheat, is mostly grown in regions where summers are typically hot and dry, and winters are mild and wet. As pointed out by Ockwell (1990), protracted periods of low rainfall, when combined with high temperatures, high evapotranspiration and soils that inadequately store moisture, usually result in problematic low yields in crops and pastures. Such poor yields are the typical outcome of drought.

The most general definition of drought is a prolonged period of acute water shortage (Stephens 1998). However, an astute yet cheeky observation is that often in rural regions, drought can best be defined as a prolonged dry period in the vicinity of an election. As shown by the Australian Farm Institute

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(2014), exceptional circumstances drought declarations that are meant to typify once in 20–25 year events occur with far greater frequency in some regions of Queensland and central New South Wales.

The Bureau of Meteorology states that serious rainfall deficiency is when rainfall is above the lowest 5 per cent of recorded rainfall but below the lowest 10 per cent (decile range 1) for the period in question, and severe rainfall deficiency is where rainfall is within the lowest 5 per cent for the period in question (BOM 2016a). In deference to political and social sensitivities that surround drought, the Bureau of Meteorology states that drought declaration is the responsibility of state and federal governments.

Due to the prevalence of drought in Australia, and the historical economic importance of agriculture to the Australian economy, drought policy has often been a policy focus for many state and federal governments (Wilhite 2003). Unsurprisingly, drought policy in Australia has also been a rich vein of scrutiny for economists (Freebairn 1983; Burdon 1995; Matthews *et al*. 1997; Botterill 2003; O'Meagher 2005; Malcolm 2006; Ha *et al*. 2007; Productivity Commission, 2009). Often economists have criticised drought policies that involve subsidies and grants, arguing that drought is just one of several business risks that farmers should accommodate. The consistent advice from economists has gained some traction, as the recent Intergovernmental Agreement on National Drought Program Reform, signed in 2013 by Australian, state and territory governments has the stated aims of encouraging farmers to better prepare for droughts and manage their business risks.

From the farmer's perspective, drought causes greater expenditure on feeding livestock, and crop production receipts are reduced due to low yields. Drought reduces the farmer's ability to generate income, service debt, replace capital items (e.g. machinery) and finance recovery (Edwards *et al*. 2009; Kingwell and Farre 2009). Drought can have long-term business consequences if the farmer's capacity to finance their cropping and livestock operations during recovery is impeded (Lawes and Kingwell 2012).

Most of the empirical evidence on the impacts of drought on Australia's agricultural industries comes from farm surveys. Such surveys are regularly undertaken in Australia (e.g. Planfarm and BankWest 2009; Crooks and Levantis 2010; Martin *et al*. 2010; ABARES 2011) and reveal how drought affects particular industries or regions. How farmers cope with drought and what characterises resilient farm businesses are issues only infrequently examined (Topp and Shafron 2006; Planfarm 2014).

Although special surveys like that of Topp and Shafron (2006) and Doudle *et al*. (2009) provide case study insights about farmers' management of drought, those studies do not follow longitudinally those farms to gauge their recovery. Two exceptions are firstly the study by Lawes and Kingwell (2012) that examined the same set of 123 farms over 6 years in a subregion of Western Australia. The period from 2004 to 2009 included consecutive drought years in 2006 and 2007. They found that over the 6 years, the equity position of 60 per cent of the farms declined. In short, the impact of the twin years of drought was that a majority of farms were made financially worse off at the end of the study period compared to the start. Another study by Planfarm (2014) examined the financial performance of farms in the eastern grain belt of Western Australia over a 6-year period ending in 2012. During this period, many farms experienced drought or poor production years. Through conducting interviews with farmers and examining their financial records, a descriptive analysis of behaviours that facilitated business resilience was undertaken.

When reviewing Australia's drought policy and its impact on farm businesses, the Productivity Commission (2009) found that in drought-affected regions, many farm businesses could survive without special assistance. Exactly how well these businesses coped financially was not clearly revealed. Hence, a motivation for this present study was to use a balanced panel of farm businesses to reveal their financial performance, given different incidences of drought and thereby identify how different farm businesses fare amid drought.

Key issues examined are how the incidence of drought affects farm financial performance; whether consecutive drought years are especially challenging and whether certain characteristics of a farm business provide financial resilience for those businesses. The next section describes the data and method of analysis to assess farm performance and the impact of the incidence of drought. Then, in Section 3, results are presented and discussed. A final section offers concluding remarks.

2. Methods

2.1 Study region and data

The study region (Figure 1) has a Mediterranean climate with hot dry summers and mild wet winters. Annual average rainfall ranges from about 650 mm on the western and southern edges of the study region, down to just under 300 mm on the inland drier edges. Most rain falls between May, when annual crops are generally sown and October. Crops are harvested in November and December. The rainfall between May and October is known as growing season rainfall (GSR). In subregions where annual rainfall is generally <450 mm, crop-only or cereal crop-dominant farming systems are prevalent. In other regions, mixed enterprise farming systems are commonplace, often involving sheep, cereals and oilseeds.

As noted by Lawes and Kingwell (2012), wheat dominates crop plantings, with barley, canola and pulse crops being far less important. Livestock production systems are dominated by sheep that graze introduced annual pastures. Sheep have historically been raised for wool, but more recently lambs and young wethers produced for meat production have become the main focus of sheep production. Sheep numbers have been in decline since the early 1990s (ABS 2013), making most farm businesses crop-dominant.

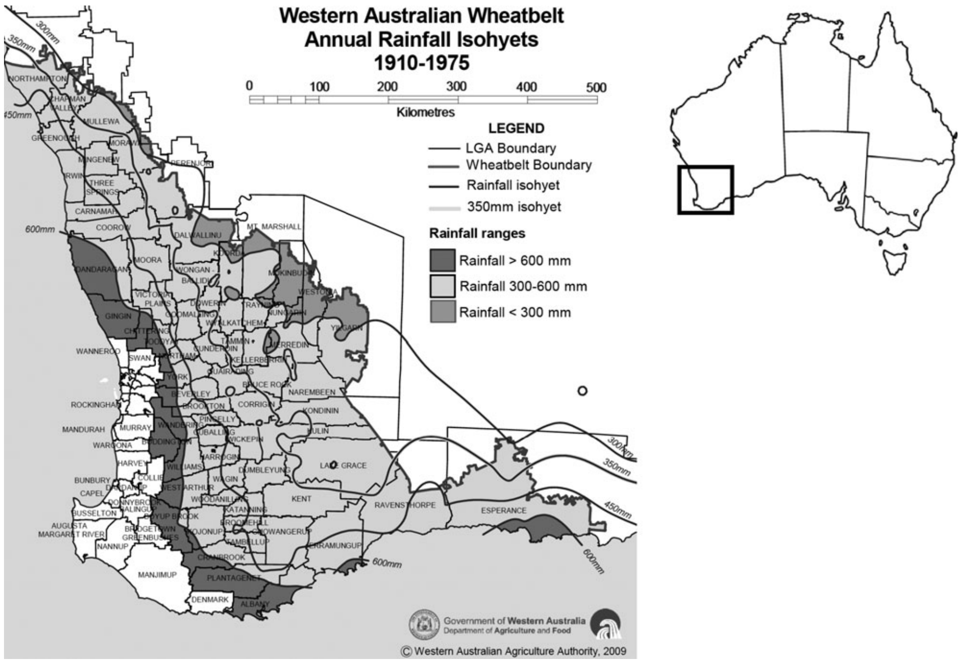

Figure 1 The study region of south-western Australia.

Three agricultural consulting firms, with farm business clients in the study region, provided economic and production information on 240 farms from 2002 to 2011. Because each consultancy firm provided different sets of physical and financial variables, and some variables were measured differently by each firm, care was taken to form a consistent unified data set. The sample size represents over 5 per cent of the farm population in the region.

Production data included the annual yield of each major crop (noting that wheat is by far the dominant crop), the area sown to each crop and the sales generated from crop, livestock and livestock products. Commodity prices were recorded for each year for each farm. GSR for each farm each year was recorded. Note, although most businesses experienced at least 1 year of drought over the decade, very few of the businesses were formally eligible for State or Federal Government drought assistance. Hence, in almost all cases, their business performance was not financially bolstered by such assistance during the decade under review.

The 240 farms were located in different environments and differed in size and enterprise composition. The decade included a few years of widespread drought, as well as years with subregional droughts, as illustrated in the Appendix S1. The appendix lists examples of the spatial distribution of wheat yield in various years in the study region.

Lawes and Kingwell (2012) used four measures of business performance in their study: return on capital (ROC), business equity (BE), the debt-to-income ratio (DI) and operating profit per hectare (OP). We used those four

Table 1 Farm business indicators

Symbol	Business indicator	Definition
OP	Operating profit per hectare	(Total operating income – total operating costs)/ total area farmed
RP	Retained profit per hectare	(Total operating income – total operating costs – personal expenses – tax payments – loan repayments – machinery replacement)/total area farmed
ROC	Return on capital	Net income/total business capital (expressed as %)
BE	Business equity	Total assets – total liabilities
DI	Debt-to-income ratio	Total liabilities/total receipts

plus an additional measure: retained profit per hectare (RP, see Table 1). Among these indicators, BE is the most likely to change gradually, although it can quickly change when major land expansion or machinery purchases are made with debt finance. The other indicators are highly dynamic, being much affected by seasonal and market conditions. These five indicators were calculated for each farm each year and where necessary were adjusted for inflation to ensure the indicators were expressed in constant 2002 dollar terms.

The farm data set in this study is the same as used by Xayavong *et al.* (2015). The data are from farms able to afford an agricultural consultant, so they may not accurately represent the farm population. For example, if only above-average farmers use consulting firms, then the data may be upwardly biased. Moreover, the data set may be affected by survivor bias whereby farms that cease operation, for whatever reason, during the decade are not represented. Xayavong *et al.* examined the representativeness of the sample, using comparisons of the sample against Australian Bureau of Statistics (2008) agricultural census small area data for the study region. No significant differences in farm characteristics, such as farm size or enterprise mix, were found. In addition, it can be noted that in Western Australia, over 40 per cent of broadacre grain farmers use various commercial advisory services including consultant and fee for service advisers (Llewellyn and D'Emden 2009; IPSOS-Eureka 2010). Moreover, the annual decline in farmer numbers in the study region is only around 1 per cent per annum (Barr 2004), and those exits are mostly not due to unviability. This suggests the farm sample represents the approximately 90 per cent of farm businesses who are likely to remain in business over a decade. Overall, however, some caution must surround extrapolating this study's findings to any wider population of broadacre farms in the study region or more particularly to other parts of Australia.

Distributions of the raw data for the variables OP, RP, ROC, BE and DI are listed in Appendix 1.

In examining the incidence and impact of drought, the following operational definition of drought applied in any year for a given farm. If the farm's GSR lay within the decile one range of rainfall received by the closest weather station that had a continuous rainfall record over the 25 year period 1983–2012, then that farm was classed as having experienced a drought in that year. Applying that definition of drought meant that the frequency of drought and the frequency of consecutive drought years could be determined for each farm.

2.2 Statistical analysis

Traditional linear regression models link the conditional mean of a response to a linear combination of covariates. However, such models prove inadequate when different parts of the conditional response distribution are suspected to behave differently or may change at different rates. For example, the incidence of drought may differently affect a heavily indebted or loss-making farm compared to a high net equity or highly profitable farm business. Quantile regression allows such differences in the farm population to be investigated. By segmenting the sample into various quantiles of farm performance, greater insights are generated about the impact of the incidence of drought on the different dimensions of farm performance. In addition, compared to traditional linear regression models, quantile regression is more robust to non-normal errors and outliers and it provides a richer characterisation of the data, allowing reporting of the impact of a covariate on the entire distribution of the variable of interest, not merely its conditional mean. Furthermore, quantile regression is invariant to monotonic transformations, such as log(·), so the quantiles of h(y), a monotone transform of y, are h(Qq (y)), and the inverse transformation may be used to translate the results back to y.

This study used a linear quantile mixed model (see Geraci 2014; Geraci and Bottai 2014) to assess how the various quantiles of each of the five indicators of farm business performance (OP, RP, ROC, BE and DI) were affected by a range of independent explanatory variables such as wheat yield (ywheat), percentage of the farm area planted to crop (pcCropArea), the incidence of drought in each production year (dummy variables), the frequency of drought across the decade (N1–N3), operating expenses per hectare of the farm (OPEXha) and a time trend (Trend). The sample population was divided into quantiles (10, 25, 50, 75 and 90th percentiles) for each metric of farm performance. Note, as no farm experienced drought in the years 2003, 2005 and 2008, those years were not included in the list of drought year dummy variables.

A long list could have been generated of variables that feasibly could affect farm performance, with drought being but one of many influences. However, as the incidence of drought is the focus of this study, a restricted list of variables that emphasises drought incidence was selected.

The model of farm business performance estimated in this study was of the following form:

$$Y_{ij} = (\beta_0 + u_j) + \sum_{k=1}^{m} (\beta_k + v_j) X_{ijk} + \sum_{l=1}^{n} \beta_l Z_{ijl} + e_{ij}, \qquad (1)$$

where Y_{ij} is the dependent variable of farm performance (i.e. OP, BE, RP, ROC and DI) in year i for farm j; X_{ijk} is one of the k explanatory variables of farm performance. The explanators included variables such as wheat yield (ywheat), per cent of farm area in crop (pcCropArea) and operating cost per hectare (OPEXha). Z_{ij} are the variables describing the incidence of drought. Drought effects were measured as drought incidence in particular years (e.g. dummy variables for drought years y_i where i = 2002, 2004, 2006, 2007, 2010 and 2011), or the number of drought years over the decade (N1–N5), and number of consecutive drought years (N.nCSDY). β_0 is the weighted average of farm performance variable, β_k and β_l are, respectively, the fixed effects of the explanatory variable and the drought indicators; u_j and v_j are the respective cluster-specific random effects. The latter two random-effect variables captured the variations of individual farm characteristics and farm management skill, and their parameter estimates are summarised in the random-effect parameters' sections in the tables of results. Note that almost all the raw measures of farm performance were adjusted by consumer price index (CPI) movements to ensure their expression in constant 2002 dollar terms. Also note that the structure of the model will likely cause drought incidence and wheat yields to be found as key explanators of farm performance as both are highly correlated. In production years impacted by drought, wheat yields in those same years will be low whilst the converse is likely in the absence of drought.

We estimated the two variants of Equation (1) using a Lqmm package in STATA (see Bottai *et al*. 2015). In the Lqmm package, the estimation of the fixed regression coefficients and the random effects' covariance matrix is based on a combination of Gaussian quadrature approximations and nonsmooth optimisation algorithms, whilst the inference of the estimation is obtained by a block bootstrapping method. For bootstrapping, we experimented with different sizes of samples, finally settling on 250 samples which allowed the five models to solve in around 18 hours.

Note that the usual problem of endogeneity, where drought reduces supply that then lifts commodity prices and boosts income, was not evident. Farms in the study region are mostly crop-dominant with around 90 per cent of all grain production in the region being sold on export markets that are not greatly responsive to production changes in the study region. Similarly, most wool, live sheep and sheepmeat sales are to export markets.

As shown in Figure 1, annual rainfall diminishes as you move inland and accordingly different types of rain-fed farming systems and sizes of farms have evolved over the decades of farming in the study region. Farms in low rainfall zones tend to be large, wheat dominant farms, whereas farms in high rainfall zones are smaller in area and are more likely to run sheep complemented with canola and cereals, including barley, wheat and oats. The sample population of 240 farms was spread across the study region with most farms being located in the medium and low rainfall zones (Table 2).

The overall likelihood of drought was similar across all rainfall zones, with 2 years of drought being similarly most common across all rainfall zones (see Table 2). In addition, 3 years of drought were less frequent than 1 year of drought and especially less frequent than 2 years of drought. The exception to the former was in the high rainfall zone where, in the study period, the likelihood of 3 years of drought was slightly higher than a single year of drought.

The greater incidence of drought in the high rainfall zone is likely to be due to two influences. Firstly, the drying trend in the south-west of WA is particularly evident in higher rainfall parts during the study period (BOM 2016b). This trend increases the likelihood of farms in the higher rainfall region having GSR that lies within the decile one range of nearby rainfall station records over the preceding 25 years. Secondly, as rainfall isohyets are spatially tighter in the higher rainfall region, when farm rainfall records are compared to those of a weather station within 25 km of the farm, there is the possibility of farms being located inland away from rainfall stations and thereby displaying less rainfall relative to that recorded at the weather station.

3. Results and discussion

Considering the data set as a whole, and not partitioning the data according to the frequency of drought or rainfall zone, all five indicators of farm business performance were significantly correlated (Table 3). The DI ratio was negatively correlated with each of the other four indicators, and farm BE was negatively correlated with the ROC. The implication is that farm businesses with higher (lower) equity tend to generate lower (higher) rates of return to capital. This could be due to better performing businesses, that is those with higher ROCs, using debt financing to expand their businesses

Table 2 Spatial characteristics of the farm sample and their frequency of drought from 2002 to 2011

	Rainfall zone†		
	High	Medium	Low
No of farms	31	142	67
Proportion of entire sample	0.129	0.592	0.279
Mean growing season rainfall (GSR) over decade (mm)	322	229	178
Median GSR over decade (mm)	311	228	178
Probability of experiencing a drought during 2002–2011	1	0.908	0.904
Probability of:			
One drought	0.194	0.303	0.313
Two droughts	0.516	0.486	0.507
Three droughts	0.258	0.113	0.119

†High rainfall is where average annual rainfall is 450–750 mm. Medium rainfall is where average annual rainfall is 325–450 mm. Low rainfall is where average annual rainfall is <325 mm.

Table 3 Correlation matrix of the five indicators of farm performance

	Debt-to-income (DI)	Operating profit (OP)	Retained profit (RP)	Business equity (BE)	Return on capital (ROC)
DI	1				
OP	−0.3337*	1			
RP	−0.3312*	0.8062*	1		
BE	−0.0833*	0.0524†	0.0491†	1	
ROC	−0.273*	0.6621*	0.6567*	−0.1419†	1

*$P < 0.001$.
†$P < 0.05$.

during the decade and thereby lowering their BE. It could also be due to businesses with high BEs engaging in income-satisficing farm management rather than striving for high rates of return in order to pay off debt.

Unlike Lawes and Kingwell (2012) who found no significant correlation between BE and OP, this study found a significant positive correlation between these variables. The reasons for the different finding is that Lawes and Kingwell's data set was only for 6 years and only considered a group of farms in the north-east of the study region as shown in Figure 1, whereas the current study is over a decade, includes a larger number of farms and is a more spatially diversified data set. The current study's results indicate that higher levels of OP and RP are associated with higher levels of BE. BE changes gradually as farmers incrementally pay off loans, mostly taken out to purchase additional farmland and major items of equipment. Higher OP and RP indicate a greater capacity to service debt and thereby increase BE in the longer term. However, when adverse climate or poor commodity prices limit the income generated by the farm, then the farm business may be unable to meet its debt repayment obligations. The response of many banks and creditors is usually to extend a line of credit (e.g. Marshall 2014; ANZ 2015), thereby increasing farm indebtedness (and thereby lessening BE), in the hope that subsequent more favourable production years will facilitate repayment of this debt.

As shown in Table 3, a significant negative correlation exists between BE and the DI ratio, indicating that an increase in DI is linked to a lowering of BE. Also the significant negative relationship between DI and OP indicates that low OP is associated with a high DI. In simple terms, farms that over the decade generated low OPs tended to also display high DI ratios.

The following subsections discuss the quantile regression results for explanators of each measure of farm performance. To economise on space and because of the similarity of results for OP and RP, only results for OP are shown in the next subsection, with results for RP listed in Appendix 2.

3.1 Operating profit per hectare

Splitting the distribution of OP into quantiles (10, 25, 50, 75, 90) and examining which explanators of OP exhibit statistical significance (Table 4a)

Table 4 (a,b) Quantile regression results for drought incidence and other explanators of operating profit per hectare (OP $/ha)

(a)

OP2	Q10	Q25	Q50	Q75	Q90
ywheat	38.389*** (2.531)	40.569*** (2.643)	43.343*** (3.229)	44.336*** (3.678)	51.051*** (5.311)
pcCropArea	−0.230 (0.102)	0.105 (0.081)	0.343*** (0.095)	0.636*** (0.126)	0.760*** (0.221)
Trend	−1.040** (0.480)	−0.126 (0.458)	0.745* (0.345)	0.871* (0.503)	0.607 (0.845)
y2002	−13.306** (6.750)	−10.009* (5.488)	−6.679 (6.631)	0.675 (8.216)	12.577 (17.275)
y2004	−7.173 (7.624)	−28.211*** (7.309)	−46.456*** (10.707)	−73.915*** (16.753)	−99.108*** (15.595)
y2006	−22.494*** (8.009)	−17.745*** (4.031)	−24.239*** (4.340)	−36.008*** (4.677)	−34.378*** (8.655)
y2007	11.191 (7.559)	11.410 (6.984)	3.049 (5.809)	−10.352* (6.032)	−1.114* (11.779)
y2010	11.327** (5.089)	2.036 (3.729)	−10.553*** (4.394)	−22.965*** (5.695)	−28.745*** (6.624)
y2011	47.754*** (10.872)	7.816 (7.329)	−26.549** (12.641)	−45.966*** (13.250)	−63.440*** (14.055)
_cons	−35.034*** (8.603)	−37.247*** (7.442)	−23.685** (10.369)	−7.014 (14.035)	6.183 (15.792)
Random-effects parameters					
_cons	254.033 (11.747)	120.125 (8.622)	342.661 (7.155)	929.153 (5.785)	2992.554 (11.536)
ywheat	103.654 (4.219)	28.696 (2.855)	0.000 (1.815)	39.313 (4.184)	470.788 (14.984)
No obs.	2,400	2,400	2,400	2,400	2,400

(b)

OP1	Q10	Q25	Q50	Q75	Q90
ywheat	37.078*** (2.761)	39.043*** (2.459)	41.945*** (3.310)	41.424*** (4.344)	51.434*** (5.555)
pcCropArea	−0.166 (0.119)	0.134 (0.090)	0.382*** (0.110)	0.713*** (0.148)	0.709*** (0.231)
Trend	−0.754 (0.519)	0.213 (0.408)	0.710** (0.360)	0.506 (0.461)	0.222 (0.838)
N1	−14.830*** (5.529)	−13.248*** (3.866)	−15.682*** (4.203)	−22.440*** (6.225)	−27.405*** (8.390)
N2	−4.499 (6.101)	−9.643** (4.425)	−17.446*** (4.695)	−30.448*** (6.037)	−36.985*** (7.222)
N3	−34.538* (19.269)	−14.456 (16.130)	−29.409** (12.387)	−30.663 (20.812)	−44.557** (19.295)
N2nCSDY	25.761 (16.523)	25.959** (10.321)	23.017*** (6.612)	12.518 (9.702)	30.689* (16.986)
N3nCSDY	49.406** (23.986)	21.662 (25.152)	36.706* (20.123)	14.015 (22.465)	14.956 (22.619)
_cons	−37.615*** (9.247)	−36.076*** (7.232)	−23.796** (9.884)	−6.062 (15.265)	28.912 (18.069)
Random-effects parameters					
cons	249.077 (12.547)	123.511 (10.113)	297.208 (7.944)	911.051 (6.992)	2188.773 (14.969)
ywheat	107.885 (3.083)	28.059 (3.113)	1.081 (2.084)	41.146 (5.153)	0.000 (18.086)
No obs.	2,400	2,400	2,400	2,400	2,400

Note ***$P < 0.001$; **$P < 0.05$; *$P < 0.1$.

reveals that across all quantiles wheat yield positively affects OP whilst drought in 2004, 2006, 2010 and 2011 negatively affected OP (for almost all quantiles). The drought in 2004 is shown to have a particularly large negative impact on OP across all quantiles. By contrast, in some other years, although drought may have depressed crop yields, some of those years (e.g. 2007 and 2010) coincided with spikes in international grain prices and so the financial impacts of drought were mollified for these mostly crop-dominant businesses.

The magnitudes of the significant negative coefficients for drought years are greater, the higher the quantile. This arises from the observation that farms with high levels of OP tend to be more crop-dominant businesses, and these businesses are accordingly more exposed financially to the incidence of drought, as drought can greatly lessen their main source of revenue, crop proceeds. More generally, when examining the structure of crop-dominant farming systems in Australia, Kingwell (2002) observed that 'a switch into more cropping means a more capital-intensive business with greater demands for working capital. With such a business structure a few poor seasons, especially if coupled with poor prices, can rapidly cripple a farm business' (p. 10). For farms in the higher quantiles of OP, the years of 2004, 2006, 2007, 2010 and 2011 in which drought in some regions was observed are shown to be significantly injurious to these farms' OP, as indicated by the magnitude of the respective drought year coefficient and *t*-test values. For example, the widespread drought of 2010 was associated with an average $23/ha decline in OP for farms in the upper quartile of OP. This severe drought in which wheat yield averaged only 1.28 t/ha across the 240 farms, however, was associated with a spike in international grain prices that boosted farm grain revenues and lessened losses. By contrast, in the drought of 2004, there was no off-setting lift in grain prices and so reductions in OP were large.

The positive impact on OP of wheat yield is a similar finding to that of Lawes and Kingwell (2012) who examined farm performance in the north-east of the study region over 6 years, 2004–2009. The importance of wheat yield as a key determinant of OP is not surprising given the crop dominance of most farm businesses in the sample population and wheat's pre-eminence as farmers' main crop choice. Because wheat revenue is the major source of income for many farm businesses and wheat plantings are often the main land use, changes in wheat revenue, driven by yield change, translate into changes in OP.

The percentage of farm area devoted to crops also has a significant positive effect on OP for farms in and above the 50th percentile grouping of farms by OP. This finding reveals that, over the decade, the greater profitability of cropping relative to wool and sheep meat production resulted in farms with crop-dominant farming systems generating mostly higher OP.

The time trend (Trend) affected the various quantiles differently. Farms in the 10th percentile grouping recorded a significant negative coefficient, whereas farms in the 50th and 75th percentile groupings recorded a significant positive coefficient. The implication is that across the 10 years, greater divergence in OP occurred between farms. Reasons for the divergence are noted in Kingwell *et al.* (2013). Farms in the 50th and 75th percentile groupings tend to be larger, more crop-dominant, with higher initial BE and lower DI. They are managed such that their operating expenses are a smaller percentage of gross farm income, and their ROC is greater. These advantages are cumulative, resulting in a widening of the absolute difference in OP between farms in the upper and lowest percentile groups.

The impact of the incidence of drought on OP is further reported in Table 4b. Results show that farms in all quantiles of OP are significantly negatively impacted by a single year of drought and all quantiles, bar the 10th percentile group, also are significantly negatively impacted by two separate years of drought across the decade. Further, a majority of quantiles are significantly disadvantaged by three separate years of drought.

However, an unexpected finding is that consecutive years of drought have a significant positive effect on the OP of farms in a majority of the quantiles. This perhaps counter-intuitive result is worth contrasting with results in Table 4a that show that when drought does impact on a business, the OP of that business in that particular year (and quantile group) is generally significantly lowered. Hence, although drought in a particular year does create financial disadvantage, it appears that there are actually some longer term beneficial adjustments that are triggered by consecutive drought (i.e. variables N2nCSDY and N3nCSDY). Similar findings listed in Appendix 2 apply to RP. Note that the significant results for the explanatory variable N3nCSDY involve 3 years of drought, two of which are consecutive years of drought. No farm in the sample population recorded three consecutive years of drought. Hence, the findings for N3nCSDY, like those for N2nCSDY, include the impacts of two consecutive years of drought.

The data set was examined to test whether the impact of consecutive drought was an artefact, merely reflecting occurrences unique to a particular subregion. However, such was not the case, as consecutive droughts were experienced by different farms across most regions. So, we conclude that those farms that experienced a consecutive drought have performed better than other farms in the same quantile grouping of OP (or RP). To gain insight about the mechanism for the superior performance, we examined how consecutive drought changed the characteristics of farms. Farms affected by consecutive drought were often forced out of sheep production or at least subsequently focused less on sheep production and more on cropping. Due to the greater relative profitability of cropping during the study period, these businesses subsequently increased their OPs. Furthermore, by reducing sheep numbers during persistent drought, these farms increased income through sheep sales and reduced the cost of supplementary feed. The end result was that farms in each quantile of OP (or RP) that experienced consecutive drought had their OP (or RP) boosted relative to other farms, in the same quantile. These other farms experienced either one drought, separate droughts or no drought at all. The consecutive years of drought encouraged and in some cases forced farmers to make structural adjustments to the enterprise mix of their farm business (i.e. greater cropping) from which those farm businesses often benefited over the decade.

An important caveat applies to these findings. Farms in this study are mixed enterprise farms and have had an opportunity to beneficially adjust their enterprise mix in response to drought frequency. Yet in some other parts of Australia, farm businesses are not mixed enterprises and have no similar opportunity to respond to drought. Hence, caution is required when attempting to extrapolate this study's findings to other regions or other periods.

3.2 Business equity

How the incidence of drought and other factors affect farm BE is reported in Table 5a,b. A main consistent significant result across all quantiles was that a time trend is positively associated with BE. Across the decade, farm BE increased, mostly due to land price inflation and increases in average farm size, funded by borrowings partly paid off during the decade. Lowering of interest rates over the decade also facilitated debt repayments for many farms.

Drought only had a significant impact in 2002, and the impact of the 2002 drought was significantly positive. However, this result needs careful explanation. As shown in the Appendix S1, the farms most likely to have experienced drought in 2002 were farms mostly in the lower rainfall regions of the study region. Yet these farms were often the farms that increased most in size over the decade, thereby boosting their BE. Hence, the dummy variable for the 2002 drought effectively tags those farms most likely to have greatly increased their BE over the decade. Hence, it is not that the drought, *per se*, increased their BE but rather that the farms that most increased their BE over the decade happened to be located in a region that experienced drought in 2002.

3.3 Return on capital

The effect on ROC of the incidence of drought and other factors is reported in Table 6a,b. A consistent significant result across all quantiles was that wheat yield and cropping intensity positively affected ROC whilst operating costs per hectare and the time trend (except for the 90th percentile group) negatively affected ROC. These findings reflect the earlier observation that, across the decade, cropping tended to be relatively more profitable than wool or sheep meat production, and therefore, crop-dominant farm businesses and businesses that achieved high wheat yields or lower operating costs per hectare often achieved higher rates of return to capital, in spite of the higher capital requirement associated with crop production.

For drought, its impact on ROC was negative and often significant. However, the exception was the situation where consecutive drought occurred. Although the sign of the coefficients was positive (i.e. consecutive drought tended to improve ROC over the decade), its effect was not significant.

Table 5 (a,b) Quantile regression results for drought incidence and other explanators of business equity (BE $)

(a)

BE2	Q10	Q25	Q50	Q75	Q90
Trend	0.099*** (0.010)	0.115*** (0.010)	0.137*** (0.014)	0.159*** (0.018)	0.142*** (0.042)
y2002	0.280* (0.161)	0.334*** (0.089)	0.531*** (0.127)	0.640*** (0.165)	0.570** (0.224)
y2004	−0.033 (0.141)	−0.091 (0.166)	−0.288 (0.295)	−0.781 (0.491)	0.126 (0.512)
y2006	0.108* (0.060)	0.044 (0.067)	0.181 (0.116)	−0.023 (0.127)	0.003 (0.162)
y2007	0.030 (0.188)	−0.271 (0.192)	−0.082 (0.230)	−0.435* (0.233)	−0.544* (0.321)
y2010	−0.096 (0.089)	−0.048 (0.081)	0.024 (0.099)	−0.010 (0.086)	−0.011 (0.170)
y2011	0.774 (0.952)	0.556 (0.888)	0.198 (0.778)	0.078 (0.490)	−1.403 (1.035)
_cons	2.452*** (0.265)	2.737*** (0.169)	3.344*** (0.385)	5.043*** (0.702)	7.243*** (1.388)
Random-effects parameters					
_cons	1.089 (0.102)	1.351 (0.122)	2.149 (0.212)	4.973 (0.380)	12.065 (1.254)
No obs.	2,400	2,400	2,400	2,400	2,400

(b)

BE1	Q10	Q25	Q50	Q75	Q90
Trend	0.132*** (0.022)	0.147*** (0.019)	0.140*** (0.020)	0.167*** (0.026)	0.118*** (0.038)
N1	0.099* (0.052)	0.109* (0.058)	0.187*** (0.071)	0.160* (0.084)	0.160 (0.129)
N2	0.097 (0.078)	0.064 (0.081)	0.091 (0.082)	−0.004 (0.081)	−0.065 (0.117)
N3	0.198 (0.200)	0.111 (0.169)	0.166 (0.234)	0.219 (0.275)	0.454 (0.363)
N2nCSDY	−0.178 (0.243)	−0.143 (0.249)	−0.073 (0.298)	−0.477 (0.313)	−0.309 (0.382)
N3nCSDY	0.885 (0.601)	−0.227 (0.569)	0.294 (1.248)	0.011 (1.169)	−0.806 (1.067)
_cons	2.674*** (0.364)	2.839*** (0.203)	3.332*** (0.457)	4.929*** (0.713)	6.531*** (1.255)
Random-effects parameters					
_cons	1.217 (0.419)	1.449 (0.144)	2.242 (0.243)	4.612 (0.376)	9.081 (1.231)
Trend	0.010 (0.294)	0.013 (0.250)	0.000 (0.135)	0.000 (0.165)	0.032 (0.197)
No obs.	2,400	2,400	2,400	2,400	2,400

Note ***$P < 0.001$; **$P < 0.05$; *$P < 0.1$.

Table 6 (a,b) Quantile regression results for drought incidence and other explanators of return on capital (ROC %)

(a)

ROC2	Q10	Q25	Q50	Q75	Q90
ywheat	4.314*** (0.421)	4.027*** (0.411)	4.994*** (0.489)	6.333*** (0.507)	8.464*** (0.928)
pcCropArea	0.028* (0.015)	0.038*** (0.014)	0.038* (0.021)	0.081*** (0.024)	0.099*** (0.031)
OPEXha	−0.024*** (0.005)	−0.020*** (0.004)	−0.012** (0.005)	−0.018*** (0.005)	−0.030*** (0.007)
Trend	−0.153*** (0.059)	−0.154*** (0.054)	−0.091* (0.052)	−0.181*** (0.058)	−0.124 (0.100)
y2002	−3.790*** (1.153)	−3.038*** (1.008)	−1.578* (0.947)	−0.101 (1.026)	2.540 (1.732)
y2004	−0.706 (0.813)	−2.409*** (0.674)	−3.763*** (0.762)	−5.063*** (1.319)	−6.121*** (1.711)
y2006	−2.435*** (0.652)	−2.239*** (0.379)	−2.924*** (0.413)	−2.796*** (0.592)	−4.013*** (0.935)
y2007	0.067 (0.944)	−0.641 (0.906)	−0.425 (0.733)	−0.168 (1.102)	−2.800 (2.320)
y2010	0.454 (0.617)	−0.032 (0.463)	−1.360** (0.534)	−1.269** (0.517)	−1.858** (0.918)
y2011	1.521 (2.598)	1.129 (1.316)	−2.563*** (0.980)	−4.197*** (1.519)	−7.692 (5.627)
_cons	−4.190*** (1.028)	−2.437*** (0.900)	−0.739 (1.240)	−0.481 (1.452)	2.341 (2.363)
Random-effects parameters					
_cons	4.538 (0.733)	2.445 (0.765)	7.794 (0.508)	20.436 (0.506)	29.311 (0.564)
ywheat	1.1 (0.587)	1.1 (0.578)	5.5 (0.428)	10.3 (0.437)	20.3 (0.468)
No obs.	2,400	2,400	2,400	2,400	2,400

(b)

ROC1	Q10	Q25	Q50	Q75	Q90
ywheat	4.218*** (0.446)	3.882*** (0.458)	4.456*** (0.541)	5.737*** (0.551)	7.627*** (0.837)
pcCropArea	0.024* (0.014)	0.047*** (0.013)	0.052*** (0.019)	0.072*** (0.023)	0.106*** (0.035)
OPEXha	−0.022*** (0.005)	−0.020*** (0.005)	−0.015*** (0.006)	−0.015*** (0.006)	−0.022*** (0.008)
Trend	−0.088 (0.058)	−0.072 (0.054)	−0.080 (0.050)	−0.171*** (0.056)	−0.226** (0.100)
N1	−2.496*** (0.620)	−2.219*** (0.400)	−2.422*** (0.409)	−2.125*** (0.538)	−2.346** (0.912)
N2	−1.042 (0.662)	−1.686*** (0.420)	−2.379*** (0.440)	−2.198*** (0.601)	−2.977*** (1.076)
N3	−3.539** (1.442)	−3.547** (1.582)	−2.666 (1.633)	−2.511* (1.465)	−2.121 (1.567)
N2nCSDY	2.676* (1.492)	1.761 (1.300)	2.413 (1.507)	1.894 (1.455)	0.311 (1.901)
N3nCSDY	5.155** (2.262)	3.449 (2.380)	1.987 (1.924)	1.994 (1.974)	0.143 (2.335)
_cons	−4.012*** (1.066)	−2.518*** (0.863)	−0.776 (1.179)	−0.079 (1.442)	1.600 (2.501)
Random-effects parameters					
_cons	0.887 (0.000)	1.064 (0.000)	0.562 (0.000)	0.439 (0.000)	0.887 (0.000)
ywheat	0.700 (0.000)	0.558 (0.000)	0.412 (0.000)	0.486 (0.000)	0.480 (0.000)
No obs.	2,400	2,400	2,400	2,400	2,400

Note ***$P < 0.001$; **$P < 0.05$; *$P < 0.1$.

Understandably these results suggest that as wheat yields and cropping intensity increase, then crop revenues are higher which helps boost ROC. Moreover, farm businesses that have much higher operating costs per hectare tend to generate lower ROC. There may be a number of practical reasons for the higher expenditures such as less fertile soils, more weedy paddocks, less reliable machinery that requires more costly servicing, smaller machinery that necessitates higher labour cost per hectare or problematic seasons in which greater expenditure on pest and disease control is required.

Regarding the incidence of drought and its impact on ROC, the unsurprising consistent result across all quartiles is that when farms experience more years of drought, then their ROC tends to be more adversely affected. Noting from Table 3 that ROC and OP are highly positively correlated, then it follows that the experience of consecutive drought that leads to an increase in OP (see Table 4a,b) also can be associated with a lift in ROC. However, as already noted, this improvement in ROC is not statistically significant. These results imply that although some farms benefit from exposure to consecutive drought insofar as drought stimulates changes in farm business management that ultimately deliver future financial reward for those businesses, those benefits are not associated with any significant lift in ROC or BE.

One concerning result for the farm industry in the study region was that across the decade, the time trend for ROC was significantly negative across all ROC quantiles, and more so for the higher quantile groups.

3.4 Debt-to-income ratio

How the incidence of drought and other factors affect the DI ratio of farm businesses is reported in Table 7a,b. Across all quantiles, the time trend, drought in some particular years (e.g. 2006, 2010) and incidences of up to 3 years of drought all significantly increased DI. By contrast, increased cropping intensity and wheat yield significantly decreased DI. Consecutive years of drought significantly increased DI in the 25th and 50th percentile quantile groups.

From Table 3, it needs to be noted that DI is significantly negatively correlated with OP, RP, BE and ROC. Conditions that lead to high levels of DI, and therefore, the likelihood of low BE, OP, RP and ROC include the cumulative impacts of several years of drought. Other contributing factors could be low wheat yields that lessen crop income and weaken the ability to repay debt. Also the time trend points to a significant increase in DI over the decade. Often farms increase their size and fund the expansion through borrowings, leading to an increase in DI. This increase in DI is also a finding consistent with the significant negative time trend for ROC mentioned in a previous subsection.

Only in the 25th and 50th percentile groups was consecutive drought significantly associated with an increase in DI. These are different results to

Table 7 (a,b) Quantile regression results for drought incidence and other explanators of the debt-to-income ratio (DI)

(a)

DI2	Q10	Q25	Q50	Q75	Q90
ywheat	−0.092*** (0.025)	−0.123*** (0.027)	−0.142*** (0.031)	−0.267*** (0.032)	−0.335*** (0.056)
pcCropArea	−0.002 (0.002)	−0.004** (0.002)	−0.006*** (0.002)	−0.005*** (0.002)	−0.007* (0.004)
Trend	0.038*** (0.007)	0.044*** (0.006)	0.059*** (0.005)	0.064*** (0.006)	0.070*** (0.009)
y2002	−0.071 (0.089)	0.058 (0.083)	0.264** (0.134)	0.408** (0.164)	1.373*** (0.481)
y2004	0.226 (0.154)	0.162 (0.193)	0.391** (0.179)	0.299 (0.209)	0.052 (0.213)
y2006	0.112** (0.056)	0.166*** (0.060)	0.284*** (0.072)	0.348** (0.162)	1.241** (0.561)
y2007	0.290*** (0.098)	0.296 (0.195)	0.740*** (0.242)	0.689** (0.319)	0.845* (0.511)
y2010	0.292*** (0.066)	0.383*** (0.069)	0.568*** (0.102)	0.719*** (0.137)	0.977*** (0.176)
y2011	0.298 (0.290)	0.292* (0.150)	−0.252 (0.177)	−0.429 (0.350)	−0.585 (0.414)
_cons	0.793*** (0.160)	1.188*** (0.165)	1.636*** (0.156)	2.188*** (0.169)	2.798*** (0.341)
Random-effects parameters					
_cons	0.121 (0.158)	0.122 (0.049)	0.199* (0.040)	0.424 (0.044)	0.770 (0.103)
ywheat	0.002 (1.576)	5.202 (1.631)	9.025* (1.257)	0.000 (0.084)	0.000 (0.160)
No obs.	2,400	2,400	2,400	2,400	2,400

(b)

DI1	Q10	Q25	Q50	Q75	Q90
ywheat	−0.079*** (0.023)	−0.113*** (0.028)	−0.165*** (0.031)	−0.297*** (0.036)	−0.384*** (0.059)
pcCropArea	−0.002 (0.002)	−0.004** (0.002)	−0.005*** (0.002)	−0.006*** (0.002)	−0.011** (0.004)
Trend	0.041*** (0.008)	0.048*** (0.006)	0.057*** (0.006)	0.064*** (0.007)	0.070*** (0.010)
N1	0.115** (0.047)	0.153*** (0.047)	0.281*** (0.071)	0.395*** (0.102)	1.113*** (0.331)
N2	0.205*** (0.068)	0.289*** (0.059)	0.325*** (0.071)	0.495*** (0.129)	0.627*** (0.219)
N3	0.434* (0.241)	0.549** (0.242)	0.769*** (0.296)	1.312*** (0.278)	1.208*** (0.256)
N2nCSDY	0.337 (0.284)	0.607* (0.324)	0.577*** (0.189)	0.183 (0.412)	−0.234 (0.356)
N3nCSDY	−0.462 (0.359)	−0.385 (0.373)	−0.534 (0.530)	−0.687 (0.661)	−0.926 (0.564)
_cons	0.710*** (0.183)	1.201*** (0.171)	1.608*** (0.167)	2.224*** (0.180)	3.172*** (0.374)
Random-effects parameters					
cons	0.099 (0.147)	0.119 (0.054)	0.242 (0.050)	0.422 (0.046)	1.0 (0.113)
ywheat	1.069 (1.216)	7.121 (1.438)	0.007 (0.757)	0.016 (0.097)	0.1 (0.171)
No obs.	2,400	2,400	2,400	2,400	2,400

Note $^{***}P < 0.001$; $^{**}P < 0.05$; $^{*}P < 0.1$.

the significant positive impact of consecutive drought on OP (and RP) reported earlier. It suggests that some farms subject to consecutive drought, relative to other farms in the same DI quantile, are not immune from worsening their DI, mostly due to the effects of loss of income and also through requiring some additional borrowings. Nonetheless, it is possible, over the longer term, to lift OP and RP. For example, some families lift their RP by restricting personal expenditure or reducing their machinery replacement costs. These behaviours have been reported by Planfarm (2014) in their survey of farmers in the eastern grain belt of Western Australia.

Planfarm (2014) analysed farmers' records over 6 years in that region, and they interviewed many farmers. The region was investigated because it was acknowledged to have experienced frequent dry or drought years, and the research funder was keen to know what business strategies were proving to be successful. When asked about the reasons for their success, many farmers pointed to their preparedness to work hard, their conservatism, control of costs and getting the big decisions right whilst also paying attention to detail. Their cost savings were reduced fertiliser inputs and lower machinery replacement costs of farm machinery. The top-ranked businesses considered that avoiding losses in poor years was as equally important as making the most of the better seasons. By contrast poor performing farm businesses, in spite of experiencing similar rainfall or paucity of rainfall, typically generated lower grain yields, operated smaller, less crop-dominant farms, had lower equity in percentage terms and were less able to capitalise on favourable production years. The analysis by Planfarm and this current analysis over a longer period and inclusive of more farms in different subregions indicates that farms affected by drought, even the same drought, can display or adopt different management behaviours that lead to different financial outcomes.

The preceding analyses reveal that drought is financially deleterious for farm businesses in the study region over the decade examined. Nonetheless, most farm businesses, in spite of their experience of drought, were able to grow their wealth over that decade. As pointed out by Planfarm (2014), farm management is crucial to such business success. In a separate study, Xayavong *et al*. (2015) also find that training undertaken by the farm family and their use of innovations, particularly key cropping innovations, have significant beneficial impacts on farm performance. A policy implication is that support for and encouragement of skill in farm management may be a better use of public funds than provision of farm input subsidies during drought. This is not to say that enhancing farmers' management skills should be fully funded by taxpayers, nor be applicable only during drought.

4. Conclusion

This study analyses the financial performance of 240 farms in a rain-fed agricultural region of Australia from 2002 to 2011. The farms were located in different environments and differed in size and enterprise composition. The decade included a few years of widespread drought, as well as years with subregional droughts or no drought. Key business indicators were examined to judge how these various businesses fared, given their different incidences of drought and different characteristics.

A key and expected finding was that exposure to drought lessened farm performance. Some droughts created larger adverse impacts than others. The more separate droughts over time that farms experienced, the worse was their financial performance relative to farms within the same quantile of farm performance. Although a drought may have a strict bio-physical definition, the financial ramifications of drought can be different in different years and different businesses can be differently affected.

Nonetheless, in spite of the incidence of drought, almost all the farm businesses were wealthier by the end of the decade of observations. Hence, in spite of drought creating financial pain, farms were able to manage their businesses such that their wealth (i.e. farm business net equity) improved. Farms achieved this by increasing their farm size and altering their farming systems towards greater cropping that often was a source of additional profit.

Another consistent, less favourable finding was that the time trend for rate of return to capital was significantly negative, and significantly positive for the DI ratio, inferring a worsening of financial performance. However, in spite of these trends, over the decade, land price appreciation occurred that allowed farm businesses to increase their net equity. The increase in the DI ratio was mostly due to greater borrowings used to fund farm expansion, to purchase additional cropping machinery and to cope with the impacts of drought.

An unexpected finding was that consecutive years of drought had a significant positive effect on the OP per hectare and RP per hectare of farms in a majority of their respective quantiles. The explanation for the better relative performance was that consecutive drought more or less forced farmers out of sheep production into additional crop production which was generally a more profitable strategy during the study period.

Overall, we conclude that the impacts of drought on farm business performance are highly nuanced. An exposure to two consecutive years of drought can generate some longer term structural change with associated financial benefits, but frequent exposure to separate droughts is unambiguously deleterious. Some measures of financial performance are adversely affected by drought and some are not. Furthermore, the financial impacts of a drought on a farm can be considerably different from the biophysical impacts. By reporting and better understanding the main metrics of farm performance, a more complete view of the financial impacts of drought on farm businesses can be generated. The important role of farm management in responding to drought indicates that support for and encouragement of skill in farm management may be a better use of public funds than provision of farm input subsidies during drought.

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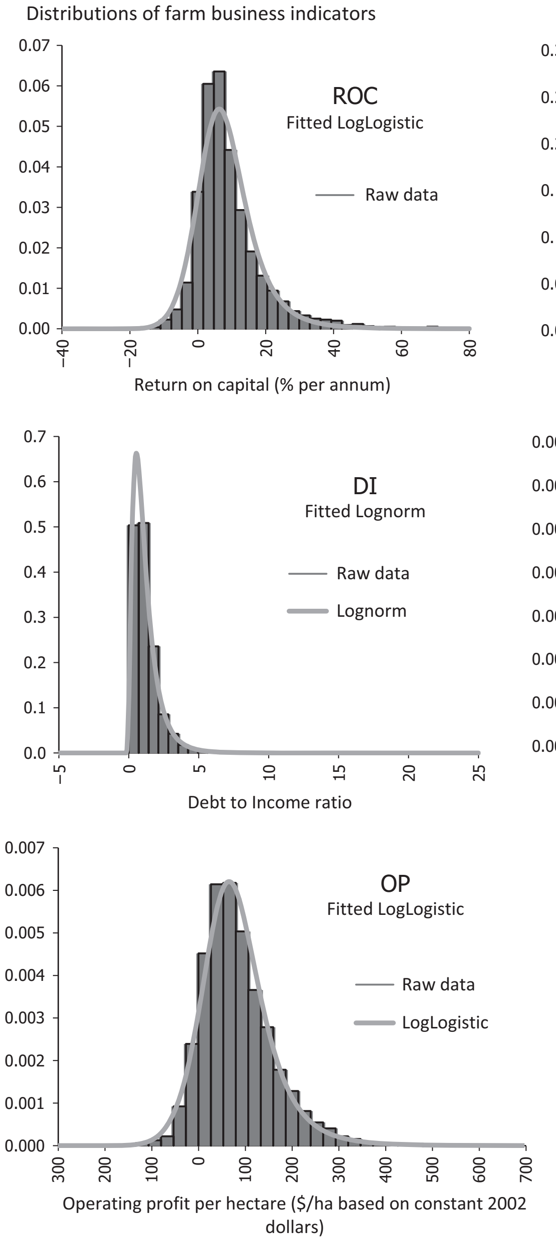
Appendix
Distributions of farm business indicators



Quantile regression results for explanators of retained profit per hectare (RP $/ha)

	Q10	Q25	Q50	Q75	Q90
RP2					
ywheat	36.260*** (3.781)	33.895*** (2.667)	36.154*** (2.838)	41.970*** (3.290)	45.589*** (5.579)
pcCropArea	−0.379*** (0.155)	−0.161 (0.127)	0.135 (0.115)	0.351** (0.150)	0.325 (0.271)
Trend	−0.860 (0.734)	−0.184 (0.563)	0.405 (0.469)	0.593 (0.509)	1.606** (0.943)
y2002	−21.928** (10.032)	−21.053*** (6.368)	−18.734** (7.590)	−8.228 (9.095)	5.598 (17.697)
y2004	−8.073 (12.449)	−32.865*** (9.594)	−60.336*** (10.136)	−76.262*** (11.069)	−105.851*** (17.750)
y2006	−27.894** (8.345)	−25.449*** (5.267)	−32.751*** (4.351)	−42.277*** (4.651)	−57.604*** (8.548)
y2007	15.528* (10.284)	13.700 (7.924)	3.113 (6.208)	−2.625 (6.151)	−27.737 (10.462)
y2010	3.434 (7.432)	−7.255 (5.043)	−19.134*** (5.086)	−21.499*** (7.450)	−29.405*** (8.946)
y2011	39.105* (19.389)	30.515** (12.126)	14.590 (17.409)	−6.877 (22.792)	−65.578** (27.987)
_cons	−88.995*** (11.572)	−68.936*** (9.959)	−54.027*** (10.146)	−35.611*** (11.561)	10.846 (16.585)
Random-effects parameters					
_cons	0.000 (18.306)	382.809 (11.801)	461.220 (5.746)	1168.394 (12.479)	2255.811 (21.159)
ywheat	281.959 (1.849)	169.869 (1.298)	89.527 (2.355)	114.136 (6.242)	348.022 (13.310)
No obs.	2,400	2,400	2,400	2,400	2,400
RP1					
ywheat	36.881*** (3.784)	32.157*** (3.070)	34.748*** (3.207)	39.473*** (3.488)	50.460*** (6.383)
pcCropArea	−0.377** (0.158)	−0.099 (0.144)	0.184 (0.143)	0.417** (0.176)	0.472* (0.281)
Trend	0.016 (0.769)	0.391 (0.505)	0.565 (0.449)	0.607 (0.595)	1.496 (1.065)
N1	−16.268** (6.561)	−22.016*** (4.766)	−26.841*** (4.328)	−28.443*** (5.502)	−21.416** (10.481)
N2	−9.731 (7.202)	−19.441*** (5.072)	−26.541*** (4.797)	−33.978*** (6.451)	−30.560*** (11.433)
N3	−19.746 (16.494)	−30.494** (12.090)	−39.521*** (12.630)	−53.601*** (15.620)	−34.248 (21.427)
N2nCSDY	19.121 (18.704)	27.433* (15.655)	28.592*** (8.890)	22.867** (9.527)	−3.895 (16.468)
N3nCSDY	56.828*** (21.895)	49.839*** (19.196)	48.959*** (15.751)	51.674*** (19.204)	16.858 (23.069)
_cons	−90.353*** (11.647)	−69.447*** (11.179)	−54.713*** (11.499)	−34.486*** (12.432)	−9.124 (17.410)
Random-effects parameters					
_cons	955.993 (17.673)	0.000 (14.356)	438.076 (5.945)	1124.068 (14.319)	2489.741 (25.106)
ywheat	366.718 (2.143)	167.963 (1.449)	95.932 (2.463)	105.549 (5.756)	287.481 (14.586)
No obs.	2,400	2,400	2,400	2,400	2,400

Note ***$P < 0.001$; **$P < 0.05$; *$P < 0.1$.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Spatial patterns of wheat yields in the study region: 2002–2011.