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Profitability, Productivity and the Efficiency of Grain Production with Climate Impact: A Case Study of Western Australia

Crawford School Research Paper No. 12-08

July 2012

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Abstract

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Keywords: productivity, profitability, Western Australia, efficiency, climate impacts, grain production.

JEL Classification:

Suggested Citation:

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Acknowledgments

Special thanks to David Feldman, Mark Sweetingham, Rob Delane, Nazrul Islam, Ross Kingwell, and workshop participants at DAFWA, Phil Kokic (CSIRO), Terry Sheales, Arif Syed, Bruce Bowen, Jim Walcott, Margaret Nicholson, Sally Thorpe, Lindsay Hogan (ABARES) for their discussions and valuable comments.

Introduction

The grains industry is Australia's most important agricultural industry, accounting for an annual gross value of production of about $6.8 billion in 2009-10 (Australian Bureau of Statistics 2011). The grains industry is also Western Australia's (WA) largest agricultural

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industry, with an annual gross value of production of around $2.4 billion in 2009-10. In Australia and Western Australia wheat is also the most important grain commodity. In 2009-10, WA produced 8.1 million tones of wheat, accounting for 37 per cent of total national wheat production (ABS 2011). As such, returns to farmers are strongly connected to world grain commodity and exchange markets. Volatilities in these markets have been compounded in recent years by extreme climate variability and a strong Australian dollar, which has served to weaken Australian exports.

This paper analyses productivity, profitability and efficiency by climate zone for the WA grains industry over the past 30 years. Following the studies by the Department of Agriculture and Food of Western Australia (2011) and Che, et.al (2012), this paper uses the Törnqvist formula index to measure and analyse movements in inputs, outputs, climate conditions, Total Factor Productivity (TFP), and TFP adjusted by climate impact for WA grains farms in six climate zones over the period 1980 to 2009-10.

Estimates provide a stochastic production frontier and technical efficiency model for six rainfall zones (including the High Rainfall North and South zones; the Medium Rainfall North and South zones and Low Rainfall North and South zones), which determine the relative importance of land, labour, capital, materials, fuel and energy inputs into wheat production and the effects of climate zone on farm efficiency; a construction of overall farm profiles in Medium Rainfall zones based on the efficiency rankings of grain farms is also generated.

Measures of the impact of climate variations are also provided, delineating productivity growth and grain price on output, and the income and profit of grain farms. The analysis is carried out for six benchmark rainfall zones for the period of 1980 to 2009-10. Data sources are mainly from broadacre ABARES surveys, the ABARES economic database, the Department of Agriculture and Food of Western Australia (DAFWA), the Australian Bureau of Statistics and the Bureau of Meteorology. All values are in 2009/10 prices. The rainfall level is calibrated to each grain farm, based on the nearest rainfall station.

Background on the WA grains industry is discussed in Part 1 of the paper. Part 2 analyses the movements of output and input factors of grain farms (land, labour, capital, material and fertilizer, fuel and energy costs). Part 3 analyses the profitability, productivity and efficiency

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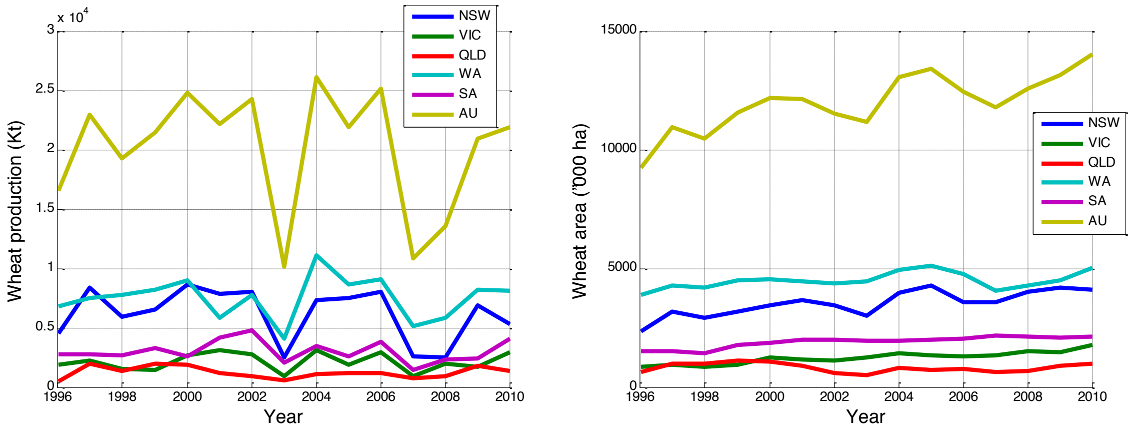
of WA grain farms. Part 4 then analyses the impacts of climate variability, productivity growth and grain price fluctuations on grain farm economic performance.

1 Background on the Western Australian grains industry

The Australian grains industry makes a significant contribution to the national economy and the agriculture sector.[1] Grain accounts for approximately 13 per cent of the value of farm production overall, with an average gross farm gate value of around $5.2 billion a year (ABS 2010). Australia's cereal producing regions are spread across the inland, eastern, south-eastern and south-western parts of the continent. The principal winter crops are wheat, barley, oats, canola and lupins, while the main summer crop is grain sorghum. Grains are often grown in conjunction with livestock. The grains industry is Australia's most important agricultural industry, accounting for an annual gross value of production of about $9 billion (ABS 2011). However, the gross value of production decreased from $9 billion in 2008-09 to $6.8 billion in 2009-10, mainly driven by decreased prices and production. In particular, there was a $1.3 billion (or 21 per cent) decrease in the value of wheat. Barley values decreased 27 per cent to $1.4 billion, and canola values fell by 17 per cent to $840 million (ABS 2011). In Australia and Western Australia wheat is the dominant grain commodity in terms of both quantity and value. The value of wheat production and its propagation area throughout Australia and by state from 1995-96 to 2009-10 are presented in Figure 1.

Figure 1: Australian wheat production and area by state, 1995/96 to 2009/10



A. Wheat production **B. Wheat area**

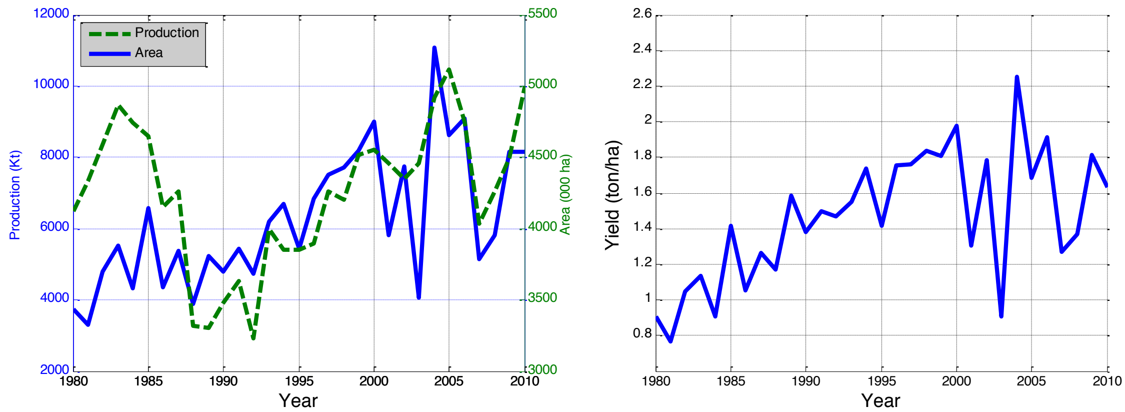
Source: Australian Bureau of Statistics, 2011.

[1] Grain includes wheat, barley, buckwheat, oats, triticale, maize, millet and panicum, sorghum and cereal rye, oilseeds and grain legumes.

The WA wheat industry has grown strongly over the past decade and now accounts for almost 40 per cent of the national harvest by volume (ABS 2011). Production has fluctuated significantly over the past decade under the impact of drought (see Figure 2, Panel A). In 2003 and 2007 wheat production fell by 35-40 per cent in comparison to more favourable years such as 2004 and 2006. While the area planted to wheat over this time period did not change substantially, average yields were greatly affected (Figure 2, Panel B).

In the past 30 years WA's grains production has increased from 5 million tonnes to 12 million tonnes, grain-growing area has increased from 5 million hectares to 7.5 million hectares, and grain yield has increased from 1.05 to 1.85 tonnes per hectare. WA exports 80 per cent of its grain. It accounts for almost 60 per cent of Australia's wheat exports by volume, 80 per cent of canola exports, 42 per cent of barley exports and 96 per cent of the lupin exports. Dominant export destinations include Japan, Indonesia, Saudi Arabia and South Korea (DAFWA, 2009).

Figure 2: Production, area and yield of the WA wheat industry, 1979/80 to 2009/10



A. Production and area **B. Yield**

Source: Australian Bureau of Statistics, 2011.

While wheat production was relatively stable throughout the 1980s and 1990s, the 2000s brought greater market fluctuations. The trend of crop area shows quite clearly three phases: a downward trend during 1979/80 to 1991/92; an upward trend during 1992/93 to 2004/05; and a downward trend during 2005/06 to 2007/08. In 2008/09 the crop area had recovered to around 4.5 million hectares. As shown in Figure 3, yield changes have corresponded closely

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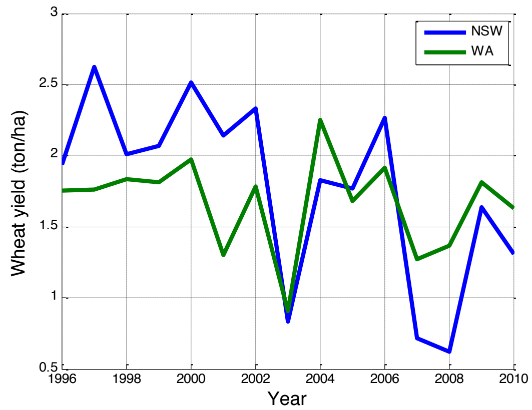
to crop area fluctuations, and by 2010 had more than doubled in comparison to yields experienced in 1980.

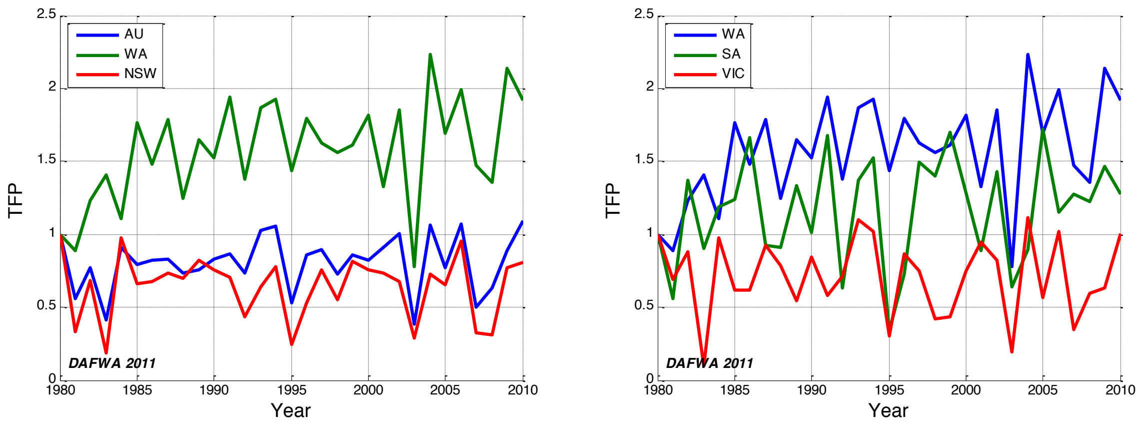
Figure 3: Wheat yield of New South Wales and Western Australia



Source: Australian Bureau of Statistics, 2011.

The comparison of Total Factor Productivity (TFP) of grain production between Western Australia and Australia, and between Western Australia and major grain states during 1979/80 to 2009/10 are presented in Figure 4. Using 1979/80 as a base year, over the past three decades TFP of grain production in Western Australia had improved relatively faster compared with Australia, New South Wales, Victoria and South Australia.

Figure 4: Productivity of grain production by state



Source: Department of Agriculture and Food of Western Australia (DAFWA), 2011.

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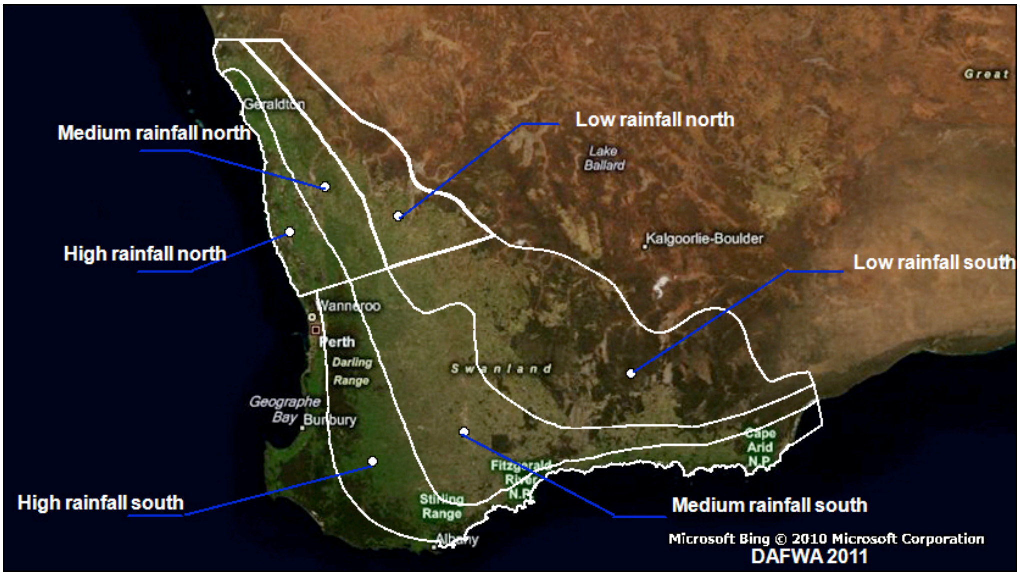
Benchmarks of WA rainfall zones have been developed through statistical performance to group together environmental regions that give similar crop performance (Bankwest 2010). Benchmarks of WA rainfall zones have been labelled 1 to 6 and are outlined in Table 1 and Figure 5.

Table 1: Benchmarks of WA rainfall zones

Rainfall area	Abbreviation	RF Zones covered	Average Annual rainfall
High rainfall North	HRFN	H1 & H2	450-750mm
High rainfall South	HRFS	H3, H4 & H5	450-750mm
Medium rainfall North	MRFN	M1 & M2	325-450mm
Medium rainfall South	MFRS	M3, M4 & M5	325-450mm
Low rainfall North	LRFN	L1 & L2	<325 mm
Low rainfall South	LRFS	L3.L4 & L5	<325 mm

Source: Bankwest 2010.

Figure 5: Benchmarks of WA rainfall zones



Sources: Developed from DAFWA 2011, Bankwest (2010), Microsoft Bing, 2010.

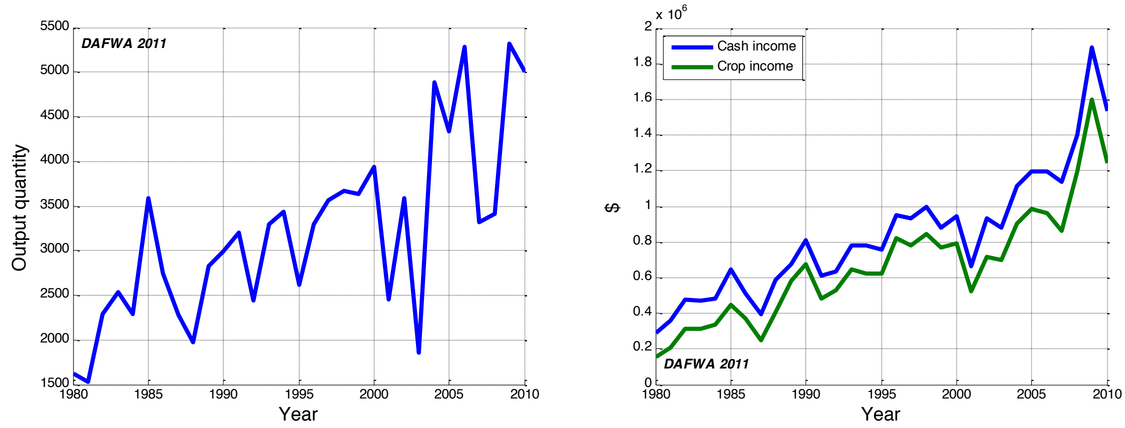
2 Movements of output and input factors of grain farms

(a) Output and revenue

Figure 6 (Panel A) presents the movements of average grain (wheat equivalent) quantity, during the period 1980 to 2010. It reveals that between 2000 and 2010 WA grain farms experienced a volatile production climate in comparison to the preceding decade, although the average growth trend was higher.

Figure 6 (Panel B) provides movements of the average cash income and income earned from the sale of crops per farm. Cash income is the total farm income including off-farm income and crop income. As Figure 5 indicates, both of these incomes have remained synchronised over the past 30 years, and the differential between them has largely remained constant. A comparison between panel A and B indicates that despite the volatility of crop output in the decade preceding 2010 (i.e. Panel A), average farm income actually grew more rapidly and consistently. This is largely attributable to the effects of high world wheat prices. Indeed, over the past 30 years crop income has more than doubled since 1990.

Figure 6: **Average grain output per farm, cash income and crop income ($/farm)**



A: **Output per farm**
wheat equivalent (ton/farm)

B: Cash income and crop income per farm *($/farm)*

Average annual cash income per farm and per crop hectare by rainfall zone in six 5-year blocks is presented in Figure 7. The average cash income has been increasing in all zones over time, and is clearly differentiated by rainfall zone. In 2007/08 to 2009/10 the average

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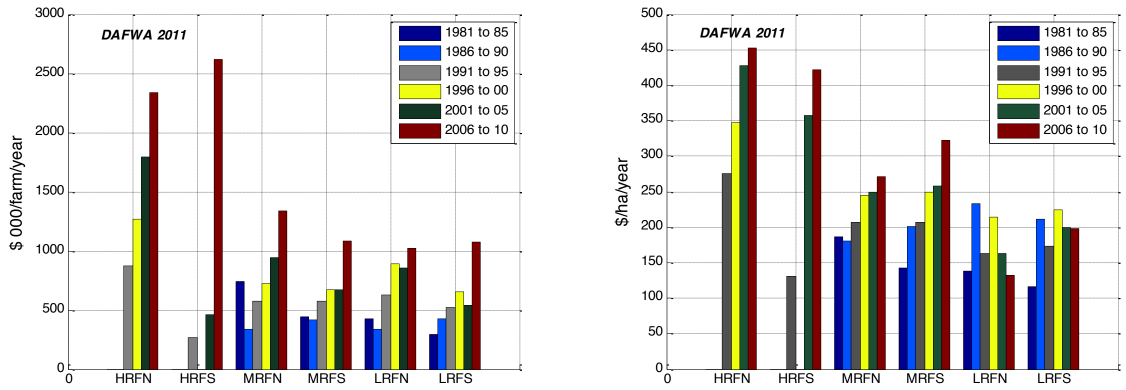
cash income per farm was highest in the HRFS ($2.3 million) and HRFN ($2.2 million) zones, followed by the MRFN and MRFS zones ($1.7 million and $1.0 million respectively) and the LRFN and LRFS zones ($1 million and $1.3 million respectively).

The average cash income per operating hectare is much higher in the high and medium rainfall zones compared with low rainfall zones. In the period 2007/08 to 2009/10 the average cash income per hectare was $452 and $417 per hectare in HRFN and HRFS zones respectively. This compares to $317 and $358 in MRFN and MRFS zones, and $99 and $184 in LRFN and LRFS zones respectively.

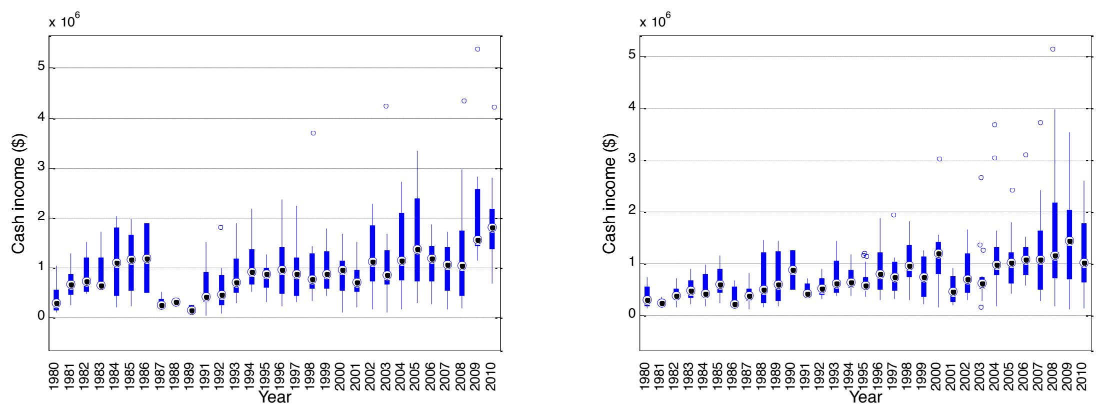
Mean value and the statistical range of yearly cash income for the Medium rainfall zones and the Low rainfall zones are presented in Figures 8 and 9.

Figure 7: Average cash income by rainfall zone



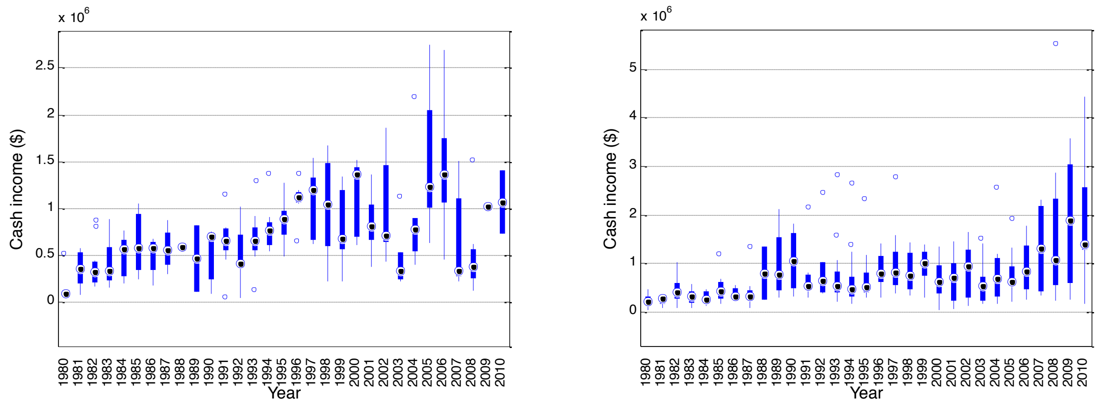
A: Average per farm ($'000/farm/year) **B: Average per operating hectare ($/ha/year)**

Figure 8: Cash income per farm in the Medium rainfall zone *($/farm)*



A: Medium rainfall north **B: Medium rainfall south**

Figure 9: **Cash income per farm in the Low rainfall zone** *($/farm)*



A: Low rainfall north **B: Low rainfall south**

Average crop income per farm and per crop hectare (dominated by grains) by rainfall zone in six 5-year blocks is presented in Tables 2 and 3 and in Figure 10. Mean value and statistics range of yearly crop income for the Medium rainfall zones and the Low rainfall zones are presented in Figures 10 and 11. It is evident that average crop income has also been increasing in all zones over time, and is clearly differentiated by rainfall zone. In 2007/08 to 2009/10 the average crop income per farm was $1.5 million and $1.8 million per farm in the HRFN and HRFS zones respectively; $1.5 million in the MRFN zone; $0.9 million in the MRFS zone; $0.9 million in the LRFN zone; and $1.1 million in the LRFS zone.

The average crop income per hectare is also much higher in High and Medium Rainfall zones compared with Low rainfall zones (Table 3). In 2007/08 to 2009/10 the average crop income per hectare was $455 and $434 per crop hectare in HRFN and HRFS zone; $413 and $466 in the MRFN and MRFS zones; and $185 and $292 in LRFN and LRFS zones respectively (Table 3 and Figure 13).

Table 2: **Average crop revenue per grains farm** *($/farm)*

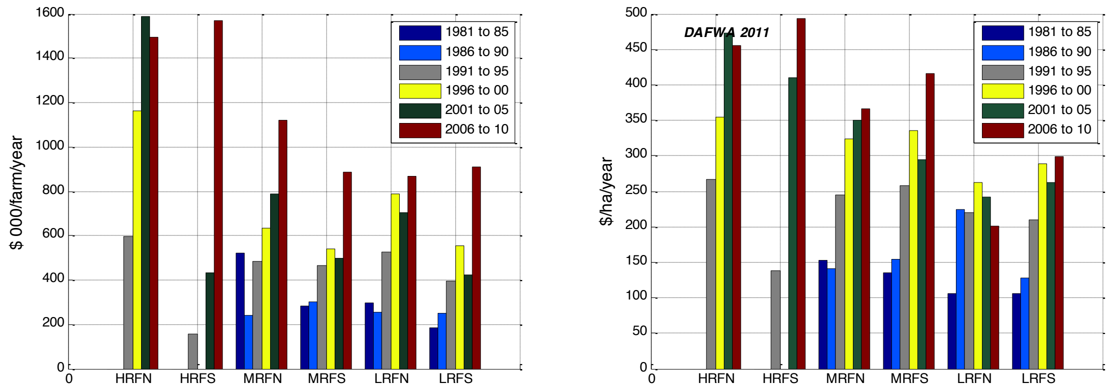
Period/zone	HRFN	HRFS	MRFN	MRFS	LRFN	LRFS
1981 to 1985			523,908	281,017	298,043	185,525
1986 to 1990			241,304	301,707	255,231	250,562
1991 to 1995	595,320	157,922	483,642	464,834	528,331	394,752
1996 to 2000	1,162,105		635,776	540,223	789,979	553,113
2001 to 2005	1,586,698	430,443	787,349	498,745	705,952	425,080
2006 to 2010	1,494,922	1,568,831	1,118,833	887,196	867,535	908,152

2008 to 2010	1,494,922	1,758,730	1,500,662	926,608	897,032	1,145,542

Table 3: Average crop income per crop hectare *($/ha)*

Period/zone	HRFN	HRFS	MRFN	MRFS	LRFN	LRFS
1981 to 1985			152.9	135.0	105.5	106.7
1986 to 1990			141.7	154.2	224.0	128.1
1991 to 1995	266.8	137.5	245.4	258.3	219.4	209.2
1996 to 2000	354.6		323.9	335.7	262.4	289.2
2001 to 2005	472.9	410.5	349.8	294.6	242.4	262.7
2006 to 2010	454.8	493.1	366.6	415.5	200.5	298.4
2008 to 2010	454.8	434.1	413.3	465.6	185.2	292.3

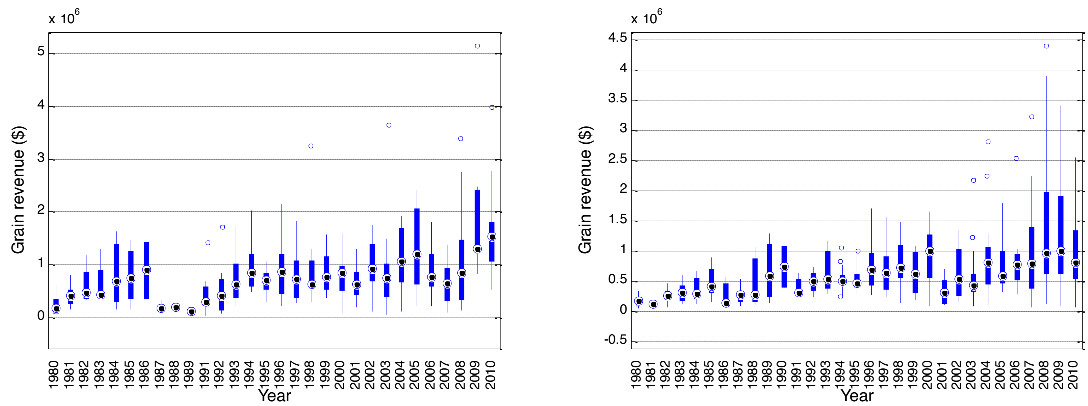
Figure 10: Average grain revenue by rainfall zone



A: Per farm ($'000/farm/year)

B: Per hectare ($/ha/year)

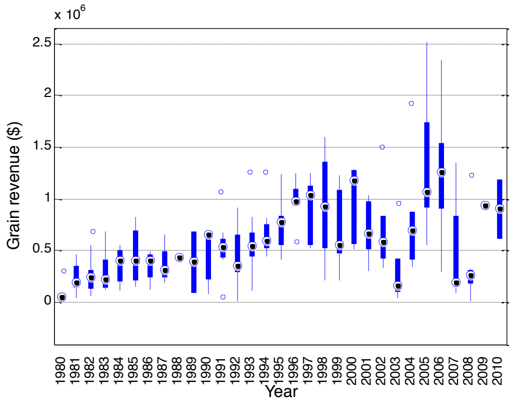
Figure 11: Grain revenue per farm: Medium rainfall zone *($/farm)*



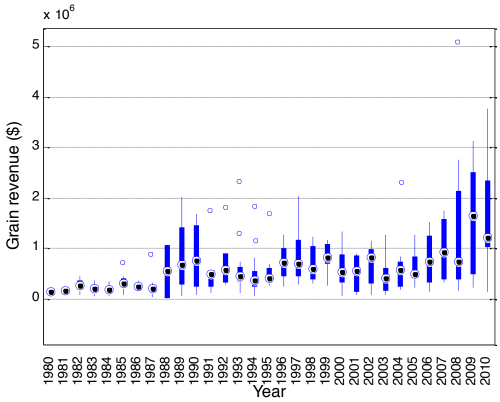
A: Medium rainfall north

B: Medium rainfall south

Figure 12: Grain revenue per farm: Low rainfall zone *($/farm)*

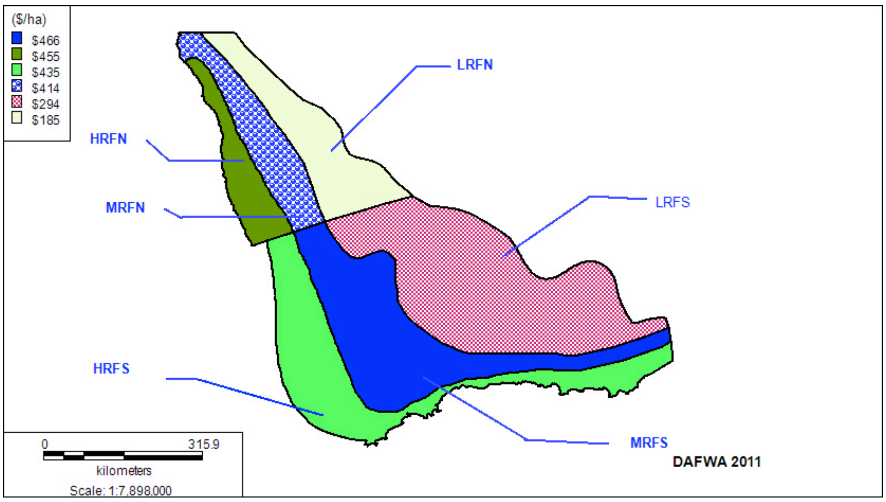


A: Low rainfall north



B: Low rainfall south

Figure 13: Average grain revenue per crop hectare, 2007/08 to 2009/10 *($/ha)*



(b) Land use

Average farm size by climate zone is presented in Figure 14. The mean value and statistical range of crop land size per farm for the Medium rainfall zones and the Low rainfall zones are presented in Figures 15 and 16. From this data it is apparent that the average size per farm has increased shapely over the past 5 years of 2006 to 2010 in Low Rainfall, Medium Rainfall North, and High Rainfall South zones. Average farm size in Low Rainfall North zone is the largest, averaging more than 4000 hectares per farm.

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Figure 14: Farm size by climate zone

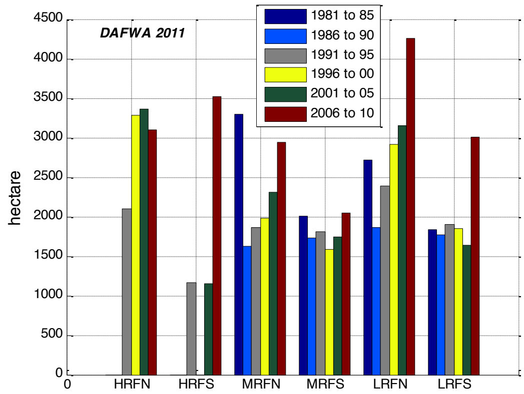
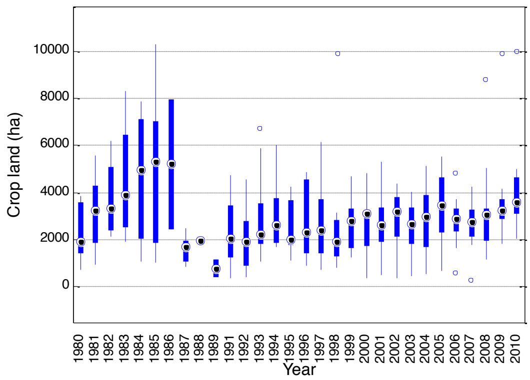
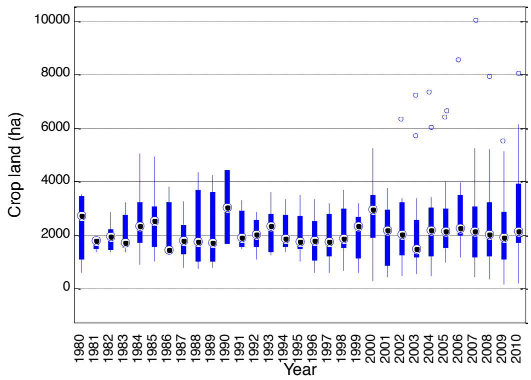


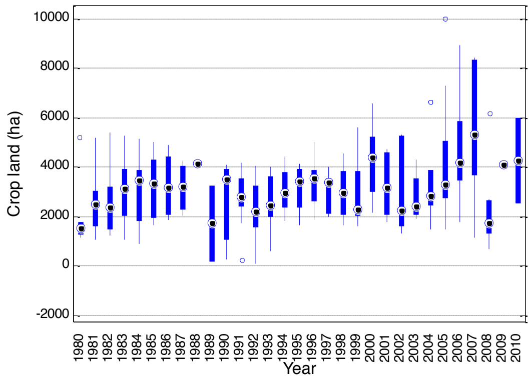
Figure 15: Crop land per farm in the Medium Rainfall zone *(ha)*



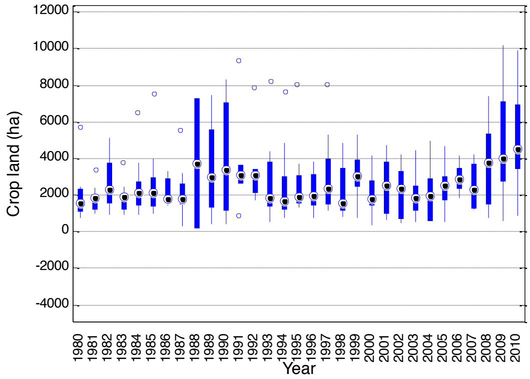


A: Medium rainfall north **B: Medium rainfall south**

Figure 16: Crop land per farm in the Low Rainfall zone *(ha)*



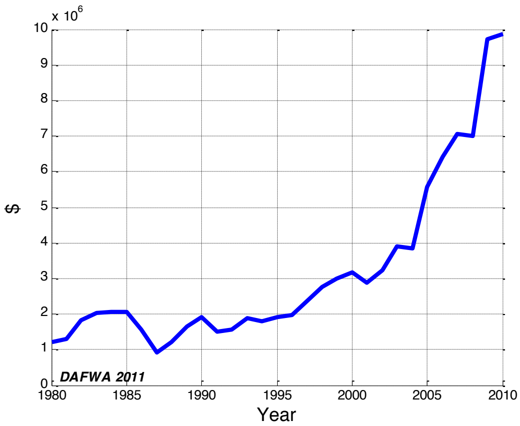
A: Low rainfall north



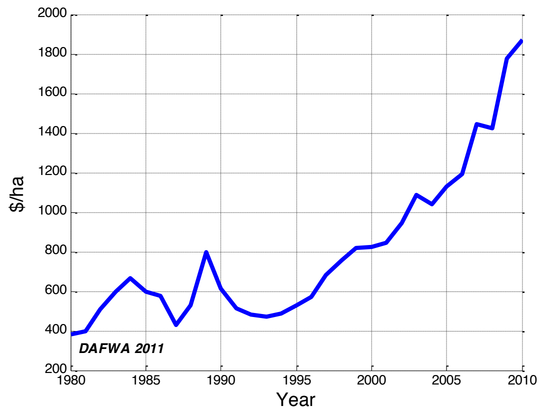
B: Low rainfall south

Average land value per farm and per hectare for each rainfall zone and for the industry as a whole have increased dramatically over time (Figures 16 and 17), especially over the past five years. In 2007/08 to 2009/10 the average land value per farm was $12.2 million in the HRFN zone, $24.7 million in the HRFS zone, $9.7 million in the MRFN, $6.4 million in the MRFS zone, $6.9 million in the LRFN zone and $7.4 million in the LRFS zone. The average land value per hectare was about $2600 in High Rainfall zone; $1800 and $2300 in the MRFN and MRFS zones, and $650 and $1100 in the LRFN and LRFS zones respectively. The value per hectare in the high rainfall zone was approximately four times that of the low rainfall zone.

Figure 17: Average land value



A: Per farm ($/farm)



B: Per hectare ($/ha)

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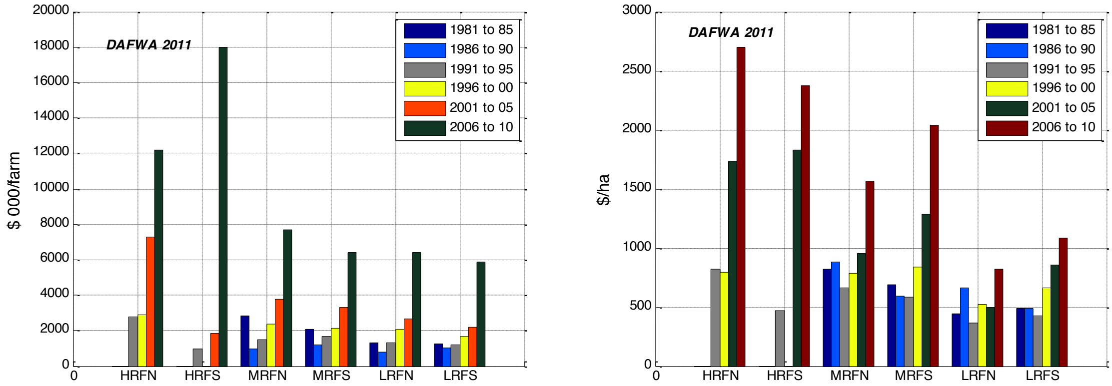
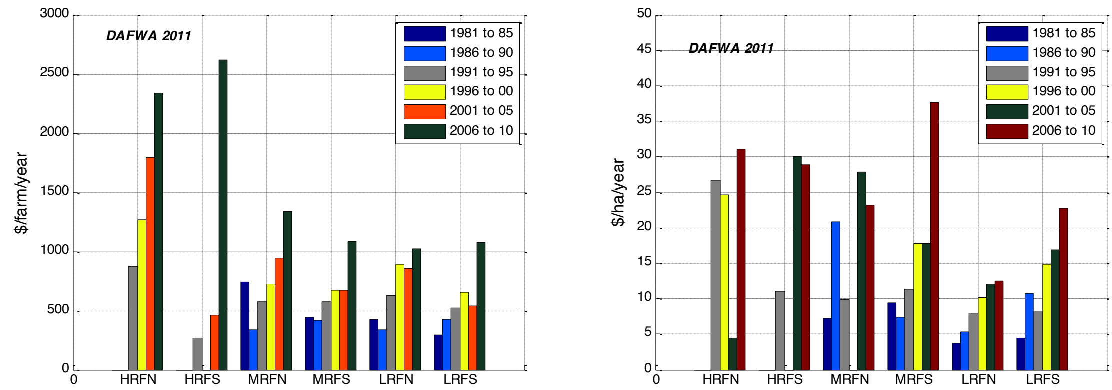
Figure 18: Average land value by rainfall zone



A: Per farm ($'000/farm) **B: Per hectare ($/ha)**

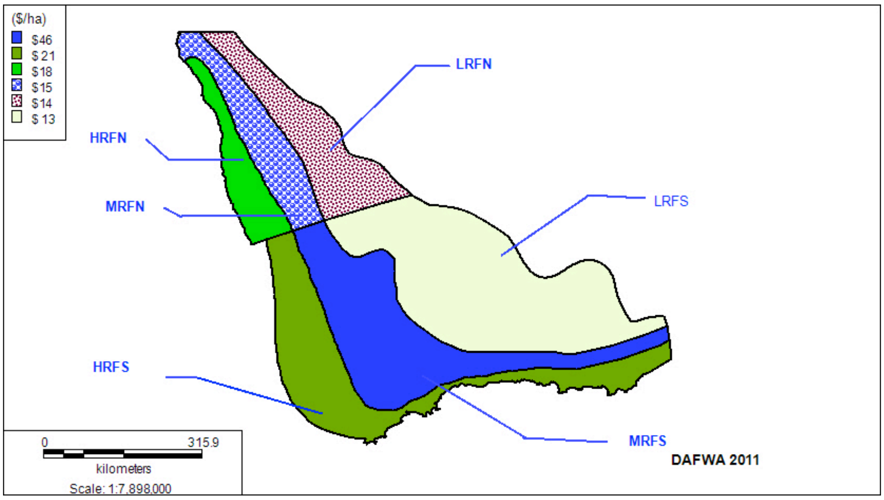
Land care costs per farm and per crop hectare have been increasing significantly over time and, like land values, have increased particularly rapidly in the past 5 years (i.e. 2006-2010), as shown in Figure 19, below. Between 2008 and 2010 the average land care cost per crop hectare was $31: $38 in the HRFN and HRFS zones; $24 and $45 in MRFN and MRFS zones; and around $13 in both the LRFN and LRFS zones (see Figure 20).

Figure 19: Average land care cost by rainfall zone



A: Per farm ($/farm/year) **B: Per hectare ($/ha/year)**

Figure 20: **Average land care cost per hectare of crop land, 2007/08 to 2009/10** *($/ha)*



(c) Capital and equipment

Average capital value is composed of plant and machinery and structure values. The average capital value by WA rainfall zones in six 5-year blocks is presented in Figure 21. In general, capital value per farm has tended to increase over time at much the same rate across all rainfall zones. At present, the average capital value of a WA grain farm is about \$1.0 million to \$1.4 million. Average capital cost per farm, shown in Figure 22, indicates that capital value and capital cost per farm has increased almost seven-fold, from around \$20,000 in 1980 to \$150,000 in 2010.

Figure 21: **Average capital value per grain farm by rainfall zone** *($'000/farm/year)*

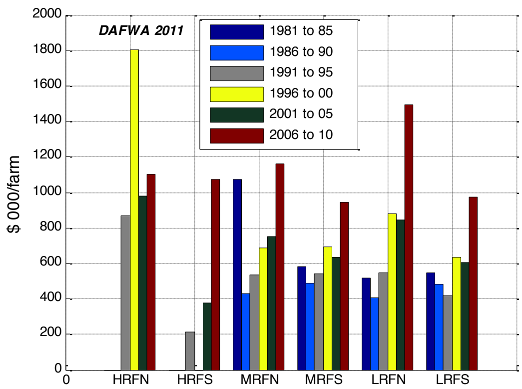
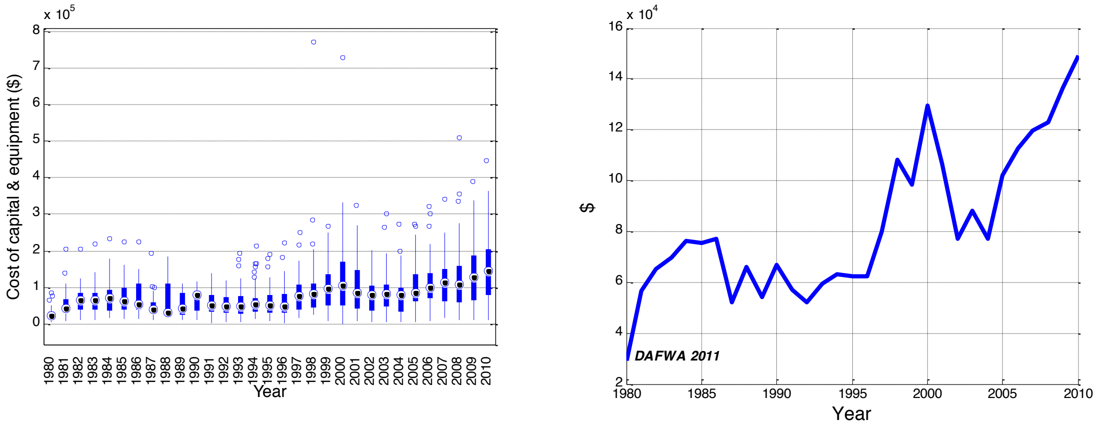


Figure 22: Cost of capital and equipment *($/farm)*

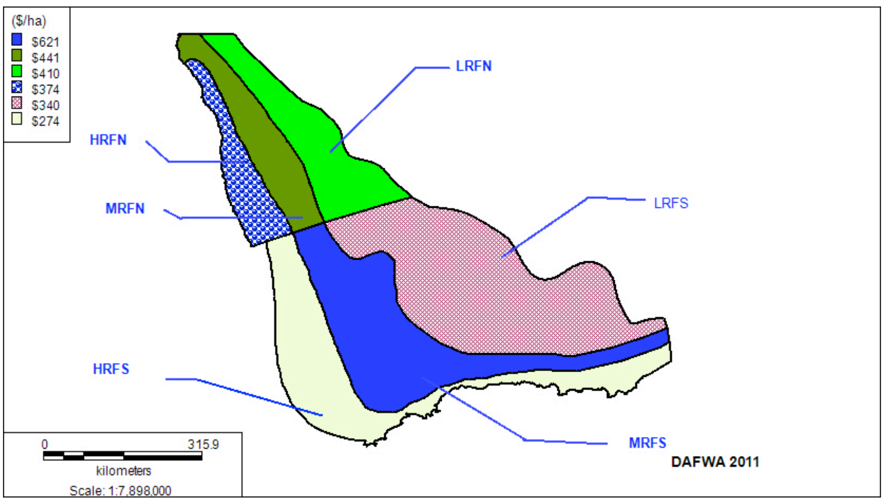


A: Cost of capital

B: Average capital cost

Figure 23 presents the average capital value used per crop hectare by rainfall zone during 2008-2010. The average capital value used per crop hectare is the highest for the MRFS zone ($621/ha), but differences between each zone are relatively small (ranging from $270/ha to $440/ha).

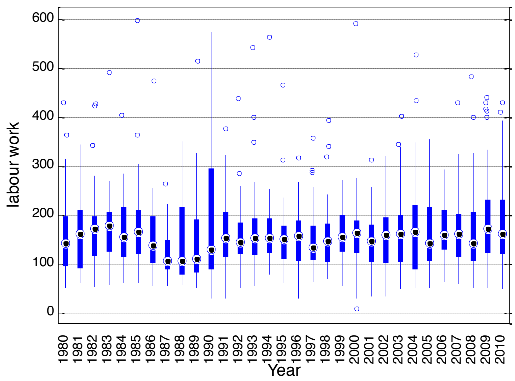
Figure 23: Average capital value used per crop hectare, 2007/08 to 2009/10 *($/ha)*

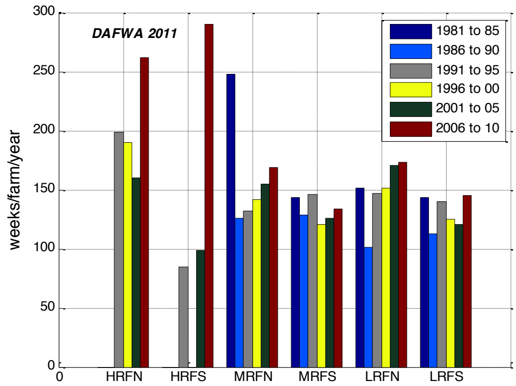


(d) Labour

Labour input (measured in weeks) includes an owner's time, family labour and hired labour. The average labour work per farm and per hectare by time and zone are presented in Figure 24. The average labour used per crop hectare by rainfall zone during 2008-2010 is much higher in HRFS and MRFS zones (0.67 day/ha and 0.51 day/ha respectively). Average labour input in remaining zones varies from 0.3 day/ha to 0.4 day/ha.

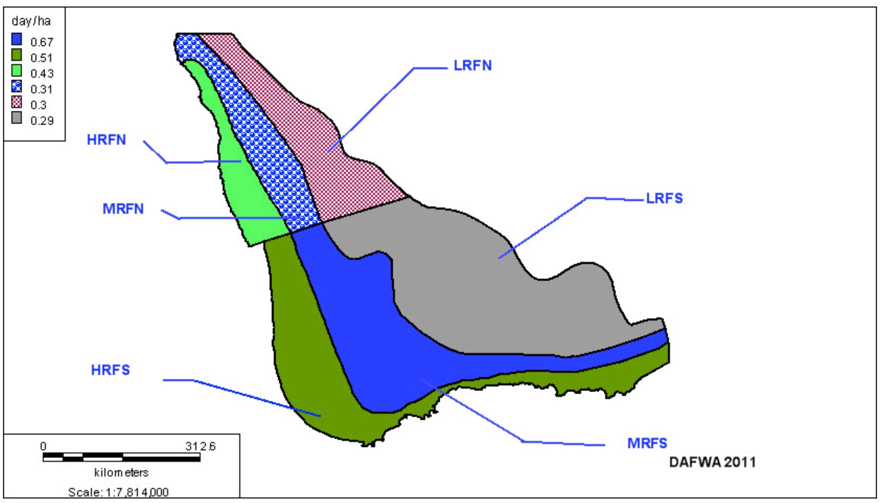
Figure 24: Labour work per farm





A: Labour work (weeks) **B: Labour work by rainfall zone (weeks)**

Figure 25: Average labour per hectare of crop land, 2007/08 to 2009/10 *(day/ha)*



Note: computed from number of weeks: 5 days is equal to one week.

(e) Materials, chemicals and fertilizers

Material costs include the purchase of chemicals, fertilizer, other material inputs, and seed. Of these, fertilizer is the most significant cost component. The average material and fertilizer cost per farm has increased sharply over the past three decades, from less than $3000 in 1980 to about $30,000 in 2009 and 2010, as shown in Figures 26 and 27. Increases in fertilizer costs have been particularly pronounced in the wake of the 2007 oil price spike (Figure 27).

Figure 26: Material & fertilizers costs per farm ($/farm)

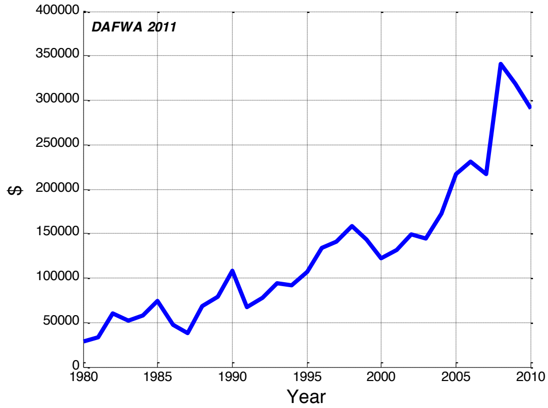
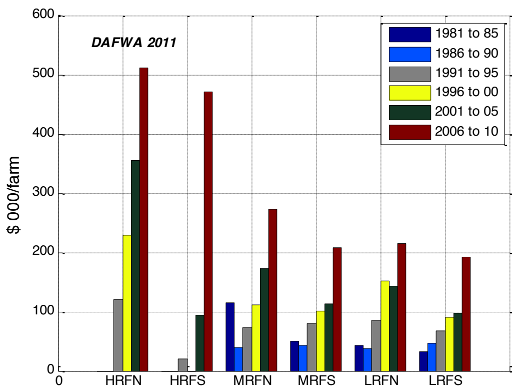
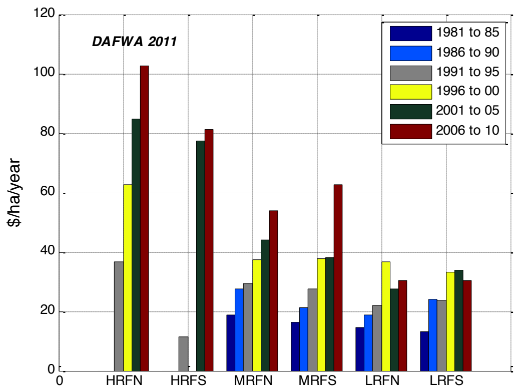


Figure 27: Average material cost by rainfall zone



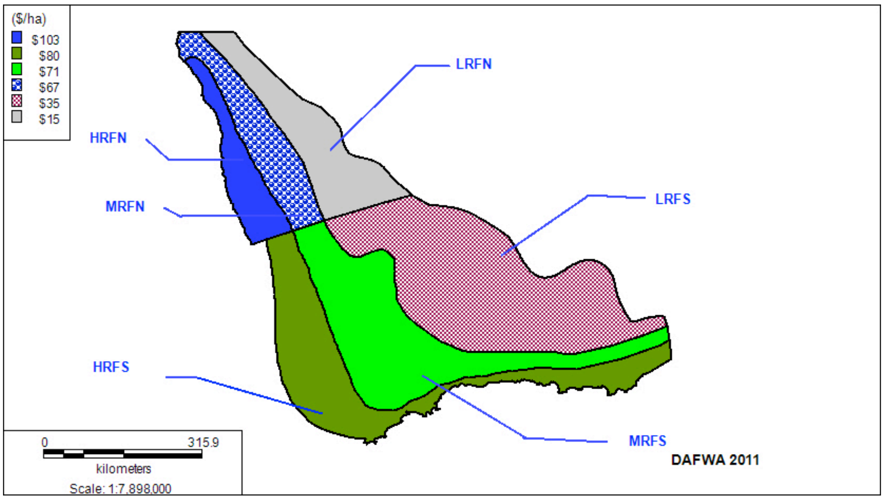
A: Per farm ($/farm/year)



B: Per hectare ($/ha/year)

The average material cost per farm and per crop hectare have increased significantly since 2006-2010 in every rainfall zone, and were much higher in the High and Medium Rainfall zones (Figure 28). Once again, this is largely reflective of a relatively high oil price affecting manufacturing and transport costs. In 2008-2010 the average material cost per crop hectare was $103 and $80 in the HRFN and HRFS zones; $70 and $67 in the MRFN and MRFS zones; and only $35 and $15 in the LRFN and LRFS zones respectively.

Figure 28: Average material costs per crop hectare, 2007/08 to 2009/10 *($/ha)*



Note: Material costs include chemical, fertilizer, material and seed.

(f) Fuel and electricity

During the study period the average fuel and electricity costs per farm increased from $20,000 in 1980 to $40,000 in 1995. However, these costs rose dramatically to $120 000 in 2009/2010. This is shown in Figure 29.

The average fuel and electricity cost per farm and per crop hectare by rainfall zone by six 5-year blocks is shown in Figure 30. In general, the average fuel and electricity cost per crop hectare has increased in every rainfall zone in each successive 5-year period. In 2008-2010 the average fuel and electricity cost per crop hectare across the rainfall zones was between $20/ha and $30/ha, but was exceptionally high ($53/ha) in the MRFS zone (see Figure 31).

Figure 29: Average costs of fuel and energy ($/farm)

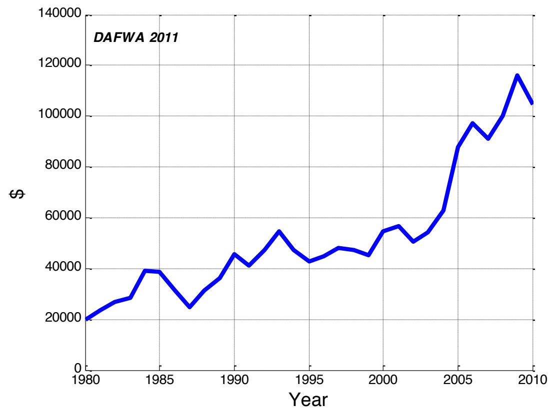
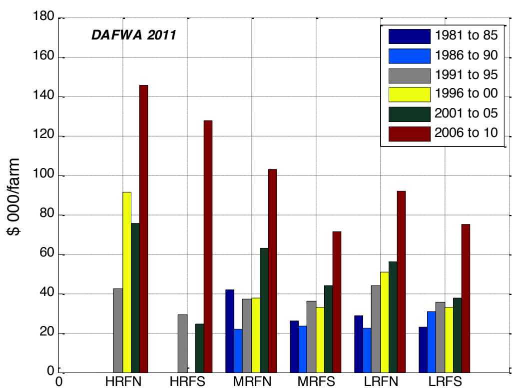
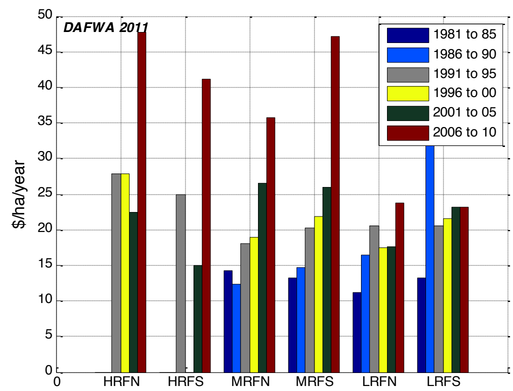


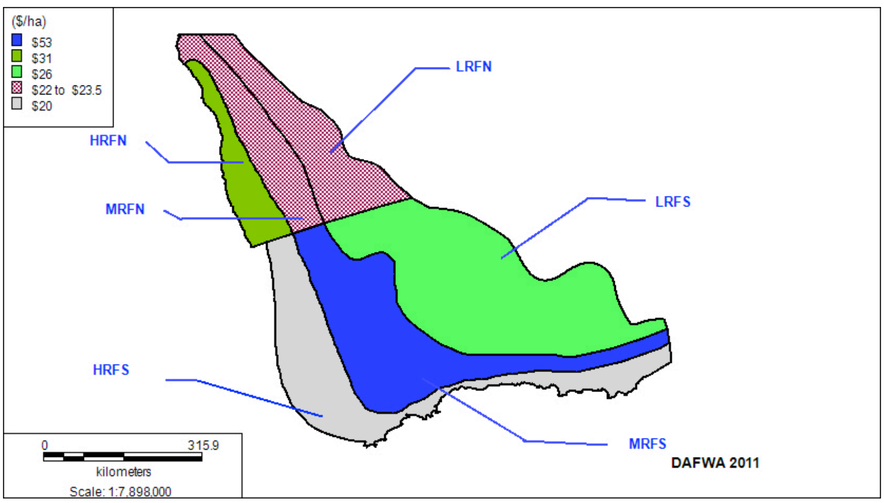
Figure 30: Average fuel and electricity cost by rainfall zone





A: **Per farm *($'000/farm/year)*** **B:** **Per crop hectare *($/ha/year)***

Figure 31: Average fuel and electricity cost per crop hectare by rainfall zone, 2007/08 to 2009/10



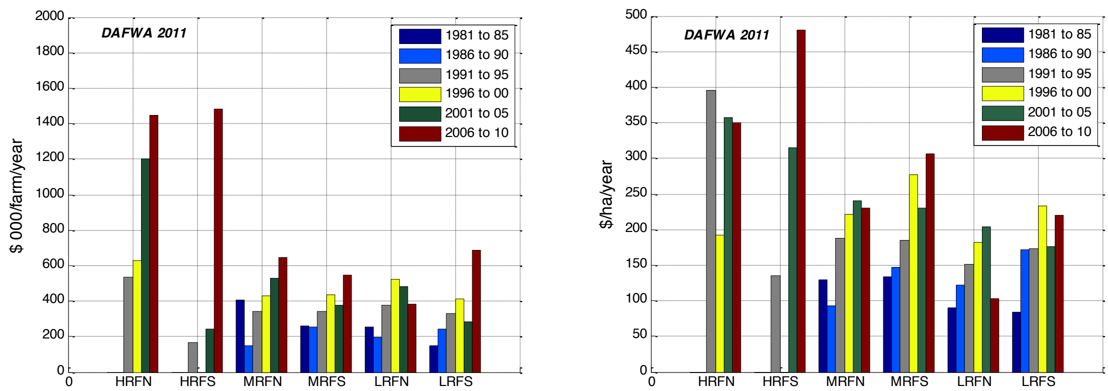
3 Profitability, productivity and technical efficiency analysis

(a) Trends in profitability

In this study net income (or farm operating profit) is measured as the difference between total crop income and the costs for land use, capital, labour, materials, fuel and electricity costs. The strong rise in average farm operating profit witnessed since 2005 across all farms in WA follows a relatively flat trend over the preceding two decades. The average rise is strongly influenced by the rise in performance by the top quartile of farms (which have exceeded improvements by the next quartile by 50 per cent). The lower quartile appears to have achieved negligible profits over an extended period, although some improvement is evident in the last five years. This is reflective of rising terms of trade benefiting export grain producers, productivity gains and expansion in crop areas being sufficient to offset rising land values, rising farm debt, and materials costs over the same period.

The average net income per farm and per crop hectare by rainfall zone is shown in six 5-year blocks in Figure 32.

Figure 32: Average net income by rainfall zone



A: Per farm *($'000/farm/year)* **B: Per hectare *($/ha/year)***

In general, the average net income per farm has increased over time in every rainfall zone. Average net income per crop hectare has fluctuated at times, but has generally been highest in the High rainfall zones, followed by in Medium rainfall zones (see Figure 31, above). In

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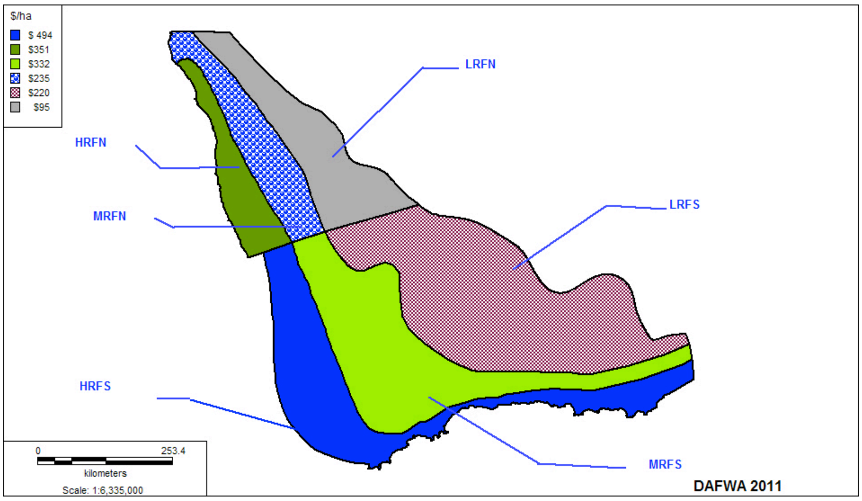
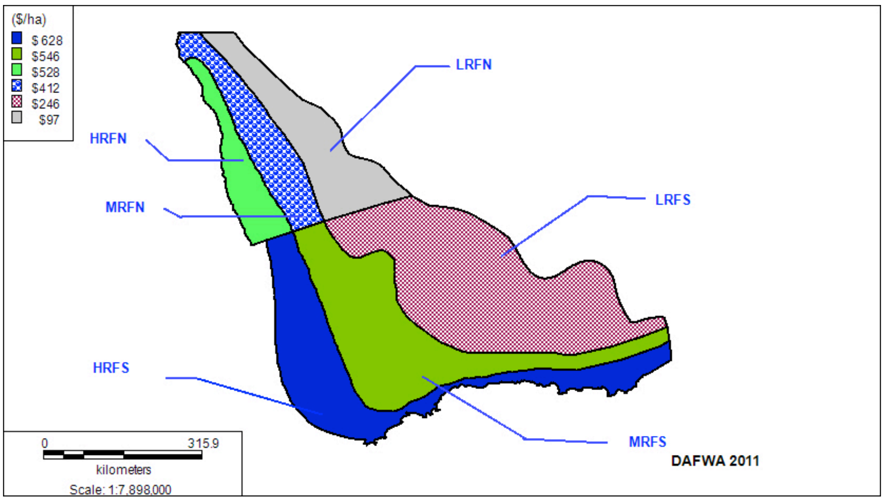
2008-2010 the average net income per crop hectare was \$351 and \$494 in HRFN and HRFS zones, \$235 and \$322 in MRFN and MRFS zones, and \$95 and \$220 in the LRFN and LRFS zones (see Figure 33).

Figure 33: Average net income per crop hectare by rainfall zone, 2007/08 to 2009/10



The trend of debt varies considerably across rainfall zones. However, in recent years (2006-2010) farm debt levels have increased substantially, especially in the High Rainfall zones. In 2008-2010 the average debt per farm per year was \$2.7 million and \$3.6 million in the HRFN and HRFS zones; \$2.2 million and \$1.3 million in the MRFN and MRFS zones; and \$1.1 million and \$1.8 million in the LRFN and LRFS zones. The average debt varied significantly among rainfall zones (see Figure 34).

Figure 34: Average debt per operating hectare, 2007/08 to 2009/10 *(\$/ha)*



(b) Productivity analysis

TFP and adjusted TFP are estimated based on equations (A.1) to (A.7) (see Appendix B). Where appropriate the quantity indexes for inputs contained in equation (A.7) are adjusted by a climate index, as in equation (A.5). A Törnqvist index is 'superlative' in the sense that it is based on a highly flexible, homogeneous translog production function, providing a second order approximation to any arbitrary twice-differentiable and linearly homogeneous production function. The adjusted coefficient of rainfall impact on wheat production was drawn from the econometric estimation analysed in Appendix C. The climate adjusted productivity trend for WA shows a strong rise during the 1980s, followed by a flatter performance during the 1990s. Gradual but fluctuating improvement has since been the rule, but variation in productivity gains between farmers and between years has increased substantially.

Table 4: Average Total Factor Productivity (TFP) and Climate Adjusted Total Factor Productivity

Year	TFP	Adjusted TFP
1980s	1.27	1.45
1990s	1.58	1.77
2000s	1.61	1.87

Total factor productivity and adjusted total factor productivity are summarised by decade for the 1980s, 1990s and 2000s in Table 4. TFP increased from 1.27 in the 1980s to 1.58 in the 1990s and 1.61 in the 2000s. With climate adjustment, the adjusted TFP increased even further from 1.45 in the 1980s to 1.77 in the 1990s and 1.87 in the 2000s.

Average TFP and adjusted TFP are shown in Figure 35. Figure 36 indicates the actual productivity at farm level and a productivity trend derived from non-linear regression. As these figures demonstrate, productivity has increased over the past 30 years, but at a decreasing rate. In drought years, the gap between TFP and adjusted TFP was relatively large, verifying the importance of rainfall on farm performance.

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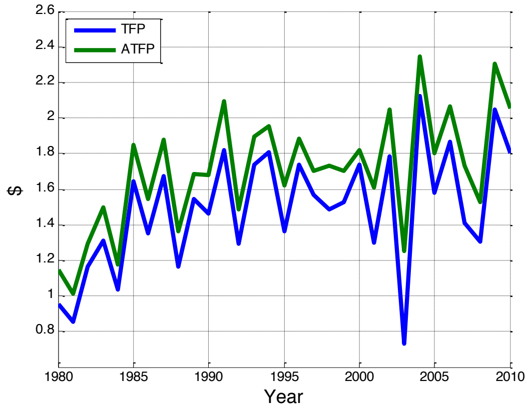
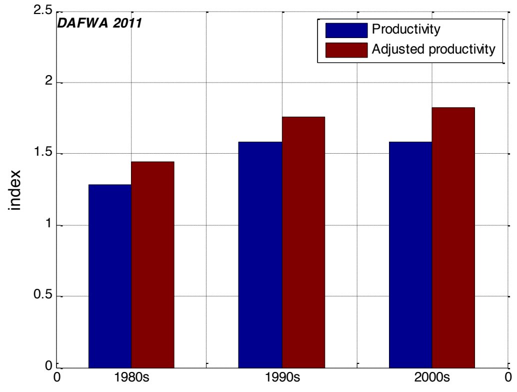
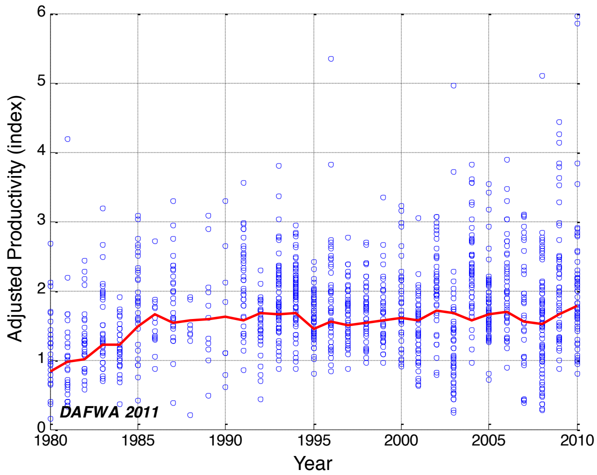
Figure 35: **Productivity and adjusted productivity with rainfall level**





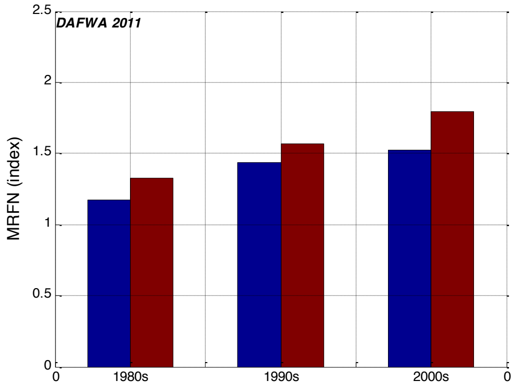
A: Average per year (index) **B: Average per decade (index)**

Figure 36 ; Farm level and regressed trend of adjusted productivity: 1980 to 2010

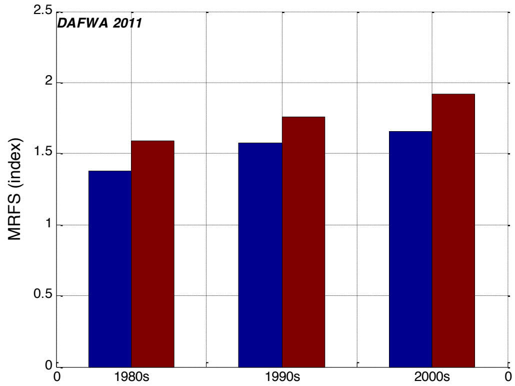


Average TFP and adjusted TFP for Medium and Low Rainfall zones, indicated in Figures 37 and 38, confirm the increasing trend of productivity that has slowed over the past decade.

Figure 37: Total Factor Productivity and Adjusted Total Factor Productivity in Medium rainfall zones

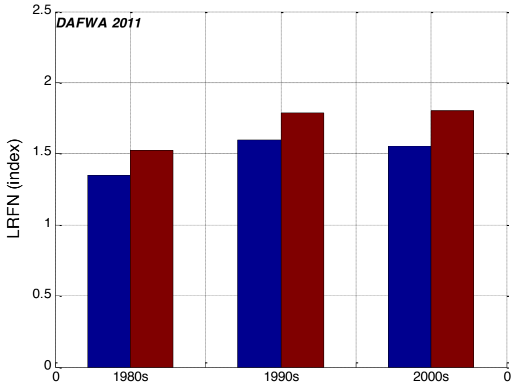


A: Medium rainfall north

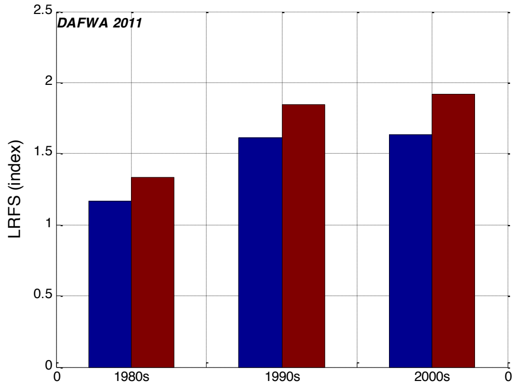


B: Medium rainfall south

Figure 38: Total Factor Productivity and Adjusted Total Factor Productivity in Low rainfall zones



A: Low rainfall north



B: Low rainfall south

(c) Stochastic frontier analysis and technical efficiency analysis

In this section we estimate a stochastic production frontier and an associated technical efficiency model in order to determine the importance of inputs in grain production and the farm-specific allocation by rainfall zone: this will explain differences in efficiency across grain farms in Western Australia. Productivity levels are partially isolated to allow for random effects and differences in levels of efficiency across WA grain farms.

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Indexing grains farms by i and year t, the specification of the stochastic production function of a given grain farm can be expressed formally by

$$(3.1) \qquad Y_{it} = LAB_{it}^{\alpha} LAND_{it}^{\beta} CAP_{it}^{\gamma} MATE_{it}^{\delta} e^{v_{it}-u_{it}}$$

for time t. Here, Y_{it} is grain output, LAB is labour, LAND is crop land, CAP is capital value, and MATE is material used (mainly including chemicals, fertilizer, seed). The error term v_{it} is assumed to be independent and identically distributed as $N(0, \sigma_u^2)$, capturing random variations in output attributable to factors beyond the control of farms, such as temperature and rainfall.

The error term u_{it} captures technical inefficiency in production—assumed to be farm-specific, non-negative random variables—independently distributed as non-negative truncations (at zero). A higher value for u implies an increase in technical inefficiency. If u is zero, the farm is considered perfectly technically efficient. Following Battese and Coelli (1995),

$$(3.2) \qquad u_{it} = \delta_0 + z_{it}\delta$$

defines an inefficiency distribution parameter for a vector, z_{it}, of farm-specific effects that determine technical inefficiency. Here, δ is a vector of parameters to be estimated.

For the basic case, the technical efficiency (TE) of the ith farm in the tth period can be defined for the expectations operator, E, as

$$(3.3) \qquad TE_{it} = \frac{E(Y_{it} | u_{it}, X_{it})}{E(Y_{it} | u_{it} = 0, X_{it})} = e^{-u_{it}} \quad .$$

Efficiency is calculated for each farm per year by

$$(3.4) \qquad E[\exp(u_i) : v_i + u_i] = \frac{1-\phi(\alpha_a + \gamma(v_i + u_i)/\sigma_a}{1-\phi(\gamma(v_i + u_i)/\sigma_a)} \exp[\gamma(v_i + u_i) + \sigma_a^2/2]$$

for $\sigma_a = \sqrt{\gamma(1-\gamma)\sigma^2}$, $\sigma^2 \equiv \sigma_u^2 + \sigma_v^2$, $\gamma \equiv \sigma_u^2/\sigma^2$ and $\phi(.)$, the density function of a standard normal random variable (Battese and Coelli 1988).

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Estimates of γ provide important information about the efficiency of WA grain farms. A value of γ close to zero implies that much of the variation in output is due to stochastic effects, whereas a value closer to one implies that substantial differences in technical efficiency exist between farms. The technical efficiency model focuses on the impacts of rainfall level on farm efficiency.

The unbalanced panel data set used in this study consists of 523 observations for 226 farms over 11 years (1999/2000 to 2009/10) for all WA. The key inputs are labour quantity (number of weeks), crop land area (hectares), capital value (Aus$), and material (Aus$).

Results for the stochastic production frontier model and the technical inefficiency model are reported in Table 5. A negative sign on a coefficient indicates that an increase in the value of that variable results in a fall in inefficiency (or a gain in efficiency). Conversely, a positive value indicates that an increase in the variable will cause an increase in inefficiency (or a loss of efficiency).

All input variables are measured in log form, so that estimated coefficient values represent 'share parameters' or elasticities. Thus, a 1 per cent increase in crop area results in an estimated increase in grain output of 0.57 per cent. Of all input variables, land has the highest coefficient (0.57), followed by plant and structure capital (0.18), materials (0.13), labour (0.07), and fuel and energy costs (0.05).

The value *D (drought)* is a dummy variable used to measure the potential effects of the drought years for WA, which tests as negative (as expected) and significant. The farm-specific features—which are considered in the technical inefficiency model—are rainfall zone areas. The efficiency (in terms of percentage) is measured by comparing a specific farm's performance with the 'best possible' farms in the observed population. Results are summarised in Figure 39.

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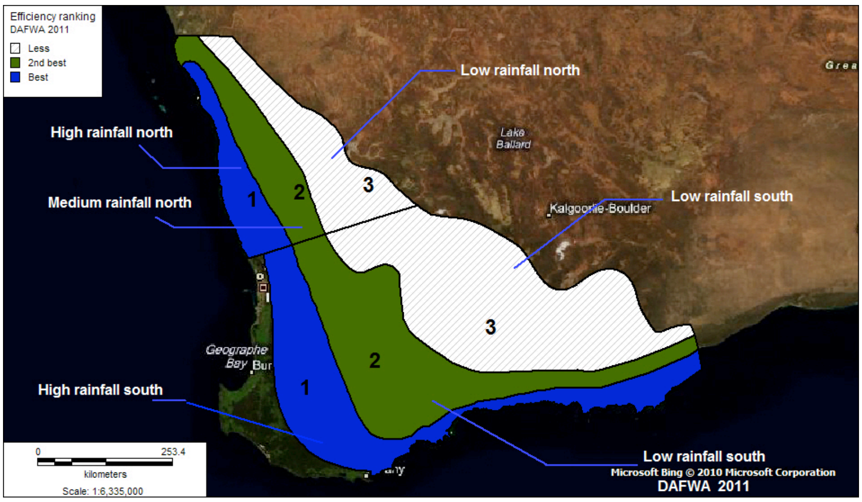
Table 5: Estimated results of efficiency analysis of grain farms *(1989/90 to 2009/10)*

	Variables are in log form	
	Results of the stochastic production function frontier model	
Variables	Maximum Likelihood Estimate	
	Coefficient	T-ratio
Constant	5.80***	22.95
Land	0.57***	11.68
Labour	0.07	1.10
Capital	0.18***	4.92
Material	0.13***	5.55
Fuel & energy	0.05*	1.21
D*(drought)*	-0.28***	6.03
	Results of the technical efficiency model	
Constant	3.48	
Low Rainfall Zones	1.73*	1.25
High Rainfall Zones	-0.99	0.67
Gamma	0.93***	15.80

*Notes: *, ** and *** denote statistical significance at the 99%, 95% and 90% level respectively.*

Figure 39: Ranking of economic efficiency by rainfall zone



For rainfall zone efficiency ranking purposes, the worst drought year (low rainfall and high temperature) in the studied period, 2002-03, is eliminated. The observed farms are divided into three groups: the *low performance* group, with efficiency <70 per cent; the *good performance* group, with efficiency from 70 to 85 per cent; and the *high performance* group, with efficiency >85 per cent. Note that the panel data has been collected over a relatively long time period (11 years) across a large number of farms in different rainfall zones. This has the effect of increasing the variance of farm performance relative to the best performing farms, but decreases the average differential between a random farm and the most efficient farm. More than half of the observed farms belong to the *good performance* group. The estimated results indicate that the farms belonging to the *high performance* group have a tendency to use higher levels of materials and capital per hectare, to plant larger areas to crop, and to experience relatively high rainfall during growing periods.

Table 6: **Farm profile by efficiency ranking**

Average value	Unit	Efficiency of farms group		
		<70 per cent	70% to 85%	>85%
Proportion in total population		23%	57%	20%
Material cost per hectare	*$/ha*	69.1	83.1	118.7
Capital cost per hectare	*$/ha*	42.9	40.5	45.2
Crop land size	*ha*	2666.2	2753.1	2849.6
Rainfall level	*mm*	206.0	230.0	234.9

4 Impacts of climate variations, price changes, and productivity growth on grains production

(a) Impact of climate variations on output and profit

The adjusted output is estimated under an assumption of a ‘perfect’ climate (in terms of rainfall) using equation A.5 (Appendix). The adjusted profit is estimated using the adjusted output and holding all other factors constant (i.e. *ceteris paribus*). The impact of climate on output and profit can be defined as the difference between the actual values and the climate adjusted values of output and profit. Average output and profit indexes are shown in Figure 40, below. Clearly, these indexes have increased from the 1980s to the 2000s, and the impacts of climate on output and profits appear to have become more pronounced with time.

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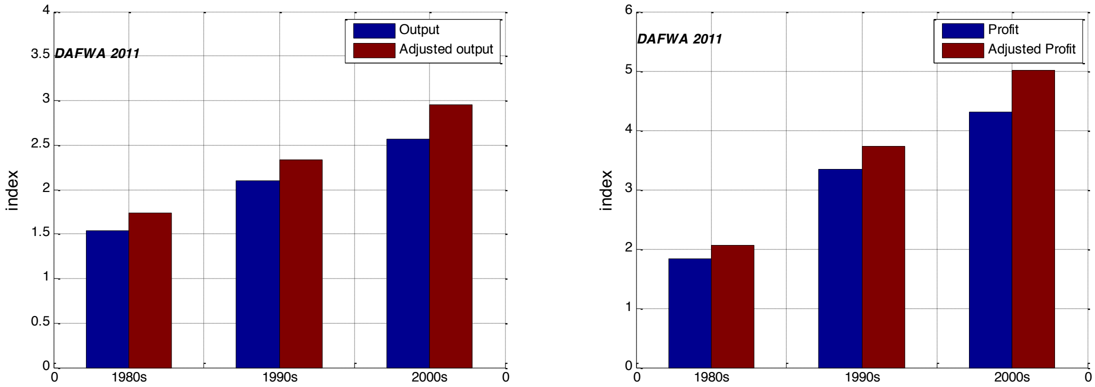
Figure 40: Impact of climate on output and profit indexes

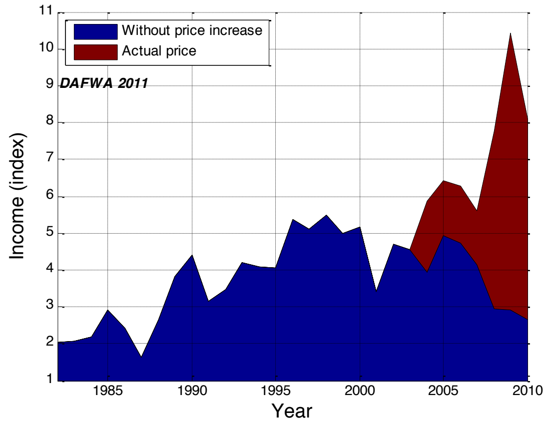


A: Output **B: Profit**

(b) Impacts of wheat price increase on income

Using the Törnqvist index approach, the aggregated input prices, output prices, and Terms of Trade can also be estimated. The trend of input price has been increasing continuously and monotonically over the past 30 years. However, the output price (measured in terms of wheat price) has fluctuated considerably, decreasing in the 1980s and increasing since 1990 (with a pronounced increase since 2004-05). To estimate the impact of grain price increases on farm income, we first calculate what incomes would have been without the increases of the past 5 to 6 years, and compare them to observed values. To get an idea of farm incomes without these pronounced price increases we assume that the wheat price is fixed at the 2004 price. The resultant farm income values can be seen in Figure 41 along with observed farm incomes. Here we can clearly see that in the absence of grain price increase since 2004 the income of WA grain farms would have been much lower. Indeed, incomes would have fallen significantly from 2005 to 2010.

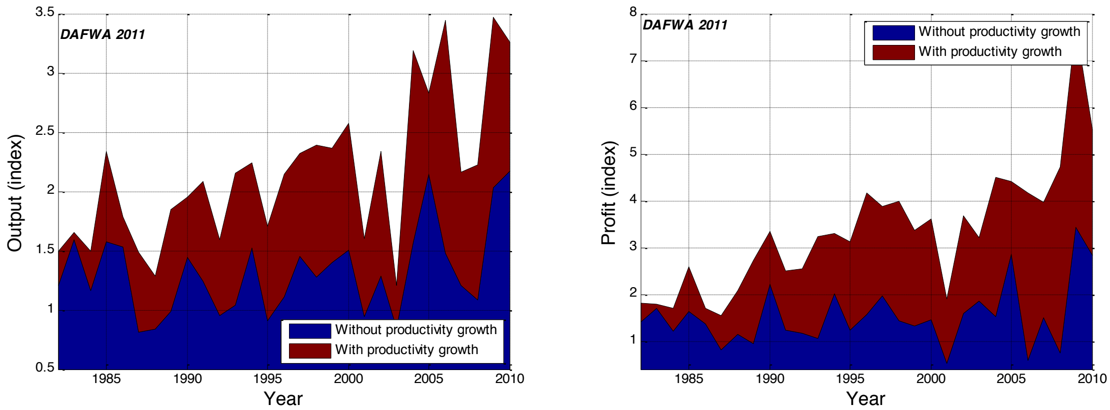
Figure 41: Trend of prices and Terms of Trade and output price impact



(c) Impact of productivity growth on output and profit

Using the same approach as outlined in section 3.2 above, the impact of productivity growth on farm output and profit is estimated by comparing a 'without' productivity gain scenario with observed values of output and profit. Results appear in Figure 42, which shows that in 2010 productivity growth actually enabled farmers to double their output and profit. In other words, without this productivity growth, average output and profit of WA grains farms would have been about half of the actual observed values.

Figure 42: Impact of productivity growth on output and income



A: Output **B: Profit**

5 Remarks

Over the past 30 years the average values per WA grain farm by farm size, land value, crop area, capital, fertilizer and materials, and fuel and energy have increased significantly. There has also been an increasing trend in the average value of output, revenue and costs of production and profit per farm over the last 30 years.

Revenue and cost varied significantly with rainfall zones. Capital, material and fertilizer costs in the low rainfall zones tend to be relatively low. Costs of production in this report by climate zone appear to be consistent with those reported by Bank West (2010).

In terms of key profitability and productivity indicators, both profit and TFP and adjusted profit and adjusted TFP (i.e. with rainfall effect adjustment) have shown an increasing trend over the past 30 years. However, adjusted profit and TFP have tended to increase at a higher rate, particularly since 2000. For all rainfall zones the rate of profit and productivity growth was higher between 1980 and 2000, but has since declined.

Along with profitability and productivity analysis, this report also provides an estimation of a stochastic production function and associated efficiency model. The technique allows us to isolate key inputs into grains production, and drivers of efficiency differences across rainfall zones. Our results indicate that efficiency in high and medium rainfall zones is generally greater than efficiencies in low rainfall zones. As we might expect, rainfall during growing time is a significant determinant of farm efficiency. Grains production exhibits constant returns to scale. Of all input variables into the stochastic production function, land area is the most important, followed by plant and equipment, materials and fertilizers, labour, energy and fuel costs. Labour is not a statistically significant variable.

The stochastic production frontier and efficiency analysis allow for a profile of farms according to efficiency ranking. By this measure, given the same rainfall conditions as those experienced in Medium Rainfall zones, farms which plant larger crop areas and which use more capital, materials and fertilizer tend to be more efficient.

The key factors influencing the economic performance of WA grain farms are: climate variability; productivity growth; and wheat prices. Rainfall during growing time is a main determinant, but it varies in its significance depending on rainfall zone. Climate conditions measured by rainfall level during growing time impacts significantly on grains production in all six rainfall zones, affecting TFP and profitability. The impacts of climate variation have increased over time.

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The average price of grain has increased substantially over last 6 years. As a consequence, average income and profit per farm has increased and compensated for the effects of less favourable rainfall conditions. Together with improvements in productivity, these high grain prices have sustained WA through a period of adverse climatic conditions.

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Appendix A: Methodology for productivity analysis

Index numbers are measures of relative change which are usually based on ratios. In this analysis the Törnqvist index is employed to measure productivity. This is a *log-change* index number based on the natural logarithms of ratios. Since both inputs and outputs are measured in value terms, an index is needed to construct real changes in the value of outputs and inputs, relative to a point of comparison (typically specified as a base year).

Formally, we define the value share of the *i*th commodity (input or output) relative to the value of all commodities as

(A.1)
$$\omega_{is} = p_{is}q_{is} / \sum_{i=1}^{n} p_{is}q_{is}$$

in base period *s*, for *n* goods, prices *p* and quantities *q*. The Törnqvist quantity index (*Q*) in log-change form for periods *t - 1* to *t* is

(A.2)
$$\log(Q_t / Q_{t-1}) = \sum_{i=1}^{n} \nu_{it} \log(q_{it} / q_{it-1})$$

where

(A.3)
$$\nu_{it} = (\omega_{it} + \omega_{it-1})/2.$$

The Törnqvist quantity index at *t* is thus

(A.4)
$$Q_t = Q_{t-1}\text{antilog}(\sum_{i=1}^{n} \nu_{it} \log(q_{it} / q_{it-1}))$$

Given that the climatic conditions are an input factor in determining farm management behaviour, the Törnqvist quantity index for any given time period is adjusted for rainfall. At *t, Q* is given by

(A.5)
$$Q_t = Q_{t-1}\text{antilog}\left[\left(\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{v}_{\mathrm{it}} \log(q_{it} / q_{it-1})\right) v_y \log(cli_t / cli_{t-1})\right]$$

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where cli_t and cli_{t-1} define the rainfall level during growing time indexed at t and t-1, respectively, and v_y is the share coefficient of climate conditions on grains production. Appendix C provides an analysis of the impact of rainfall on grain production.

Using equations (A.1) to (A.5), a Törnqvist index is calculated for both inputs and outputs, taken separately, with a chain-indexed base normalised to 100 for all variables. The ratio of Törnqvist outputs to inputs adjusted with climate conditions is therefore used to measure TFP. This is given by

$$\text{(A.6)} \qquad \ln TFP_{st} = \ln \frac{Output_{st}}{Input_{st}}$$

between periods s and t, or

$$\text{(A.7)} \qquad \ln TFP_{st} = \frac{1}{2}\sum_{i=1}^{n}(\omega_{is}+\omega_{it})(\ln y_{it}-\ln y_{is}) - \frac{1}{2}\sum_{j=1}^{M}(\upsilon_{js}+\upsilon_{jt})(\ln q_{jt}-\ln q_{js})$$

by weighted shares, for now y output and q inputs. Where appropriate, the quantity indexes for inputs contained in equation (A.7) are adjusted by a climate index, as in equation (A.5). A Törnqvist index is 'superlative' in the sense that it is based on a highly flexible, homogeneous translog production function, providing a second order approximation to any arbitrary twice-differentiable and linearly homogenous production function.

Using panel data from the ABARE annual grain farm survey data, DAFWA, ABS and BOM over the period of 1979/80-89 to 2009-10, a time series of the Törnqvist indexes is measured to analyse movements in inputs, outputs, TFP, adjusted TFP (i.e. for climate) and the terms of trade.

Appendix B: Estimation of the impact of rainfall variations on wheat production

Figure B1 shows average monthly rainfall and maximum temperature of the wheat growing season in the wheat belt area, 1980-2009. It can be observed that 2002-03 is the worst

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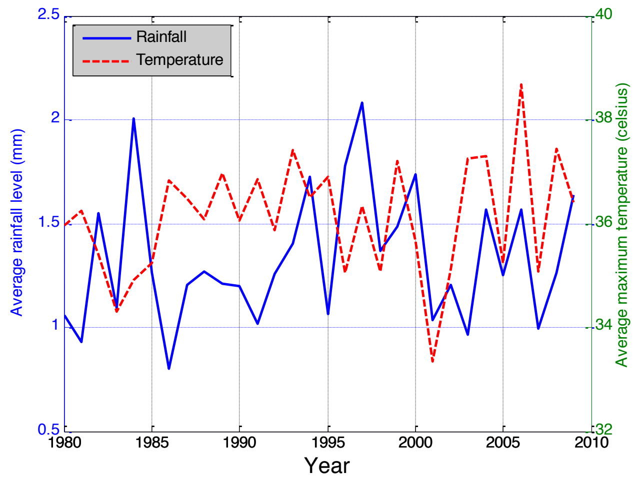
drought year based on the combination between a low average rainfall level and a high maximum temperature. 2007-2008 is also the year with very low average rainfall level and very high maximum temperature.

Figure B1: Average daily rainfall (mm) and maximum temperature (Celsius) of wheat growing seasons in the wheat belt area, 1980-2009



Source: computed from the sources of Australian Bureau of Meteorology, 2009.

The model of impact of rainfall and drought on grain yield is given by

(B1) $$Yield = A(time)^{\alpha_1}(rain)^{\alpha_2}(drought2003)^{\alpha_3}$$

where *yield* is measured in terms of kg per hectare; *time* represents the technology trend; *rain* is the average daily rainfall level during wheat growing season (mm); and *drought2003* is the dummy variable for the drought year 2002-2003.

The econometric specification is given by

(B2) $$\log(Yield) = const + \alpha_1(time) + \alpha_2(rain) + \alpha_3(drought2003)$$

Table B1 presents the econometric results of the estimation of impact of rainfall on WA grain yield over 1979/80 to 2008/09.

All estimated parameters are highly significant. The time trend indicates that grain yield had been increasing continuously at a rate of approximately 1 per cent per year. The increase in the average daily rainfall level by 1 per cent can lead to an increase of 0.37 per cent of yield. Along with the impact of low rainfall in a severe drought year of 2002-2003 the yield was reduced further by 21 per cent. The F statistics indicate that the regression is highly significant, at 99 per cent. The regression passed the diagnostic tests. The unit root tests of *log(yield)* and *log(rain)* indicate that the hypothesis that the variables are non-stationary is rejected at 99 per cent significant.

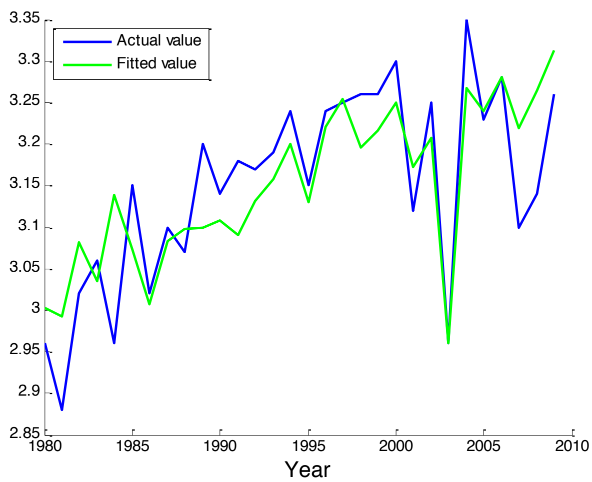
Table 7: Estimation of impact of rainfall in the wheat belt region on grain yield
(Dependent variable: yield (kg/ha))

Variable	Coefficient	Std. Dev
Constant term		
Time trend		
Rainfall level		
Drought 2003		
Number of observations: 30 (from 1979/80 to 2008/09)		
R-square: 0.66	F-stat: F(3,26): 17.02	
S.E of regression: 0.07		
Diagnostic tests: pass for order 1-3		
Function of form: pass		
Unit root test for *log(yield)* and *log(rain)*: pass at 95 and 99 per cent of significant.		

*Note: All variables are in logarithm forms. Numbers in parentheses are asymptotic standard errors. ***, **, and * statistically significant from zero at 99%, 95% and 90% level of significance.*

A plot of actual and fitted values of the regression is indicated in Figure 48.

Figure B2: Plot of actual and fitted values of regression (logarithm value of yield *(kg/ha)*



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