Decomposing Productivity and Efficiency among Western Australian Grain Producers

Peter R. Tozer and Renato Villano

We provide empirical evidence to decompose productivity growth of a group of producers into technical change and efficiency measures at the farm level. Using four years of farm-level data from forty-five grain producers in the low- to medium-rainfall zone of Western Australia, we decompose productivity numbers to analyze total factor productivity. The results show that producers are generally technical, mix, and scale efficient, but the results for input and output mix efficiencies vary. The outcomes for input mix efficiency suggest that producers face some rigidity in their production decisions. In contrast, output mix efficiency suggests that most producers adjust their output mixes to account for different seasonal conditions and enterprise mixes.

Key words: crop production, efficiency, productivity

Introduction

Improving total factor productivity (TFP) is seen as necessary for producers to remain competitive and profitable, particularly in markets where they face declining terms of trade (O'Donnell, 2010). Without increasing scale, higher TFP can be achieved in several ways, such as increasing output from the same level of inputs, generating the same level of output with a lower level of inputs, or changing the mix of inputs and or outputs. When changing output or input levels, the impact on profitability is typically positive. In the first case total revenue increases while costs remain constant, and in the second case revenue remains constant but costs decrease. An example of these types of changes comes from the adoption of precision agriculture technology in cropping systems. In this situation, producers reduce variable inputs by reducing overlaps of fertilizer or chemical application and, in some cases, increasing output, grain production, or placing inputs more accurately (Robertson et al., 2007).

Previous research studying efficiency or TFP has taken various approaches. One method is to compare the TFP of a sector over a period of time at a regional, state, or national level to analyze the impact of changing economic circumstances on that particular sector. For example, O'Donnell (2010) took a programming approach that evaluated the technical efficiency and TFP of the Australian agricultural sector from 1970 to 2001 and compared these measures to various countries, including the United States, New Zealand, and Canada. In that study, O'Donnell showed that TFP increased in years that terms of trade declined. Ball et al. (2001) utilized a Fisher's index approach and regression analysis to compare the productivity of farm sectors across a range of European countries and the United States from 1973 to 1993. That study suggested that the range of productivity levels of European producers narrowed relative to that of the United States during the period analyzed. Additionally, there was a positive correlation between capital accumulation and

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growth in productivity (Ball et al., 2001). However, Ball et al. (2001) did not estimate technical efficiency measures for each country over time.

In a review of public investment in research and development in Australian agriculture, Mullen (2007) analyzed numerous previous studies on productivity growth in the sector that utilized index construction and regression analysis techniques similar to Ball et al. (2001). Mullen concluded that public investment in research and extension translated into improvements in TFP but cautioned that the results must be interpreted with due consideration given to the assumptions made in these types of research.

An alternative to analyzing the TFP of a sector is to study the productivity of individual units within a sector. Alexander and Kokic (2005) used an approach similar to Ball et al. (2001) to investigate the productivity of a cross-section of Australian grain producers from three production zones over three different years. Their research used cross-sectional data to estimate TFP and the impact that various management factors—including stocking rates, tillage methods, environmental factors such as moisture availability, and farmer characteristics (such as education level or participation in off-farm educational programs)—had on factor productivity. Alexander and Kokic used three years of data to study how other influences, such as year, impacted TFP, but their data did not cover the same farms across the three years (i.e., it was not panel data). The study concluded that, as expected, moisture availability was a significant variable in estimating the TFP of producers within a year and was significant in most zones and most years. Other factors, including soil degradation and waterlogging, also affected productivity.

Various authors have studied productivity growth or factors affecting growth in Western Australian farming systems over time. Coelli (1996) used aggregate data for the state from 1953 to 1988 and concluded that productivity growth had occurred at a rate of 2.7% per year and that technical change was due to technology saving materials and services. In a different approach, Salim and Islam (2010) studied the impact of research and development expenditure on TFP growth and found that research and development expenditure had a unidirectional effect on TFP but also showed that TFP growth was significantly impacted by climate change. Using a very different method, Ahammad and Islam (2004) developed models of different production systems within three broad climatic zones in Western Australia. Their research demonstrated the impact on price elasticities of assuming homogenous production models within a state or assuming the same production model for all production systems in a country. They suggested that researchers take a regional rather than state or national approach to production systems to create credible analyses.

Using four years of panel data for fifty producers in Western Australia, Tozer (2010) analyzed the technical efficiency of these producers and showed how this efficiency varied over the time period. That study utilized a stochastic frontier analysis to model a simplified production function incorporating rainfall and fertilizer application rates to estimate a wheat yield production function and factors affecting the efficiency of wheat production. Tozer concluded that efficiency is stochastic in nature and may not be controlled fully by the producer. Unlike previous studies, Tozer examined technical efficiency only and not total factor productivity.

Data envelopment analysis (DEA) is another method for estimating the technical or allocative efficiency of individual producers. This method has been widely used in studying the efficiency of various agricultural industries in Australia, such as dairy (Fraser and Cordina, 1999) and wool production (Fraser and Hone, 2001), but there have been few applications to grain production in Australia (see for example Henderson and Kingwell, 2001).

O'Donnell (2010) proposed a method for estimating TFP and various measures of efficiency using an extension of the standard DEA model. Technical, scale, and mix efficiency can be decomposed using this method. The first two efficiencies are calculated in typical DEA analyses (allocative efficiency can also be calculated if prices and costs are available). The third measure of efficiency, mix efficiency, is novel in the O'Donnell (2010) framework. In previous studies such as Tozer (2010), Fraser and Hone (2001), and Henderson and Kingwell (2001), the evaluation of farmers' performance focused on estimating technical efficiency, which measures the distance of

observed output from the frontier and does not take into account possible inefficiencies attributed to output and input mix. Output (input) mix efficiency is defined as the ability to improve overall productivity by changing the output (input) mix of the business while holding the input (output) set fixed (O'Donnell, 2010). In other words, mix efficiency is the potential increase in productivity due to economies of scope rather than scale, as in the typical DEA model.

We utilize O'Donnell's (2010) framework to estimate the technical and mix efficiencies and the TFP for a panel of grain producers in the Northern Agricultural Region of Western Australia. This study enhances the literature regarding efficiency measurement, particularly mix efficiency studies, since this is one of the initial applications of the decomposition technique at the micro-unit level. Previous studies using the decomposition technique have typically been at an aggregated level (see for example O'Donnell, 2010). The information generated can provide assistance to researchers as to which aspect of mix efficiency (input or output) is more flexible and can be adjusted more easily in seasons when conditions may be uncertain as well as the impact of this flexibility on other efficiencies in the system. Furthermore, information about factors that constrain productivity and productivity growth provides policy makers with guidance as to which investment (research and development or extension) would provide the highest return (O'Donnell, 2010). Also, as mix efficiency is affected by the relative prices of inputs and outputs, assistance on policies such as taxes, subsidies, or programs that change relative prices can be determined. One example of a policy that changes relative prices for primary producers in Australia is the fuel-tax rebate (Commonwealth of Australia, 2002), which reduces the cost of diesel for primary producers and changes the relative costs of crop and livestock production. Since crop production requires significantly more diesel than does livestock production, the rebate has the potential to change the mix of activities within a farm system.

Western Australian Agriculture

Agriculture in some form is undertaken throughout most of Western Australia. The state can be divided into three major regions (high rainfall, low to medium rainfall, and pastoral), with some agriculture undertaken in the tropical north. The high rainfall zone is in the far southwest corner of the state; dairy, viticulture, and horticulture dominate agricultural production due to the weather and proximity to Perth, the state capital and major population center. The low to medium rainfall zone covers the southwest corner of the state, north and east of the high rainfall zone to Northampton in the north, as far east as Esperance, and to the northeast out to the 250 mm isohyet. Agriculture in this zone is dominated by broadacre cropping and livestock activities. Agriculture in the remainder of the state (except for a relatively small area in the Ord River Scheme in far northern Western Australia) is dominated by pastoral or very extensive low-stocking-rate sheep and cattle activities, with sheep dominant in the southern pastoral regions and cattle in the north.

This study focuses on the Northern Agricultural Region (see figure 1). Due to the Mediterranean climate (cool, wet winters and hot, dry summers) in this region, the principal crop is wheat with some other cereals, including barley and oats. Crops such as field peas, chickpeas, lupins, and canola are used in rotation. The main livestock activity is self-replacing Merino flocks producing wool and lambs, with some cattle and exotic sheep breeds—such as Dorpers—using principally annual pastures with some areas of perennial pastures. Rainfall patterns limit cropping activities to winter crops.

Method of Analysis

Total factor productivity change can be decomposed into technical change and TFP efficiency changes, where TFP change can be further decomposed into technical, scale, and mix efficiency change.
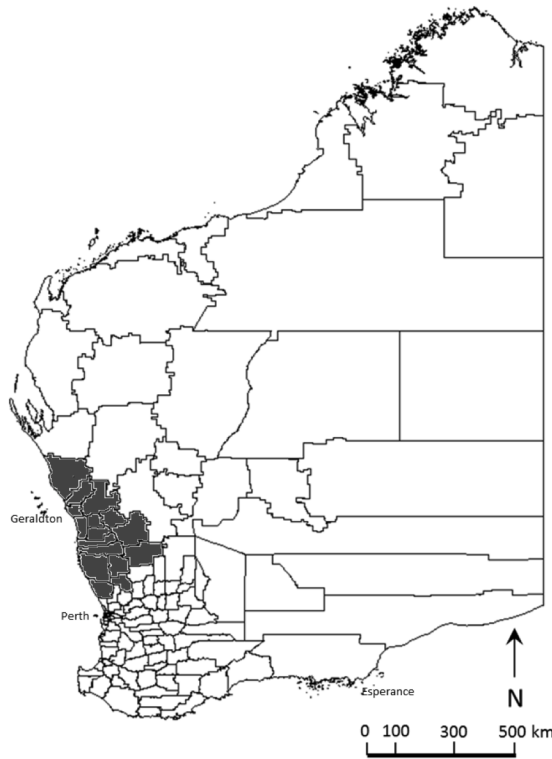
Figure 1. Map of Western Australia Showing Location of the Northern Agricultural Region

Following, O'Donnell (2008, 2012), we assume that $\boldsymbol{q}_{nt}$ and $\boldsymbol{x}_{nt}$ are output and input vectors for firm n in period t. Total factor productivity (TFP) is the ratio of all outputs generated from the set of inputs used to produce the output. This can be measured as

$$(1) \qquad\qquad TFP_{nt} = \frac{Q_{nt}}{X_{nt}},$$

where Q_{nt} is the aggregate level of output from firm n and X_{nt} is the aggregated inputs of the firm in time t.[1] Australian agricultural producers have faced declining terms of trade (input costs increase at a faster rate than output prices) for many years, but the rate of decline in terms of trade has slowed somewhat in the past decade (Australian Bureau of Agricultural and Resource Economics and Sciences, 2010). O'Donnell (2010) demonstrated that producers' profitability can be decomposed into two measures, terms of trade and TFP, and demonstrated that increasing (decreasing) terms of trade can induce declining (increasing) productivity.

TFP change for two firms, n and m, and two time periods, period s to t, can be measured as

$$(2) \qquad\qquad TFP_{ms,nt} = \frac{TFP_{nt}}{TFP_{ms}} = \frac{Q_{nt}/X_{nt}}{Q_{ms}/X_{ms}} = \frac{Q_{ms,nt}}{X_{ms,nt}},$$

where $Q_{ms,nt}$ and $X_{ms,nt}$ are multiplicatively complete output and input quantity indexes, respectively, as defined in O'Donnell (2008, 2010).

Following O'Donnell (2008, 2010), efficiency measures can be decomposed into output technical, mix, and residual scale efficiencies or input technical, scale, and residual mix efficiencies. Figure 2 depicts the analytical framework in stylized form.

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[1] The aggregate input and output quantities are obtained using aggregator functions with properties that are nonnegative, nondecreasing, and linearly homogenous (see O'Donnell, 2012, for further details).
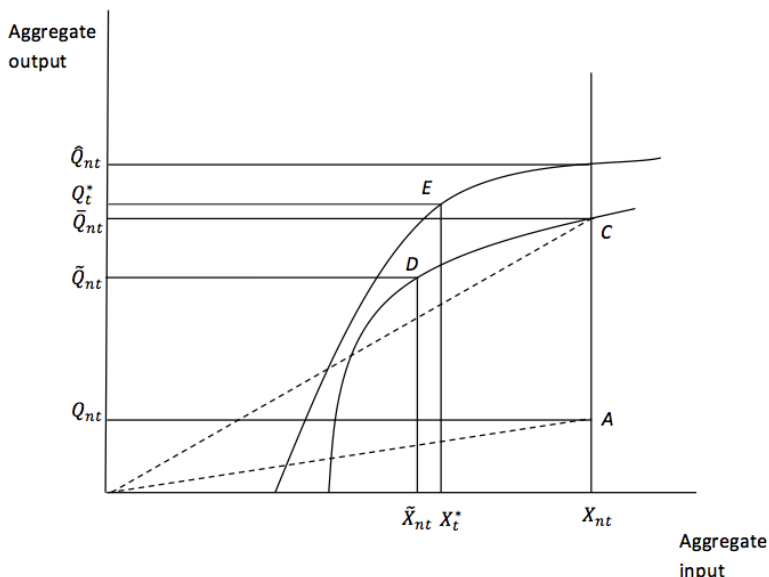
Figure 2. Measures of Efficiency

Notes: Adapted from O'Donnell (2010).

Measures of efficiency can be calculated based on the orientation of production technology. An output orientation considers a maximal proportional expansion of the output vector given sets of inputs. An input orientation characterizes the production technology by looking at a minimal proportional contraction of the input vector given an output vector. From figure 2, measures of technical efficiency can be obtained as follows. Output-technical efficiency (OTE) is given as

$$(3) \qquad OTE_{nt} = \frac{Q_{nt}}{\bar{Q}_{nt}}.$$

Accordingly, output-oriented scale efficiency (OSE) is defined as

$$(4) \qquad OSE_{nt} = \frac{\bar{Q}_{nt}/X_{nt}}{\tilde{Q}_{nt}/\tilde{X}_{nt}}.$$

The output-oriented mix efficiency (OME) is given as

$$(5) \qquad OME_{nt} = \frac{\bar{Q}_{nt}}{\hat{Q}_{nt}}.$$

The residual output-orientated scale efficiency is defined as

$$(6) \qquad ROSE_{nt} = \frac{\hat{Q}_{nt}/X_{nt}}{Q_t^*/X_T^*}.$$

The residual mix efficiency (RME) is defined as

$$(7) \qquad RME_{nt} = \frac{\tilde{Q}_{nt}/\tilde{X}_{nt}}{Q_t^*/X_T^*},$$

where $\bar{Q}_{nt}$ is the maximum aggregate output that is technically feasible when x_{nt} is used to produce a scalar multiple of q_{nt}, $\hat{Q}_{nt}$ is the maximum aggregate output that is feasible when using x_{nt} to produce any output vector, $\tilde{Q}_{nt}$ and $\tilde{X}_{nt}$ are the aggregate output and input obtained when TFP is

Table 1. Summary Data for Output, 2004–2007

Year	Wheat (t/ha)	Lupins (t/ha)	Barley (t/ha)	Canola (t/ha)	Wool (kg/hd)
2004	1.98	0.86	1.76	0.41	4.08
	(0.54)	(0.57)	(0.77)	(0.58)	(2.06)
2005	2.22	1.27	1.77	0.51	3.79
	(0.45)	(0.77)	(1.08)	(0.70)	(2.13)
2006	1.33	0.49	1.08	0.16	4.61
	(0.54)	(0.47)	(0.87)	(0.33)	(1.44)
2007	1.83	0.86	1.78	0.37	4.32
	(0.88)	(0.67)	(1.25)	(0.60)	(1.04)

Notes: Values in parentheses are standard deviations.

maximized subject to the constraint that the output and input vectors be scalar multiples of $\boldsymbol{q}_{nt}$ and $\boldsymbol{x}_{nt}$, (O'Donnell, 2010, p. 533), and Q_t^* and X_T^* denote the TFP-maximizing aggregate output and aggregate input.

The O'Donnell (2008, 2010, 2011) measure of overall productive efficiency of a firm is defined as the ratio of observed TFP to the maximum possible using the available technology:

$$(8) \quad TFPE_{nt} = \frac{TFP_{nt}}{TFP_t^*} = \frac{Q_{nt}/X_{nt}}{Q_{nt}^*/X_{nt}^*} = OTE_{nt} \times OME_{nt} \times ROSE_{nt} = OTE_{nt} \times OSE_{nt} \times RME_{nt}.$$

In an input orientation, this measure of productive efficiency can be expressed as

$$(9) \quad TFPE_{nt} = ITE_{nt} \times IME_{nt} \times RISE_{nt} = ITE_{nt} \times ISE_{nt} \times RME_{nt},$$

where

$$(10) \quad ITE_{nt} = \frac{\bar{X}_{nt}}{X_{nt}};$$

$$(11) \quad ISE_{nt} = \frac{Q_{nt}/\bar{X}_{nt}}{\tilde{Q}_{nt}/\tilde{X}_{nt}};$$

$$(12) \quad IME_{nt} = \frac{\hat{X}_{nt}}{\bar{X}_{nt}};$$

$$(13) \quad RISE_{nt} = \frac{Q_{nt}/\tilde{X}_{nt}}{Q_{nt}^*/X_{nt}^*}.$$

The estimation of these concepts either requires sets of distance functions and linear programming problems or can be estimated using parametric models as shown in O'Donnell (2012). The measures in equations (10) to (13) are estimated using the program Decomposition of Productivity Index Numbers (DPIN 3.0) (O'Donnell, 2010, 2011). The Fare-Primont index developed by O'Donnell (2012) was used to obtain measures of productivity and efficiency by allowing for technical change and variable returns to scale (VRS). All input and output variables are normalized to unit means (O'Donnell, 2011). The models use constructed aggregate numbers, but the data presented in tables 1 and 2 report average per hectare values to show year-to-year variation in some inputs and outputs.

In using this method, we have considered the different components that measure movements in the production frontier, movements toward and away from the frontier, and measures associated with the economies of scale and scope. The method is slightly different from the directional distance function approach; in the O'Donnell (2010) approach no assumptions are made about the direction taken to achieve the production frontier, whereas in the directional distance function an assumption must be made as to the "correct" direction needed for each firm to reach the production frontier (Coelli et al., 2005). However, in the O'Donnell (2010) approach the direction of movement to the frontier is made through the choice of orientation, either input or output.

Table 2. Summary Data for Inputs, 2004–2007

	Nitrogen	Phosphorus	Effective Rainfall	Fuel	Sheep Expenses	Operating Costs	Wages and Salaries
Year	kg N/ha	kg P/ha	mm	$/ha	$/hd	$/ha	$
2004	47.74	10.20	193	26.48	15.77	101.65	105,254
	(15.12)	(3.10)	(45)	(11.33)	(12.39)	(32.72)	(42,876)
2005	48.38	9.74	249	31.33	15.84	96.35	105,149
	(16.42)	(2.73)	(46)	(11.29)	(13.65)	(30.04)	(39,805)
2006	28.26	8.00	128	33.80	22.67	84.88	103,220
	(15.21)	(2.94)	(36)	(12.93)	(20.46)	(32.51)	(39,580)
2007	34.01	8.59	164	33.20	19.46	89.41	105,753
	(19.34)	(3.62)	(61)	(16.15)	(20.57)	(37.14)	(41,628)

Notes: Wages and salaries include an allowance for management of $50,000 per year plus 1% of gross asset value of business. Values in parentheses are standard deviations.

Data and Variables

Data from forty-five farms were sourced from a farm management consultant's database. Farm businesses in the database were located in the low-medium rainfall zone of the Western Australia wheatbelt. The data include numerous production and financial variables such as total farm area, total crop area, individual crop yields and area, fertilizer and chemical inputs, fuel usage, gross income, fixed and variable costs, equity level, and return on capital and equity. The version of the decomposition algorithm used in this research required a balanced data set (O'Donnell, 2011),[2] forty-five farms were selected from a database of approximately 300 businesses based on the availability of four continuous years of data from 2004 to 2007. Also, using a balanced data set allows us to determine whether patterns of change in efficiency occur within and across businesses over the period of study. The summary data presented in tables 1 and 2 are averages per hectare across the four years of the study that show the year to year variability, which may not be apparent when presenting total inputs or outputs.

All output variables in the models are expressed in total (metric tons) produced per farm. The outputs in the current study are those generated by a typical farming system in the region studied. Other crops may also be grown (such as oats, oats for hay, or legume field crops, including field peas or chickpeas), but these are not included in the output generated because these crops typically represent a very small fraction of total output. Not all crops or wool are produced in any one year due to seasonal rainfall, rotational requirements, or crop preferences of a producer, and in the case of wool some producers have taken livestock out of the system completely. In the data set there are seven producers that have no livestock, cattle, or sheep in their system; these producers are included in the analysis.

In the empirical estimation, all input variables are expressed as total for the whole farm. It is implicitly assumed in the analysis that soil type, although variable across the state, is homogenous in the region of study. The variables included in the model are effective rainfall (RF) measured in millimeters (mm) and total nitrogen (N) and phosphorus (P) inputs. Effective rainfall is an adjusted rainfall measure with an allowance made for evaporation in both the summer and during the growing season and is measured as

$$(14) \qquad RF = 30\% \times \; summer \; rainfall \; + \; (growing \; season \; rainfall \; - \; 50mm),$$

where summer is January through March and the growing season is April through October (Tozer, 2010). Effective rainfall rather than total water availability is used because data on soil water content or soil water availability were not available. From table 2 it is possible to see the variability in effective rainfall in a year and across the four years represented in the model. Typically,

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[2] Newer versions of the DPIN software do not require balanced data sets.

Western Australia has a Mediterranean-type weather pattern with hot, dry summers and mild, wet winters. Total average rainfall in the region, measured at Geraldton—the major city in the Northern Agricultural Region—in summer (January–April) is 61mm, and average growing season rainfall is 309mm (Bureau of Meteorology, 2011). The seasonal break is a trigger point for producers to begin sowing operations and is assumed to occur when more than 25mm of cumulative rainfall over three days is received after April 15. Rainfall in 2006 was the lowest on record for Western Australia and the seasonal break was extremely late, which is the reason for the low application rate of nitrogen in 2006. Many producers delayed sowing crops until late in the growing season. If they did sow crops, they applied low levels of nitrogen to reduce the potential economic losses in the event that crop failure resulted from lack of rain later in the season. The first year, 2004, was a "typical" year for the representative farms. The year 2005 was an above average year and 2007 was a below average year in terms of rainfall and wheat yield across the wheat production zone of Western Australia.

The other input variables included represent other major costs to the business. Technical efficiency and productivity are quantity concepts, and inputs would ideally be expressed in physical units, but this type of data is rarely available. Instead, we used various cost measures, which were deflated by the index of prices paid for agriculture (Australian Bureau of Agricultural and Resource Economics and Sciences, 2010). Operating costs capture all other operating costs excluding fertilizer, fuel, sheep expenses, and labor and included herbicide and pesticides, contracting, freight, and seed costs. The wages and salaries costs are generated from payments to nonfamily permanent and casual labor, excluding contractors, and an allowance for management. The management allowance is calculated as a fixed base of $50,000 plus 1% of the gross asset value of the business, with the $50,000 representing a labor market value for the owner/manager's labor input and the 1% representing the management value of the skills of the owner/manager. This variable also serves as a proxy for capital investment in the business. Sheep expenses are separated out of the operating costs to allow for differences in input cost breakup between cropping and sheep enterprises.

Results and Discussion

The results of the decomposition are presented in table 3 and figures 3, 4, 5, and 6. Table 3 shows that overall average technical efficiencies, either input or output, are relatively high. However, there is some variation in mix efficiencies, particularly IME, in year-to-year comparisons when taking the very dry year of 2006 into account. The annual average of output mix efficiency varies over the study period, ranging from 0.9671 to 0.9899 with an overall mean of 0.9790. Across all years, the range of output mix efficiency is 0.4768 to 1, and within years the ranges are 0.8064 to 1 in 2004, 0.8999 to 1 in 2005, 0.6338 to 1 in 2006, and 0.4768 to 1 in 2007. The distribution of all efficiency scores is also presented in figure 3, which shows that approximately 80% of the scores are efficient (i.e., with a score of 1). The distribution also shows that a further 18% of scores fall in the range 0.9 to 0.99 and only three scores fall outside these two ranges (one in 2006 and two in 2007). Figure 4 presents the distribution of output efficiency scores for each year of the study. This figure follows a pattern similar to the aggregated frequencies shown in figure 3, with the positioning of the mode consistently in the highest range in all years. Figure 4 shows a slight increase in output mix efficiency aver the first three years of the study, then a decline in 2007.

In contrast to the output mix efficiencies, the average input mix efficiency ranged from 0.8931 to 0.9510, with the lowest values corresponding to the low rainfall years of 2006 and 2007, demonstrating that producers did not or could not adjust their input mixes to cope with changing production systems and the impact of dry years, or—alternatively—that producers were simply minimizing their costs in these years. This could also suggest that there is some form of rigidity in the production process that limits producers from fully adapting their input mix to changes in the production process. This rigidity could take the form of crop/pasture rotational constraints, crop preferences of the grower, or fixed capital constraints such as shearing sheds or machinery capacity.

Table 3. Average Output and Input Technical and Output and Input Mix Efficiencies for Each Year

Year	Average OTE	Average OME	Average OSE	Average ITE	Average IME	Average ISE	Average ROSE	Average RME	TFPE	Technical Change (Compared to 2004)
2004	0.9957	0.9813	0.9937	0.9971	0.9510	0.9932	0.6511	0.6419	0.6355	1.0000
	(0.0220)	(0.0438)	(0.0264)	(0.0155)	(0.0638)	(0.0278)	(0.1440)	(0.1353)	(0.1387)	
2005	0.9984	0.9899	0.9881	0.9995	0.9484	0.9870	0.6243	0.6231	0.6172	1.0721
	(0.0108)	(0.0249)	(0.0291)	(0.0033)	(0.0737)	(0.0305)	(0.1794)	(0.1735)	(0.1792)	
2006	0.9990	0.9850	0.9683	0.9995	0.8931	0.9678	0.5765	0.5796	0.5668	0.9211
	(0.0041)	(0.0576)	(0.0811)	(0.0022)	(0.1240)	(0.0812)	(0.2149)	(0.2072)	(0.2159)	
2007	0.9943	0.9671	0.9617	0.9964	0.9198	0.9596	0.6198	0.6089	0.5934	0.9393
	(0.0299)	(0.1127)	(0.1258)	(0.0207)	(0.1052)	(0.1274)	(0.2262)	(0.2226)	(0.2380)	
All Data	0.9968	0.9790	0.9779	0.9981	0.9781	0.9767	0.6179	0.6134	0.5772	
	(0.0194)	(0.0685)	(0.0779)	(0.0131)	(0.0969)	(0.0788)	(0.1933)	(0.1875)	(0.2053)	

Notes: Values in parentheses are standard deviations.
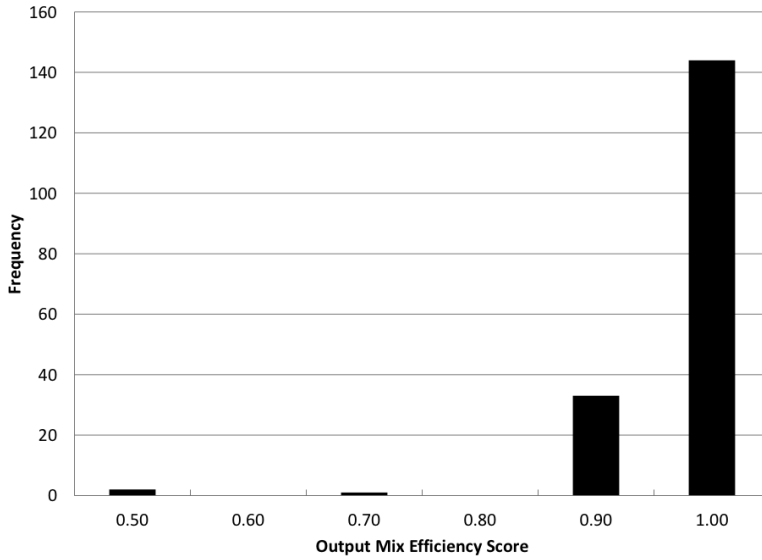
Figure 3. Distribution of Output Mix Efficiency Scores for All Observations, 2004–2007
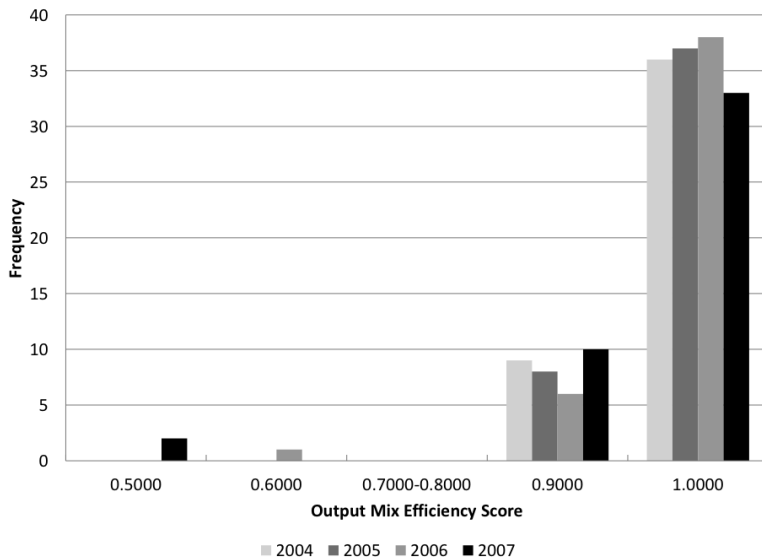

Figure 4. Distribution of Output Mix Efficiency Scores, 2004–2007

The lowest average efficiencies in the drought year and the following low rainfall yield could also be explained by the large amount of inputs used at the beginning of the cropping year. In many crop systems in the region of study, up to half of the inputs are applied at sowing to take advantage of soil moisture or rainfall events. Thus there is limited flexibility when the year takes a disadvantageous turn (e.g., toward drought). Within-year variability of input mix efficiency is also slightly higher than for output mix efficiency. In 2004 the range was from 0.7469 to 1, in 2005 the range was 0.6186 to 1, 0.5779 to 1 in 2006, and 0.5969 to 1 in 2007. Also, as shown in figure 5 the distribution of efficiencies is skewed to the left, indicating that in general producers are relatively efficient in their input mix combinations, even when the input mix differs from year to year; approximately 90% of
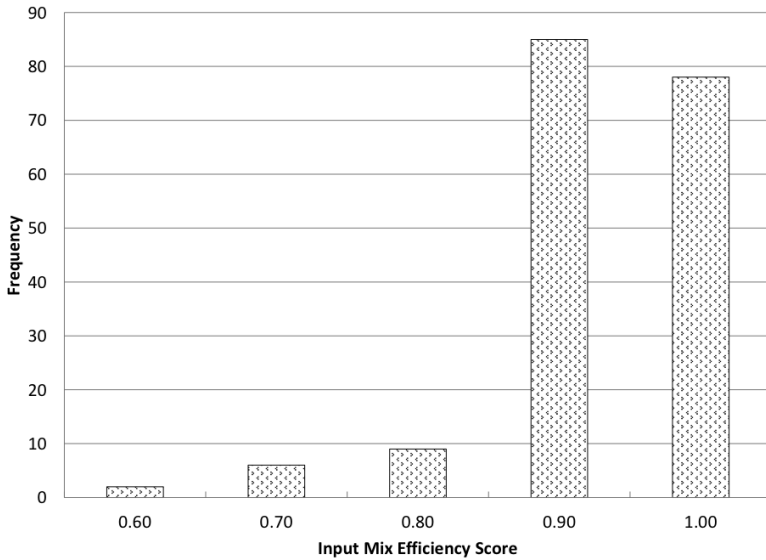
Figure 5. Distribution of Input Mix Efficiency Scores for All Observations, 2004–2007
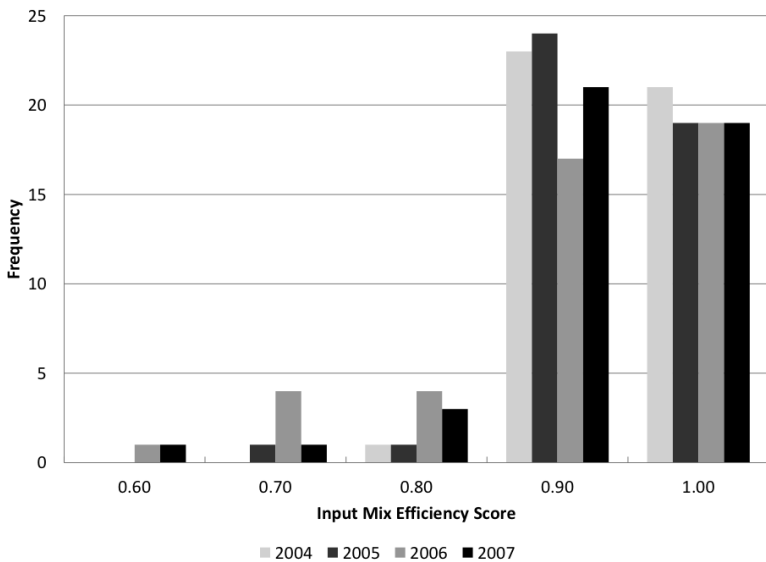

Figure 6. Distribution of Input Mix Efficiency Scores, 2004–2007

observations of input mix efficiency scores were greater than 0.9. The challenges of changing input mix are shown in figure 6. This figure follows a pattern similar to that of output efficiency in that the frequencies for a bad year have moved to the left, with the mode for 2007 in the 0.9–0.99 range rather than 1 and more observations in the 0.70–0.79 and 0.80–0.89 ranges than in earlier years. The average and above average years had distributions with a large number of observations in the higher efficiency ranges, whereas in the poor years, particularly 2006, the distributions had relatively more observations in the lower end of the efficiency scores.

Scale efficiency scores tended to follow a pattern similar to those of output or input mix efficiencies—relatively high with low variability in 2004 and 2005—but in 2006 and 2007 scale

Table 4. Average Output and Input Technical and Output and Input Mix Efficiencies for the Firms Listed across All Years

Firm ID	Average OTE	Average OME	Average OSE	Average ITE	Average IME	Average ISE	TFPE
10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9749
25	0.9510	0.8649	0.9647	0.8615	0.8809	0.9497	0.5405
35	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.3456
40	0.9858	0.9670	0.9557	0.9920	0.9038	0.9495	0.4795
41	1.0000	0.9846	0.8176	1.0000	0.9779	0.8176	0.3783
44	1.0000	1.0000	0.8231	1.0000	1.0000	0.8231	0.4991

efficiency scores declined and became more variable. A relatively simple explanation can be given for this effect: some producers simply reduced crop area or livestock numbers in the two bad years as a risk mitigation tactic, but the area of the farm remained constant. For example, producer 44 (table 4) reduced crop area from approximately 2,400 ha in 2006 to 550 ha in 2007; the scale efficiency score for this producer in the first three years was 1 and fell to 0.2923 in 2007.

Technical factor productivity efficiency (TFPE), shown in equation (9), is the product of technical, (residual) mix, and (residual) scale efficiencies. As discussed above and shown in table 3, most producers were technical, scale, and mix efficient, with average scores close to 1, yet average TFP across years was 0.5724. Thus, firms are not maximizing TFP even though they are technically, mix, or scale efficient; the difference between maximum TFP and actual TFP is determined by the ROSE or RME. The ROSE measures the "distance" from the position of the firm on the unrestricted production frontier to the point of maximum productivity, point E (figure 2), and is essentially a scale effect. However, changes in input and or output mix can also occur (thus the use of the residual term). Movements from the mix restricted frontier (point D) to the unrestricted frontier (point E) are captured by the RME. Again, much of the change is due to mix, but there can be some scale effects (hence the residual term). On average, the residual output-oriented scale efficiency is approximately 61.8%. In the same manner, the average residual mix efficiency is 61.4% after taking into account the pure technical efficiency and scale efficiency. Thus, producers are not producing at the point of maximum productivity even though they are technically, mix, or scale efficient in their use of inputs when producing outputs. Table 3 also presents technical change and technical efficiency values over the period of study. The average TFP efficiency was 57.7%, measured as the ratio of an individual firm's TFP each year divided by the highest TFP of all firms in each year. While average levels of output technical, mix, and scale efficiency are high, TFP efficiency was relatively lower, driven mostly by lower levels of residual scale and mix efficiencies. Total factor productivity and TFP efficiency followed similar trends as technical and mix efficiency in that these measures descreased in the drier years of 2006 and 2007.

Solow (1957, p. 312) defines technical change as "any kind of shift in the production function." Romer (1990) suggests that technical change occurs as a result of a new set of instructions becoming available and that these instructions can be used repeatedly until a newer set is developed. Hence, technical change encompasses changes in the production set because of changes in the production environment. Average technical change over the period was -1.5% when compared to the 2004 baseline, which is below Salim and Islam's (2010) finding of 2.2% for Western Australian broadacre agriculture from 1977–78 up to 2005–06. However, care must be taken in interpreting the technical change over such a short period, particularly with the impact of drought in 2006 and a below average year in 2007. The impact of the drought year on technical change can be seen in table 3. In 2005, technical change was 7.7% compared to 2004, whereas technical progress declined and fell by 15% in 2006 compared to 2004, when producers reduced inputs or changed production techniques. This type of response was also observed in Coelli et al. (2005). However, technical progress rebounded slightly in 2007 by 1.8%, indicating that producers responded to improved seasonal conditions,

could change their production possibility sets,[3] and positive technical growth occurred. Therefore, in the context of Solow (1957) and Romer (1990), the drought imposed a technical change when producers reverted back to an "older" set of instructions.

Table 4 summarizes the various efficiencies for a sample of firms in the data set; firms were selected to provide examples of different tactics over the period of study. The table demonstrates the differences between individual firms in the region. Producer 10 in table 4 was on the efficiency frontier in all years for input/output technical and mix efficiencies. This producer also had the highest TFPE, with a score of 1 in two years and greater than 0.9 in the other two years. Producer 10 had a mix of cereal grains and lupins in their TFP maximizing enterprise mix and no sheep or canola. One potential reason for this producer's efficiency is that they are located in one of the low rainfall zones, and their ability and skill to respond to dry years (such as 2006 and 2007) may be enhanced compared to producers in the medium and high rainfall zones, as they are confronted with these situations more often than producers in the other rainfall zones. Similar efficiency scores were achieved by producer 35, except that this producer's TFPE for was well below average at 0.3456. There are several potential reasons for these relatively low efficiency scores. The first is that this producer is relatively small in terms of overall scale of production, which is captured in the residual scale efficiency, ROSE and RISE, scores of 0.30 to 0.41. Producer 35 also grew a much smaller area of wheat and had relatively high sheep numbers for the area of the farm. However, even though the relative scale of production was small, producer 35 was technically, mix, and scale efficient. In contrast to the relative efficiency of producer 10, producers such as 25 or 40 had average technical, mix, or scale efficiency scores below 1. The technical efficiency score for producer 25 was 1 in 2004, 2005, and 2006, but fell to 0.8038 in 2007; this was principally due to very low yields of wheat and lupins in 2007. Producer 25 was input mix efficient in 2004 and 2005 but not 2006 and 2007, indicating the impact of the dry season on the expected profitable crop mix in those two years, as producer 25 forsook scale or mix efficiency for profitability. As noted earlier, O'Donnell (2010) suggested that profit and efficiency are conflicting goals, so producers will sacrifice mix or scale efficiency for profits to ensure they can survive in the long term, particularly in years when profits are expected to be low (e.g., drought years). In contrast to producer 25, producer 40 was technically and mix efficient in the dry years (2006 and 2007) but not in the better years (2004 and 2005), which could again be explained by the conflicting goals of efficiency and profitability.

Johansen (1959) proposed that there is substitution between labor and capital when investors are considering a capital investment. However, once the investment is made (i.e., the capital or machine is installed into the production system) no substitution between labor and capital is possible. This is what is now commonly termed the putty-clay model of investment; that is, plasticity, or substitution (putty), is allowed *ex ante* of an investment decision, but fixity, or non-substitution (clay), occurs *ex post*. The putty-clay hypothesis implies that the productivity of capital of a certain vintage is essentially fixed and that this fixity remains until the capital item is replaced. Once that capital item is replaced, the productivity of the firm increases, as it is assumed that newer technology is more efficient (Gilchrist and Williams, 2000). Examining the input mix efficiency scores shows that there is fixity in the production decisions of some producers and that this rigidity in mix may be due to a putty-clay effect of the technology available to individual producers. A putty-clay effect may also be present in the decision-making ability of some producers (i.e., in the human capital) due to the age of producers (i.e., older producers may be "fixed" in their choice of rotation or crop/variety), therefore lowering the input mix efficiency, even though they may be mixing the outputs efficiently.

One point that is apparent from the analysis is that uncertainty is present in all decisions made by producers in the sample. O'Donnell, Chambers, and Quiggin (2010) suggest that efficiency analyses made in the presence of uncertainty can lead to biased measures of efficiency. Input decisions are made by producers prior to the state of nature occurring, and therefore any efficiency measures are

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[3] The production possibilities set contains all feasible input and output combinations (Chambers, 1988). Therefore, the production possibility set can change as expected inputs (e.g., rainfall) vary, which can affect the feasible set of input/output combinations.

impacted by the state of nature (O'Donnell, Chambers, and Quiggin, 2010). In the current study, producer decisions are made once the state of nature has been at least partially revealed. This is especially evident in the drought year of 2006, when producers applied very little fertilizer, as shown in table 2. This is consistent with producers making state-dependent decisions rather than the outcomes being state contingent. However, outputs in the current study could be somewhat state contingent in some cases, as producers do not have full information with respect to future rainfall events at planting time. However, the level of bias in the results would not be as high as suggested by O'Donnell, Chambers, and Quiggin (2010). The levels of the technical efficiency measured in this study suggest that producers can, and did, change their production practices through changes in input use and output mix to account for the states of nature as they occurred.

Conclusion

This research decomposed the efficiency scores of a set of grain producers in Western Australia into output, input, and technical efficiencies using the technique laid out by O'Donnell (2010). The results showed that producers are confronted with some rigidities in production, as seen in the low input mix efficiencies, whereas the output mix efficiencies indicate that producers can and do change their output mixes to improve the efficiency of their production systems. Previous research has shown that productivity increases are essential to the growth of an economy and for producers within that economy to remain competitive, both with producers within the economy and those from competing economies. However, productivity growth within the Australian agricultural production sector is slowing after several decades of steadily increasing growth (Mullen 2007, among others). The current research shows that economic progress of individuals within the economy is limited by the rigidities of their production systems, and that it may not be possible for producers to increase their economic progress without investing in new technology. Alternatively, rigidities caused by producers' personal preferences, such as crop selection or rotation policy, are embedded in the producers' human capital set and are difficult to alter, thus limiting progress somewhat. These rigidities present interesting problems for both researchers and extension agencies with a mandate to enhance productivity or increase productivity gains within the grains sector, as it is not possible in some cases to remove these rigidities in short periods of time as could be possible with new technologies.

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