Australian Government
Australian Bureau of Agricultural and Resource Economics and Sciences

AARES
Australian Agricultural and Resource Economics Society
9–11 February 2011, Melbourne, Victoria

11.06

Productivity and farm size in Australian agriculture: reinvestigating the returns to scale

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Abstract

Higher productivity among large farms is often assumed to be a result of increasing returns to scale. However, using farm-level data for the Australian broadacre industry, it was found that constant or mildly decreasing returns to scale is more typical. On examining the monotonic change in marginal input returns as farm operating size increases, it was found that large farms achieve higher productivity through changes in production technology rather than through changes in scale. The results highlight the disparity between 'returns to scale' and 'returns to size' in Australian agriculture. They also suggest that improving productivity in smaller farms would depend more on their ability to access advanced technologies than their ability to simply expand. The implications for ongoing structural adjustment in Australian agriculture are discussed.

Keywords; returns to scale, returns to size, production function, technology progress, structural adjustment, Australian agriculture

Acknowledgments

The authors thank many people who provided valuable data assistance or feedback on earlier drafts of this article, including Hiau Joo Kee. All remaining errors are our responsibility. The views expressed here are those of the authors and not necessarily of ABARES or the ABS.

ABARES project: 43025

ISSN: 1447-3666

1 Introduction

Previous studies commonly identify a positive relationship between farm size and productivity growth. The paper extends this work by asking: how do larger farms achieve higher productivity than smaller farms in the Australian broadacre industry? Understanding the determinants of productivity growth has important implications for ongoing structural adjustment and the overall performance in Australian agriculture.

Structural adjustment—in response to changes in technology, demand, climate, social values, policies and the global economy—has been a key force behind productivity growth and competitiveness within the agriculture sector (Musgrave 1990). However, while ongoing structural adjustment is highly desirable, it is widely accepted that economic losses may still be experienced by some farmers and farm sectors (Musgrave 1990, Lawrence and Williams 1990, Nelson et al. 2005).

For many decades, the Australian Government has introduced measures to stimulate structural adjustment as well as measures to minimise consequent losses and hardships. In some cases, however, government involvement has hindered structural adjustment and hence productivity growth, which creates a desire to understand more broadly the drivers of productivity differences across farms and the potential role for rural adjustment programs.

Structural adjustment includes changes in land, labour, capital and resource use. In response to shifts in physical, policy, economic and social factors associated with farming, the ability of Australian farmers to effectively adapt and reallocate resources is a sign of resilience. For several decades there has been a steady reduction in farm numbers and a trend toward a smaller number of larger, amalgamated farms. Farm businesses most likely to exit industry are ones that are unviable and unable to readily adapt to changing conditions and those where the principal operators choose to retire.

In examining this trend in farm numbers and average business operating size, it is apparent that larger farms are typically more resilient, productive and profitable than their smaller counterparts. Over the past three decades, a positive relationship between farm size and productivity has been observed in the broadacre sector (Nossal et al. 2008). Larger farms also demonstrate higher rates of return and overall profits (Productivity Commission 2005). A similar relationship has been found between size and performance in other developed economies, including the United States and European Union (see, for example, Hallam 1991, OECD 1995, Chavas 2001).

A typical economic explanation for relatively high performance among large farms is increasing returns to scale. Economists have therefore questioned the future of the small family farm in Australian agriculture and the ability of smaller farms to adapt to change. Of particular interest is the sector's ability to take advantage of emerging international markets where volumes required are large and price competition is intense. Furthermore, the pace and progress of structural adjustment in the sector has been seen by some to be hindered by the continued existence of significant numbers of smaller, yet tightly held, farms.

In this paper the positive relationship between farm size and productivity is examined and an empirical framework used to test the contribution to this relationship of increasing returns to scale. The relevance of farm production technology (measured as input mix) in determining productivity differences between large and small farms is also examined. Investigation of these potential drivers of productivity growth has important implications for ongoing structural adjustment, and can help industry and policy stakeholders develop an improved understanding of adjustment processes.

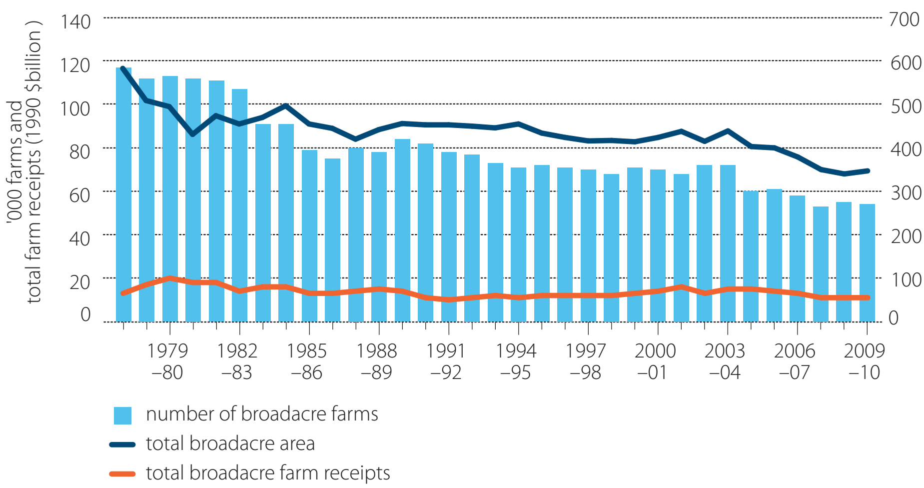
2 Trends in broadacre agriculture

The Australian broadacre farm sector, which comprises cropping, mixed cropping–livestock, sheep, beef and mixed livestock producers, is the focus of this study. The sector accounts for more than 60 per cent of Australian agriculture in terms of production value (ABARE 2009). In 2006–07 there were 58 000 broadacre farms, which produced output to the gross value of $19.8 billion. More than two-thirds of total output is exported.

Trends in the number of broadacre farms, their output value (based on farm cash receipts) and land area operated are shown in figure a. Although the number of broadacre farms in Australia halved 1977–78 and 2006–07, the gross value of output per farm (in real terms) has remained relatively stable. Concurrently, the average land area operated per farm increased by 30 per cent, and the average total capital value per farm increased 16 times, despite a decline in the total land area operated by broadacre farmers.

Broadacre farms have become larger, more capital-intensive enterprises on average. In the past three decades the number of farms with an expected value of operations above $500 000 increased by 32 per cent, while the number with an output value of less than $100 000 fell by 58 per cent.

a Number of broadacre farms, total output value and land area operated
1977–78 to 2006–07



Source: ABARE AAGIS data.

Productivity and farm size have been compared in previous studies of broadacre agriculture. Larger broadacre farms tend to have significantly higher total factor productivity than their smaller counterparts. In previous ABARE studies, the smallest third of broadacre producers demonstrated little productivity improvement (Knopke et al. 1995; ABARE 2004). Larger farms also recorded higher rates of return and profitability than smaller farms (Knopke et al. 2000, Hooper et al. 2002, Gleeson et al. 2003). These findings suggest that large operating scale is one of the factors driving productivity and profitability in broadacre agriculture (Knopke et al. 2000).

Two explanations have typically been offered to explain the positive correlation between farm size and productivity. One is the presence of increasing returns to scale or 'economies of scale' (Knopke et al. 1995, Knopke et al. 2000); the other is that emerging technologies have favoured farms with a relatively large operating size, leading to greater scope for input substitution and improved access to capital for financing developments in management and farming practices (Knopke et al. 1995, Hooper et al. 2002). The following analysis aims to assess each explanation from both theoretical and empirical perspectives.

3 A theoretical framework: returns to scale versus returns to size

Although in practice the concepts of 'returns to scale' and 'returns to size' are often used interchangeably, production theory distinguishes between the two under particular conditions. Based on Frisch's (1965) work on the relationship between production technology and U-shaped average cost curves, Hanoch (1975) proved that the two concepts are equivalent only if the input usage changes proportionally with size. Following this, Chambers (1984) introduced specific production technologies (such as homothetic or ray-homogenous technologies) to explain the interrelationship between the two concepts.

This work was systematically summarised in two important theorems by McClelland et al. (1986), followed by Revier (1987), Färe (1988), and McClelland (1988) and Boussemart et al. (2006). First, returns to scale and returns to size are equivalent if, and only if, the production technique is homothetic such that there is no change in the relative proportion of various inputs usage.[1] Second, elasticity of size is the envelope of elasticity of scale, which implies that returns to size is generally greater than returns to scale.

The above literature helps explain the inconsistency found between returns to scale and returns to size. Assume that a producer can produce an output with various inputs using a given production technology:

$$Y = f(X) \tag{1}$$

where Y denotes total output, X denotes a vector of various inputs (such as labour and capital) used in production and $f(.)$ is a generalised production function shaping the combination of inputs used in production. To link the output change with a producer's operating size (i.e. a proportional increase in all inputs) (k), the generalised production function can be reformulated as $f(kX) = G[k, X/|X|, f(X)]$, where $|X|$ is the Euclidian norm of the original input vector X and $X/|X|$ is a ray from the origin in Euclidian N space.

Following McClelland et al. (1986), it is assumed that production takes a ray-homothetic technology. This gives $G[k, X/|X|, f(X)] = k^{H(X/|X|)} \cdot f(X)$ and thus equation (1) can be rearranged as:

$$Y = f(kX_0) = \cdot k^{H(X/|X|)} \cdot f(X_0) \tag{2}$$

where $H(X/|X|)$ is assumed to be a strictly positive and bounded function.[2]

1 When the output increase is due to change in the relative proportion of inputs usage, one cannot claim it as resulting from scale change. Actually, it is just an income effect.

2 This assumption is reasonable since the marginal product value of one unit of input should always be equal to its marginal costs. Given that perfect competition holds for factor marks, marginal input costs are equal for all producers, independent of scale, and hence the marginal product of one unit of input should also be equal.

Differentiating both sides of equation (2) with respect to the producer's operating size (k) gives the returns to size as $\partial \ln Y / \partial \ln k = H(X/|X|)$. Defining γ as the elasticity of scale (that is, the proportional change in output resulting from a proportional change in all inputs) and $a \cdot h(X/|X|-1)$ as the output increase due to the changing relative proportion of inputs used (Färe and Mitchell 1995), the producer's returns to operating size can be decomposed into two components: returns to scale effect (captured by γ) and the input substitution effect (captured by $a \cdot h(X/|X|-1)$). For continuance, this effect is linked here to technology change.

Thus, the return to operating size under the assumption of profit maximisation can be written as:

$$H(X/|X|) = \gamma + a \cdot h(X/|X|-1) \qquad (3)$$

Alternatively, from duality theory, the returns to producers' operating size, under the assumption of cost minimisation, can also be defined as the proportional change in output associated with a proportional change in cost, as derived from Y=TC. Taking the first derivative leads to $\partial \ln Y / \partial \ln TC = AC / MC = \eta^{-1}$, where AC and MC are the producer's average and marginal costs and η is the elasticity of costs (Chambers 1984). Applying the duality theorem to equalise returns to size obtained from profit maximisation and cost minimisation, equation (3) can be used to specify the relationship between the returns to scale and returns to size of producers:

$$\gamma = \eta^{-1} - a \cdot h(X/|X|-1) \qquad (4)$$

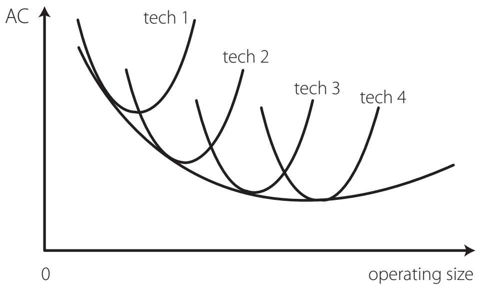
Increasing all inputs proportionally gives $h(X/|X|-1) = 0$. In this case, the returns to scale are equivalent to the returns to size γ=η^{-1}. Since η^{-1} is always greater than or equal to 1 in a competitive market (McClelland et al. 1986), it follows that increasing returns to scale must occur for production in the longer term.[3] Alternatively, if an increase in operating size is associated with some technological change that alters the relative input shares used in production, decreasing returns to scale can coexist with increasing returns to size.

By way of illustration, a possible relationship between average cost and operating size is shown in figure b. For a given technology (for example, tech 1, tech 2), average cost tends to decrease with operating size up to some capacity beyond which average cost begins to increase.[4] However, as operating size increases, it enables a switch from one technology to another. For example, as producers become larger they can afford to use more advanced technology in production (through increasing capital investment), which leads to a shift from tech 1 to tech 2. This shift is usually accompanied by some change in input mix (for example, capital to labour use ratio). As a consequence, average cost can decrease further irrespective of whether there exists increasing returns to scale. This implies that the benefits of increasing operating size can be a result of increasing returns to scale or technological progress made possible by increasing operating size, or a combination of both.

3 Reflecting McClelland et al. (1986), $\eta^{-1} = \mu(1-S_\pi)$, where S_π is the average share of economic profits and μ is the corresponding mark-up of price above marginal cost. In a competitive market, S_π is small and μ is more than or equal to one, and thus $\eta^{-1} > 1$.

4 Under increasing returns to scale, average cost falls as size increases; under decreasing returns to scale, average cost increases as size increases; and under constant returns to scale, average cost is not affected by operating size.

b Relationship between average cost and operating size



The above analysis indicates that agriculture may not experience increasing returns to scale in the long run. In fact, limitations in land availability and quality, labour availability and seasonal conditions might act to limit the opportunities for increasing returns to scale. This suggests that the positive relationship between farm operating size and productivity is more likely to result from innovation and technology uptake by farmers as their farm size increases (Chavas 2008). Other studies, including McClelland et al. (1986), Färe (1988) and Basu and Fernald (1997), came to similar conclusions.[5] In the following section, this theory is tested further using data from Australian broadacre farms.

5 In the context of agricultural production, McClelland et al. (1986) and subsequently Färe (1988) acknowledged that the returns to scale concept is too narrow to explain the differences in performance between large and small size farms. This discussion is elaborated on by Basu and Fernald (1997), who highlight that technological change and demand shocks can play a role in explaining the higher productivity of large farms over small ones.

4 Data collection and estimation strategy

Drawing on the theoretical framework discussed earlier, this section details the farm-level data used for this study and specifies a three-step empirical methodology for examining the relationship between productivity and farm size, as well as other likely determinants. More specifically, the analysis includes estimating the production function and the impact of operating size, identifying the returns to scale when production technology is assumed to be homothetic and testing the existence of heterogeneous production technology for farms of different size.

Data collection and variable definition

The dataset used in this study is from the Australian agriculture and grazing industry survey carried out by ABARES. The annual survey covers agricultural establishments across five broadacre farm types, including cropping specialists, mixed crop–livestock, sheep specialists, beef specialists and mixed sheep–beef for six states and two territories. After eliminating outliers and survey farms with missing variables, the sample contained 39 560 observations for the period from 1977–78 to 2006–07.

The three major variable types in the analysis were outputs, inputs and farm size category dummies. Outputs form the dependent variable and inputs and farm size dummies are the independent variables. To eliminate the impact of price changes across establishments, regions and over time, aggregate farm outputs were defined as a Fisher quantity index, using prices of 13 output products as weights, while farm inputs are classed into four categories (land, labour, capital, and materials and services) and also aggregated using a Fisher quantity index of inputs, estimated and weighted using the prices of 23 inputs. In addition, the EKS formula was applied in the estimation process for each index to ensure transitivity and thus comparability of outputs and inputs across farms and over time.

To capture the impact of farm size on productivity, farms were split into three categories according to their size—small, medium and large—and dummy variables were assigned to each of these categories. Farm size is based on dry sheep equivalents (DSEs), which is a physical measure of farm operating size associated with land capable of supporting one DSE per annum. A DSE is the energy required to maintain a 50 kilogram wether at constant weight (Davies 2005). Hectares of rangeland were converted to hectares of arable land by dividing total carrying capacity measured in DSEs (where 1 cattle = 8 DSEs) by 12 DSEs/ha. Large farms were those forming the top 30 per cent of the sample, ranked by size of output (in DSE terms); small farms were those in the bottom 30 per cent: and medium farms were the remainder.

Table 1 contains the output and input indices for each broadacre farm type according to farm size. As farm size increases, use of all inputs increases. However, input mix does not increase proportionately between large and small farms. In particular, large farms tend to use more land and intermediate inputs and have a higher capital to labour use ratio relative to small farms. This is consistent across each of the broadacre farm types and indicates likely differences in production technology between large and small farms, implying that the assumption of homothetic production technology across farms with different operating size might be invalid.

1 Broadacre farm output and input indexes by operating size and sectors, 1977–78 to 2006–07

	number	output index	land index	labour index	capital index	intermediate inputs Index
All broadacre	34 915	1.89	4.58	1.50	1.72	1.80
		(2.31)	(16.82)	(1.21)	(2.42)	(2.15)
Small-sized farms	10 475	0.38	0.73	0.74	0.53	0.50
		(0.16)	(4.06)	(0.32)	(0.38)	(0.32)
Medium-sized farms	13 965	1.22	2.62	1.28	1.23	1.26
		(0.37)	(9.96)	(0.61)	(0.94)	(0.72)
Large-sized farms	10 475	4.29	11.04	2.54	3.55	3.82
		(2.97)	(27.06)	(1.61)	(3.63)	(2.90)

Note: Standard errors in parentheses.

Empirical model specification

With the assumption of the homothetic production technology, the input–output relationship for broadacre farms can be represented using a simple Cobb–Douglas production function:

$$\begin{aligned}\ln Y_{it} &= \beta_0 + \beta_1 \ln Land_{it} + \beta_2 \ln Labour_{it} + \beta_3 \ln Capital_{it} + \beta_4 \ln Materials_{it} \\ &\quad + \sum \theta_t D\_Year_t + \sum \vartheta_r D\_Region_r + \sum \kappa_i D\_Industry_i + \varepsilon_{it}\end{aligned} \tag{5}$$

where Y_{it} represents farmer i's output at time t, and $\ln Land_{it}$, $\ln Labour_{it}$, $\ln Capital_{it}$ and $\ln Materials_{it}$ represent the log of land, labour, capital and purchased materials and services, which are different inputs. $\sum \vartheta_r D\_Region_r$, $\sum \kappa_i D\_Industry_i$ and $\sum \theta_t D\_Year_t$ are three groups of dummy variables used to control the regional (or state), industry and time specific effect respectively.

To consider the impact of farm size on farm performance (in terms of output with constant input), two dummy variables for the medium-sized and large-sized farms have to be incorporated into the regression. Thus, equation (5) can be rewritten as:

$$\begin{aligned}\ln Y_{it} &= \beta_0 + \beta_1 \ln Land_{it} + \beta_2 \ln Labour_{it} + \beta_3 \ln Capital_{it} + \beta_4 \ln Materials_{it} + \beta_5 DM_{it} + \beta_6 DL_{it} \\ &\quad + \sum \theta_t D\_Year_t + \sum \vartheta_r D\_Region_r + \sum \kappa_i D\_Industry_i + \varepsilon_{it}\end{aligned} \tag{6}$$

where DM_{it} and DL_{it} take the value of 1 if farm i at time t is classified as the medium-sized farm or the large-sized farm and 0 otherwise.

The estimation of equation (6) with the ordinary least square (OLS) regression technique may be biased because of a potential endogeneity problem. There are many unobserved time-invariant, farm-specific characteristics, such as farmers' education levels and management skills, that could improve farm performance while being positively correlated with size. Without controlling for these factors, the regression estimates are likely to be overestimated. To deal with this problem, both first-differencing and panel data regression techniques were adopted. Thus, equation (6) can be rearranged as:

$$d\ln Y_{it} = \beta_0 + \beta_1 d\ln Land_{it} + \beta_2 d\ln Labour_{it} + \beta_3 d\ln Capital_{it} + \beta_4 d\ln Materials_{it} + \beta_5 dDM_{it} + \beta_6 dDL_{it} \\ + \sum \theta_t D\_Year_t + \sum \vartheta_r D\_Region_r + \sum \kappa_i D\_Industry_i + u_i + \varepsilon_{it} \qquad (7)$$

and

$$\ln Y_{it} = \beta_0 + \beta_1 \ln Land_{it} + \beta_2 \ln Labour_{it} + \beta_3 \ln Capital_{it} + \beta_4 \ln Materials_{it} + ?+ \beta_5 DM_{it} + \beta_6 DL_{it} \\ + \sum \theta_t D\_Year_t + \sum \vartheta_r D\_Region_r + \sum \kappa_i D\_Industry_i + u_i + \varepsilon_{it} \qquad (8)$$

where u_i represents the unobserved time invariant factors specific to farm i, and $d(.)$ denotes change of a variable between two continuous years.

Equations (7) and (8) can be used for two purposes: to examine the relationship between farm size and productivity and to examine whether farms can benefit from increasing returns to scale. In particular, for the second purpose, a Chow test should be made to verify the hypothesis of $\beta_1 + \beta_2 + \beta_3 + \beta_4 > 1$. If the sum of estimated input elasticities (land, labour, capital and intermediate input) is greater than 1, increasing returns to scale prevails.

Further, the assumption that farms with different sizes adopt the homothetic production technology needs to be tested. This is important because, from equation (4), if farms with different sizes do not exhibit homothetic production technology, increasing returns to scale will not be a necessary condition for larger farms performing better than smaller ones. To test this, equations (7) and (8) were revised by introducing the interaction of the two dummy variables (for medium-sized and large-sized farms respectively) with input variables for land, labour, capital and intermediate inputs to yield:

$$d\ln Y_{it} = \beta_0 + \beta_1 d\ln Land_{it} + \beta_2 d\ln Labour_{it} + \beta_3 d\ln Capital_{it} + \beta_4 d\ln Materials_{it} \\ + \alpha_{11} dDM_{it} + \alpha_{12} dDM_{it}\_\ln Land_{it} + \alpha_{13} dDM_{it}\_\ln Labour_{it} + \alpha_{14} dDM_{it}\_\ln Capital_{it} + \alpha_{15} dDM_{it}\_\ln Materials_{it} \\ + \alpha_{21} dDL_{it} + \alpha_{22} dDL_{it}\_\ln Land_{it} + \alpha_{23} dDL_{it}\_\ln Labour_{it} + \alpha_{24} dDL_{it}\_\ln Capital_{it} + \alpha_{25} dDL_{it}\_\ln Materials_{it} \\ + \sum \theta_t D\_Year_t + \sum \vartheta_r D\_Region_r + \sum \kappa_i D\_Industry_i + u_i + \varepsilon_{it} \qquad (9)$$

and

$$\begin{aligned} d\ln Y_{it} &= \beta_0 + \beta_1 d\ln Land_{it} + \beta_2 d\ln Labour_{it} + \beta_3 d\ln Capital_{it} + \beta_4 d\ln Materials_{it} \\ &+ \alpha_{11} dDM_{it} + \alpha_{12} dDM_{it}\_\ln Land_{it} + \alpha_{13} dDM_{it}\_\ln Labour_{it} + \alpha_{14} dDM_{it}\_\ln Capital_{it} + \alpha_{15} dDM_{it}\_\ln Materials_{it} \\ &+ \alpha_{21} dDL_{it} + \alpha_{22} dDL_{it}\_\ln Land_{it} + \alpha_{23} dDL_{it}\_\ln Labour_{it} + \alpha_{24} dDL_{it}\_\ln Capital_{it} + \alpha_{25} dDL_{it}\_\ln Materials_{it} \\ &+ \sum \theta_t D\_Year_t + \sum \vartheta_r D\_Region_r + \sum \kappa_i D\_Industry_i + u_i + \varepsilon_{it} \end{aligned} \quad (10)$$

where $DM_{it}\_\ln Land_{it}$, $DL_{it}\_\ln Land_{it}$, $DM_{it}\_\ln Labour$, $DL_{it}\_\ln Labour_{it}$, $DM_{it}\_\ln Capital$, $DL_{it}\_\ln Capital$, $DM_{it}\_\ln Materials$ and $DL_{it}\_\ln Materials$ are interaction terms between DM_{it}, DL_{it} and land, labour, capital and materials and services.

Equations (9) and (10) can be used to test whether farms of different size share homothetic production technology. A proportional increase in the use of all inputs should not change marginal returns to those inputs in a perfectly competitive market. The null hypothesis is that if the production technology is homothetic there would not be a significant difference in the estimated relative elasticities for each input (including land, labour, capital and intermediate inputs) between large and small farms. This is captured by identifying the significance of the interactions between the farm size dummies and input variables.

Finally, it could be argued that the Cobb–Douglas production function is too simple to reflect the diversity of farm production technology. To extend the empirical test to a more general framework a similar exercise was also undertaken using a trans-log production function.
A series of robustness checks was also carried out for each of the five farm types in the broadacre sector.

5 How does farm size affect productivity?

The estimated results for the broadacre sector as a whole and for individual industries are shown in tables 2–5.

Farm productivity, size and returns to scale

First, the impact of farm size on broadacre farm productivity was estimated (based on equation (6), assuming homothetic production technology across farms of different sizes). The results are presented in column 1 of table 2. After controlling for land, labour, capital, and materials and services, the estimated elasticities of farm output to size category are positive and significant at the 1 per cent level. The magnitude of these estimated elasticities shows that medium and large farms have on average a 0.29 per cent and 0.48 per cent higher output than small farms (when variations in input use are well controlled for). This result suggests that larger farms are more productive than smaller ones.

2 Estimation of the input–output relationships, all broadacre farms, 1977–78 to 2006–07

	ordinary least squares	first differencing	panel (random effects)	panel (fixed effects)
Dependent Variable: ln_output				
ln_land	0.039***	0.076***	0.016***	0.032***
	(0.004)	(0.014)	(0.003)	(0.007)
ln_labour	0.124***	0.108***	0.218***	0.171***
	(0.014)	(0.020)	(0.014)	(0.014)
ln_capital	0.361***	0.237***	0.315***	0.232***
	(0.011)	(0.017)	(0.009)	(0.008)
ln_materials	0.389***	0.163***	0.299***	0.192***
	(0.020)	(0.022)	(0.022)	(0.022)
Medium_Size_Dummy	0.293***	0.198***	0.315***	0.226***
	(0.011)	(0.014)	(0.010)	(0.011)
Large_Size_Dummy	0.482***	0.441***	0.582***	0.464***
	(0.019)	(0.024)	(0.015)	(0.017)
Number of observations	35 916	23 650	35 916	35 916
R-square	0.811	0.266	0.834	0.305
Estimated Return to Scale (RTS)	0.913	0.584	0.849	0.627
Chow Test Value (Chi 2)	60	139	224	366
H0: IRTS and CRTS (Wald Test at 1% level)	Rejected	Rejected	Rejected	Rejected

Note: *, ** and *** represent statistical significance at the 10 per cent, 5 per cent and 1 per cent levels, respectively.

3 Return to scale for all broadacre farms, 1977–78 to 2006–07

	ordinary least squares	first differencing	panel (random effects)	panel (fixed effects)
Dependent variable: ln_output				
ln_land	0.082***	0.090***	0.056***	0.040***
	(0.004)	(0.017)	(0.004)	(0.007)
ln_labour	0.163***	0.119***	0.278***	0.199***
	(0.015)	(0.021)	(0.018)	(0.015)
ln_capital	0.386***	0.230***	0.335***	0.228***
	(0.012)	(0.017)	(0.010)	(0.008)
ln_materials	0.444***	0.170***	0.349***	0.207***
	(0.021)	(0.023)	(0.024)	(0.023)
Number of observations	35 916	23 650	35 916	35 916
R-square	0.798	0.244	0.815	0.274
Estimated Return to Scale (RTS)	1.075	0.609	1.018	0.675
Chow Test Value (Chi 2)	8	10		251.
H0: IRTS and CRTS				
(Wald Test at 1% level)	Not Rejected	Reject	Not Rejected	Reject

Note: *, ** and *** indicate coefficients are significant at the 10 per cent, 5 per cent and 1 per cent levels, respectively.

As was mentioned in section 4, the estimated results from the OLS regression may be overestimated because of endogeneity caused by unobserved farm-specific factors. To deal with this problem, first-differencing regression and panel data regression techniques were used to re-examine the input–output relationship of broadacre farms. The estimated results are shown in columns 2–4 of table 2. Compared with those from the OLS regression, the estimated coefficients from the first-differencing regression and the panel data regression are smaller, indicating some endogeneity due to the presence of unobserved farm-specific factors that contribute to farm productivity according to farm size. Yet the estimated elasticity of farm output to size category from the first-differencing regression and the panel data regression remain positive and significant at the 1 per cent level. This result further confirms the finding that larger farms perform better than smaller ones in terms of productivity.

The second task was to test whether the higher productivity of large farms is due to increasing returns to scale. The null hypothesis is that there are increasing returns to scale (the elasticities of land, labour, capital and intermediate inputs add up to more than 1) under the assumption of homothetic production technology. The Chow test was used to examine this hypothesis by using the OLS, first differencing and panel data regressions. As shown in table 3, the Chow test results for the null hypothesis (the presence of increasing returns to scale) in all cases have been rejected at the 1 per cent level. Increasing returns to scale does not explain the disparity between large and small farms.

Homothetic versus non-homothetic production technology

If productivity differences among small, medium and large farms cannot be explained by increasing returns to scale, what does explain the observation? From equation (4) it is known that returns to size and returns to scale can diverge from each other if the production technology is non-homothetic. In other words, if large farms use a different input mix from small farms because they use a different production technology, the difference in production technology is likely to explain the productivity difference. To test this hypothesis, interaction terms between farm size dummies and the various inputs into the regression were incorporated. Based on equations (9) and (10), the estimation results from the OLS, first differencing and panel data regression (with fixed effects) are shown in table 4.

4 Production technology and farm size, all broadacre farms

	ordinary least squares	first differencing	panel (random effects)	panel (fixed effects)
Dependent Variable: ln_output				
ln_land	0.063***	0.062***	0.022***	0.009
	(0.006)	(0.016)	(0.007)	(0.009)
ln_labour	0.096***	0.111***	0.163***	0.118***
	(0.018)	(0.024)	(0.017)	(0.017)
ln_capital	0.387***	0.260***	0.357***	0.277***
	(0.015)	(0.022)	(0.012)	(0.012)
ln_materials	0.385***	0.150***	0.342***	0.204***
	(0.025)	(0.026)	(0.026)	(0.027)
Medium_Size_Dummy	0.169***	0.234***	0.268***	0.251***
	(0.018)	(0.026)	(0.018)	(0.021)
Large_Size_Dummy	0.381***	0.466***	0.541***	0.487***
	(0.021)	(0.036)	(0.024)	(0.028)
Medium_Size_Dummy × ln_land	–0.060***	0.028**	–0.012*	0.022**
	(0.007)	(0.011)	(0.007)	(0.009)
Medium_Size_Dummy × ln_labour	0.084***	0.002	0.052*	0.051*
	(0.027)	(0.030)	(0.027)	(0.026)
Medium_Size_Dummy × ln_capital	–0.080***	–0.059***	–0.067***	–0.063***
	(0.019)	(0.022)	(0.015)	(0.016)
Medium_Size_Dummy × ln_materials	–0.041	0.015	–0.050	0.001
	(0.038)	(0.041)	(0.036)	(0.034)
Large_Size_Dummy × ln_land	–0.041***	0.026*	–0.008	0.031***
	(0.007)	(0.015)	(0.008)	(0.012)
Large_Size_Dummy × ln_labour	0.091***	–0.027	0.116***	0.103***
	(0.023)	(0.034)	(0.029)	(0.027)
Large_Size_Dummy × ln_capital	–0.116***	–0.087***	–0.072***	–0.070***
	(0.018)	(0.025)	(0.018)	(0.018)
Large_Size_Dummy × ln_materials	0.065**	0.070*	–0.074*	–0.027
	(0.033)	(0.038)	(0.042)	(0.039)
Constant	–0.156***	–0.020	–0.268***	–0.277***
	(0.027)	(0.042)	(0.023)	(0.031)
Number of observations	35 916	23 650	35 916	35 916
R–square	0.813	0.268	0.835	0.308

Note: *, ** and *** indicate coefficients are significant at the 10 per cent, 5 per cent and 1 per cent levels, respectively.

As shown in table 4, the estimated coefficient for the interaction terms between size category and the various inputs are jointly significant at the 1 per cent level. This implies that, compared with small farms, the marginal returns to land and labour in medium and large farms are smaller, while the marginal returns to capital in medium and large farms are larger, suggesting that large and small farms have adopted different production technologies (or, given their different input mixes, the production technology is non-homothetic). In particular, large and medium farms have a relatively high elasticity of land and labour but relatively low elasticity of capital, suggesting that larger farms may use more capital to substitute for land and labour.

A possible explanation for this phenomenon is that as farms become larger they can afford more advanced production technologies (in particular, more investment in machinery), which help to push their production frontier outwards. In this context, technological progress and farmers' financial capacity are likely to be two important factors determining the relationship between farm size and productivity, rather than increasing return to scale per se.

Disparity across broadacre industries: a robustness check

It is possible that the above finding is due to an aggregation problem. As argued by Griliches (1957) and Basu and Fernald (1997), production techniques employed in different broadacre farm types (such as crops, beef or sheep) may lead to an overestimation or underestimation of elasticities to inputs that have been aggregated. To test this issue, the estimation process was repeated by using data for each individual farm type. The estimation results are shown in tables 5 and 6, and three key findings can be ascertained from these results.

First, similar to the results obtained from the aggregate data, large farms in each industry have higher productivity than small farms. As is shown in table 5, the estimated elasticity of farm size dummies for large farms is much larger than that for medium farms (and both are significant at the 1 per cent level). This implies that there is a positive relationship between farm size and productivity in each farm type.

Second, although the estimated elasticities of aggregate inputs differ across industries, none of them pass the hypothesis test for increasing returns to scale at the 1 per cent level. After addressing the endogeneity problem through the first differencing and panel data regressions, the estimated aggregate elasticity of inputs with the assumption of homothetic production technology is significantly less than 1 for the crop specialists, the sheep specialists and the beef specialists.

Third, there are significant differences in input mix among farms with different sizes in each industry, although these have significant industry-specific characteristics. For example, large crop specialists are more likely to use fewer materials and services than smaller ones, while larger beef specialists are more likely to use relatively more capital and materials to substitute for land and labour. This, along with the findings above, suggests that technology differences rather than returns to scale are more likely to generate the differences in productivity among farms in different size categories.

As shown in table 7, the results for individual broadacre farm types are similar to those for the broadacre sector as a whole. Large and medium-sized farms have a higher capital to labour use ratio in their mix of inputs.

In sum, Australian broadacre farms (either as a whole or by farm type) have been found to not exhibit increasing returns to scale—for the larger part the reverse is true. Yet larger farms are observed to display higher productivity than their smaller counterparts. In this regard, the adoption of different production technologies among farms of different size plays a more important role than size itself in distinguishing productivity among farms.

5 Estimation of the input-output relationship by broadacre farm type, 1977–78 to 2006–07

	crop specialist		sheep specialist		beef specialist	
	first differencing	panel (fixed effects)	first differencing	panel (fixed effects)	first differencing	panel (fixed effects)
Dependent Variable: ln_output						
ln_land	0.027	0.014	0.061**	0.049***	0.251***	0.034*
	(0.019)	(0.012)	(0.025)	(0.010)	(0.091)	(0.020)
ln_labour	0.041	0.151***	0.170***	0.239***	0.048*	0.155***
	(0.061)	(0.034)	(0.035)	(0.021)	(0.028)	(0.026)
ln_capital	0.143***	0.145***	0.256***	0.211***	0.243***	0.268***
	(0.054)	(0.026)	(0.015)	(0.013)	(0.041)	(0.016)
ln_materials	0.108**	0.238***	0.058**	0.122***	0.076**	0.118***
	(0.048)	(0.064)	(0.024)	(0.027)	(0.029)	(0.028)
Medium_Size_Dummy	0.288***	0.245***	0.144***	0.199***	0.164***	0.249***
	(0.058)	(0.032)	(0.027)	(0.023)	(0.036)	(0.037)
Large_Size_Dummy	0.541***	0.568***	0.339***	0.420***	0.349***	0.513***
	(0.071)	(0.049)	(0.040)	(0.032)	(0.070)	(0.055)
Number of observations	3604	6642	3877	6625	6009	9328
R-square	0.437	0.420	0.279	0.356	0.195	0.224
Estimated Return to Scale (RTS)	0.318	0.547	0.545	0.621	0.617	0.574
H0: IRS and CRS † (Wald Test at 1% level)	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected

Note: *, ** and *** indicate coefficients are significant at the 10 per cent, 5 per cent and 1 per cent levels, respectively.
† Null hypothesis of increasing returns to scale (IRS) and constant returns to scale (CRS).

6 Production technology and farm size by broadacre farm types

	crop specialist		sheep specialist		beef specialist	
	first differencing	panel (fixed effects)	first differencing	panel (fixed effects)	first differencing	panel (fixed effects)
Dependent Variable: ln_output						
ln_land	-0.031	0.004	0.042**	0.014	0.226***	–0.041
	(0.038)	(0.022)	(0.021)	(0.016)	(0.087)	(0.040)
ln_labour	0.029	0.109**	0.170***	0.166***	0.059	0.063*
	(0.073)	(0.048)	(0.043)	(0.033)	(0.039)	(0.033)
ln_capital	0.145**	0.144***	0.276***	0.255***	0.255***	0.306***
	(0.067)	(0.038)	(0.021)	(0.023)	(0.054)	(0.026)
ln_materials	0.139**	0.207***	0.067*	0.128***	0.064*	0.233***
	(0.061)	(0.062)	(0.037)	(0.036)	(0.038)	(0.036)
Medium_Size_Dummy	0.398***	0.244***	0.239***	0.244***	0.273***	0.315***
	(0.101)	(0.066)	(0.056)	(0.043)	(0.075)	(0.063)
Large_Size_Dummy	0.459***	0.423***	0.451***	0.449***	0.404***	0.586***
	(0.113)	(0.079)	(0.069)	(0.050)	(0.138)	(0.082)
Medium_Size_Dummy × ln_land	0.052	–0.007	0.078***	0.044***	0.065*	0.059*
	(0.049)	(0.029)	(0.022)	(0.014)	(0.034)	(0.031)
Medium_Size_Dummy × ln_labour	–0.032	0.052	–0.001	0.102**	–0.036	0.058
	(0.088)	(0.068)	(0.054)	(0.048)	(0.047)	(0.052)
Medium_Size_Dummy × ln_capital	0.021	–0.004	–0.034	–0.052*	–0.035	–0.057*
	(0.066)	(0.046)	(0.028)	(0.028)	(0.050)	(0.033)
Medium_Size_Dummy × ln_materials	–0.095	–0.006	–0.027	0.009	0.064	–0.029
	(0.078)	(0.091)	(0.045)	(0.053)	(0.057)	(0.044)
Large_Size_Dummy × ln_land	0.073	0.026	0.103***	0.053***	0.127**	0.080*
	(0.047)	(0.028)	(0.028)	(0.018)	(0.054)	(0.041)
Large_Size_Dummy × ln_labour	0.153	0.056	–0.023	0.143***	0.005	0.152***
	(0.105)	(0.066)	(0.069)	(0.048)	(0.059)	(0.049)
Large_Size_Dummy × ln_capital	–0.071	–0.011	–0.086***	–0.086***	–0.031	–0.055
	(0.075)	(0.050)	(0.033)	(0.029)	(0.059)	(0.036)
Large_Size_Dummy × ln_materials	0.159**	0.195***	–0.006	–0.033	–0.017	–0.157***
	(0.079)	(0.070)	(0.039)	(0.046)	(0.044)	(0.045)
Constant	–0.186*	–0.526***	–0.203***	–0.332***	–0.229*	–0.569***
	(0.097)	(0.078)	(0.066)	(0.049)	(0.120)	(0.086)
Number of observations	3604	6642	3877	6625	6009	9328
R-square	0.444	0.428	0.290	0.367	0.197	0.233

Note: *, ** and *** indicate coefficients are significant at the 10 per cent, 5 per cent and 1 per cent levels, respectively.

7 Returns to scale by broadacre industry groups

	crop specialist		sheep specialist		beef specialist	
	first differencing	panel (fixed effects)	first differencing	panel (fixed effects)	first differencing	panel (fixed effects)
ln_land	0.044*	0.031**	0.269***	0.041**	0.068**	0.061***
	(0.024)	(0.014)	(0.096)	(0.021)	(0.028)	(0.011)
ln_labour	0.057	0.182***	0.050*	0.165***	0.186***	0.288***
	(0.064)	(0.037)	(0.028)	(0.028)	(0.035)	(0.023)
ln_capital	0.153***	0.158***	0.239***	0.264***	0.243***	0.200***
	(0.055)	(0.028)	(0.041)	(0.016)	(0.016)	(0.014)
ln_materials	0.113**	0.265***	0.080***	0.127***	0.055**	0.130***
	(0.050)	(0.069)	(0.030)	(0.029)	(0.023)	(0.032)
Constant	–0.179*	–0.274***	–0.231*	–0.245***	–0.200***	–0.080***
	(0.093)	(0.060)	(0.121)	(0.045)	(0.058)	(0.027)
Number of observations	3604	6642	6009	9328	3877	6625
R-square	0.417	0.383	0.187	0.205	0.251	0.304
RTS	0.368***	0.635***	0.638***	0.596***	0.552***	0.678***
H0: IRS and CRS (Wald Test at 1% level) †	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected

Note: *, ** and *** indicate coefficients are significant at the 10 per cent, 5 per cent and 1 per cent levels, respectively.
† Null hypothesis of increasing returns to scale (IRS) and constant returns to scale (CRS).

6 Implications

This paper examines the relationship between productivity and farm size among Australian broadacre farms. While the benefits of increasing farm size, as observed over the past 30 years, have often been largely attributed to increasing returns to scale, the results of this analysis suggest this is not the case. Australian broadacre farms typically exhibit decreasing returns to scale, suggesting a more complex relationship between farm size and productivity. Although larger farms perform better, it has been found that these productivity differences are determined by differences in production technology rather than returns to scale. These results are consistent for the broadacre sector as a whole and for individual industry types (cropping, beef and sheep), and emphasise the disparity between returns to scale and returns to size in Australian agriculture.

The results imply that smaller farms are less able to shift resource and production technology as circumstances change, and hence exhibit lower productivity. In some cases, technologies are clearly not well suited to smaller farm enterprises. For example, use of advanced cropping machinery might be viable only on farms above a minimum size because it is not feasible to adopt a fractional part of a technology. However, in other cases, it is likely that farm area itself is not the limiting factor. Small farms might not easily shift resource allocation because of, for example, limited business management resources, market access or availability of finance. In addition, smaller farms might also have insufficient stocks of the human, social, natural, financial or physical capital required to cope with adjustment pressures (Ellis 2000).

The findings are relevant for ongoing structural adjustment in the broadacre sector. As circumstances change, the capacity and preparedness of farms to make changes to resource allocation is important, particularly in a context of increased climate variability. Regardless of size, increasing the ability of farms to shift production technology is likely to increase resilience and productivity in the farm sector.

The potential benefits of greater adoption of technology among broadacre farms have been highlighted by Hughes et al. (2011). Hughes et al. find that, while technology (as measured by the production frontier) continues to advance, uptake by the vast majority of farms is lagging. Possible constraints to innovation adoption examined elsewhere include the high and increasing trend of land prices; lifestyle factors, including off-farm work; the ageing farmer population; and a lack of information and skills (Marsh 2010; Barr 2005).

Governments have played a role in improving resilience and innovation adoption––for example, through capacity building, information and training, and R&D. However, in continuing to facilitate (and avoid hindering) the structural adjustment process, government should remove inappropriate regulatory impediments that reduce the flexibility of farms to determine efficient resource allocations.

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