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Contributed Paper

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The joint effects of technical efficiency and risk exposure on mixed enterprise farm output variability in Western Australia

ABSTRACT

This study quantifies the importance of inefficiency and risk as sources of production variability in Western Australian mixed crop - livestock broadacre farm businesses. Sources of farm level observable heterogeneity are examined as determinants of inefficiency and risk through application of Greene's True Fixed Effects stochastic production framework in a Cobb-Douglas functional form. Empirical Analysis is undertaken through a balanced panel of farm data from 274 operations between 2002 and 2011. Results indicate output variability is mainly a consequence of risk as opposed to technical inefficiency. Degree of production specialization, costs of finance, and capital structure are shown to be significant to inefficiency. Production specialization, rainfall variability, and capital structure are shown to be significant to and increase risk.

Keywords: risk exposure, technical inefficiency, stochastic frontier analysis, mixed enterprise farms

1. Introduction

For farm businesses, the technical inefficiency of farm production and the risks to which farm production is exposed are jointly likely to influence farm output variability.

Only a few studies have chosen to examine technical efficiency of farm exposure and risk in agricultural production. Tiedemann and Lataczs-Lohmann (2013) observed in their study of a small sample organic and conventional farms in Germany find that variability of production risk has a greater effect on output variability than technical inefficiency. Bokusheva and Hockman (2006) also find that production risk has a greater relative effect on output variability than technical inefficiency.

A small number of authors have noted factors that effect production risk and technical inefficiency. Villano and Fleming (2006) in their analysis of Filipino rice producers study the impact of a diverse range of sociological, environmental and methodological factors on technical efficiency and production uncertainty. Chang and Wen (2011) in a study of Taiwanese rice producers examine the impact of off-farm income on technical efficiency and production risk and observe that farmers that have off farm income were able to accommodate increased production risk, but not necessarily at higher technical inefficiency. Jaenicke, Frechette, and Larson (2003) investigate the effect of input use on inefficiency and production risk for cotton production in West Tennessee.

In Western Australia, Mugera and Nyambane (2014) find that for broadacre farms technical efficiency is positively influenced by short term debt, tax liability and capital investment, whilst negatively influenced by off-farm revenue generating activities.

In Australian agriculture more broadly, there are several studies that examine technical efficiency in farm production (Battese, Coelli 1995; Doucouliagos, Hone 2000; Fraser, Hone 2001; Fraser, Horrace 2003; Kompas, Che 2006) or examine changes in total factor productivity and its components (Nossal, Sheng, Zhao, Gunasekara 2009; Tozer, Villano 2013; Sheng, Zhao, Nossal, Zhang 2014; Islam, Xayavong, Kingwell 2014) . Climate variability is a key feature of Western Australian agriculture (CSIRO & Bureau of Meteorology 2007; Hennessy et al 2008) and adverse risk from climate change presents substantial risk for farmers in southern Australia (Garnaut 2010; Asseng, Pannell 2012), which indicates that considerable merit exists for the joint study of production risk and technical inefficiency.

The present study proposes to determine the contributions of risk and technical inefficiency to output variability for mixed crop-livestock farms in south west Western Australia through the application of a 'true effects' stochastic frontier analysis. The study identifies sources of observable heterogeneity amongst these farms that significantly affect risk.

The farms in the present study are broadacre dryland operations that receive low levels of government assistance and subsidization relative to farm operators in several other developed countries.

The paper is organized as follows: section 2 provides an overview of the prior studies of technical efficiency and risk; section 3 details the analytical framework and the data used; section 4 presents the empirical findings and section 5 states the study conclusion and implications.

2. Technical efficiency and production risk in farm business

Technical Efficiency represents the effectiveness with which a given set of inputs is used to produce an output (Farrell 1957). Many sources of observable heterogeneity between farms globally have been shown in prior studies to significant affect the farm's technical efficiency.

Studies of capital structure and technical efficiency (Lambert, Bayda 2005; Emvalomatis, Oude Lansik, Stefanou 2008) have provided divergent results. Some results provide support for both Agency theory (Jensen, Meckling 1976) and free cash flow theory (Jensen 1984). Free cash flow theory asserts that higher debt usage will increase technical efficiency, since management will need to exercise increased vigilance to avoid the negative consequences of failure to service their obligations. Conversely, agency theory proposes that debt and technical efficiency would be inversely related, as a consequence of the difficulty associated to lenders being able to monitor borrowers and hence imposing higher costs of credit.

Analysis of the impact of credit constraints on technical efficiency in agriculture (Blancard, Boussemart, Briec, Kerstens 2006; Davidova, Latruffe 2007) suggests the possible presence of both agency theory and signalling theory (Ross 1977, Hubbard 1998), where the preferences of lenders affect farm investment capacity and hence technical efficiency. Increased investment, for example, has been observed to increase technical efficiency (Doucogliagos, Hone 2000; Kumbhakar, Bokusheva 2009).

Production specialization (Featherstone, Langemeier, Ismet 1997; Bokusheva, Hockman, Kumbhakar 2012) is an indicator of resource allocation and input use, and is also a likely influence on technical efficiency. Production specialization should allow farmers to concentrate on specific production processes and increase technical efficiency. Increased education and experience (Dhungana, Nuthall, and Nartea 2004) in theory should translate to increased skill and knowledge, which also should promote increased technical efficiency.

The significance of the effect of farm size (Byrnes, Färe, Grosskopf, Kraft 1987; Hallam, Machado 1996; Mugera, Langemeier 2011), subsidisation (Serra, Zilberman, Gil 2008), and technology choice (Kompas, Nhe Che 2006; Mayan, Balagtas, Alexander 2010) on technical efficiency has also been addressed in prior studies.

In Western Australia, Mugera and Nyambane (2014) observed short term debt use, increased tax liabilities (a consequence of increased profitability) and capital investment were important in raising technical efficiency, a finding which is consistent Sheng, Zhao, Nossal, Zhang's (2014) study of how new production technology can increase production efficiency.

Chavas (2008) identified two primary sources of risk in price uncertainty (i.e. market prices for inputs and outputs) and production uncertainty (such as industrial action, climate, and technological change). Uncertainty of demand and the irreversibility of investment decisions have been shown in the context of farms in the south east of the United States to influence investment decisions (Isik, Coble, Hudson, House 2003) and land development decisions in the Kyrgyz Republic (Savastano, Scandizzo 2009). Output price volatility can affect the global crop acreage (Haile, Kalkuhl, von Braun 2013), while input price stability has promoted increased adoption of new technology (Schonegold, Sunding 2014).

Technological progress has been shown by Kim and Chavas (2003) to reduce farmer's risk exposure and downside risk. Regulatory policy has been shown to influence farmer risk perception. For example, Koundouri, Laukkanen, Myyra, Nauges (2009) examine the increase in non-random income components of Finnish farmers following Finland's accession into the European Union. They found that the EU's decoupling policies affected farmer's input use and crop use through adjustment of farmer's risk attitudes. Increased environmental uncertainty has been shown to induce an increase in production diversification by farmers to mitigate such risks (Baumgärtner, Quaas 2009). Production specialization would be anticipated to increase production risk, based on the application of portfolio theory (Markowitz 1952).

3. Methodology and Data

3.1 Theoretical Modelling

This study uses stochastic frontier analysis ('SFA') to determine the impact of observable farm level heterogeneity on technical efficiency and risk in Western Australian farm businesses. SFA is a parametric method that invokes assumptions about parameters' random errors.

SFA was first proposed as an extension of prior deterministic studies by Aigner, Lovell and Schmidt (1977) who applied a half normal distribution of the error term. Independently, Meeusen and Van den Broeck (1977) applied an exponential distribution. The adopted functional form of the SFA model used in thre present study follows that proposed by Aigner et al:

$$y_{it} = f(x_{it}, z_i) + v_{it} \pm u_{it} = \beta' x_{it} + \mu' z_i + v_{it} \pm u_{it}$$

$$i = 1, \ldots, N,\ t = 1, \ldots, T$$

$$v_{it} \sim N[0, \sigma_v^2]$$

$$\mathrm{u}_{it} = |U_{it}|, \text{ where } U_{it} \sim N[0, \sigma_u^2] \perp \mathrm{v}_{it}$$

In the above stated function, y_{it} represents output, x_{it} represents a vector of inputs or input prices, z_i is a vector of firm specific characteristics, v_{it} is a random error associated to factors beyond the production entity's control (weather, political or economic shocks etc), u_{it} represents of inefficiency, *i* represents an individual producer and *t* represents an individual production period.

3.2 Empirical Modelling

Construction of the study variables is outlined in Appendix 1. A Box-Cox transformation (Box, Cox 1964) is applied to generate a functional form:

$$y^{\lambda} = \frac{y^{\lambda} - 1}{\lambda}$$

The Box-Cox transformation tests four models:

(i) Theta- independent and dependent variables subject to a separate transformation:

$$y_i^{\theta} = \beta_1 x_{1j}^{\lambda} + \beta_2 x_{2j}^{\lambda} + ... + \beta_2 x_{2j}^{\lambda} + \varepsilon_j$$

(ii) Lambda- independent and dependent variable subject to a common transformation:

$$y_i^{\lambda} = \beta_1 x_{1j}^{\lambda} + \beta_2 x_{2j}^{\lambda} + ... + \beta_2 x_{2j}^{\lambda} + \varepsilon_j$$

(iii) Right Hand Side- dependent variable only subject to a transformation:

$$y_i^{\lambda} = \beta_1 x_{1j} + \beta_2 x_{2j} + ... + \beta_2 x_{2j} + \varepsilon_j$$

(iv) Left Hand Side- independent variable only subject to transformation:

$$y_i = \beta_1 x_{1j}^{\lambda} + \beta_2 x_{2j}^{\lambda} + ... + \beta_2 x_{2j}^{\lambda} + \varepsilon_j$$

This study directs specific attention to the test of three common functional forms in application of the Box Cost test:

Linear: $y^{\lambda} = y - 1$ if λ=1

Log specification: $y^{\lambda} = \ln(y)$ if λ=0

Multiplicative inverse: $y^{\lambda} = 1 - \frac{1}{y}$ if λ=-1

Post specification of functional form, a Hausman Test (Hausman 1978) was utilised to differentiate between whether the panel data was subject to fixed and random effects. A Hausman test has a null hypothesis (H_0) that the random effects estimator (b_1) is preferred as it consistent and efficient; under the alternative hypothesis (H_A), the fixed effects (b_0) estimator is preferred since it is at least consistent. In consideration of a standard linear model y=bX+e, the Wu-Hausman Test Statistic is:

$$H = (b_1 - b_0)'(Var(b_0) - Var(b_1))^{\dagger}(b_1 - b_0),$$

Where † indicates a Moore-Penrose pseudo inverse[1].

The Hausman test indicates that a Fixed Effects model is preferred (refer '4.Results'). A fixed effects SFA estimator (see Schmidt, Sickle 1984; Cornwell, Schmidt, Sickles 1990; Kumbhakar 1990; Lee, Schmidt 1993) is free of distributional assumptions and requires only the statement of the conditional mean; it also allows for correlation between effects and time varying regressors. These benefits, however, are somewhat negated in the above cited estimators by the loss of the individual identity in the conventional fixed effects formulation as stated below:

$$y_{it} = \alpha + \beta' x_{it} - Su_i + v_{it}$$

$$= \alpha_i + \beta' x_{it} + v_{it},$$

Where $\alpha_i = \alpha - Su_i$

The loss of this identity is because the effects are only measured relative to the 'best' (most efficient) within the sample.

Estimation of the stochastic frontier model in this study is undertaken through application of an extended 'true' fixed effects ('TFE') model as proposed by Greene (2005, 2005a), which addresses the loss of individual identity. This model provides an important advancement of prior fixed effects formulations that are derivative of the Schmidt and Sickles (1984) formulation ($y_{it} = \alpha_i + \beta' x_{it} + v_{it}$) in that time variant inefficiency, u_{it}, is separated from α_i, a group specific constant. The problematic non-consideration of time variant inefficiency and the preclusion of covariates that do not vary through time are also problems that this approach removes (Greene 2005a). Furthermore, heterogeneity may be correlated with group variables under the TFE approach. Consistent with the presence of heteroscedasticity in both error terms v_{it} and u_{it}, the TFE model is stated as:

$$\begin{aligned}
y_{it} &= \alpha_i + \beta' x_{it} + v_{it} \pm u_{it} \\
u_{it} &\sim N^+(0, \sigma^2_{uit}) \\
v_{it} &\sim N(0, \sigma^2_{vit}) \\
\sigma^2_{uit} &= g(z_{it}; \gamma) \\
\sigma^2_{vit} &= h(z_{it}; \delta)
\end{aligned}$$

Consistent with the specification of Greene (2005a), the log likelihood function is estimated as a fixed effects model:

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[1] Moore Penrose pseudoinverse: M(m,n;K), where m,n is a vector of m x n matrices and K is representative of *R* or *C*. For A $\in$ M(m,n;K) a pseudo inverse of A is matrix $A^+ \in$ M(m,n;K) s.t.:
i)$AA^+A=A$
ii) $A^+AA^+=A^+$
iii)$(AA^+)^*=AA^+$
iv)$(A^+A)^*=A^+A$

$$LogL = \sum_{i=1}^{N}\sum_{i=1}^{T}\log\left[\frac{1}{\Phi(0)}\Phi\left(-\lambda\left(\frac{y_{it}-\alpha_{it}-\beta' x_{it}}{\sigma}\right)\right)\phi\left(\frac{y_{it}-\alpha_{i}-\beta' x_{it}}{\sigma}\right)\right],$$

where is the Φ standard normal Cumulative Density Function and ϕ is the standard normal density.

Post maximization of the Log Likelihood function, the JLMS estimator (Jondrow, Materov, Lovell, Schmidt 1982) is used to estimate u_{it} given:

$$\mathrm{E}\left[u_{it}\middle|\varepsilon_{it}\right] = \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{\phi(\alpha_{it})}{1-\Phi(\alpha_{it})}-\alpha_{it}\right]$$

$$\varepsilon_{it} = v_{it} \pm u_{it} = y_{it} - \alpha - \beta' x_{it}$$

$$\sigma = [\sigma_v^2 + \sigma_u^2]^{\frac{1}{2}}$$

$$\lambda = \frac{\sigma_u}{\sigma_v}$$

$$\alpha_{it} = \pm\varepsilon_{it}\frac{\lambda}{\sigma}$$

Where $\phi(\alpha_{it})$ is the standard normal density and $\Phi(\alpha_{it})$ is the cumulative density function evaluated at α_{it} (Greene 2005).

Estimation of technical efficiency allows for the calculation of the proportions of output variability attributable to inefficiency and risk. Subject to the assumption of a half normal distribution for the inefficiency term, the calculation proposed by Kumbhakar and Lovell (2003) was utilized where π is the net profit of the operation:

$$\sigma^2 = \sigma_v^2 + Var_u = \sigma_v^2 + \left(\frac{\pi-2}{\pi}\right)\sigma_u^2$$

3.3 Study region and farm data

The farm data used in the analysis covers the period from 2002 to 2011. 274 farms located in south west Western Australia who engaged one of three major agricultural consultancies (PlanFarm, Evans & Grieve, and Farmanco) collected annual data on farm operations and finances. Only farms that provided data for all ten seasons were included in this data set. This induces some potential bias in the failure to capture the entry and exit of farm businesses (see Foster, Haltiwanger, Syverson 2008).

South west Western Australia is characterized by large scale broadacre dryland farms that operate crop, mixed, and/or livestock production subject to a Mediterranean climate. The primary crops are wheat, barley, canola, lupins and oats. Farms produce one dryland crop per annum. Sheep account for the majority of livestock held on these farms. The smallest property surveyed between 2002 and 2011 was 365 Hectares, the largest was 16,988 Hectares.

A broad range of information was recorded in the survey including items such as annual rainfall, land size and allocation, labour use, crop production values and quantities, variable and fixed cost expenditure values, financial particulars inclusive of farm income, asset and liability measurements, farm owner characteristics inclusive of educational attainment, age range, and family structure, as well as producer and consumer price indexes.

3.4 Index of variables

As per the requirements of the preferred methods, an output variable, input variables and variables that account for observable heterogeneity were constructed from the data set. Table 1 provides a summary of the variables used in this analysis; for an explanation as to the construction of the variables, refer to Appendix 1.

Table 1. Variable Summary

Measure	μ	σ	95% Conf. Interval	
Dependent Variable				
Output (y)	8514.378	139.0449	8241.735	8787.021
Input Variables				
Labour (x_1)	164.6722	8.796342	147.424	181.9203
Crop inputs (x_2)	3261.089	48.33898	3166.305	3355.874
Operational costs (x_3)	1054.119	14.75511	1025.187	1083.052
Livestock production inputs (x_4)	1865.226	35.87414	1794.883	1935.569
Growing season rainfall (x_5)	242.9417	1.796394	239.4192	246.4641
Observable Heterogeneity: Inefficiency				
Production specialization (z_{1u})	-.444960	.0064421	-.457592	-.432328
Cost of finance (z_{2u})	-3.10806	.0229454	-3.15305	-3.06306
Capital structure (z_{3u})	-1.57787	.0195554	-1.61622	-1.53953
Experience (z_{4u})	2.822458	.0142255	2.794562	2.850353
Education (z_{5u})	1.448458	.0160055	1.417071	1.479845
Observable Heterogeneity: Uncertainty				
Production specialization (z_{1v})	-.444960	.0064421	-.457592	-.432328
Capital Structure (z_{2v})	-1.57787	.0195554	-1.61622	-1.53953
Price variability index (z_{3v})	.3226207	.0012094	.3202493	.3249921
Rainfall variability index (z_{4v})	.3413043	.0029839	.3354534	.3471552
Regulatory change- Wheat Export Marketing Act 2008 (z_{5v})	.6	.0093437	.5816786	.6183214

3.5 Model Estimation

Following the program method set forth in Belotti, Daidone, Ilardi and Atella (2012), the panel data set was analysed using STATA.

4. Results

The initial test undertaken was for the model specification as per the BoxCox test. Investigation of the theta, lambda, right hand side and left hand side transformations yielded only one common functional form as nominated in Section 3.2 that was not strongly rejected. This was the lambda restriction whereupon both the dependent and independent variables were transformed subject to a lambda equal to zero.

Table 2. BoxCox Test Results

Test	Restricted	LR statistic	P-Value
H_0	Log Likelihood	χ^2	Pr(>χ^2)
λ= -1	-27491.659	10624.29	0.000
λ = 0	-22179.856	0.69	0.407
λ = 1	-23415.786	2472.55	0.000

The test result in Table 2 indicates that a logrithmic transformation cannot be strongly rejected.

Table 3. Hausman Test

	(b)	(B)	(b-B)	√(diag(V_b-V_B))
	Fixed	Random	Difference	Standard Error
Ln(x_1)	.13058	.1997125	-.0691326	.0106289
Ln(x_2)	.0506916	.052157	-.0014654	.0033765
Ln(x_3)	-.021635	-.028098	.0064636	.0042172
Ln(x_4)	.009864	.0087022	.0011618	.0021929
Ln(x_5)	.6499038	.6346067	.0152972	.0073728

Test: H_0- difference in coefficients not systematic

χ^2 (5) = (b-B)'[(V_b-V_B) $^{-1}$](b-B)

= 52.19

Pr(>χ^2)= 0.0000

The Hausman test confirms the rejection of the null hypothesis that individual-level effects are adequately modelled by a random-effects model. Henceforth a fixed effects model is instituted.

In accordance with the results of the Hausman test, Greene's true fixed effects model is applied to a Cobb Douglas function transformed as per the Box Cox test results.

Table 4. Stochastic frontier analysis- production inputs

Frontier	Coef.	Std. Err.	z	P>z	95% C.I.	
Ln(x_1)	.1139937	.0236324	4.82	0.000***	.067675	.1603123
Ln(x_2)	.0408997	.020476	2.00	0.046**	.0007675	.0810318
Ln(x_3)	.003998	.0243186	0.16	0.869	-.043665	.0516616
Ln(x_4)	.0127434	.010143	1.26	0.209	-.007136	.0326233
Ln(x_5)	.4932979	.0286455	17.22	0.000***	.4371538	.549442

*= 10% significance, **= 5% significance, ***= 1% significance

As per the functional form specified, the coefficients estimated represent the output elasticities of each of inputs, with rainfall shown to have the greatest effect followed by labour. Both are significant at a one percent level.

The inefficiency coefficients estimated by the true fixed effects model are detailed in Table 5A that shows that production specialization, costs of finance and financial risk aversion are all significant at a 1% level. Increased crop specialization is shown to reduce inefficiency, while higher costs of finance and debt use are shown to increase inefficiency. Education and Experience were both shown to reduce inefficiency, though neither was significant.

Table 5A. Analysis of sources of farm level observable heterogeneity on technical inefficiency

σ_u	Coef.	Std. Err.	Z	P>z	95% C.I.	
z_{1u}	-2.50477	.2401946	-10.43	0.000***	-2.97554	-2.03399
z_{2u}	.3437249	.0765304	4.49	0.000***	.1937281	.4937216
z_{3u}	-.288143	.086803	-3.32	0.001**	-.458274	-.118012
z_{4u}	-.028306	.129989	-0.22	0.828	-.283080	.2264674
z_{5u}	-.059130	.1265258	-0.47	0.640	-.307116	.1888555
constant	-2.61676	.5221552	-5.01	0.000***	-3.64016	-1.59335

The reduction in inefficiency associated with increased crop specialization is in accord with the findings of Bokusheva, Hockman, and Kumbhakar (2012) in their study of Russian agriculture from 1999 to 2009. Increased crop specialization may allow for increased mechanization, which promotes increased technical efficiency. The finding that increased debt is negative and significant to technical inefficiency lends support to free cash flow theory and indicates that farmers become more diligent when faced with the heightened penalty of default. The positive and significant impact of borrowing costs (capital constraints) on technical inefficiency is further in accord with agency theory and is consistent with the findings of Blancard, Boussemart, Briec, and Kerstens (2006) in their study of capital and expenditure constraints on farms in Nord-pas-de-Calais, France

The negative impact of age on technical inefficiency indicates that increased experience promotes technical efficiency. The negative relationship between education and technical efficiency indicates that farmers with higher educational attainment are more technically efficient.

Estimation of risk in response to sources of observable heterogeneity indicates that production specialization, price variability and rainfall variability are positive and significant at a 1% level regarding production risk. As crop production as a percentage of total production increases, so does production risk. This finding is consistent with theoretical expectation as specified by portfolio theory (Markowitz 1952). Increased risk as a consequence of a higher debt to equity ratio is also in direct alignment with theoretical expectation. The introduction of the Wheat Export Market Act in 2008 that deregulated wheat export marketing in Australia is not significant in affecting risk.

Table 5B. Analysis of sources of farm level observable heterogeneity on risk

σ_v	Coef.	Std. Err.	Z	P>z	95% C.I.	
z_{1v}	2.03733	.3063006	6.65	0.000***	1.436992	2.637668

z_{2v}	.3612944	.0872042	4.14	0.000***	.1903774	.5322114
z_{3v}	.9138366	.6659282	1.37	0.170	-.391358	2.219032
z_{4v}	1.588657	.4231207	3.75	0.000***	.7593559	2.417959
z_{5v}	.0821041	.119164	0.69	0.491	-.151453	.3156613
constant	-2.18009	.2945215	-7.40	0.000***	-2.75734	-1.60284

The next stage of the estimation is the estimation of technical inefficiency, u ; this is done through application of the JLMS estimator (refer section 3.2). Post estimation of u , the variance of the inefficiency term, σ_u^2 , and the variance of output, σ_y^2 , are used to calculate risk variance, σ_v^2 , as per the method set forth by Khumbakar and Lovell (2003). In application of this method, variability of risk (σ_v = 0.6669) is shown to have a substantially greater impact on output variability (σ_y = 0.7185) than variability of technical inefficiency (σ_u = 0.2675).

In comparison of the coefficients obtained from the inefficiency and risk variable analysis, it is observed that production specialization and capital structure have a significant and positive effect on risk while having a significant and negative impact on technical inefficiency. As output variability is more strongly influenced by risk variability than technical inefficiency variability, this supports the premise that farmers should seek to prioritise actions that reduce risk variability.

Reduction in cost of capital, positive and significant to technical inefficiency, may represent the best means to address output variability for Western Australian farmers. Reduction in the cost of capital would increase the accessibility of technology to diversify production and allow for investment in technologies that could reduce technical inefficiency. Decreased borrowing charges would also lower total liabilities for a fixed amount, or alternately allow farmers to borrow more money for equal repayments.

Reductions in borrowing costs for farmers could be promoted through initiatives that decrease asymmetry between the information available to borrowers and lenders in consonance with agency theory; this would be to the mutual benefit of farmers and lenders as it would reduce the business risk of both parties.

5. Conclusion

This article is the first in the context of Australian agriculture that seeks to quantify risk and technical inefficiency conjunctively to determine their relative impact on output variability. The data considered is a balanced panel of 274 farms for the sample period of 2002 to 2011. A stochastic frontier analysis is undertaken subject to a true fixed effects specification as defined by Greene (2005) that allows for the separate identification of time variant inefficiency and risk. Sources of observable heterogeneity amongst farms are examined as exogenous variables in the variance functions of the time variant inefficiency and risk to determine their significance to these conditions. Through the application of the JLMS estimator and the output variability decomposition of Kumbhakar and Lovell (2003), the standard deviations of inefficiency and uncertainty are calculated to examine their relative effect on the variability of output.

The following conclusions may be drawn from this study. First, the study finds that variability in risk has a greater effect on output variability in the context of mixed crop – livestock operations in Western Australia than variability in technical efficiency does. Second, the study finds that production diversification and capital structure are important factors in determination of both technical efficiency and uncertainty at the farm level; increased specialization and debt use is associated with a reduction in technical inefficiency while both increase uncertainty. Increased risk as a consequence of increased volatility in rainfall and output prices is directly concordant with theoretical expectation. The significance of higher interest costs to increased technical inefficiency indicate the perception of farm business quality in lending is a significant driver of technical efficiency for mixed output farm businesses in Western Australia.

These findings suggest that farmers in Western Australia will substantially benefit from policy that promotes the mitigation of capital costs through the promotion of information symmetry and transfer mechanisms. Policy that better educates farmers in the presentation of information to financial lenders and financial management may assist in this regard. As variability of production risk is more significant to output variability than the variability of technical inefficiency, initiatives that promote production diversification could also offer positive benefits and security for farmers.

APPENDIX 1

Table A1. Variable Construction

Measure	Description
Dependent Variable	
Output (y)	The total revenue of farm operations that have been normalized through application of an overall consumer price index figures with a 2002 base year.
Production Inputs	
Labour (x_1)	The aggregate of both casual labour and permanent labour used on a farm; measured in weeks.
Crop inputs (x_2)	This variable was constructed as a three step process. First, the expenditure on fertilizer, chemicals, seeds and fuel were normalized over their respective consumer price index figures with 2002 assumed as a base year. This is done since actual price data is not available.
Operational costs (x_3)	This variable was constructed as per the Crop Input variable except with the original input expenditures being contract services (exclusive of labour), administration, and repairs and maintenance expenditure.
Livestock production inputs (x_4)	Again this variable was constructed through the process of normalization of individual component's expenditure levels with the subsequent aggregation of these inputs. The inputs used were livestock purchased and expenditure on livestock production.
Growing season rainfall (x_5)	This is the rainfall recorded between April and November, which is the growing season in South West region of Western Australia.
Observable Heterogeneity: Inefficiency	
Production specialization (z_{1u})	Farm specialization was represented by the natural log function of the land area under production used for crop production divided by the total land area under production.
Cost of finance (z_{2u})	The natural log of the ratio of interest expenses as a percentage of total liabilities is used to highlight heterogeneity in the cost of finance for farms.
Capital Structure (z_{3u})	This was represented through the natural log of the ratio of total liabilities to total equity, i.e. the farm's capital structure. An increase in this ratio is indicative of reduced risk aversion.
Experience (z_{4u})	This was represented by the farm operator's age. In the data surveyed, only banded data was provided with classification ranges of 30-45, 45-60, 60-70, and 70+. The variable was constructed by through application of the encode function is Stata to convert the survey results to a format conducive for statistical analysis.
Education (z_{5u})	This has been represented by farm operator education. The data surveyed provides three banded results: Secondary, Tertiary Technical and Tertiary University. These were converted for statistical analysis by the application of the encode function in Stata.
Observable Heterogeneity: Uncertainty	
Production specialization (z_{1v})	See z_{1u}
Capital Structure (z_{2v})	See z_{3u}
Price variability index (z_{3v})	The natural log of the ratio of crop values over aggregate crop production was calculated for each year for each farm. The standard deviation of this function was calculated based on the ten years available for each farm on a per farm basis. 70% of farmers in the study data set were 45 years of age or older; as a result their decision making can be assumed to be based on information accrued over a longer period. Further it may be assumed that a farmer who experienced increased price variability in the period of 2002 to 2011 could be anticipated to have experienced increased price variability in prior periods.
Rainfall variability index (z_{4v})	The natural log of growing season rainfall is calculated for each farm. The standard deviation of this function was calculated based on the ten years available for each farm on a per farm basis. 70% of farmers in the study data set were 45 years of age or older; as a result their decision making can be assumed to be based on information accrued over a longer period. Further it may be assumed that a farm who experienced increased rainfall variability in the period of 2002 to 2011 could be anticipated to have experienced increased price variability in prior periods.

Regulatory change (z_{5v})	A dummy variable was constructed to account for the introduction of the federal *wheat export marketing act* of 2008, with a score of '1' representative of years prior to 2008 and '0' representative of years after

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