Estimating Production Response of Broadacre Farms in Western Australia: The Nexus of Empirics and Economics Revisited[1]

Vilaphonh Xayavong
Department of Agriculture and Food, Western Australia,
3 Baron-Hay Court,
South Perth, WA 6151,
Australia

Nazrul Islam
Department of Agriculture and Food, Western Australia,
3 Baron-Hay Court,
South Perth, WA 6151,
Australia

Ruhul Salim[2]
School of Economics & Finance
Curtin Business School (CBS)
P. O. Box U1987,
Perth, WA 6845,
Australia
(Email: ruhul.salim@cbs.curtin.edu.au)

Abstract: Reliable estimates of elasticities are fundamental requirement to accurate economic forecasting and valid analyses of the impacts of changes in government policies or international events. The aim of this paper is thus, to estimate production response for broadacre farms in Western Australia by using a normalized quadratic profit function for the period 1977/78 to 2005/06. The result reflects the imposition of curvature restrictions for a normalized profit function, and estimated elasticities are found to be less elastic in the short run. The results from this exercise can be used in a number of ways, depending on the policy objective in mind, such as simulation for forecasting agricultural production.

I. INTRODUCTION

Production response estimates (demand and supply elasticities) in agriculture have relied almost exclusively on the multi-product framework (Weaver 1983, Fisher and Wall 1990, Nguyen *et al*. 2008). This framework is particularly suitable for modelling Australian broadacre farms

1 The authors would like to thank John Connell for his support in undertaking this research.
2 Corresponding author: (ruhul.salim@cbs.curtin.edu.au)

where farmers have to make decisions about the optimal mix of inputs and outputs with given prices of inputs and outputs. However, there has been a growing debate as to whether the empirical properties of production response derived from the multi-product framework are consistent with the behavioral assumption in the duality theory of production. This issue in turn could affect the reliable estimates of elasticities which are fundamental requirement to accurate economic forecasting and valid analyses of the impacts of changes in government policies or international events.

The crux of the debate is particularly related to whether to estimate cost or profit function and which types of functional form should be used, as well as imposing restrictions on profit and cost functions when properties of those functions are violated by the estimation models and data (Lusk *et al*. 2002, Barnett and Pasupathy 2003, Wolff 2009). Our review of literature suggests that the duality theory may not always hold in empirical work. This depends on many factors such as risk, stochastic error or data quality, and selected functional forms. We also found that the normalized quadratic function have more advantage than other functional forms, although all of flexible functional forms often fail to pass the regularity property tests. As such, imposing curvature restrictions on normalized quadratic function is needed while the monotonicity condition needs to be checked if the cross price elasticities are more than unity. To examine these points the aim of this paper is to estimate the production response of broadacre farms in Western Australia by employing a normalized quadratic profit function to the ABARE's (Australian Bureau of Agricultural and Resource Economics) quasi-micro farm level data for the period 1977/78 to 2005/06. The result reflects the imposition of curvature restrictions for a normalized profit function, while estimated elasticities are found to be less elastic in the short run. The estimated elasticities are consistent with previous studies.

The rest of this paper is organized as fellows: Section II addresses issues concerning the estimation methods of production response through a brief survey of literature. The specification of production technology of broadacre farm in Western Australia and data used for the estimation are discussed in Section III. Section IV presents the estimates of elasticities, which are compared with those of the older studies. Some concluding remarks and policy implications are offered in the final section.

II. SOME ISSUES IN THE ESTIMATES OF PRODUCTION RESPONSE

Estimates of production response have been approached from different ideological and methodological aspects but two approaches appear to have dominated the study on production of broadacre farms in Australia. One of the approaches assumes that the optimal mix of output is set independently of the optimal mix of input, and hence output price. Although this approach simplifies the modelling and the analysis of agricultural commodity production, it has been criticized for ignoring the production of multi-product pattern which is widely adopted in broadacre farms (McKay *et al*. 1983, Livernois and Ryan 1989). An alternative approach, which is widely adopted in recent year, is based on the duality theory of production where either multi-product cost or profit function is specified and estimated (Ahammad and Islam 2004 and Nguyen *et al*. 2008).

Basically, the duality theory of production states that a profit maximising farmer also minimising cost, and that given a perfectly competitive market the unrestricted profit function contains the same economic information as the indirect cost function. In this regard, the dual relationship allows researchers to recover production technology parameters from an estimation of either a profit or a cost function. However, in practice there are issues associated with the selection between cost and profit estimation. The main difference between these two approaches is that output is treated as exogenous in the cost function while output is treated as endogenous in the profit function. This makes the profit function more appropriate in portraying the farmers' behavior as an optimiser. However, one can use a cost function along with the optimal output decision rule as an additional equation to avoid the criticism of endogeneity assumption on output (Kumbhakar and Tsionas 2008).

While the dual relationship exists in theory, it may not always hold in empirical application. Indeed, Burgess (1975), Weaver (1983), and Lusk *et al*. (2002) found that the dual relationship fail to hold due to factors such as risk and stochastic error. Thompson and Langworthy (1989) also demonstrated that elasticities calculated from primal and dual approaches will never be consistent if a selected functional form is not identically matched with the underlying data-generating process. However, in some cases, the dual relationship is held (Asche *et al*. 2007, and Gao and Featherstone 2008). Therefore, choosing between cost and benefit functions may also depend on quality of data, data availability, ease of estimation, or other empirical consideration.

Other issues are the choice of functional forms and imposing curvature conditions on functional forms, to satisfy with assumptions on farmers' optimal behaviors. This requirement is to ensure that a selected functional form can be complied with or tested for homogeneity, symmetry, regularity (monotonicity and curvature) conditions required by the properties of profit and cost functions.[3] For example, the popular constant elasticity of substitution (CES) and Cobb-Douglas functions are characterized by homogenous technologies and satisfy the regularity conditions but these functions are restrictive by fixing the elasticities of substitutions and not allowed for formal testing of the underlying economic theory. Uzawa (1962) also proved that the CES function cannot attain arbitrary elasticities with more than two good. This led to the introduction of various types of flexible functional forms which can provide first order approximation to arbitrary supply or demand function without imposing unwarranted a priori restrictions on elasticities of supply or demand.[4]

Three flexible functional forms dominate the recent empirical production economic literature are Translog, Generalize Leontief, and Normalized Quadratic. However, as the number of commodities in the model grew, it proved to be impossible to impose the correct curvature conditions on the first two functional forms without destroying the flexibility of the functional forms. While Diewert and Walse (1988) suggested that the normalized quadratic

[3] In netput or net output definition, outputs are represented by a positive quantity whereas inputs by a negative quantity.

[4] Most of the available flexible functional forms used in production and consumption analyses are derived from second-order series expansions. These included the translog model of Christensen, Jorgenson, and Lau (1973) and the AIDS (almost ideal demand system) model of Deaton and Muellbauer (1980) use Taylor series expansions in logarithms; while the generalized Leontief model of Diewert (1971) uses a Taylor series expansion in square roots, and the Laurent models of Barnett (1983) use the Laurent series expansion.

functional form is the only functional form that restrains from this problem, most of the empirical applications of the flexible functional form exhibit frequent violations of regularity conditions at many data points (Perroni and Rutherford 1998).

A series of studies such as Moschini (1999), Barnett (2002), Lusk *et al*. (2002), and Barnett and Pasupathy (2003) noted that violations of the regularity conditions may call into question the applicability of the duality theory to a particular data set. In other words, the violations of the regularity condition indicates the second-order condition for optimizing behavior fails, and so the duality theory. Therefore, the inferences resulting from derived estimating equation become invalid. While regularity-preserving techniques require satisfaction of both curvature and monotonicity conditions, Barnett and Pasupathy (2003) suggested that imposition of curvature may induce violations of monotonicity which otherwise would not have occurred. This gave rise to the debate as to whether imposing regularity restriction to comply with optimizing behavioral assumptions is valid. In deed, Mundlak (2000, p.327) notes that 'those studies where convexity is not confirmed should go no further because the remaining results have no theoretical support.'

Despite the violation of regularity condition of the flexible functional forms, Barnett and Pasupathy (2003) and Wolff (2009) suggested that the regularity-preserving techniques should be maintained. As Wolff (2009) explained, the regularity violation is caused by the approximation nature of flexible functional forms but their tracking is closed to the true data generation process. In this regards, the regularity-preserving techniques are indispensable. In deed, Edwards and Terrell (2004) examined the impact of imposing the monotonicity and concavity restrictions on cost function and found that the restrictions do improve the precision of elasticity estimates, efficiency estimates and forecasting accuracy. Barnett and Usui (2006) also found that monotonicity violations in the normalized-quadratic functional form are especially likely to occur when elasticities of substitution are greater than unity. As such, imposing curvature restrictions on this type of functional form one only needs to check the monotonicity condition if the cross price elasticities are more than unity.

III. THE EMPIRICAL MODEL AND DATA

To examine the nexus of empirics and the duality theory of production, we use a short-run profit function approach to characterize and estimate the WA broadacre agricultural production system. The normalized-quadratic form is selected for representing a profit function and it can be expressed as follows:

$$\Pi / P_m = \alpha_0 + \sum_{i=1}^{m-1} \alpha_i \left(P_i / P_m\right) + \sum_{i=m+1}^{n} \beta_i Z_i + \frac{1}{2} \sum_{i=1}^{m-1} \sum_{j=1}^{m-1} \gamma_{ij} \left(P_i / P_m\right)\left(P_j / P_m\right) + \frac{1}{2} \sum_{i=m+1}^{n} \sum_{j=m+1}^{n} \theta_{ij} Z_i Z_j + \frac{1}{2} \sum_{i=1}^{m-1} \sum_{j=m+1}^{n} \delta_{ij} \left(P_i / P_m\right) Z_j \quad (1)$$

where Π denotes the short-run profit (i.e., gross returns minus variable costs; also called variable profit); P is the vector of the prices of m 'netput' (or 'net outputs' implying outputs if positive quantity and variable inputs if negative quantity); Z is the vector of (n-m) quasifixed (i.e. fixed in the short run) inputs and other exogenous factors (for example, level of technological know-how); and the $\alpha, \beta, \gamma, \theta, \delta$ are parameters. Note that the mth netput is the numeraire in the model, and nominal profit and all prices are normalized by its price (P_m).

The normalized-quadratic function is a flexible functional form based on a second-order-Taylor's expansion to approximate the true short-run profit function. To characterize a well-behaved profit function, the normalized-quadratic functional form must satisfy the following conditions:

- Linear homogeneity in prices implies that nominal profit (as opposed to normalized profit) will increase by the same proportion of an increase in all prices (of inputs and outputs).
- Symmetry implies that the second-order partial derivatives of profit function must be invariant to the order of differentiation. This condition requires:

$$\alpha_{ij} = \alpha_{ji} \text{ for } \forall i,j = 1,2,\dots,(m-1). \quad (1)$$

- Monotonicity requires that all the estimated values for output supply and input demand associated with the profit function must be positive at all data points.
- Convexity in prices is a curvature condition that requires the Hessian matrix of price derivatives ($A = [\alpha_{ij}]$) to be positive semi-definite. This condition ensures that net supply functions have the correct sign.

Hotelling's Lemma (Hotelling 1932) is used to derive the set of net supply equation associated with (1):

$$Y_i = \partial\left(\Pi / P_m\right) / \partial\left(P_i / P_m\right) = \alpha_i + \sum_{j=1}^{m-1} \gamma_{ij}\left(P_i / P_m\right) + \sum_{j=m+1}^{n} \delta_{ij} Z_i \quad (2)$$

$$\text{for } \forall i, j = 1,2,\dots,(m-1).$$

where Y is a vector of netputs; and the Ps, Zs and αs are as defined above. Equation (2) represents an output supply equation when Y_i is positive and a variable input demand equation when Y_i is negative. Equations (1) and (2) form our empirical model for WA agricultural production. Note that the net supply equation for the numeraire (mth netputa) can be recovered from equations (1) and (2), and hence is not explicitly included in the empirical model.

The elasticities that measure the production response to prices and other factors can be estimated from equations (1) and (2) as follows: The elasticity of the supply of the i th netput (Y_i) with respect to the price of the j th netput (P_i) denoted by η_{ij} can be defined as:

$$\eta_{ij} = \frac{\partial Y_i / Y_i}{\partial P_j / P_j} = \frac{\partial Y_i}{\partial P_j} \times \frac{P_j}{Y_i} = \gamma_{ij} \times \frac{\left(P_j / P_m\right)}{Y_i} \quad \forall i, j = 1,2,\dots,(m-1) \quad (3)$$

Equation (3) measures own-price elasticity when $i = j$, and cross-price elasticity when $i \neq j$. The corresponding elasticities for the numeraire netput can be derived indirectly using the property of "linear homogeneity in prices" of the profit function (1) as follows:

$$\eta_{mi} = -\eta_{im}\frac{Y_i \times (P_i / P_m)}{Y_m}; \; \eta_{mm} = -\sum_{j=1}^{m-1}\eta_{mj}; \tag{4}$$

$$\text{and } \eta_{im} = -\sum_{j=1}^{m-1}\eta_{ij}; \; \forall i = 1,2,...,(m-1)$$

We use the ABARE's (Australian Bureau of Agriculture and Resource Economics) annual farm surveys of broadacre agricultural industries to estimate the model. These data are for 28 years covering the period 1977-78 to 2005-06. The details of construction of variable and data series and the summary of descriptive statistics of data series are given in Appendix 1.

IV. ANALYSIS OF EMPIRICAL RESULTS

As requirement for regression analysis, data used for the estimation must be stationary. We used four methods of unit root test in panel data: Levin-Lin-Chu (LLC), Breitung, Im-Pesaran-Shin (IPS), and Fisher-type tests using Augmented Dickey Fuller (ADF-Fisher). The former two assume common unit root process in series, while the latter two individual unit root process is assumed. The null hypothesis of the tests is that the series contains a unit root, and the alternative is that the series is stationary. The tests are estimate for two cases: individual effect and individual effect plus individual linear trends. The summary of the test result is in *Table 1*.

Table 1: Unit Root Test

Variables	Individual effect				Individual effects + individual linear trends			
	Common unit root process		Individual unit root process		Common unit root process		Individual unit root process	
	LLC	Breitung	IPS	ADF-Fisher	LLC	Breitung	IPS	ADF-Fisher
Q1	0.358	-3.298***	-0.176	6.918	-2.209**	-4.246***	-4.961***	31.548***
Q2	-1.701**	-3.017***	-1.091	18.660***	-5.941***	-3.112***	-4.664***	28.989***
Q3	-2.875***	1.159	-2.418***	15.619**	-1.639**	-2.944***	-2.552***	16.111**
Q4	0.262	-0.46	0.748	4.194	-2.533***	-1.422*	-1.430*	10.045
Q5	-2.278**	2.155**	-1.878**	15.232**	-3.163***	-0.683	-3.270***	20.929***
Q6	-1.782**	-0.927	-1.857**	12.538*	-2.072**	2.190**	-0.63	6.77
Q7	2.304**	-1.704**	-0.872	8.53	-4.413***	-3.023***	-2.722***	17.062***
Q8	2.259	-2.082**	3.434	0.139	0.203	1.64	-2.784***	19.823***
P1	-0.983	-1.492*	0.191	3.528	-1.727**	-0.684	-1.784**	11.716*
P2	-4.260***	-4.929***	-6.644***	46.995***	-1.589*	-2.754***	-6.342***	41.114***
P3	1.726**	-1.033	-0.308	5.506	-3.439***	-0.436	-3.022***	20.343***
P4	-0.871	-1.616*	-0.533	5.91	-2.224**	-0.403	-3.216***	19.846***
P5	-1.638**	-0.388	-0.928	7.819	-0.62	1.02	2.058	0.585
P6	-1.777**	-3.303***	-1.27	9.44	-2.313**	-1.856**	-1.903**	12.736**
P7	-1.473*	-1.048	0.587	2.578	-4.706***	-0.348	-3.174***	20.163***
P8	2.259	-2.082**	3.434	0.139	0.203	1.64	-2.784***	19.823***
SP	-2.788***	-2.341***	-1.885**	13.150**	-3.545***	-1.976**	-2.275**	14.346**

Notes: ***, **, and * respectively represents the significant levels at 1%, 5%, and 10%.

Over all, the test report under IPS and ADF-Fisher statistics for the case of Individual + individual linear trends suggest that we reject the null hypothesis of most series. Although we could not reject the null hypothesis for Q6 and P5 series in previous case, we can reject the null for Q6 under LLC, IPS and ADF-Fisher for the case of individual effect and under LLC and Breitung for the case of Individual + individual linear trends. As for P5, the test of LLC statistics suggests that P5 is stationary. Therefore, we conclude that all series are stationary. Notice that as the null hypothesis of most series is rejected based on test statistics under the case of Individual + individual linear trends intercept and linear trends. This reflects the fact that data used in the estimation have linear trends (*Figures 1* & *2* in Appendix 1).

To estimate the model, we added a stochastic structure in equations (1) and (2) and estimated this system equations using linear and non-linear seemingly unrelated regressions (SURE) command in *SHAZAM* (Whistler *et al*. 2004). We also add region dummies and time trends to capture the data characters discussed in unit root test section. We use 1-year lagged price as a proxy for the expected output price.

The linear SURE method was used for the estimate of unrestricted model (*i.e*., unrestricted curvature on profit function). The result reported in *Table 2* shows that some estimates of own price elasticities (see the diagonal entries) have a wrong sign. This suggests that the curvature condition of profit function is violated. Therefore, the empirical model of profit function is not satisfied the duality theory of production.

Table 2: Estimated Elasticities from Unrestricted Curvature of Profit Function

	1	2	3	4	5	6	7	8	9
1. Wheat	-3.336	0.248	-0.505	0.010	-0.199	-0.073	1.278	-0.197	2.775
2. Barley	0.154	-0.143	0.606	0.129	0.037	0.001	-0.378	-0.021	-0.384
3. Other crops	-0.358	0.692	0.094	0.016	0.229	0.057	0.368	0.068	-1.166
4. Beef-cattle and other	0.008	0.175	0.019	-0.012	0.147	0.045	-0.512	-0.039	0.167
5. Sheep and lamb	-0.170	0.051	0.276	0.148	0.186	-0.221	0.210	-0.097	-0.384
6. Wool	-0.171	0.002	0.187	0.125	-0.606	-0.184	0.946	-0.263	-0.036
7. Other agriculture	1.156	-0.552	0.471	-0.548	0.222	0.365	-1.733	0.413	0.205
8. Materials and services	0.242	0.041	-0.119	0.057	0.139	0.137	-0.559	-0.069	0.130
9. Labour	-3.518	0.785	2.088	-0.251	0.570	0.019	-0.287	0.135	0.458

To overcome the curvature violation, we proceed to impose the semi-definiteness condition on the profit function by using the method due to Diewert and Wales (1988). This method involves the replacement of the Hessian matrix of the second-order partial derivatives of the profit function (A), as:

$$A = BB^T.$$

where

$$B \equiv \left[\beta_{ij}\right] \text{ and } \beta_{ij} = 0, \text{ for } 1 \le i < j \le (m-1) \text{ and}$$
$$\text{for } j = k+1, \ldots, (m-1) \text{ when } k < (m-1).$$

B^T is the transpose matrix of B, which is a lower-triangle matrix of order (m – 1) with zeros in its last (m – 1 – k) columns. Note that our model comprises seven outputs and two variable inputs so that m = 9. Therefore, we can set k = 1, 2, . . . , 8.

The estimated result with imposing curvature condition is reported in *Table 3*. The elasticities are computed at the sample means and will therefore represent the state-average elasticities for WA in the short-run. Estimated elasticities at the sample mean of each region are reported in Appendix 2.

Table 3: Estimated Elasticities from Restricted Curvature of Profit Function

	1	2	3	4	5	6	7	8	9
1. Wheat	0.520***	-0.380***	-0.227***	-0.311***	-0.340***	0.062***	0.502***	0.023	0.153*
	(0.091)	(0.066)	(0.056)	(0.053)	(0.039)	(0.018)	(0.071)	(0.033)	(0.090)
2. Barley	-0.212***	0.206***	0.207***	0.131***	0.109***	0.001	-0.220***	-0.029*	-0.193***
	(0.037)	(0.062)	(0.038)	(0.026)	(0.027)	(0.008)	(0.038)	(0.015)	(0.076)
3. Other crops	-0.128***	0.209***	0.501***	0.012	0.056*	0.021*	-0.074	0.045**	-0.642***
	(0.032)	(0.038)	(0.094)	(0.046)	(0.032)	(0.011)	(0.051)	(0.021)	(0.089)
4. Beef-cattle and other	-0.293***	0.221***	0.020	0.232***	0.128***	-0.003	-0.365***	-0.058*	0.118
	(0.050)	(0.044)	(0.076)	(0.052)	(0.044)	(0.017)	(0.046)	(0.032)	(0.083)
5. Sheep and lamb	-0.263***	0.152***	0.077*	0.105***	0.355***	-0.114***	-0.108**	-0.067***	-0.137**
	(0.030)	(0.038)	(0.045)	(0.036)	(0.042)	(0.015)	(0.047)	(0.023)	(0.068)
6. Wool	0.154***	0.003	0.094*	-0.009	-0.370***	0.158***	-0.065	0.031	0.004
	(0.046)	(0.038)	(0.053)	(0.046)	(0.049)	(0.040)	(0.060)	(0.048)	(0.063)
7. Other agriculture	0.393***	-0.309***	-0.103	-0.304***	-0.109**	-0.020	0.520***	0.012	-0.079
	(0.055)	(0.054)	(0.071)	(0.038)	(0.048)	(0.018)	(0.082)	(0.039)	(0.085)
8. Materials and services	-0.027	0.061*	-0.094**	0.072*	0.102***	-0.014	-0.018	-0.222***	0.139**
	(0.038)	(0.031)	(0.045)	(0.039)	(0.035)	(0.022)	(0.059)	(0.063)	(0.065)
9. Labour	-0.197*	0.447*	1.470***	-0.162	0.229**	-0.002	0.129	0.154**	-2.067***
	(0.116)	(0.175)	(0.203)	(0.113)	(0.114)	(0.032)	(0.140)	(0.072)	(0.378)

Note: ***, **, * indicate 1%, 5% and 10% significant level respectively.

Table 4: Comparison of Estimated Own Price Elasticities with other Australian Farm Studies

	This study for WA	Wicks & Dillon (1978)	Vincent et al (1980)	Fisher & Wall (1990)	Johnson et al (1990)	Low /Hinchy (1990)	Ahammad/Islam(2004)
Data period	1978-2005	1975-76	1953-74	1973-87	1953-74	1978-87	1978-97
By all zones							
Wheat	0.52	1.10	-	-	-	0.37	1.23
Sheep	0.36	-	-	-	-		1.11
Cattle	0.23	0.69	-	-	-	0.84	0.02
Wool	0.16	0.25	-	-	-	0.99	0.53
By pateral zone							
Wheat	0.52	0.29	2.65	2.67	1.69	-	1.23
Sheep	0.35	-	-	0.39	0.29	-	1.11
Cattle	0.23	0.49	1.01	0.43	0.68	-	0.02
Wool	0.16	0.49	0.08	0.53	0.29	-	0.53
By w heat sheep zone							
Wheat	0.35	1.31	0.77	0.62	0.55	-	1.23
Sheep	0.40	-	0.23	0.36	0.37	-	1.11
Cattle	0.13	0.46	0.26	0.11	0.37	-	0.02
Wool	0.15	0.17	0.26	0.04	0.26	-	0.53
By high rainfall zone							
Wheat	0.03	0.89	0.62	-	0.89	-	1.23
Sheep	0.97	-	0.11	0.49	0.31	-	1.11
Cattle	0.33	0.56	0.34	0.16	0.26	-	0.02
Wool	0.20	0.32	0.06	0.19	0.16	-	0.53

Table 3 reveals that the own price elasticity for all netput (except labor) are inelastic. The estimate reflects a similar result in other studies reported in *Table 4*. The reason of why the estimated elasticities are inelastic could be explained by the nature of agricultural production process. As Griffith *et al*. (2001) indicated, the agricultural production are subject to its biological constraints such as cropping seasons, rotation patterns, pasture growth patterns and livestock gestation periods, and the long lead times in bringing new land into use; although farmers can adjust the composition of outputs and input such labor in the short run they can not adjust fixed endowments of livestock, land and capital; this means the short run response to price change is limited. Also notice that the wheat and other agricultural product tend to be larger that the livestock estimates. This may be due to there is more flexibility to alter cropping acreages than livestock numbers, as significant changes in planting decisions can be made from year to year while animal breeding strategies take a much longer period to implement (Vere *et al*. 1993).

V. SUMMARY AND CONCLUSION

This study examines the debate on the estimation of production response in agriculture. The debates are related to selections between cost or profit function and types of functional form to be used to estimate the production response. The debates also concerns whether imposing curvature conditions on profit and cost functions is valid. After reviewing the literature, we found that the duality theory may not always hold in empirical work. This depends on many factors such as risk, stochastic error or data quality, and selected functional forms. We also found that the normalized quadratic function has more advantage than other functional forms, although all of flexible functional forms often fail to pass the regularity condition in the duality theory. As such, there is a requirement to impose curvature restriction if normalized quadratic function is used and monotonicity condition need to be checked if the cross price elasticities are greater than unity. We examined the above-mentioned issues by estimating production response for broadacre agricultural farms in Western Australia. A normalized quadratic profit function is estimated using the ABARE's quasi-micro farm level data for the period 1977/78 to 2005/06. The result reflects the imposition of curvature restrictions for a normalized profit function, and estimated elasticities are found to be less elastic in the short run. The estimated elasticities are also consistent with previous studies (Wicks and Dillon 1978, Fisher and Wall 1990 and Ahammad and Islam 2004).

The results from this exercise can be used in a number of ways, depending on the policy objectives of researchers. Historically, the agriculture sector is impacted by government policy initiatives that affect prices of agricultural output, the impact of such intervention on demand and/ or supply can be analyzed on the basis of own and cross price elasticities of demand and supply. Another area of application is simulation for forecasting agricultural production or modelling supply response due to internal or external shocks. Such exercises bear significant importance in the face of changing climatic conditions and ever increasing population in order to ensure sustainable agricultural production in Australia and elsewhere in the world.

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APPENDIX 1: SOURCES OF DATA

The price and quantity data series on an average farm level inputs use and outputs production was sourced from ABARE. This data series is for the years 1977-78 to 2005-06 and it is principally based on ABARE's annual farm surveys of broadacre agriculture industries. The raw database has values and quantities for 12 output and 27 input items. For the modelling purpose outputs are grouped into seven and inputs into three. To aggregate diverse groups of outputs and inputs the divisia indexing procedure was used. Where quantity variables were not available, ABARE derived them by deflating the farm survey value data with the appropriate ABARE's prices paid and received indices (ABARE, 1995b). The prices used are farm gate price.

The 12 output can be broadly grouped to include: grains, meat, wool and other farm incomes. The grains output includes harvested amount wheat, barley, oats, sorghum, oilseeds and other crops. Except for other crops, quantities are measured in tonnes. The implicit prices for these grains were calculated by deflating the values by their respective quantities. For other crops the quantity data is provided by ABARE in index form.

The meat output category includes quantity of sales and positive operative gains of sheep, lamb, beef cattle and other livestock animals. The quantity data is provided in index form. Implicit prices for these items were calculated by deflating their respective values with quantity indices. Wool output is measured in kilograms of wool shorn. The wool price is calculated by deflating the value of wool shorn by the quantity. Other farm income: is measured in index form and the implicit unit price is calculated by deflating the total farm receipt by the quantity index.

The three input groups are capital, labour and materials and services. Capital is composed of land, plant and machinery, structures and livestock. The value variables for land and livestock (beef cattle and sheep) are the opportunity costs of investing funds in those capital items. These are calculated as the average capital value (that is, the average of opening and closing values) multiplied by a real interest rate. The value variables for plant and structures capital are the opportunity costs plus depreciation. In the case of land, the expected value of land which partly reflects the future productivity gains is not included.

Quantity variable used for land is the area operated. For beef cattle and sheep, it is the average of opening and closing numbers. For building and plant capital, it is the average value of capital stock deflated by the respective prices paid indices for each. Unit prices of each of the capital items are calculated by dividing the values by the respective quantities for every item.

Labour consists of four items - owner operator and family labour, hired labour, shearing costs, and stores and rations. The value of owner operator and family labour input is imputed using weeks worked and an award wage. The value of hired labour is wages paid, and the values of shearing and stores and rations are expenditure. The quantity variables for owner operator and family labour and hired labour are number of weeks worked. Expenditure deflated by a shearing prices paid index is the quantity variable for shearing.

Materials and services include purchases and positive operating gains of sheep, beef cattle and other livestock animals; purchases or user costs of chemicals, livestock materials, fodder, fertilizer, seeds, fuel, and other materials; motor vehicle sundry costs, rates and taxes, administrative costs, miscellaneous livestock costs, contracts, repairs, and other services. Quantities of these inputs are provided in index in the database.

Unit prices for these inputs are calculated by deflating the total value by their respective quantity indices.

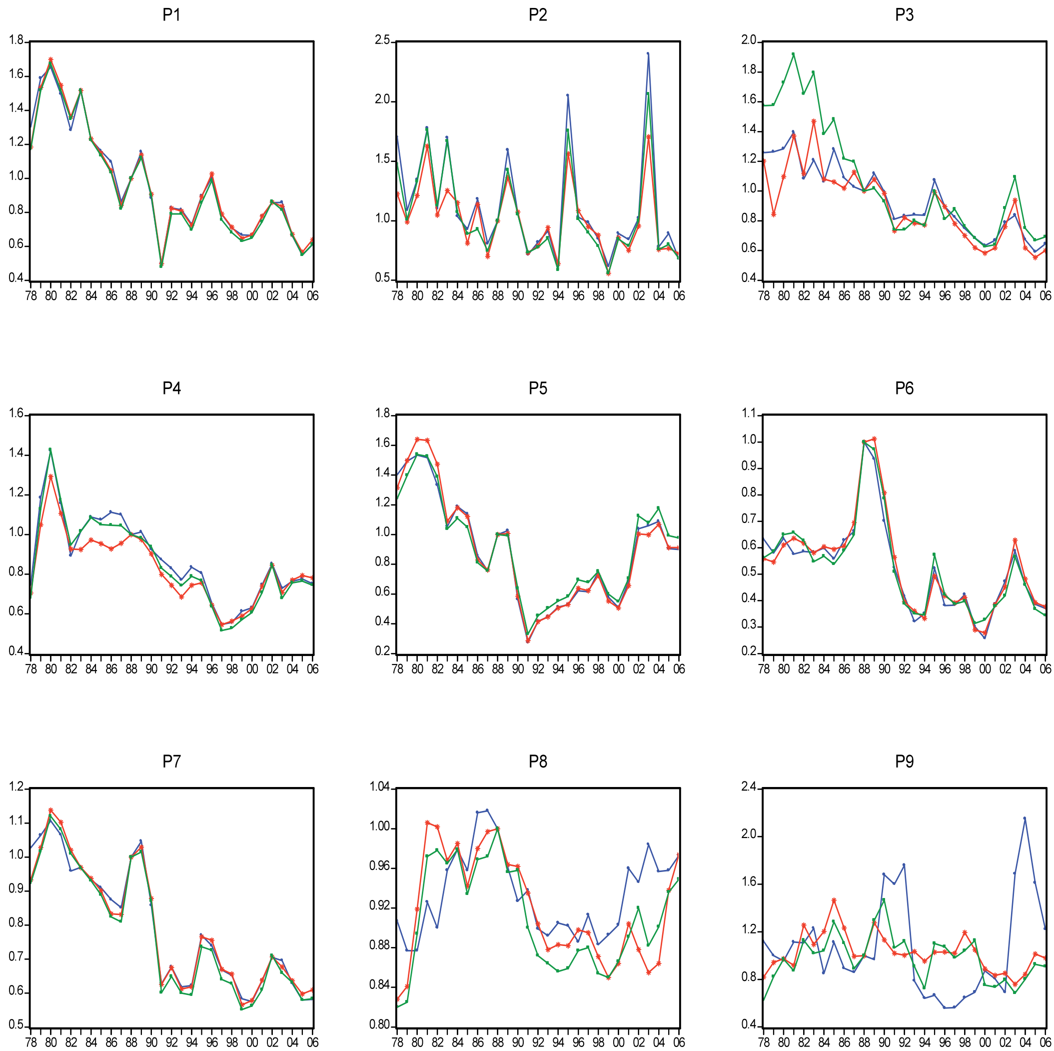
Table 1A: Summary Statistics for Data used in the Estimation

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Probability	Sum	Sum Sq. Dev.	Observations
P1	0.96	0.86	1.70	0.48	0.32	0.70	2.50	8.07	0.02	83.76	8.74	87
P2	1.06	0.99	2.40	0.56	0.38	1.29	4.38	31.13	0.00	92.11	12.16	87
P3	0.97	0.90	1.92	0.55	0.30	0.99	3.58	15.34	0.00	84.69	7.93	87
P4	0.85	0.81	1.43	0.52	0.20	0.55	3.06	4.42	0.11	74.30	3.41	87
P5	0.90	0.91	1.64	0.28	0.35	0.33	2.21	3.90	0.14	77.95	10.54	87
P6	0.53	0.54	1.01	0.26	0.18	1.02	3.96	18.30	0.00	46.03	2.64	87
P7	0.79	0.74	1.14	0.55	0.18	0.37	1.68	8.36	0.02	68.51	2.74	87
P8	0.92	0.91	1.02	0.82	0.05	0.05	1.96	3.98	0.14	80.14	0.22	87
P9	1.02	1.00	2.15	0.56	0.28	1.32	5.81	53.83	0.00	88.94	6.56	87
Q1	7.99	1.58	73.10	0.00	15.02	2.69	9.83	274.15	0.00	694.82	19411.36	87
Q2	2.03	1.44	9.10	0.06	1.73	2.13	7.49	138.80	0.00	176.99	255.93	87
Q3	2.04	1.25	12.43	0.19	2.21	2.76	11.23	356.26	0.00	177.85	421.22	87
Q4	1.83	1.37	5.43	0.57	1.08	1.02	3.28	15.30	0.00	158.95	99.40	87
Q5	1.36	0.98	6.35	0.50	0.99	2.56	11.00	326.60	0.00	117.96	84.18	87
Q6	0.98	1.00	1.87	0.22	0.30	0.06	2.84	0.14	0.93	85.03	7.58	87
Q7	1.63	1.16	6.67	0.23	1.25	1.56	5.49	57.77	0.00	141.54	134.39	87
Q8	1.24	1.20	3.01	0.41	0.46	0.76	4.17	13.39	0.00	108.03	18.22	87
Q9	1.09	1.01	2.01	0.63	0.30	0.95	3.55	14.20	0.00	95.08	7.87	87
Q10	1.03	1.01	1.40	0.78	0.15	0.39	2.48	3.18	0.20	89.18	1.81	87
SP	3.63	3.00	10.62	0.70	1.84	1.04	4.46	23.52	0.00	315.59	290.62	87

Figure 1A: Plots of Quantity Data used in the Estimation

Note: the subscript numbers stand for quantities of 1: wheat, 2: Barley, 3: Other crops, 4.Beef&OtherMeat, 5: Sheep & Lamp, 6: Wool, 7: Other Agriculture, 8: Material & Service, 9: Capital, 10: Labour. Green line represents data for high rainfall zone (scale measure in right axis), while red and blue lines for pastoral zone and wheat-sheep zone (scales measure in left axis).

Figure 2 A: Plots of Price Data used in the Estimation



Note: the subscript numbers stand for prices of 1: wheat, 2: Barley, 3: Other crops, 4.Beef&OtherMeat, 5: Sheep & Lamp, 6: Wool, 7: Other Agriculture, 8. Green line represents data for high rainfall zone, while red and blue lines for pastoral zone and wheat-sheep zone.

APPENDIX 2. ELASTICITIES ESTIMATED FOR THREE AGRICULTURAL ZONES IN WA

Elasticities estimated at sample mean of WA pasteral zone									
	1	2	3	4	5	6	7	8	9
1. Wheat	0.519***	-0.380***	-0.226***	-0.311***	-0.340***	0.062***	0.502***	0.023	0.153*
	(0.091)	(0.067)	(0.057)	(0.054)	(0.040)	(0.019)	(0.071)	(0.033)	(0.090)
2. Barley	-0.211***	0.205***	0.206***	0.131***	0.109***	0.001	-0.219***	-0.028**	-0.193***
	(0.037)	(0.062)	(0.038)	(0.026)	(0.028)	(0.009)	(0.039)	(0.015)	(0.076)
3. Other crops	-0.127***	0.208***	0.500***	0.012	0.056*	0.021*	-0.074	0.044**	-0.641***
	(0.032)	(0.039)	(0.094)	(0.046)	(0.033)	(0.012)	(0.052)	(0.022)	(0.089)
4. Beef-cattle and other	-0.292***	0.221***	0.020	0.231***	0.127***	-0.003	-0.365***	-0.057*	0.117
	(0.050)	(0.044)	(0.077)	(0.053)	(0.044)	(0.018)	(0.047)	(0.032)	(0.083)
5. Sheep and lamb	-0.262***	0.151***	0.077*	0.104***	0.354***	-0.113***	-0.107**	-0.066***	-0.137**
	(0.031)	(0.038)	(0.045)	(0.036)	(0.043)	(0.015)	(0.048)	(0.023)	(0.069)
6. Wool	0.154***	0.003	0.094***	-0.009	-0.370***	0.157***	-0.065	0.030	0.004
	(0.047)	(0.039)	(0.053)	(0.047)	(0.050)	(0.041)	(0.060)	(0.048)	(0.063)
7. Other agriculture	0.393***	-0.309***	-0.103	-0.304***	-0.109**	-0.020	0.519***	0.012	-0.078
	(0.056)	(0.054)	(0.072)	(0.039)	(0.049)	(0.019)	(0.083)	(0.039)	(0.085)
8. Materials and services	-0.026	0.058**	-0.089**	0.068*	0.096***	-0.014	-0.017	-0.208***	0.130**
	(0.037)	(0.030)	(0.043)	(0.038)	(0.034)	(0.021)	(0.056)	(0.059)	(0.062)
9. Labour	-0.191	0.432***	1.420***	-0.156	0.222**	-0.002	0.125	0.144**	-1.996***
	(0.113)	(0.110)	(0.197)	(0.110)	(0.111)	(0.031)	(0.136)	(0.069)	(0.375)
Elasticities estimated at sample mean of WA wheat sheep zone									
	1	2	3	4	5	6	7	8	9
1. Wheat	0.353***	-0.249***	-0.149***	-0.204***	-0.242***	0.042***	0.346***	0.017	0.087
	(0.062)	(0.044)	(0.038)	(0.035)	(0.028)	(0.013)	(0.049)	(0.024)	(0.062)
2. Barley	-0.162***	0.152***	0.153***	0.097***	0.088***	0.001	-0.170***	-0.023**	-0.134**
	(0.028)	(0.046)	(0.028)	(0.019)	(0.022)	(0.007)	(0.030)	(0.012)	(0.056)
3. Other crops	-0.120***	0.190***	0.458***	0.011	0.055*	0.020*	-0.071	0.045**	-0.588***
	(0.030)	(0.035)	(0.086)	(0.042)	(0.033)	(0.011)	(0.049)	(0.022)	(0.082)
4. Beef-cattle and other	-0.171***	0.125***	0.011	0.131***	0.078***	-0.002	-0.217***	-0.035*	0.080*
	(0.030)	(0.025)	(0.044)	(0.030)	(0.027)	(0.010)	(0.028)	(0.020)	(0.048)
5. Sheep and lamb	-0.279***	0.155***	0.079*	0.107***	0.396***	-0.123***	-0.116**	-0.075***	-0.144***
	(0.033)	(0.039)	(0.047)	(0.037)	(0.048)	(0.017)	(0.052)	(0.026)	(0.072)
6. Wool	0.146***	0.003	0.086*	-0.008	-0.368***	0.152***	-0.062	0.031	0.020
	(0.045)	(0.035)	(0.049)	(0.043)	(0.049)	(0.040)	(0.058)	(0.048)	(0.060)
7. Other agriculture	0.369***	-0.279***	-0.094	-0.276***	-0.108**	-0.019	0.495***	0.012	-0.099
	(0.053)	(0.049)	(0.065)	(0.035)	(0.048)	(0.018)	(0.079)	(0.039)	(0.082)
8. Materials and services	-0.024	0.051**	-0.079**	0.061*	0.093***	-0.013	-0.016	-0.204***	0.130**
	(0.034)	(0.026)	(0.039)	(0.034)	(0.033)	(0.020)	(0.053)	(0.058)	(0.059)
9. Labour	-0.146	0.345**	1.222***	-0.160*	0.209**	-0.010	0.156	0.152**	-1.770***
	(0.104)	(0.096)	(0.170)	(0.096)	(0.104)	(0.029)	(0.128)	(0.069)	(0.333)
Elasticities estimated at sample mean of WA high rain fall zone									
	1	2	3	4	5	6	7	8	9
1. Wheat	0.034***	-0.024***	-0.017***	-0.020***	-0.023***	0.004***	0.033***	0.002	0.012**
	(0.006)	(0.004)	(0.004)	(0.004)	(0.003)	(0.001)	(0.005)	(0.002)	(0.006)
2. Barley	-0.368***	0.342***	0.413***	0.228***	0.199***	0.001	-0.382***	-0.050**	-0.383***
	(0.064)	(0.104)	(0.076)	(0.046)	(0.050)	(0.015)	(0.067)	(0.026)	(0.137)
3. Other crops	-0.183***	0.287***	0.828***	0.017	0.084*	0.031*	-0.107	0.064**	-1.023***
	(0.046)	(0.053)	(0.156)	(0.066)	(0.050)	(0.018)	(0.074)	(0.031)	(0.143)
4. Beef-cattle and other	-0.414***	0.299***	0.033	0.328***	0.189***	-0.005	-0.518***	-0.081*	0.168
	(0.071)	(0.060)	(0.125)	(0.075)	(0.066)	(0.026)	(0.066)	(0.045)	(0.130)
5. Sheep and lamb	-0.680***	0.376***	0.230*	0.272***	0.965***	-0.303***	-0.280**	-0.174***	-0.405**
	(0.080)	(0.095)	(0.135)	(0.095)	(0.116)	(0.041)	(0.124)	(0.061)	(0.190)
6. Wool	0.185***	0.004	0.130*	-0.011	-0.468***	0.195***	-0.078	0.037	0.004
	(0.057)	(0.045)	(0.074)	(0.056)	(0.063)	(0.051)	(0.073)	(0.058)	(0.082)
7. Other agriculture	0.900***	-0.677***	-0.273	-0.698***	-0.263	-0.047**	1.194***	0.027	-0.162
	(0.128)	(0.119)	(0.189)	(0.089)	(0.117)	(0.044)	(0.190)	(0.091)	(0.205)
8. Materials and services	-0.029	0.062**	-0.115**	0.077*	0.114***	-0.016	-0.019	-0.236***	0.161**
	(0.042)	(0.032)	(0.056)	(0.043)	(0.040)	(0.025)	(0.064)	(0.067)	(0.074)
9. Labour	-0.257**	0.526***	2.021***	-0.176	0.295**	-0.002	0.126	0.179**	-2.713***
	(0.124)	(0.136)	(0.282)	(0.136)	(0.138)	(0.039)	(0.159)	(0.082)	(0.469)
Note: ***, **, * indicate 1%, 5% and 10% significant level respectively.									