



**AgEcon** SEARCH  
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search  
<http://ageconsearch.umn.edu>  
[aesearch@umn.edu](mailto:aesearch@umn.edu)

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

# **Contracts for Land Retirement under Asymmetric Information**

**Australian Agricultural and Resources Economics Society  
AARES 50<sup>th</sup> Annual conference  
08 -10 February 2006, Sydney NSW**

Jananee Raguragavan<sup>1</sup>, Ben White<sup>2</sup> and Robert C. Chambers<sup>3</sup>

---

<sup>1</sup> School of Agriculture and Resource Economics, University of Western Australia

<sup>2</sup> Corresponding Author: School of Agriculture and Resource Economics, University of Western Australia, 35 Stirling Hwy, Crawley WA 6009 Australia. e-mail: [bwhite@are.uwa.edu.au](mailto:bwhite@are.uwa.edu.au)

<sup>3</sup> University of Maryland and University of Western Australia  
The Authors acknowledge the support of an ARC Discovery Grant

# Contracts for Land Retirement under Asymmetric Information

## Abstract

A land retirement policy whereby land is taken out of agriculture and converted to natural vegetation or forestry has the potential to reduce environmental damage related to dryland salinity in Western Australia. This paper uses some recent results in the theory of directional distance functions (Chambers and Fare, 2004) to analyse alternative policy designs for a land retirement scheme. The results indicate that a fixed price scheme is inefficient compared with a first-best solution, but performs adequately. A scheme requiring a fixed proportion of area retired by all producers is inefficient. A separating solution, based on mechanism design, gives a small but significant increase in welfare compared to a fixed price scheme.

Key words: Agri-environmental policy, distance functions, efficiency, mechanism design

**JEL classifications: Q12**

## 1. Introduction

Land retirement policies, such as the EU set-aside scheme and CRP in the US, where a regulator aims to retire a proportion of the agricultural land in a region to achieve environmental objectives are increasingly important policy instruments. The issue addressed here is how should a land retirement scheme be designed when there is an asymmetry of information between the regulator and farmers. Chambers, (1987, 2002b) addresses the general problem of asymmetric information in agricultural policy using mechanism design. Mechanism design has also been proposed as an approach to agri-environmental policy (Wu and Babcock, 1996; Moxey, *et al.*, 1998; Bontems, *et al.*, 2005) and land retirement policy (Smith, 1995; Bourgeon *et al.*, 1995).

Despite a large number of theoretical models based on mechanism design the number of empirical applications has been small. Realistic applications are to be found in Smith (1995) who analyses a land retirement scheme by regions in the US; Bourgeon *et al.* (1995) apply mechanism design to the EU Set-aside scheme; and Bontems *et al.* (2005) design an optimal non-linear production tax/subsidy to address non-point source pollution. The reason for lack of applications is that they must resolve difficult empirical issues related to defining compliance cost functions and how they vary across farms when the farm population are heterogeneous. Firm type in most theoretical models is a single parameter which measures technical efficiency. In practice a number of other unobservable variables determine compliance cost including endowments of fixed factors of production, and allocative efficiency. The theoretical models developed in this paper are applied for a sample of farms in the Greater Southern region of Western Australia for the crop year 1999.

The remainder of the paper is organised as follows. Section 2 presents a theoretical model of the regulator's problem. Section 3 presents the approach to empirical modelling. Section 4 presents results and Section 5 concludes.

## 2. Regulation Model

A regulator, who acts as a Stackelberg leader (Laffont and Tirole, 1993, p56) sets up a scheme to retire land to maximise welfare. Farm profit, for allocatively efficient farms, is given by the restricted profit function  $\pi(p, w, a^h, \bar{x}^h, \theta^h)$  where  $p$  and  $w$  are vectors of output and input prices,  $a^h$  is hectares farmed subject to fixed inputs other than land  $\bar{x}^h$ . Farm type is represented by technical efficiency  $\theta^h$ , land area and endowment of fixed resources. The reservation profit is  $\pi_0^h = \pi_0(p, w, a_0^h, \bar{x}^h, \theta^h)$  where  $a_0^h$  is the initial land area. The environmental benefit associated with crop land retirement is captured by  $v > 0$ .

Following Laffont and Tirole (1993, p56), the welfare function is:

$$\text{Maximize}_{\alpha^h, b^h} \sum_h \{v\alpha^h a_0^h - (\pi_0^h - \pi(p, w, a^h, \bar{x}^h, \theta^h)) - \lambda b^h \alpha^h a_0^h \} \quad (1)$$

where welfare is maximised with respect to the transfer payment per hectare  $b^h$  and the proportion of land retired  $\alpha^h$ . The welfare function comprise three components: the first gives the environmental benefit of land retirement, the second gives the compliance cost as the difference between the reservation profit and profit with land retirement and the third gives taxpayer cost as the transfer payment per hectare weighted by the shadow price of public funds,  $\lambda$ . This welfare function simplifies to:

$$\text{Maximize}_{\alpha^h, b^h} \sum_h \{ \pi(p, w, a^h, \bar{x}^h, \theta^h) - \lambda b^h \alpha^h a_0^h \} \quad (2)$$

by assuming the scheme retires a fixed total area and noting that the reservation profit is constant and can be dropped from the welfare function.

For first-best (Policy 1a), by assuming that firms are allocatively efficient, (2) is maximised subject to an individual rationality constraint

$$\pi_0^h \leq \pi(p, w, a^h, \bar{x}^h, \theta^h) + b^h \alpha^h a_0^h \quad \forall h \quad (3)$$

and a land retirement constraint:

$$\sum_h \alpha^h a_0^h = \tau \sum_h a_0^h. \quad (4)$$

where the sum of land retired ( $r^h = \alpha^h a_0^h$ ) by individual farms equals the target proportion  $\tau$  of the total area. Each farm is offered an individual contract which specifies the proportion of the base area to be retired and the transfer payment per hectare.

Policy 1b is where farms are assumed to take decisions based vectors of farm specific ‘wrong prices’,  $p^h, w^h$ . As for Policy 1b each farm is offered individual contracts.

A fixed price scheme (Policy 2) offers all farms a fixed price per hectare  $\bar{b}$  for land retired and allows the farms to decide on the area retired. Policy 3 offers a fixed price and fixed area scheme and includes constraint (4) and

$$r^h = \tau a_0^h \quad \forall h \quad (5)$$

where, all producers are constrained to retire a fixed proportion of their land. This scheme is equivalent to the EU set-aside scheme.

Policy 3 and 4 are pooling policies where there is no differentiation between farm types. Policy 1 offers separate contracts to each farmer, but may not be applicable where farms self-select. A separating solution, if it is optimal, specifies a menu of contracts which require producers to retire different proportions of the land area in exchange for different rates of payment per ha. Policy 4 is an adaptation of Policy 1 and includes incentive compatibility constraints, which ensures efficient self selection.

$$\pi(p, w, \alpha^h a_0^h, \bar{x}^h, \theta^h) + b^h \alpha^h a_0^h \geq \pi(p, w, \alpha^k a_0^k, \bar{x}^h, \theta^h) + b^k \alpha^k a_0^k \quad h, k \in H; \quad h \neq k. \quad (6)$$

Thus each firm identified in the population as a ‘type’ and has a policy given by  $\{b^h, \alpha^h\}$ . The left hand side of (6) gives the producer’s profit of selecting the contract intended for type  $h$ . The right hand side gives the profit derived by type  $h$  selecting the contract intended for type  $k$ .

### 3. Estimating Compliance Costs

A Directional output distance function (Chambers, 2002) is estimated to measure the technical and allocative efficiency of farms. The output distance function allows maximum expansion of the output in a specified direction and is defined as follows: firm  $h$  produce a vector of outputs  $y \in \mathfrak{R}_+^m$  using a vector of inputs  $y \in \mathfrak{R}_+^n$ . Technology is defined as a set:

$$T \subset \mathfrak{R}_+^n \times \mathfrak{R}_+^m : T = \{(x \in \mathfrak{R}_+^n, \mathfrak{R}_+^m) : x \text{ can produce } y\}$$

The technology,  $T$ , satisfies the regularity conditions of no free lunch, is closed and convex, and has free disposability of inputs and outputs (Chambers, 2002). The output distance function is defined as follows:

$$\bar{D}_o(x, y; g_y) = \max\{\beta \in R : (y + \beta g_y) \in T\}, g_y \in R_+^m, (0, m) \neq (0^n, 0^m)$$

The firms operating on the frontier, where the value of the output distance function is zero, indicates that no further output expansion in the direction is feasible. Firms operating below the frontier are inefficient and the output distance measures the inefficiency of these firms.

The directional output distance function is a complete functional representation of the technology in that:

$$\bar{D}_o(x, y; g_y) \geq 0 \text{ if and only if } y \in T \quad (7)$$

Where (7) implies that  $x$  can produce  $y$  if and only the distance function is nonnegative. In addition it is assumed that the output distance function satisfies the translation property so that:

$$\bar{D}_o(x, y + \theta g_y; g_y) = \bar{D}_o(x, y; g_y) - \theta, \quad \theta \in R \quad (8)$$

### ***3.1. The Technical and Allocative Efficiency***

Chambers and Fare (2004), establish the determination of technical and allocative efficiency for a distance function where the translation property holds. Their approach is based on Nerlove (1965) and states that an allocatively efficient firm solves the following profit maximization problem given technical efficiency  $\theta$ .

$$\begin{aligned}\pi_0 &= \sup \left\{ py - wx : (\bar{D}_o x, y, \mathbf{g}_y) \leq \theta \right\} = \sup \left\{ py - wx : \bar{D}_o(x, y + \theta \mathbf{g}_y, \mathbf{g}_y) \leq 0 \right\} \\ &= \theta p \mathbf{g}_y + \pi(p, w)\end{aligned}\quad (9)$$

which follows from the translation property (8). Equation (9) is in a *normalized* form by dividing through by  $p \mathbf{g}_y$  to give:

$$\hat{\pi}_0 = \pi(\hat{p}, \hat{w}) + \theta$$

For the directional vector adopted here  $p \mathbf{g}_y$  is the sum of output prices. Chambers and Fare (2004) define the difference between normalized maximal profit and normalized observed profit

$$\pi(\hat{p}, \hat{w}) - \hat{\pi}_0$$

as Nerlovian profit efficiency. Nerlovian efficiency can be decomposed into allocative and technical efficiency using the approach of Lau and Yotopolous (1971) who assume that each firm perceive the ‘wrong’ price vectors  $p^h$  and  $w^h$  when taking input and output decisions.

$$\begin{aligned}\sup \left\{ p^h y - w^h x : (\bar{D}_o x, y, \mathbf{g}_y) \leq \theta \right\} &= \sup \left\{ p^h y - w^h x : \bar{D}_o(x, y - \theta \mathbf{g}_y, \mathbf{g}_y) \leq 0 \right\} \\ &= \theta p^h \mathbf{g}_y + \pi(p^h, w^h)\end{aligned}$$

Assuming that the profit function is differentiable we obtain:

$$y(p^h, w^h, \theta) = \theta \mathbf{g}_y + \Delta_p \pi(p^h, w^h)$$

$$x(p^h, w^h) = -\Delta_w \pi(p^h, w^h)$$

by Hotelling’s Lemma. The observed profit with allocative inefficiency is

$$\pi_0^{ai} = \theta p \mathbf{g}_y + py(p^h, w^h, \theta) - wx(p^h, w^h)$$

If we normalize by  $p \mathbf{g}_y$ , add the normalised maximal profit to both sides, and rearrange to give:

$$\pi(\hat{p}, \hat{w}) - \hat{\pi}_0^{ai} = \left\{ \pi(\hat{p}, \hat{w}) - \hat{p}y(p^h, w^h, \theta) - \hat{w}x(p^h, w^h) \right\} - \theta$$

The first term in brackets gives allocative efficiency as the difference between normalised profit and the profit at the outputs and inputs for the ‘wrong’ prices calculated using normalised prices.

Relating the conditions for profit maximization to the distance function gives the following first order conditions for an interior solution



$$p^h = -\Delta_y \vec{D}_o(x, y; g_y) p^h g_y \quad (10)$$

$$w^h = \Delta_x \vec{D}_o(x, y; g_y) p^h g_y \quad (11)$$

These first-order conditions are employed in the empirical regulation model analysis.

### 3.2 Functional Form

Ideally, the functional form for the distance function must satisfy two requirements, first it should be flexible, and second it should satisfy the translation property (8). This narrows the choice of tractable output distance functions to the quadratic form proposed by Chambers (1998):

$$\vec{D}_o(x^h, y^h; g_y) = \alpha_0 + \sum_{i=1}^n \alpha_i x_i^h + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \alpha_{ij} x_i^h x_j^h + \frac{1}{2} \sum_{k=1}^m \sum_{l=1}^m \beta_{kl} y_k^h y_l^h + \sum_{i=1}^n b_i y_i^h + \frac{1}{2} \sum_{i=1}^n \sum_{k=1}^m \gamma_{ik} x_i^h y_k^h \quad (12)$$

Following Färe *et al.* (2001) and Aigner and Chu (1968) the output distance function (12) is estimated using linear programming. Where the parameters  $\alpha_0$ ,  $\alpha_i$ ,  $\alpha_{ij}$ ,  $\beta_{kl}$ ,  $b_k$  and  $\gamma_{ik}$  are selected to

$$\text{minimize } \sum_h \vec{D}_o(x_0^h, y_0^h; g_y) \quad (13a)$$

subject to

$$\vec{D}_o(x_0^h, y_0^h; g_y) \geq 0, \quad \forall h \quad (13b)$$

$$\Delta_y \vec{D}_o(x_0^h, y_0^h; g_y) \leq 0, \quad \forall h \quad (13c)$$

$$\Delta_x \vec{D}_o(x_0^h, y_0^h; g_y) \geq 0, \quad \forall h \quad (13d)$$

where  $y_0^h$  and  $x_0^h$  give the observed input and output use where land is included in the input vector.

The output distance function inherits its properties from the output possibility set and to ensure functional form in (12) satisfy these properties, the minimisation problem in (13a) is solved subject to the following restrictions: (13b) constrains each firm to produce on or below the production frontier. Restrictions (13c) and (13d) ensure free disposability of inputs and outputs.

The following parameter restrictions ensure the output distance function satisfies the translation property (Chambers, 1998):

$$\alpha_{ij} = \alpha_{ji} \text{ and } \beta_{kl} = \beta_{lk}; \sum_{k=1}^m b_k = -1; \sum_{l=1}^m \beta_{kl} = 0, \quad k = 1, \dots, m; \sum_{k=1}^m \gamma_{kl} = 0, \quad i = 1, \dots, n$$

If the output set is assumed to be convex then the distance function is concave in outputs (Chambers, 2002). The curvature restriction is imposed using Lau's (1978) Cholesky decomposition method to ensure the Hessian matrix  $H$  for the distance function is negative semi-definite. The approach requires that the Hessian is given by

$$H = LDL'$$

where  $D$  a diagonal matrix of Cholesky values and  $L$  is a lower triangular matrix. For the distance function (12) weak concavity is imposed by reparametrizing the parameters and ensured the Cholesky values are constrained to be non-positive. The advantage of the quadratic functional form is that the Hessian matrix is parametric, thus global concavity can be imposed on the estimated distance function (Chambers, 1989).

### **3.3 Empirical Regulation Model**

The profit function is not derived explicitly in this analysis; instead profit depends upon finding the maximum profit which is achievable given the firm's fixed input constraints and technical efficiency. Policy 1 involves solving the following nonlinear programming problem:

$$\text{Maximize } \sum_h \{\pi^h - \lambda b^h \alpha^h a_0^h\} \quad (14a)$$

subject to

$$\bar{D}_o^*(x^h, y^h; \mathbf{g}_y) \geq \theta^h, \quad \forall h \quad (14b)$$

$$\Delta_y \bar{D}_o^*(x^h, y^h; \mathbf{g}_y) \leq 0, \quad \forall h \quad (14c)$$

$$\Delta_x \bar{D}_o^*(x^h, y^h; \mathbf{g}_y) \geq 0, \quad \forall h \quad (14d)$$

$$\pi^h = py^h - wx^h \quad \forall h \quad (14e)$$

$$r^h = (a_0^h - a^h) \quad \forall h \quad (14f)$$

$$\sum_h r^h = \tau \sum_h (a_0^h) \quad \forall h \quad (14g)$$

$$a^h \leq a_0^h \quad \forall h \quad (14h)$$

$$(\pi_0^h - \pi^h) - b^h r^h \geq 0 \quad \forall h \quad (14i)$$

That is, the regulator's objective function is maximised, subject to a series of constraints that derive from the estimated distance function,  $\bar{D}_o^*(x^h, y^h; \mathbf{g}_y)$  that is (14b) the firm's efficiency is not increasing, the solution is at a point in the technology set where the output does not increase the distance and inputs do not reduce the distance. Equation (14e) gives the profit after land retirement. A land retirement variable  $r^h$  is defined by (14f). Equation (14g) is a land retirement constraint which specifies that a proportion of the original area  $\tau$  is retired. Equation (14h) ensures that the crop area is reduced. Equation (14i) is an individual rationality constraint.

Policy 1b can be assessed assuming allocative inefficiency, by taking the shadow prices of outputs  $p^h$  and inputs  $w^h$  measured at the firms current input and output mix and forming the constraints:

$$\mathbf{p}^h = \Delta_y \bar{D}_o^*(\mathbf{x}^h, \mathbf{y}^h; \mathbf{g}_y) p^h \mathbf{g}_y$$

$$\mathbf{w}^h = \Delta_x \bar{D}_o^*(\mathbf{x}^h, \mathbf{y}^h; \mathbf{g}_y) p^h \mathbf{g}_y$$

For the fixed price policy, Policy 2, the profit maximisation problem is identical except that the individual farm transfers  $b^h$  are replaced by a fixed transfer payment  $\bar{b}$  per hectare, farms are allowed to select the area of their farm retired.

Policy 3 requires a fixed price and a fixed proportion of the farm area to be retired. This problem is the same as Policy 2 except that the land retirement constraint (14g) is replaced by:

$$r^h = \tau a_0^h \quad \forall h$$

Policy 4 requires that producers self-select from a menu of contracts which are give as a transfer payment per hectare  $b^h$  and as a proportion of the area retired  $\alpha^h$  is the same as Policy 1 except for the addition of the incentive compatibility (IC) constraint

$$\pi^{hh} + b^h \alpha^h a_0^h \geq \pi^{hk} + b^k \alpha^k a_0^h \quad h, k \in H; \quad h \neq k.$$

All variable input and output vectors for firms are modified to give  $x^{hk}$  and  $y^{hk}$ , that is the input and output level when the firm selects ‘wrong contracts’. Note that this leads to  $(H^2 - H)$  additional constraints for the IC constraint and the profit constraints. The complete nonlinear programming problem is given below:

$$\text{Maximize}_{\alpha^h, b^h} \sum_h \{ \pi^{hh} - \lambda b^h \alpha^h a_0^h \} \quad (15a)$$

subject to

$$\bar{D}_o^*(x^{hk}, y^{hk}; g_y) \geq \theta^h \quad h, k \in H \quad (15b)$$

$$\Delta_y \bar{D}_o^*(x^{hk}, y^{hk}; g_y) \leq 0 \quad h, k \in H \quad (15c)$$

$$\Delta_x \bar{D}_o^*(x^{hk}, y^{hk}; g_y) \geq 0 \quad h, k \in H \quad (15d)$$

$$\pi^{hk} = p y^{hk} - w x^{hk} \quad (15e)$$

$$r^{hk} = \alpha^k a_0^h \quad (15f)$$

$$\sum_h r^{hh} = \tau \sum_h (a_0^h) \quad (15g)$$

$$a^h \leq a_0^h \quad (15h)$$

$$(\pi_0^h - \pi^{hh}) - b^h \alpha^h a_0^h \geq 0 \quad (15i)$$

$$\pi^{hh} + b^h \alpha^h a_0^h \geq \pi^{hk} + b^k \alpha^k a_0^h \quad h, k \in H; \quad h \neq k. \quad (15j)$$

#### 4. Data

The data were derived from farm accounts and physical records for a sample of farms in the Great Southern region of Western Australia for 1999. Descriptive statistics for the 61 farms for the 1999 crop year are given in Table A1 in the Appendix. Outputs are given as two aggregate revenue measures: one for crop output and the other for livestock output. Defining outputs as revenues assumes that prices are constant across farms. This is a reasonable assumption for crops which are largely sold to a single cooperative (CBH). Similarly, livestock output is dominated by wool and lamb for the export market and tends to pass through a small number of regional markets. The inputs machinery, services and crop input are given as total costs under these headings. Land is given as hectares, labour as full-time equivalent weeks and stock head as the equivalent of the number of breeding ewes on the basis of forage requirements. Further definitions and units are given in Table A2.

### 5. Results

#### 5.1 Estimation

The estimation of the distance function was carried out using LP algorithm (GAMS Corporation, 1996). Table A3 presents the parameter estimates of the output distance function. Parameters are estimated using the curvature restriction that the distance function is concave in output. Technical, allocative and profit efficiency measures are given in Table A4. Notably firms appear to be relatively technically efficient, but have a low degree of allocative efficiency.

## **Table 1 about here**

### ***5.2 Policy Comparison***

The welfare functions and transfer payment per hectares values are compared for the different policies in Table 1. In the case of Policy 1 (first-best) and Policy 4 (asymmetric information) the transfer payments are given as a range indicating how they vary amongst those farms participating in the scheme. A number of conclusions can be derived from the results. First fixed area schemes Policy 3 are clearly inferior to other policies. This, undifferentiated contract is administratively easy but due to the higher transfer payment will lead to some farmers being overcompensated. Policy 2 (fixed price) performs well and is only slightly inferior to the first-best and asymmetric information policy. The first-best policy with allocative inefficiency (Policy 1b) stands out as giving some unusual results: the welfare value is reduced because firms respond to the policy on the basis of the wrong prices, as the transfer payments are based on a comparison with actual profit rather than maximal profit these are reduced, finally, with the wrong prices area restrictions can actually increase profit by fortuitously increasing a firms allocative efficiency.

### **6. Conclusion**

This paper proposes a non-parametric approach to policy design applied to a land retirement scheme. The analysis makes use of some recent results by Chambers and Fare (2004) on the decomposition of profit efficiency into allocative and technical efficiency. It highlights the issue in mechanism design of determining what is meant by firm type. Here it is defined as technical and allocative efficiency, plus the endowment of fixed factors.

The results indicate that a fixed price scheme is relatively efficient compared with a hypothetical first-best solution. Forcing all farmers to retire a fixed proportion of their area

significantly reduces the efficiency of a land retirement policy. A separating solution based on mechanism design gives a small but significant increase in welfare.

## References

- Aigner, D. J., Chu, S. F., 1968. On Estimating the Industry Production Function. *American Economic Review*, 58, 826-39.
- Bourgeon, J., Jayet, P., Picard, P., 1995. An Incentive to Land Set-aside Programs. *European Economic Review*, 39, 487-1509.
- Bontems P., Rotillon G., Turpin N., 2005. Self-selecting Agri-environmental Policies with an Application to the Don Watershed. *Environmental & Resource Economics* 31, 275-301.
- Chambers, R. G. 1989. Recent Developments in Production Economics. *Economic Record*, 65, 243-264.
- Chambers, R. G. 1992. On the Design of Agricultural Policy Mechanisms. *American Journal of Agricultural Economics*, 74, 646 –654.
- Chambers, R. G. 1998. Input and Output Indicators. In: Fare, R. Grosskopf, S., Russell,R.R.(Ed.), *Index Numbers: Essays in Honour of Sten Malmquist*. Norwell: Kluwer.
- Chambers, R. G. 2002a. Exact Nonradial Input, Output, and Productivity Measurement. *Economic Theory*, 20, 751-766.
- Chambers, R. G. 2002b. Information, Incentives and the Design of Agricultural Policies. In Gardner, B. L. and Rausser, G. C. *Handbook of Agricultural Economics*. Amsterdam: North-Holland.
- Chambers, R. G., Chung, Y., Fare, R., 1996. Benefit and Distance Functions. *Journal of Economic Theory*, 70, 407-419.
- Chambers, R. G., Chung, Y., Fare, R. 1998. Profit, Directional Distance Functions, and Nerlovian Efficiency. *Journal of Optimization Theory and Applications*, 98, 351-364.
- Chambers, R. G., Fare, R., 2004. Additive Decomposition of Profit Efficiency. *Economic Letters*, 84, 329-334.
- Fare, R., Grosskopf, S., Weber, W.L., 2001. Shadow, Prices of Missouri Public Conservation Land, *Public Finance Review*, 29, 444-460.
- GAMS Development Corporation, 1996. *GAMS The Solver Manual*. GAMS Development Corporation: Washington DC.
- Laffont, J.J, Tirole, J., 1993. *A Theory of Incentives in Procurement and Regulation*, Cambridge: MIT Press
- Lau, L.J., 1978. Testing and Imposing Monotonicity, Convexity and Quasi-Convexity Constraints, In: Fuss, M., McFadden, D (Ed.), *Production Economics: A Dual Approach to Theory and Applications*, 1, Amsterdam: North-Holland, pp. 409 – 53.
- Lau, L.J., Yotopoulos, P. A., 1971. A Test for Relative Efficiency an Application to Indian Agriculture. *American Economic Review*, 61, 94-109.
- Moxey, A., White, B., Ozanne, A., 1999. Efficient Contract Design for Agri-environmental Policy. *Journal of Agricultural Economics*, 50, 187-202.
- Nerlove, M., 1965. *Estimation and Identification of Cobb-Douglas Production Functions*, Rand McNally Company, Chicago. Illinois
- Smith, R.B.W., 1995. The Conservation Reserve Program as a Least-cost Land Retirement Mechanism. *American Journal of Agricultural Economics*, 77, 93-105.

Wu J.J., Babcock B.A., 1996. Contract Design for the Purchase of Environmental Goods from Agriculture. *American Journal of Agricultural Economics* 78, 935-945.



**Table 1 Comparison of Policy Options on Contract Design**

|                   | <b>Policy(1a)</b>            |                                    | <b>Policy(1b)</b>              |                                    | <b>Policy(2)</b>         |                            | <b>Policy(3)</b>            |                            | <b>Policy(4)</b>              |                                    |
|-------------------|------------------------------|------------------------------------|--------------------------------|------------------------------------|--------------------------|----------------------------|-----------------------------|----------------------------|-------------------------------|------------------------------------|
|                   | <b>Allocative efficiency</b> |                                    | <b>Allocative inefficiency</b> |                                    | <b>Fixed-price</b>       |                            | <b>Fixed-price and Area</b> |                            | <b>Asymmetric Information</b> |                                    |
| % of land retired | Welfare Millions Dollars     | Transfer Payment (Range) \$ per ha | Welfare Millions Dollars       | Transfer Payment (Range) \$ per ha | Welfare Millions Dollars | Transfer Payment \$ per ha | Welfare Millions Dollars    | Transfer Payment \$ per ha | Welfare Millions Dollars      | Transfer Payment (Range) \$ per ha |
| 5                 | 94.0                         | 12.00-16.78                        | 28.6                           | 7.058-26.130                       | 93.0                     | 16.78                      | 90.5                        | 24.87                      | 93.8                          | 6.01-10.23                         |
| 10                | 91.5                         | 21.25-36.49                        | 28.6                           | 6.558-85.045                       | 89.5                     | 36.49                      | 86.7                        | 44.83                      | 89.6                          | 21.25- 71.43                       |
| 15                | 88.9                         | 21.25-39.01                        | 28.4                           | 6.090 -26.130                      | 86.9                     | 39.01                      | 84.0                        | 48.10                      | 88.3                          | 21.25- 345.09                      |
| 20                | 86.1                         | 21.25-39.33                        | 28.6                           | 3.829-85.049                       | 84.5                     | 39.33                      | 80.3                        | 67.27                      | 85.8                          | 21.25- 816.34                      |
| 25                | 83.4                         | 21.25-39.62                        | 28.7                           | 5.429-93.718                       | 81.9                     | 39.62                      | 76.3                        | 92.91                      | 83.3                          | 21.25- 251.08                      |

## Appendix

**Table A1 Variable Descriptions**

| Variable          | Description  | Unit      |
|-------------------|--|-----------|
| Crop revenue      | Crop revenue in calendar year  | \$        |
| Livestock revenue | Revenue from wool, lamb and cattle sales   | \$        |
| land              | Cleared land area  | ha        |
| labour            | Family and hired labour  | weeks     |
| machinery         | Total value of machinery   | \$        |
| Livestock         | Stock numbers adjusted to ewe equivalents  | Head ewes |
| crop inputs       | Fertiliser, seed and sprays  | \$        |
| services          | Includes overheads postage, phone, subscriptions, accounting and consultancy costs | \$        |
| rain              | Farm rain during cropping season 1999  | mm        |

**Table A2 Descriptive Statistics for Farm Data 1999 (N=61)**

| Subscript | Units             | Average   | SD     | max    | min     |       |
|-----------|-------------------|-----------|--------|--------|---------|-------|
| 1         | crop revenue      | \$        | 437002 | 312698 | 1573255 | 7373  |
| 2         | livestock revenue | \$        | 42252  | 47291  | 265015  | 0     |
| 1         | Land              | Ha        | 2095   | 1245   | 7644    | 520   |
| 2         | Machinery         | \$        | 444597 | 421879 | 2625000 | 34250 |
| 3         | livestock         | hd (ewes) | 2449   | 2184   | 15655   | 0     |
| 4         | labour            | weeks     | 96     | 43     | 283     | 48    |
| 5         | crop inputs       | \$        | 155597 | 115166 | 583147  | 17006 |
| 6         | rain              | mm        | 442    | 90     | 682     | 279   |
| 7         | service           | \$        | 128887 | 70687  | 431247  | 42388 |

**Table A3 - Parameter Estimates**

| Parameter     |           |
|---------------|-----------|
| $\alpha_0$    | -0.078    |
| $\alpha_1$    | 0.002     |
| $\alpha_2$    | 0.287     |
| $\alpha_3$    | 0.004     |
| $\alpha_4$    | 0.757     |
| $\alpha_5$    | 0.063     |
| $\alpha_6$    | 0.012     |
| $b_1$         | -0.219    |
| $b_2$         | -0.781    |
| $\alpha_{11}$ | -1.000E-6 |
| $\alpha_{12}$ | -0.001    |
| $\alpha_{13}$ | -2.846E-6 |
| $\alpha_{14}$ | -1.672E-8 |
| $\alpha_{15}$ | 1.394     |
| $\alpha_{16}$ | 2.572E-6  |
| $\alpha_{21}$ | -0.001    |
| $\alpha_{22}$ | -1.814E-5 |
| $\alpha_{23}$ | -6.506E-4 |
| $\alpha_{24}$ | 2.1997E-4 |
| $\alpha_{25}$ | 0.002     |
| $\alpha_{26}$ | 2.9947E-4 |
| $\alpha_{31}$ | -2.846E-6 |
| $\alpha_{32}$ | -6.506E-4 |
| $\alpha_{33}$ | -2.291E-5 |
| $\alpha_{34}$ | -0.004    |
| $\alpha_{35}$ | -0.01     |
| $\alpha_{36}$ | -2.543E-4 |
| $\alpha_{41}$ | -1.672E-8 |
| $\alpha_{42}$ | 2.199     |
| $\alpha_{43}$ | -0.004    |
| $\alpha_{44}$ | -0.003    |
| $\alpha_{45}$ | -0.030    |
| $\alpha_{46}$ | -0.004    |
| $\alpha_{51}$ | 1.3942E-4 |
| $\alpha_{52}$ | 0.002     |
| $\alpha_{53}$ | -0.001    |
| $\alpha_{54}$ | -0.030    |
| $\alpha_{55}$ | -0.019    |
| $\alpha_{56}$ | 0.073     |
| $\alpha_{61}$ | 2.5725E-6 |
| $\alpha_{62}$ | 2.9947E-4 |
| $\alpha_{63}$ | -2.543E-4 |
| $\alpha_{64}$ | -0.004    |
| $\alpha_{65}$ | 0.073     |
| $\alpha_{66}$ | -4.479E-5 |
| $\beta_{11}$  | 0         |
| $\beta_{12}$  | 0         |
| $\beta_{21}$  | 0         |
| $\beta_{22}$  | 0         |
| $\gamma_{12}$ | -9.398E-5 |
| $\gamma_{11}$ | 0.002     |
| $\gamma_{22}$ | -0.006    |
| $\gamma_{21}$ | -0.023    |
| $\gamma_{31}$ | 0.001     |
| $\gamma_{32}$ | 0.004     |
| $\gamma_{41}$ | 0.008     |
| $\gamma_{42}$ | 0.020     |
| $\gamma_{51}$ | -0.001    |
| $\gamma_{52}$ | 0.009     |
| $\gamma_{61}$ | -0.002    |
| $\gamma_{62}$ | -0.013    |

Outputs: Crop =1, livestock =2; Inputs: Land = 1, Machinery = 2, Livestock = 3, Labour = 4, Crop inputs 5, Rain = 6, Services = 6

**Table A4 Technical and Allocative Efficiency**

| Firm No | $\pi_0$ | $\pi(p^s, w^s)$ | $\pi(p, w)$ | $\bar{D}_o(x^h, y^h; 1)$ | NE      | AE     |
|---------|---------|-----------------|-------------|--------------------------|---------|--------|
| 1       | 2.556   | 5.827           | 15.689      | 0.200                    | 6.5665  | 4.931  |
| 2       | 0.814   | 2.149           | 11.914      | 0.205                    | 5.55    | 4.8825 |
| 3       | 4.534   | 8.182           | 19.011      | 0.110                    | 7.2385  | 5.4145 |
| 4       | 2.260   | 5.211           | 13.3        | 0.105                    | 5.52    | 4.0445 |
| 5       | 2.399   | 4.088           | 15.63       | 0                        | 6.6155  | 5.771  |
| 6       | 1.941   | 5.247           | 14.72       | 0                        | 6.3895  | 4.7365 |
| 7       | 0.469   | 3.393           | 12.714      | 0.254                    | 6.1225  | 4.6605 |
| 8       | 5.118   | 11.189          | 21.045      | 0                        | 7.9635  | 4.928  |
| 9       | 0.687   | 2.406           | 10.95       | 0                        | 5.1315  | 4.272  |
| 10      | 5.800   | 13.835          | 16.586      | 0                        | 5.393   | 1.3755 |
| 11      | 1.120   | 2.946           | 12.928      | 0.108                    | 5.904   | 4.991  |
| 12      | 1.013   | 3.029           | 10.333      | 0.037                    | 4.66    | 3.652  |
| 13      | 0.469   | 2.162           | 14.132      | 0.030                    | 6.8315  | 5.985  |
| 14      | 2.077   | 4.523           | 15.798      | 0.164                    | 6.8605  | 5.6375 |
| 15      | 0.820   | 3.877           | 14.277      | 0.756                    | 6.7285  | 5.2    |
| 16      | 1.928   | 5.575           | 14.485      | 0.362                    | 6.2785  | 4.455  |
| 17      | 3.185   | 6.632           | 13.102      | 0.213                    | 4.9585  | 3.235  |
| 18      | 0.961   | 3.017           | 11.02       | 0.179                    | 5.0295  | 4.0015 |
| 19      | 1.370   | 3.272           | 12.918      | 0.144                    | 5.774   | 4.823  |
| 20      | 0.362   | 3.945           | 9.759       | 0.209                    | 4.6985  | 2.907  |
| 21      | 5.256   | 8.509           | 15.457      | 0                        | 5.1005  | 3.474  |
| 22      | 9.080   | 17.876          | 24.69       | 0                        | 7.805   | 3.407  |
| 23      | 5.142   | 9.587           | 20.407      | 0.017                    | 7.6325  | 5.41   |
| 24      | 1.511   | 3.106           | 10.332      | 0                        | 4.4105  | 3.613  |
| 25      | 0.371   | 1.95            | 9.684       | 0.084                    | 4.6565  | 3.867  |
| 26      | 0.748   | 6.414           | 18.824      | 0.280                    | 9.038   | 6.205  |
| 27      | 0.609   | 2.173           | 12.217      | 0.157                    | 5.804   | 5.022  |
| 28      | 1.237   | 3.728           | 12.562      | 0.118                    | 5.6625  | 4.417  |
| 29      | 0.975   | 3.58            | 9.501       | 0.329                    | 4.263   | 2.9605 |
| 30      | 0.612   | 3.651           | 11.201      | 0.128                    | 5.2945  | 3.775  |
| 31      | 1.645   | 3.091           | 13.332      | 0.034                    | 5.8435  | 5.1205 |
| 32      | 5.998   | 11.798          | 22.305      | 0.121                    | 8.1535  | 5.2535 |
| 33      | 1.995   | 5.181           | 12.632      | 0.121                    | 5.3185  | 3.7255 |
| 34      | 0.673   | 4.014           | 15.849      | 0.289                    | 7.588   | 5.9175 |
| 35      | 0.892   | 3.693           | 11.526      | 0.193                    | 5.317   | 3.9165 |
| 36      | 1.771   | 3.816           | 10.578      | 0.654                    | 4.4035  | 3.381  |
| 37      | 2.442   | 6.098           | 12.869      | 0.192                    | 5.2135  | 3.3855 |
| 38      | 2.060   | 5.672           | 13.128      | 0.247                    | 5.534   | 3.728  |
| 39      | 3.917   | 8.877           | 24.291      | 0.098                    | 10.187  | 7.707  |
| 40      | 1.944   | 4.642           | 12.641      | 0.219                    | 5.3485  | 3.9995 |
| 41      | 1.836   | 7.427           | 19.229      | 0.317                    | 8.6965  | 5.901  |
| 42      | 1.603   | 5.325           | 19.407      | 0.385                    | 8.902   | 7.041  |
| 43      | 1.616   | 3.493           | 12.852      | 0.036                    | 5.618   | 4.6795 |
| 44      | 7.613   | 11.617          | 21.107      | 0                        | 6.747   | 4.745  |
| 45      | 3.257   | 8.199           | 19.652      | 0.886                    | 8.1975  | 5.7265 |
| 46      | 1.724   | 5.736           | 14.15       | 0.357                    | 6.213   | 4.207  |
| 47      | 1.182   | 5               | 15.302      | 0.696                    | 7.06    | 5.151  |
| 48      | 0.690   | 2.498           | 12.963      | 0.550                    | 6.1365  | 5.2325 |
| 49      | 5.026   | 9.74            | 20.621      | 0                        | 7.7975  | 5.4405 |
| 50      | 2.287   | 5.7             | 17.196      | 0                        | 7.4545  | 5.748  |
| 51      | 2.874   | 6.352           | 17.963      | 0.152                    | 7.5445  | 5.8055 |
| 52      | 3.705   | 5.918           | 14.377      | 0.210                    | 5.336   | 4.2295 |
| 53      | 2.765   | 5.072           | 14.831      | 0.133                    | 6.033   | 4.8795 |
| 54      | 5.369   | 9.521           | 23.228      | 0                        | 8.9295  | 6.8535 |
| 55      | 2.669   | 6.473           | 17.236      | 0.175                    | 7.2835  | 5.3815 |
| 56      | 1.431   | 3.558           | 14.128      | 0.184                    | 6.3485  | 5.285  |
| 57      | 2.348   | 5.235           | 17.999      | 0.084                    | 7.8255  | 6.382  |
| 58      | 2.589   | 9.948           | 26.317      | 0.430                    | 11.864  | 8.1845 |
| 59      | -0.503  | 1.548           | 9.529       | 0.369                    | 5.016   | 3.9905 |
| 60      | 3.111   | 8.908           | 27.238      | 0.278                    | 12.0635 | 9.165  |
| 61      | 1.538   | 3.287           | 15.932      | 0.442                    | 7.197   | 6.3225 |