An Economic Evaluation of a Pest Management Control Program: 'Outfox the Fox'

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NSW DEPARTMENT OF
PRIMARY INDUSTRIES

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Abstract: Foxes are regarded as a serious pest of environmental and grazing systems in Australia. The fox is a recognised predator of native wildlife and has been a significant contributor to the population decline of many native mammal, bird and reptile species. There are also claims that foxes may account for up to 30% of lamb mortalities in some areas, while mortality due to predation of 2 to 5% is more likely in most regions. The 'Outfox the Fox' program was established by NSW Agriculture in conjunction with a number of Rural Land Protection Boards to achieve a more strategic and coordinated fox baiting program. This program relies on a community driven and integrated management approach to the problem. The main features are to synchronise baiting across landholders at least twice a year, undertake baiting during periods when the fox is most susceptible, regularly check and replace baits, and continue until the bait take declines. A stochastic economic surplus and benefit-cost analysis model was developed to evaluate this program. The change in annual economic surplus due to the 'Outfox the Fox' program was $3.4m. The benefit-cost analysis showed that the project provided a significant return on public investment with a mean net present value of $9.8m and a mean benefit-cost ratio of 13.0:1. The stochastic analysis indicated that there was a very low probability of this program providing a negative economic return.

Keywords: benefit cost analysis; research evaluation; economic surplus; fox

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Executive Summary

The European Red Fox (*Vulpes vulpes*) is a pest animal widely distributed across Australia. First introduced in the 1840's in southern Victoria for recreational hunting, foxes are now estimated to occupy 98% of New South Wales. Foxes result in substantial environmental damage through competition and predation of wildlife, as well as spreading weed seeds. The main agricultural impact from foxes is predation on lambs and goat kids. Although it is difficult to measure impact, foxes may prey on 10-30% of lambs in some areas.

The most commonly used fox control techniques are lethal baiting, shooting, trapping, den fumigation, den destruction and exclusion fencing. Fertility control through immunocontraception has been investigated as an alternative or supplementary means of fox control, as has chemical fertility control. Other measures such as the use of guard animals has been promoted in recent years but not yet fully evaluated in Australia.

The 'Outfox the Fox' program is a large strategic, coordinated fox baiting program in New South Wales that involves 20% of the State's Rural Land Protection Boards. The program was established by the former NSW Agriculture (now part of NSW Department of Primary Industries) with an extension focus to improve the efficacy and cost-effectiveness of landholder fox baiting practices by promoting best practice techniques, and specifically to encourage landholders to group bait. The major feature of this program is that it involves a coordinated and community based approach to managing foxes using an existing technology. Consequently, the benefits arise from coordinated action, with the benefit rising with the number of participants until some asymptote is reached.

Approach to the evaluation

The primary economic outcome from the program is reduced mortality of juvenile livestock from fox predation. The lamb market is likely to benefit most from the program given that fox predation is a significant source of lamb mortality. Predation by foxes directly reduces the number of lambs weaned and marketed, thus reducing the supply of lamb in the sheep meat market. An economic surplus model of the Australian lamb industry was developed to estimate the economic benefit of the program. The model had a dissagregated regional form, with separate regions for the area under review, the rest of Australia, and the rest of the world. Due to uncertainty in the impacts of the program and a number of the adoption parameters, a stochastic analysis was adopted whereby the marking percentage of lambs, lamb price, maximum adoption and the period of maximum adoption were specified as random variables. The shift in the commodity supply function was estimated directly from changes in lamb marking percentages, which were assumed to increase by (in absolute values) between 1 and 5% due to the program.

A benefit-cost analysis model was developed to measure the return on investment from the 'Outfox the Fox' program. The annual benefit estimated using the model was the total change in economic surplus due to the program, adjusted by the annual level of adoption. The costs of the program comprised various salary and operational expenditures incurred by NSW Agriculture, Rural Land Protection Board's and other state government agencies.

Economic, social and environmental effects

The economic surplus model indicated that the 'Outfox the Fox' program has the potential to generate a mean increase in annual economic surplus of $3.36m. This is comprised of a gain to producers in the study region of $2.44m, a $2.75m loss to producers in the rest of Australia, and gains to consumers within the region and rest of Australia of $0.05m and $2.55m respectively. There were also distribution impacts outside of Australia to international consumers (gain of $33.41m) and international producers (loss of $32.35m). There was significant variation in the total change in economic surplus represented by the standard deviation of $1.10m compared to the mean $3.36m, implying a coefficient of variation of 32.7.

The benefit-cost analysis model indicated that public investment in the 'Outfox the Fox' program provides a positive economic return. The analysis resulted in a mean NPV of $9.83m, and a mean BCR of 13.0:1. Although there was a large range in the NPV, with a minimum of $1.22m and a maximum of $28.54m, there were no negative returns. Likewise, the BCR results indicate that the program would always result in a reasonable return on investment, with a minimum value of 2.5:1 and a maximum of 35.8:1.

Foxes are one of the major exotic predators that threaten the survival of Australian fauna, and have contributed to the decline of many species of reptiles, mammals and birds. Consequently, any large-scale reduction in fox densities as a result of the 'Outfox the Fox' program could generate significant environmental and biodiversity benefits. To achieve any environmental benefit would require that the reduction in fox density from the program occurs in areas where there is wildlife as well as agricultural impact.

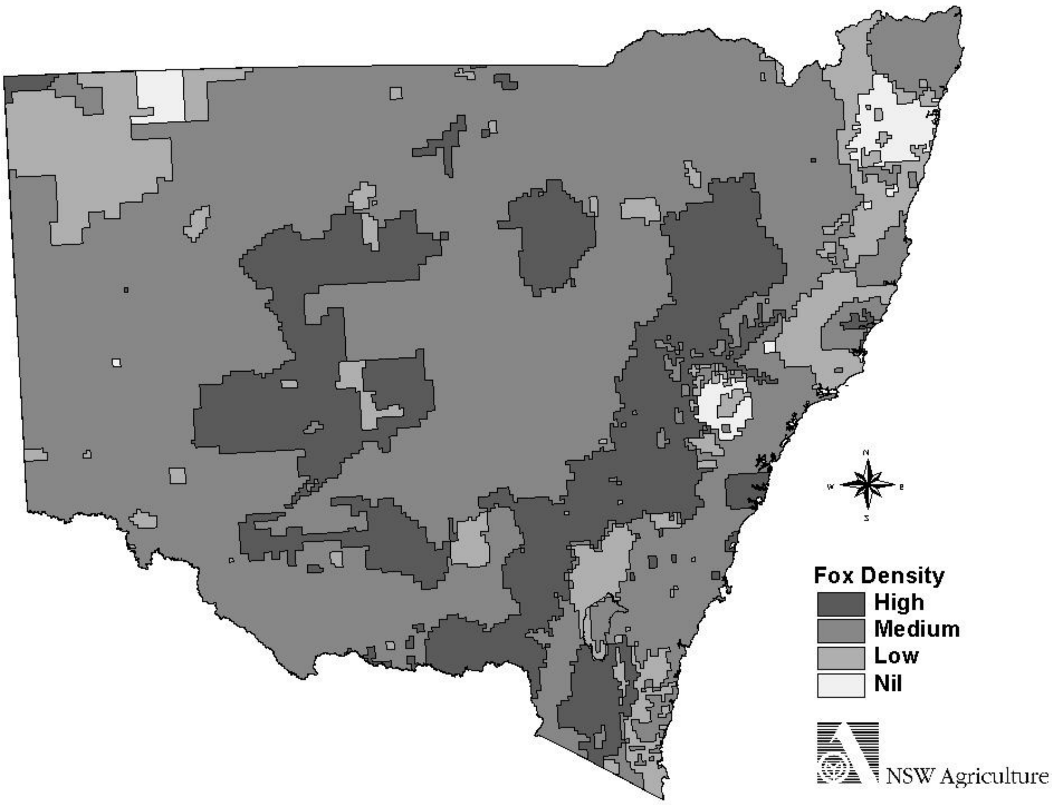
The economic benefits of a program such as 'Outfox the Fox' are shared by graziers, agribusiness and consumers in the form of increased income and can have important social consequences for regional communities. However, because of the small size of the program the social impact is likely to be marginal. One area of potential positive social impact from the program is the success of the community based integrated management approach that was taken to the problem. Community based approaches to managing problems (eg. Landcare, Bushcare) have been claimed to have a positive impact on social capital.

1. Introduction

The European Red Fox (*Vulpes vulpes*) was introduced into southern Victoria for recreational hunting in the 1840's (Rolls 1969). The fox quickly expanded its range and is now distributed widely across the Australian mainland with the exception of the wet tropics. This distribution was mostly achieved within 100 years of its introduction (Jarman 1986).The distribution of the fox is similar to that of the rabbit and is one of the most widely spread feral animals in mainland Australia.

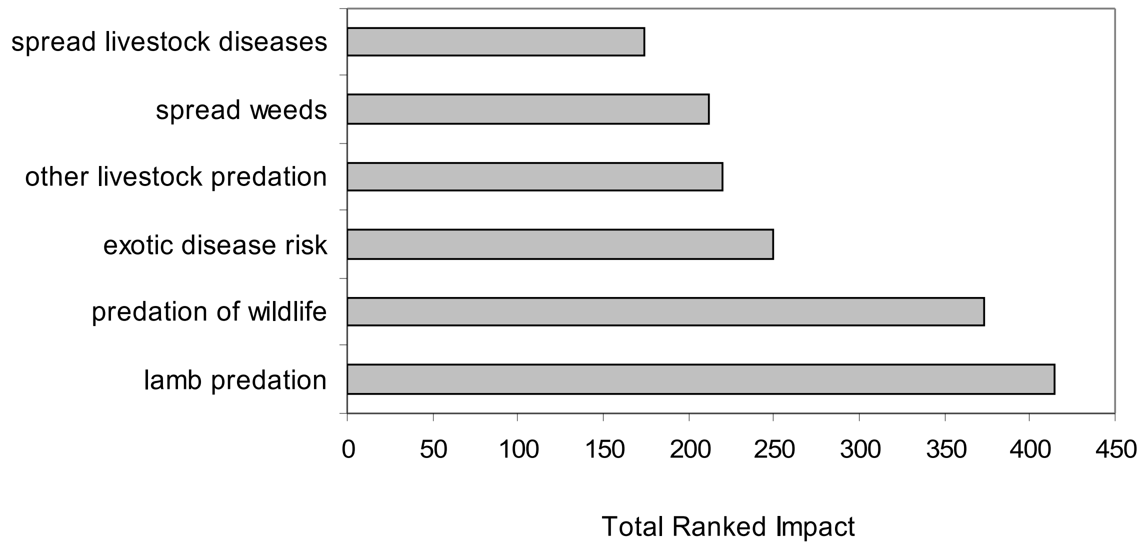
A survey of fox distribution and density across NSW Rural Land Protection Board (RLPB) districts found that this pest animal occurs in 98% of the state (West and Saunders 2003). Foxes inhabit 172,419 km^2 (21%) of New South Wales at high density, 541,601 km^2 (66%) at medium density, and 90,189 km^2 (11%) at low density (Figure 1). There were only a few areas (16,093km^2 or 2%) of New South Wales where foxes were reported as being absent. These areas were around Grafton, within northern Wollemi National Park (near Singleton), and within north-western Wanaaring RLPBs. The highest densities of foxes were perceived to be within the Cobar, Hillston, Hay, Narrandera, Coonamble, Tamworth, Mudgee-Merriwa, Central Tablelands, Young, Gundagai, Hume, Cooma and Bombala RLPB Districts.

Figure 1. **Estimated density of foxes in NSW**



The success of the fox is attributable to a highly adaptable and unspecialized lifestyle with no specific habitat requirements (Corbet and Harris 1991). Foxes are highly mobile and secretive animals with a high reproductive potential and opportunistic diet (Saunders et al. 1995). Foxes result in substantial environmental damage through competition and predation of wildlife, as well as spreading weed seeds (Figure 2). The main agricultural impact from foxes is predation on lambs and goat kids. Although it is difficult to measure impact, foxes may prey on 10-30% of lambs in some areas (Saunders et al. 1995). Despite this perception, the impact of foxes on agricultural production remains largely unquantified (Saunders et al. 1995) although recent research presents strong evidence of their impacts on wildlife (Kinnear et al. 1988; Priddel 1989).

Figure 2. Ranked impacts of foxes in NSW



Source: West and Saunders (2003)

The economic impact of foxes in Australia has been estimated at $228 million per annum (McLeod 2004), which was comprised of $18 million from sheep production losses, $190 million in environmental impacts, and management and research costs of $20 million. The agricultural impact was estimated by assuming a 2% predation loss from the value of 35 million lambs marked per year, at a cost of $25 per head. These production losses do not consider market price effects or the distribution of impact between producers and consumers.

The agricultural impact of foxes is therefore mostly a function of the predation of livestock. Unfortunately, there is no clear relationship between fox densities and lamb predation. Studies of the effect of fox predation show a range from as little as 0.2% of lambs affected on a property in Scotland (White et al. 2000) up to 30% of lambs in western New South Wales (Lugton 1993). Greentree et al. (2000) estimated that fox predation was the probable cause of death for a minimum of 0.8% and a maximum of 5.3% of lamb carcasses in south-eastern Australia. There is also evidence that individual killer foxes kill lambs habitually (Rowley 1970). Such foxes can cause serious losses in individual flocks and both Turner (1965) and Moore et al. (1966) describe such events. Saunders et al. (1995) consider that the largest single factor in lamb losses is associated with birth and mismothering and, moreover, the economic impact of fox predation is likely to vary by region and across time.

The most commonly used fox control techniques are lethal baiting, shooting, trapping, den fumigation, den destruction and exclusion fencing (Saunders et al. 1995). Fertility control through immunocontraception has been investigated as an alternative or supplementary means of fox control (Bradley et al. 1998) as has chemical fertility control (Marks et al.

1996). Other measures such as the use of guard animals has been promoted in recent years (Olsen 1998) but not yet fully evaluated in Australia. An indication of proportional use of different control strategies based on New South Wales data is given in Table 1 (West and Saunders 2003).

Table 1. Proportional use of techniques used to control the impact of foxes throughout New South Wales

Control	%
Poison baiting-1080	74
Ground shooting	13
Den fumigation	4
Guard animals	3
Trapping	3
Exclusion fencing	2
Fox drives	1

A number of management practices can be introduced that will enhance lamb survival and limit the level of lamb predation by foxes. These practices aim to have low fox numbers throughout the year, a short-term abundance of food at lambing spread over many properties and reductions in mismothering. They include:

- Synchronised lambing with neighbours.
- Short lambing period.
- Good ewe condition.
- Reduced ewe disturbance.
- Good lambing shelter.
- Good aspect of lambing paddocks (north-east).
- Good management practices (eg. shearing, joining, flock health).
- Good bloodlines - mothering abilities and ewe fertility standardised by ultrasound.
- Good pasture management.
- Supplementary feeding (when necessary) to an optimal nutritional level.
- Stocking rate selected correctly from its relationship to DSE of the property.
- Good fox management practices (eg. baiting).
- Lambing at the time of lowest food demand by foxes.
- Reduced fox harbour (remnant habitat) and den sites in vicinity of lambing paddocks.

The objective of this paper is to present an economic analysis of an integrated fox management program established by NSW Agriculture, ‘Outfox the Fox’. The analysis involves a combination of an economic surplus analysis to estimate the benefits of the program and a benefit-cost analysis to determine the return on public investment. The structure of this report involves a description of the program in section 2, followed by the economic framework in section 3. The results are presented in section 4, and a discussion is given in section 5.

2. The 'Outfox the Fox' Program

The 'Outfox the Fox' program is a large strategic, coordinated fox baiting program in New South Wales that involves 20% of the State's RLPBs. The program was established by NSW Agriculture with an extension focus to improve the efficacy and cost-effectiveness of landholder fox baiting practices by promoting best practice techniques, and specifically to encourage landholders to group bait (Balogh et al. 2001). NSW Agriculture is now part of NSW Department of Primary Industries.

The major feature of this program is that it involves a coordinated and community based approach to managing foxes using an existing technology. Consequently, the benefits arise from coordinated action, with the benefit increasing with the number of participants until some asymptote is reached. A coordinated group approach to pest management is more effective than individual action and has a number of advantages (after Olsen 1998). These include:

- Makes effective use of resources, local skills and experience.
- Enables the pest animal problem to be tackled over a larger area and facilitates more strategic and usually longer term management of the damage.
- Encourages strong ownership of the problem by the group through greater cohesiveness.
- Encourages others who may be reluctant to undertake pest control to be involved in the program through peer pressure.
- Promotes a greater interest and awareness within the group and local community of the problem and the potential solutions..

In the case of foxes, group control is particularly important because of the ability of this animal to rapidly re-invade areas where control operations have been undertaken (Saunders et al. 1995). The 'Outfox the Fox' program specifically aims to:

- Synchronise baiting within a control group.
- Bait at least twice a year.
- Undertake baiting during periods when the fox is most susceptible.
- Regularly check and replace baits that are taken.
- Continue the baiting program until bait take declines.

The 'Outfox the Fox' program commenced in September 1999 with six RLPBs participating and has since grown to over 1000 member landholders using almost 50,000 baits each period. The program targets March/April, when juvenile foxes disperse from their natal den to seek their own territory, and August/September when vixens require additional food for whelping. These periods also coincide with the majority of spring and autumn lambings.

A survey of RLPBs involved in the program found that with the introduction of the 'Outfox the Fox' program there was an increase in both the frequency of baiting and the proportion of landholders involved in group baiting (Balogh et al. 2001). Furthermore, the survey determined that the program recruited landholders who were not previously baiting but using other less effective techniques, such as shooting, or those who were not controlling foxes at all. These results suggest that relatively high adoption rates of best practice techniques and industry benefits can be achieved with this program.

3. The Economic Methods

3.1 The markets affected by the 'Outfox the Fox' program

The primary outcome from the program is reduced mortality of juvenile livestock from fox predation. The markets that may benefit from reduced predation are the beef, goat, mutton, lamb and wool industries. Both the mutton and beef industries are unlikely to be affected by the program as predation by foxes is a relatively minor source of mortality of calves and adult sheep and cattle. Although goat industries such as mohair, cashmere and goat meat are affected by foxes, these form relatively minor industries in a national context and were not considered in the analysis.

The lamb market is likely to benefit most from the program since fox predation is a significant source of lamb mortality. Predation by foxes directly reduces the number of lambs weaned and marketed, thus reducing the supply of lamb in the sheep meat market. There may also be a benefit to the wool industry from the program given the joint nature in production of wool and sheep meat. Merino self-replacing enterprises, a wool production system, are equally susceptible to fox predation as are first- and second-cross lamb enterprises. A greater survival of Merino ewe lambs results in a larger number of replacement ewe hoggets in farming systems, leading to greater wool production as well as reduced ewe replacement costs.

To avoid double any counting of the production benefits, the program was considered only relevant to the Australian lamb industry. Accordingly, any benefits that may accrue to the wool industry from greater lamb survival were considered captured through measurement of lamb industry responses.

3.2 The economic surplus model

The economic surplus model considered appropriate for this evaluation was the small open economy model with no distortions (Alston et al. 1995). The form of this model was disaggregated into two Australian regions; the affected region (REG), and the rest of Australia (ROA). A third region, the rest of the world (ROW), was included to complete the framework. The relevant changes in producer surplus (ΔPS), consumer surplus (ΔCS) and total economic surplus (ΔES) equations are as follows.

$$\Delta PS_{REG} = P_0 Q_{REG}(K - Z)(1 + 0.5Z\varepsilon_{REG}) \tag{1}$$

$$\Delta CS_{REG} = P_0 C_{REG} Z(1 + 0.5Z\eta_{REG}) \tag{2}$$

$$\Delta PS_{ROA} = -P_0 Q_{ROA} Z(1 + 0.5Z\varepsilon_{ROA}) \tag{3}$$

$$\Delta CS_{ROA} = P_0 C_{ROA} Z(1 + 0.5Z\eta_{ROA}) \tag{4}$$

$$\Delta PS_{ROW} = -P_0 Q_{ROW} Z(1 + 0.5Z\varepsilon_{ROW}) \tag{5}$$

$$\Delta CS_{ROW} = P_0 C_{ROW} Z(1 + 0.5Z\eta_{ROW}) \tag{6}$$

$$\Delta ES = \sum_{REG}^{3} \Delta PS + \sum_{REG}^{3} \Delta CS \quad (7)$$

$$Z = \frac{\varepsilon K}{\varepsilon + \eta} \quad (8)$$

Where K is the program-induced supply shift parameter, Z is the relative price change, ε and η are the price elasticities of supply and demand, P_0 is the equilibrium price, Q is the equilibrium supply of the commodity, and C is the consumption (demand) of the commodity (Table 2). These equations are solved for both the wool and lamb industries. The equilibrium price is a random input, defined by a triangular probability distribution (Table 2).

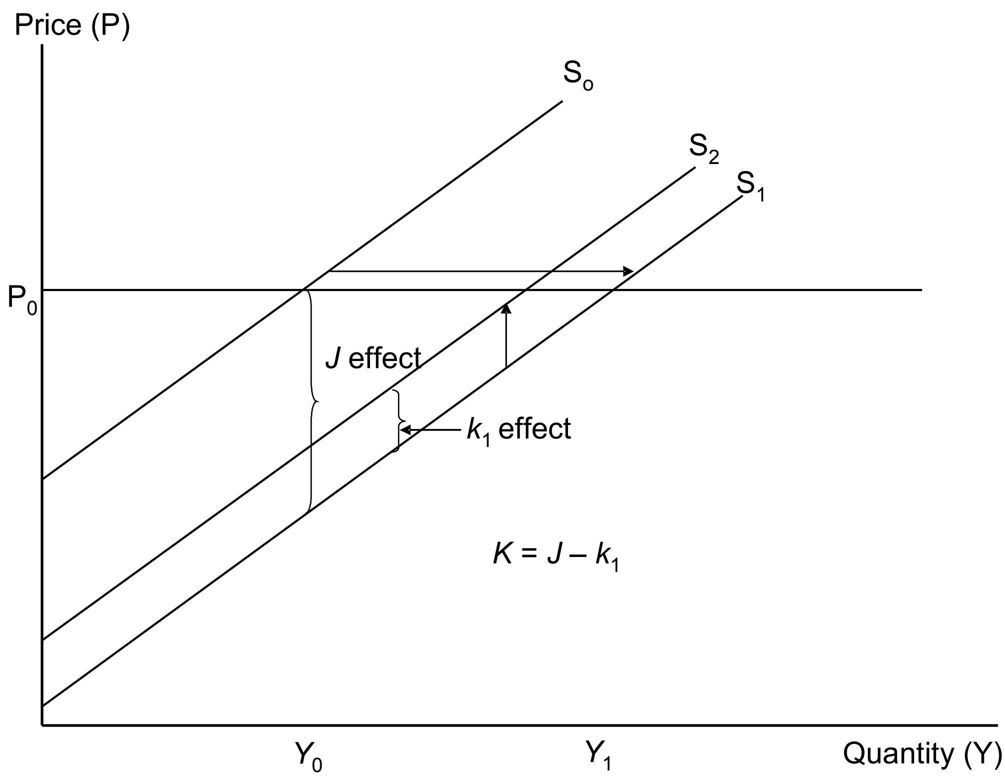
Table 2. Model parameters

	Unit	Code	Lamb
Economic surplus model:			
Supply of commodity in region	t	Q_{REG}	75558
Supply of commodity in rest of Australia	t	Q_{ROA}	226672
Supply of commodity in rest of world	t	Q_{ROW}	2660000
Consumption of commodity in region	t	C_{REG}	4289
Consumption of commodity in rest of Australia	t	C_{ROA}	210161
Consumption of commodity in rest of world	t	C_{ROW}	2747780
Supply elasticity in region		ε_{REG}	0.30
Supply elasticity in rest of Australia		ε_{ROA}	1.40
Supply elasticity in rest of world		ε_{ROW}	2.00
Demand elasticity in region		η_{REG}	0.80
Demand elasticity in rest of Australia		η_{ROA}	1.54
Demand elasticity in rest of world		η_{ROW}	2.00
Benefit cost model:			
Simulation period	years	T	20
Discount rate	%	r	4
Initial adoption	%	A_0	1
Period of adoption growth	years	λ_A	1
Capital costs	$	*KCOST*	99225
Operating costs	$	*OCOST*	47250

3.3 The research-induced supply shift (*K*) parameter

The commodity supply shift (K) is a critical parameter in the economic surplus estimate of the benefit of the program. The supply shift is composed of two components: (a) changes in the productivity that would occur if input use was held constant at the optimum that applied prior to the change, and (b) changes in the input mix to optimize input combinations under the change induced by the program. A realistic estimate of the supply shift requires not only the reduction in the per unit cost of production from a production increasing technology, but also the <u>increase</u> in the cost of production required to achieve the new level of production output. This is illustrated in Figure 3, where a production-increasing technology shifts the supply function from S_0 to S_1. A greater output can be obtained for any level of cost of production. However, to actually achieve this new potential production level requires additional production costs (eg. drenching and vaccination in the case of livestock, harvest and marketing costs in the case of grain crops). Consequently, there is a corresponding increase in unit costs associated with the technology and this is reflected in the shift in the supply function from S_1 to S_2. Thus the true supply shift from a production increasing technology is from S_0 to S_2.

Figure 3. The effect of a research induced production increasing technology upon the supply function of a commodity



In this study there is a direct production increasing impact by reducing lamb predation by participation in the 'Outfox the Fox' program by landholders. There will also be a corresponding increase in some input costs due to the higher lamb numbers that result from reduced mortality. These include higher drenching, marking, marketing, and shearing costs due to the greater sheep numbers.

For the first component of the supply shift calculation, the relative increase in production will result into an equal, proportional, rightwards shift of industry supply in the quantity direction (i.e. dY/Y = E(Y) = J). To translate this into a measure of K (the percentage shift down of supply in the price direction), the value of J is divided by the elasticity of supply (i.e. $K = J/\varepsilon$ = E(Y)/ε). The value of ε is a critical factor in converting the production change to an industry level, per unit, cost saving and according to Alston et al. (1995, p340) when information on supply elasticities is lacking it is often expedient to use a supply elasticity of 1.0. The Australian supply elasticities given in Table 1 are used in this study. For the second component of the supply shift calculation, the supply shift due to increased production costs (k_1) is a function of the change in total costs ($E(VC)$) and production ($E(Y)$).

Gross margin enterprise budgets for two sheep activities (first cross lambs, second cross lambs) were used to derive the value of J and the change in per unit input costs. These budgets were established for a flock size of 1000 ewes and derive the relevant production and cost changes related to a parameter change. The lamb marking percentage within the gross margin budgets was the relevant parameter for the measuring the production impact of the 'Outfox the Fox' program and was varied so as to estimate the supply shift impact. Following Alston et al. (1996, p360) K was calculated as:

$$K = \frac{E(Y)}{\varepsilon_{ROA}} - \frac{E(VC)}{1 + E(Y)} \tag{9}$$

Where $E(VC)$ is the proportional change in input costs as a result of the research-induced production increase. It was assumed that the program resulted in an increase in lamb marking percentages (in absolute terms) of between 1 and 5% (Table 3). Using dressed carcass weights of 18.5 kg for lambs and 25 kg for hoggets, the derivation of K for an absolute 5% increase in lamb marking for a 1000 ewe enterprise is given in Table 4. In the table Y is lamb production (kg), VC is the variable production costs ($), and the subscripts 0 and 1 refer to without and with the program respectively.

The measurement of K follows that described by Figure 3, where the initial supply shift is represented by J (for first cross lambs $J = 0.0397$), however the true supply shift (i.e. K) is reduced by the increased production costs represented by k_1 (for first cross lambs $k_1 = 0.0125$).

Table 3. Triangular probability distribution parameters

	Unit	Code	Min	Mode	Max
Lamb marking percentage increase	%		1	3	5
Supply shift (K)		K	0.005	0.016	0.030
Price	$/t	P_0	1820	2600	3380
Maximum adoption		A^{max}	0.30	0.40	0.50
Period of maximum adoption	years	λ_M	3	7	10

Table 4. Supply shift calculations for a 5% absolute increase in lamb marking for 1000 ewe prime lamb enterprises

	Unit	Lambs (first cross)	Lambs (second cross)
Lamb marking – without program	%	93	113
Lamb marking – with program	%	98	118
Y_0	kg	19125	20350
Y_1	kg	20187	21275
VC_0	\$/kg	29499	35159
VC_1	\$/kg	29888	35471
$E(Y) = (Y_1 – Y_0)/Y_0$		0.0556	0.0455
$J = E(Y)/\varepsilon_{ROA}$		0.0397	0.0325
$E(VC) = (VC_1 – VC_0)/VC_0$		0.0132	0.0089
$k_1 = E(VC)/(1+E(Y))$		0.0125	0.0085
$K = J – k_1$		0.0272	0.0240

3.4 Defining the 'with-project' and 'without-project' scenarios

For most evaluations of a research program it is important to define 'with-project' and 'without-project' scenarios. A 'without-project' scenario captures the case where some research in the project area is likely to still occur in the absence of the research program. For example, in the case of breeding new grain varieties, there may be spillage of an innovation from breeding varieties in other states ore countries. Consequently, the research program usually brings forward the benefits from some new innovation, and that innovation may deliver greater benefits to an industry than may otherwise have occurred. For example, in the case of breeding the varieties developed may be more applicable to a certain region. It is therefore necessary to measure both the research benefits foregone and the research costs avoided due to the research (Marshall and Brennan 2000).

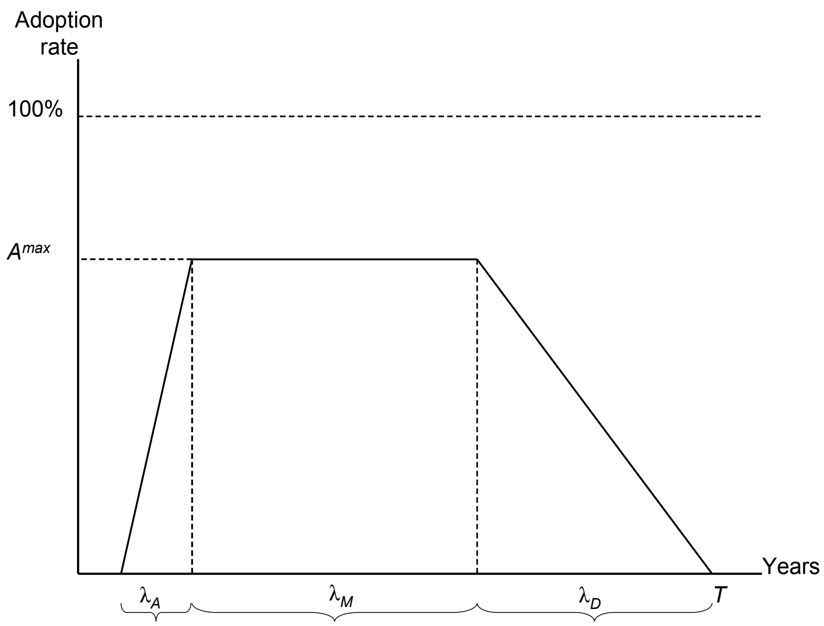
We have considered a number of alternative 'without-project' scenarios for evaluating the 'Outfox the Fox' program. The difficulty in deriving a meaningful 'without' scenario is that any innovation similar to the 'Outfox the Fox' program is likely to be simply the same program of collective control lagged by several of years. Consequently, despite the convincing arguments of Marshall and Brennan (2000) of the need to specify a 'without-project' scenario, for this evaluation we considered it more appropriate to assume in the absence of the Outfox the Fox program that no alternative program would be developed during the period of program evaluation. To avoid potential biases in estimating the benefits of the program, we have included a period of disadoption of the benefits once the program is complete. We do not consider it likely that there would be ongoing benefits from the project without an investment in maintenance research or extension.

An important component of measuring a research benefit is the maximum adoption within an industry of the research (A^{MAX}), the time path of achieving this adoption and its eventual decline (i.e. disadoption). The logistic adoption curve is often used in research and extension program evaluations as it reflects the case where adoption slowly increases until an asymptote is reached. The main impact of extension programs is usually to speed up the adoption process of a technology, which can be reflected in the logistic adoption lag structure.

Despite the ‘Outfox the Fox’ program being largely extension focussed a trapezoidal adoption lag structure was considered more appropriate. The trapezoidal adoption profile involves a growth phase where a technology is taken up (λ_A), then a period of full adoption (λ_M), and finally a decline phase (λ_D) during which the technology depreciates or becomes progressively abandoned (Figure 4).

The rationale for this approach is that the ‘Outfox the Fox’ program results in a rapid adoption of best fox baiting practices, and for a period of time full adoption would be expected to occur due to social and peer group pressures. However, as the program itself has only a limited life, there will be a steady decline in the best management practices as the messages from the program become lost, new participants enter the industry, individuals feel there is no longer a need to control foxes. Implicit with this approach is the assumption that nothing else would have happened in terms of coordinated fox control in the absence of the program. For this particular problem this is a realistic assumption.

Figure 4. The trapezoidal adoption profile



The annual rate of adoption (A_t) is calculated as follows.

$$A_t = A_{t-1} + \frac{\left(A^{\max} - A_0\right)}{\lambda_A - 1} \qquad \text{(for } 1 < t < \lambda_A\text{)} \qquad (10)$$

$$A_t = A^{\max} \qquad \text{(for } \lambda_A \leq t \leq \lambda_A + \lambda_M\text{)} \qquad (11)$$

$$A_t = A_{t-1} - \frac{A^{\max}}{T - \left(\lambda_A + \lambda_M\right)} \qquad \text{(for } \lambda_A + \lambda_M \leq T\text{)} \qquad (12)$$

Where A_0 is the initial level of adoption in year 1, T is the time horizon (years), and t is an index of time (year).

3.5 The region affected by the program

The region under review is comprised of the following RLPBs; Forbes, Condobolin, Young, Molong, Central Tablelands, Dubbo, Wagga Wagga, Yass, Mudgee/Meriwa, Gundagai. This region accounts for approximately 20% of Australian sheep numbers (ABARE 2001).

It is not appropriate to apportion the region's share of the Australian lamb and wool industries on the basis of sheep numbers alone. This region is a relatively major producer of lambs, whereas the importance of wool production is relatively minor in a national context. Consequently, the regions share of Australian lamb production is estimated at around 25% (Table 2). For the purpose of the economic surplus analysis it is assumed that 2% of the total Australian lamb consumption of 214,450 tonnes occurs within the study region (i.e. C_{REG}).

3.6 Benefit-cost analysis

A benefit-cost analysis model was developed to calculate the net present value (NPV) and benefit-cost ratio (BCR) from investment in the 'Outfox the Fox' program. The study required estimates of annual costs (C) from the program in addition to the benefits (B) as defined by ΔES. The relevant equations for the benefit-cost analysis are as follows.

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} \qquad (13)$$

$$BCR = \frac{\sum_{t=0}^{T} B_t / (1+r)^t}{\sum_{t=0}^{T} C_t / (1+r)^t} \qquad (14)$$

Where r is the discount rate. There are two sources of project costs; capital costs (*KCOST*) comprising salaries and other on-costs in setting up the program, and ongoing operating costs (*OCOST*). Capital costs were assumed to occur for 5 years and comprise 5% of the time of a NSW Department of Primary Industries(DPI) Livestock Officer (Balogh) and a full time equivalent (FTE) for time spent at meetings and organizing baiting programs by RLPB and National Parks and Wildlife Service (NPWS) officers. The capital costs are thus derived as:

DPI – $0.05(70000 \times OC) = 4725$
Other – $70000 \times OC = 94500$
$KCOST_{t=1,5}$ – 99225

Where OC is the on-costs (1.35) used for deriving administrative and overhead costs, and an average annual FTE salary of \$70,000 for a professional officer is used.

Annual operating costs usually involve extension activities and unit costs such as the costs of baiting. In this case, the 'Outfox the Fox' program is unlikely to result in any significant additional operating costs from baiting as RLPB officers already devote time to fox baiting programs, and landholders incur similar baiting costs without the program. The difference is that the program focuses these activities at twice yearly intervals, rather than as a continuous activity throughout the year. There is an argument that these costs may be less with the program as it requires fewer baits and given that it occurs over a shorter period the annual effort by RLPB officers may be less. Despite these arguments a small annual operating cost of ½ a FTE ($47,250) for the first 10 years of the program is included to account for any administrative or operating costs incurred by DPI, RLPB or NPWS officers in promoting and coordinating the 'Outfox the Fox' program.

The annual benefit from the program is simply a function of the change in economic surplus and the trapezoidal adoption function.

$$B_t = \Delta ES \times A_t$$

4. Results

4.1 Economic impacts

The economic framework involved a 10,000 iteration simulation of the stochastic economic surplus analysis and benefit-cost analysis model. The summary statistics of the analysis are reported in Table 5, and the cumulative density functions (CDFs) are graphically reported for the economic surplus analysis (Figures 5 and 6) and the benefit-cost analysis (Figure 7). The full model was written in the R language (http://www.r-project.org) and is presented in the Appendix.

The economic surplus model indicates that the 'Outfox the Fox' program has the potential to generate a mean increase in annual economic surplus of $3.36m. This is comprised of a $2.44m gain to producers in the study region, a $2.75m loss to producers in the rest of Australia, and gains to consumers within the region and rest of Australia of $0.05m and $2.55m respectively. There were also distribution impacts outside of Australia to international consumers (gain of $33.41m) and international producers (loss of $32.35m).

There was significant variation in the total change in economic surplus represented by the standard deviation of $1.10m compared to the mean $3.36m, implying a coefficient of variation of 32.7. This variability is also reflected in the spread in economic surplus values estimated from the 10,000 iterations of the model with a minimum of $0.82m and a maximum of $7.15m. This result indicates that although there is a chance of a low economic benefit, the analysis did not measure any observations of losses in economic surplus from the program. A better indication of variability is the CDF of change in economic surplus (Figure 5) as the maximum and minimum represent only the extreme values of a simulation, each having a low probability of occurrence. The CDF given in Figure 5 indicates the probabilities of achieving certain economic surplus outcomes from the 'Outfox the Fox' program. For example, there is a 25% probability that the program would achieve in increased economic surplus of less than $2.5m. This can be alternatively stated that there is a 75% probability that the program will result in an increased economic surplus greater than $2.5m.

There is significant variability in the distribution impacts upon producers and consumers within the region and the rest of Australia (Figure 6). For simplicity the international producer and consumer effects of the program were excluded. The CDF for each region can be interpreted in a similar manner as for the CDF of total economic surplus.

Table 5. Economic surplus analysis and benefit-cost analysis summary statistics derived from the stochastic simulation model of the 'Outfox the Fox' program

	Mean	Standard deviation	Minimum	Maximum
Economic surplus analysis ($m):				
ΔES	3.36	1.10	0.82	7.15
ΔPS_{REG}	2.44	0.80	0.60	5.19
ΔCS_{REG}	0.05	0.02	0.01	0.11
ΔPS_{ROA}	-2.75	0.91	-5.86	-0.67
ΔCS_{ROA}	2.55	0.84	0.62	5.44
ΔPS_{ROW}	-32.35	10.65	-68.65	-7.91
ΔCS_{ROW}	33.41	11.00	8.17	71.20
Benefit-cost analysis:				
Net present value ($m)	9.83	3.98	1.22	28.54
Benefit-cost ratio	13.0	4.9	2.5	35.8

Figure 5. Cumulative density function for change in total economic surplus (ΔES) due to the 'Outfox the Fox' program

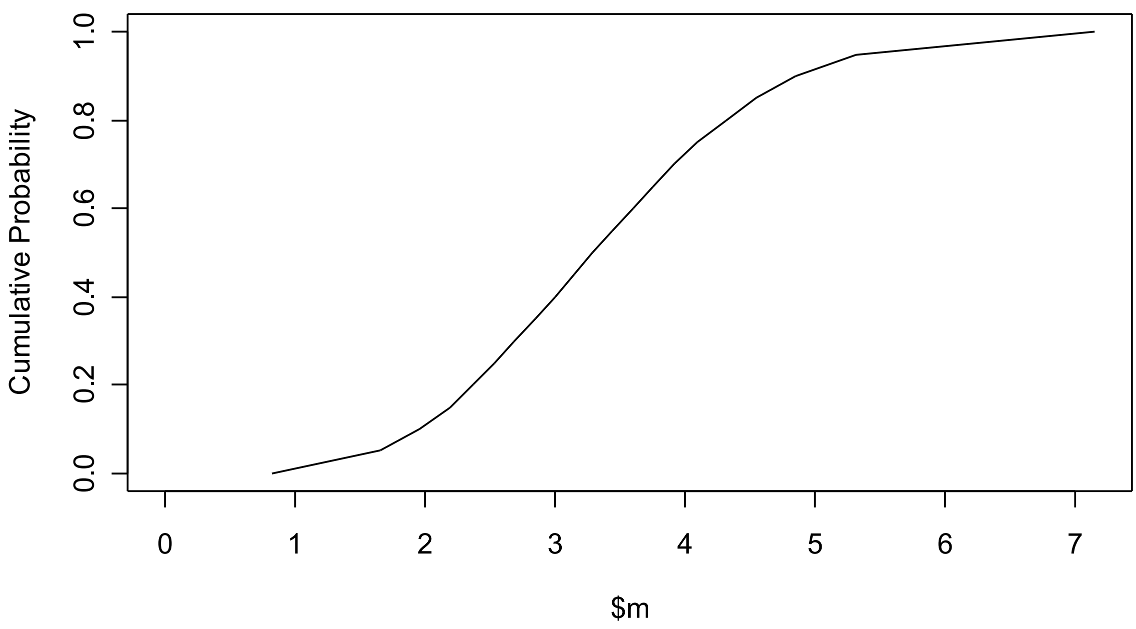
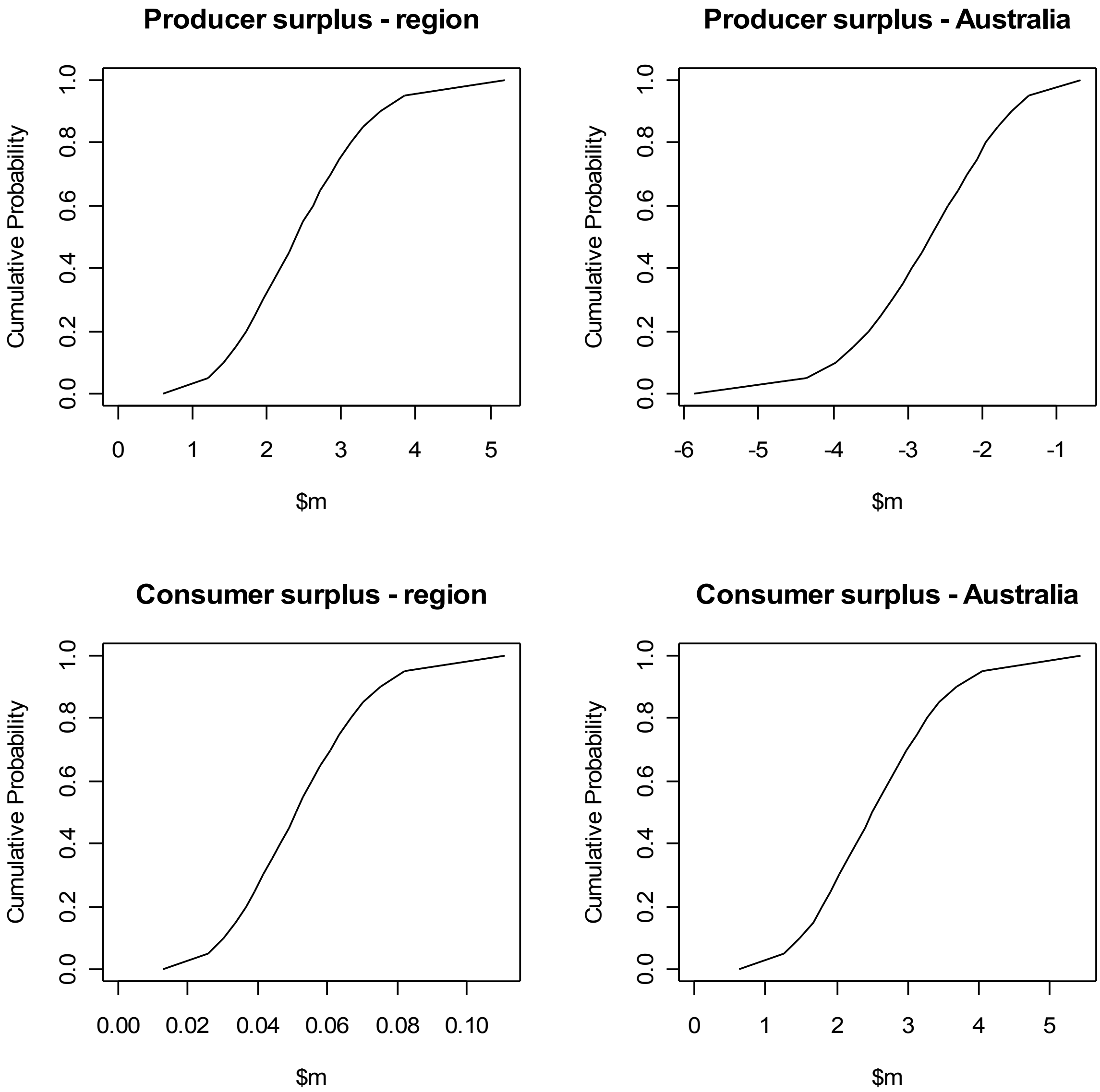


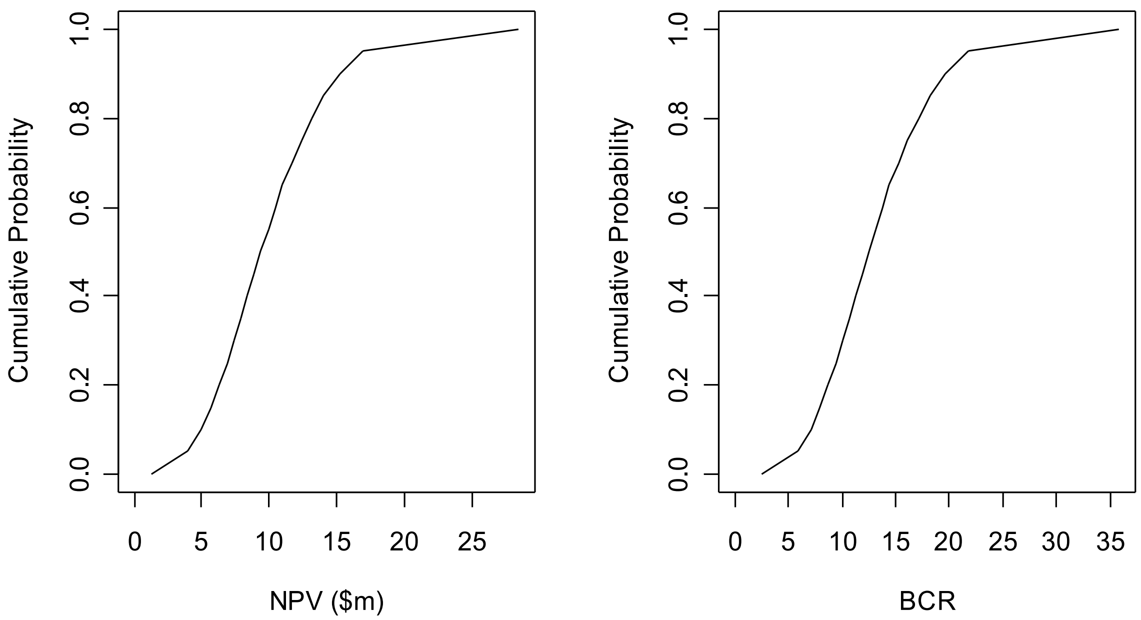
Figure 6. Cumulative density functions for change in producer surplus (ΔPS) and consumer surplus (ΔCS) for the study region and rest of Australia due to the 'Outfox the Fox' program



The summary statistics from simulation of the benefit-cost model (Table 5) indicate that public investment in the 'Outfox the Fox' program provides a positive economic return. The analysis resulted in a mean NPV of $9.83m, and a mean BCR of 13.0:1. Although there was a large range in the NPV, with a minimum of $1.22m and a maximum of $28.54m, there were no negative returns observed. Likewise, the BCR results indicate that the program would always result in a reasonable return on investment, with a minimum value of 2.5:1 and a maximum of 35.8:1.

The CDFs associated with the NPV and BCR graphically illustrate the simulation model results (Figure 7). The benefit-cost analysis results suggest that there is a very low probability that either of these two investment criteria would be at an unacceptable level for the program. For instance, there is only a 30% probability that the BCR for this program would be less than 10:1, while the probability that the program achieving a BCR less than 5:1 is about 5%.

Figure 7. Cumulative density functions of net present value (NPV) and benefit-cost ratio (BCR) from investment in the 'Outfox the Fox' program



4.2 Environmental and social impacts

Foxes are one of the major exotic predators that threaten the survival of many Australian wildlife species (Saunders et al. 1994) and have contributed to the decline of many species of reptiles, mammals and birds. According to McLeod (2004) the environmental costs associated with foxes ($190m) are considerably greater than their agricultural impact ($17.5m), and in a survey by West and Saunders (2003) predation of wildlife was rated a serious consequence of foxes (Figure 2). Consequently, any large-scale reduction in fox densities as a result of the 'Outfox the Fox' program could generate significant environmental benefits. To achieve any environmental benefit would require that the reduction in fox density from the program occurs in areas where there is wildlife as well as agricultural impact.

The economic benefits of a program such as 'Outfox the Fox' are shared by graziers, agribusiness and consumers in the form of increased income and can have important social consequences for regional communities. However, because of the small size of the program in comparison to the size of the national lamb and wool industries, the social impact is likely to be marginal despite a welfare gain of $2.44m to producers in the affected region and a welfare loss of $2.75m to producers in the rest of Australia. One area of potential positive social impact from the program is the community based integrated management approach to the problem taken. Community based approaches to managing problems (eg. Landcare, Bushcare) have been claimed to have a positive impact upon social capital (Grafton and Knowles 2004).

5. Discussion

This paper presents an economic analysis of the vertebrate pest management program 'Outfox the Fox'. Foxes are a serious predator of native wildlife and lambs in Australia. First introduced in Australia for recreational hunting the fox now occupies approximately 98% of New South Wales, with particularly high densities throughout the temperate perennial pasture zone of the state. This zone is also a major producer of lambs and wool.

Foxes are regarded as one of the major causes of population decline in a range of native mammals, birds and reptiles. There are also claims that foxes may account for up to 30% of lamb mortalities in some areas, however mortality due to predation of 2 to 5% is more likely in most regions.

The 'Outfox the Fox' program was established by the former NSW Agriculture in conjunction with a number of Rural Land Protection Boards (RLPB) to achieve a more strategic and coordinated fox baiting program. This program relied on a community driven and integrated management approach to the problem rather than the introduction of any new technology. The main features were to synchronise baiting across landholders at least twice a year, undertake baiting during periods when the fox is most susceptible, regularly check and replace baits, and continue until the bait take declines. The benefits of the program are directly proportional to the number of participants. Consequently, 'Outfox the Fox' shares similar features to other community based programs such as Landcare where the production, ecological and economic gains are derived from the coordinated and catchment management approach to the problem. This also leads to potential free-rider problems that ultimately can diminish the effectiveness of such programs, however, this issue has not been addressed in this analysis. Moreover, there is likely to be some optimal level of community involvement that maximises social welfare that has not been considered.

For a production increasing technology problem where multiple products arise from the production system (eg. wool and lambs) it is not appropriate to simply add together the partial equilibrium changes in producer and consumer surplus for each industry. This is due to the potential for double counting of both the quantity effect and the change in unit costs of production from a technology. One method to overcome these problems is to adopt a general equilibrium model, where feedbacks between different markets are captured and quantified. Development of a general equilibrium framework was beyond the capacity of this analysis, and the approach taken here was to consider only the benefits to the lamb industry. This was justified on the basis that lamb production is of considerably greater importance within the study region than merino wool production.

A stochastic economic surplus and benefit-cost analysis model was developed for measuring the economic benefits of the 'Outfox the Fox' program. This involved a disaggregated economic surplus model of the Australian lamb industry, with separate regions for the study area, the rest of Australia and the rest of the world. The total change in economic surplus as a result of the program was used as the benefit measure in the benefit-cost analysis. The capital and operating costs were estimated as being comprised of the direct salary and on-costs of NSW Agriculture and RLPB officers involved in the program.

The change in economic surplus due to the 'Outfox the Fox' program was \$3.36m when fully adopted. The distributional impacts of the program were that producers in the area influenced by the program had welfare gains, producers in the rest of Australia and the rest of the world had welfare losses, and consumers in both Australia and the rest of the world gained in economic welfare. The benefit-cost analysis showed that the project provided a positive return on public investment with a mean net present value of $9.83m and a mean benefit-cost ratio of 13.0:1. The stochastic analysis indicated that there was no probability of this program providing a negative economic return. The study identified that environmental benefits could be obtained from a reduction in fox numbers in environmentally sensitive areas, however social impacts are likely to be marginal due to the small-scale of the program.

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Appendix: The R Model Code

```
# STOCHASTIC SIMULATION OF ECONOMIC SURPLUS CHANGES AND BENEFIT-COST ANALYSIS
# ============================================================================

# ECONOMIC EVALUATION OF THE 'OUTFOX THE FOX' PROGRAM
# ----------------------------------------------------

# Glossary:
# REG - Australian region where technology applies
# ROA - rest of Australia
# AUS - Australia
# ROW - rest of world
# S   - supply
# D   - demand
# n   - demand elasticity
# e   - supply elasticity
# K   - vertical supply shift
# Z   - K/elasticity relationship
# dPS - change in producer surplus
# dCS - change in consumer surplus
# dTS - change in total economic surplus
# W   - wool industry
# L   - lamb industry
# M   - mutton industry

source("C:/CRAM/rtriangle.r")
source("C:/CRAM/bca.r")

# Number of iterations for simulation
NSim <- 10000

# Wool input data (W)
# -------------------
# Specify equilibrium quantities and prices
SWreg <- 32000    # supply of wool in region (t)
SWroa <- 608000   # supply of wool in ROA (t)
SWaus <- 640000   # supply of wool in Australia (t)
SWrow <- 1805530  # supply of wool in ROW (t)
DWreg <-   0      # wool consumption in region (t)
DWroa <- 18300    # wool wool consumption in ROA (t)
DWaus <- 18300    # wool wool consumption in Australia (t)
DWrow <- 2427230  # wool consumption in ROW (t)

# Price of wool in region, ROA, Australia, ROW ($/t equivalent)
TPwool <- cbind(6500, 7500, 8500)
Pwool <- rtriangle(n=NSim, min=TPwool[1], mode=TPwool[2], max=TPwool[3])

# Specify wool supply and demand elasticities
nWreg <- 1.0      # region wool demand elasticity
nWroa <- 0.8      # ROA wool demand elasticity
nWaus <- 0.8      # Australian wool demand elasticity
nWrow <- 2.0      # ROW wool demand elasticity
eWreg <- 0.3      # region wool supply elasticity
eWroa <- 1.4      # ROA wool supply elasticity
eWaus <- 1.4      # Australian wool supply elasticity
eWrow <- 1.5      # ROW wool supply elasticity

# Sheep meat input data
# ---------------------
# Specify equilibrium quantities and prices - lamb industry (L)
SLreg <- 75558    # supply of lamb in region (t)
SLroa <- 226672   # supply of lamb in ROA (t)
SLaus <- 302230   # supply of lamb in Australia (t)
SLrow <- 2660000  # supply of lamb in ROW (t)
DLreg <- 4289     # lamb consumption in region (t)
```

```
DLroa <- 210161   # lamb consumption in ROA (t)
DLaus <- 214450   # lamb consumption in Australia (t)
DLrow <- 2747780  # lamb consumption in ROW (t)

# Price of lamb in region, ROA, Australia, ROW ($/t equivalent)
TPlamb <- cbind(1820, 2600, 3380)
Plamb <- rtriangle(n=NSim, min=TPlamb[1], mode=TPlamb[2], max=TPlamb[3])

# Specify lamb supply and demand elasticities
nLreg <- 0.8      # region lamb demand elasticity
nLroa <- 1.54     # ROA lamb demand elasticity
nLaus <- 1.54     # Australian lamb demand elasticity
nLrow <- 2.0      # ROW lamb demand elasticity
eLreg <- 0.3      # region lamb supply elasticity
eLroa <- 1.4      # ROA lamb supply elasticity
eLaus <- 1.4      # Australian lamb supply elasticity
eLrow <- 2.0      # ROW lamb supply elasticity

# Specify equilibrium quantities and prices - mutton industry (M)
SMreg <- 70000    # supply of mutton in region (t)
SMroa <- 257810   # supply of mutton in ROA (t)
SMaus <- 327810   # supply of mutton in Australia (t)
SMrow <- 3990000  # supply of mutton in ROW (t)
DMreg <-    0     # mutton consumption in region (t)
DMroa <- 101610   # mutton consumption in ROA (t)
DMaus <- 101610   # mutton consumption in Australia (t)
DMrow <- 4216200  # mutton consumption in ROW (t)

# Price of mutton in region, ROA, Australia, ROW ($/t equivalent)
TPmutton <- cbind(910, 1300, 1690)
Pmutton <- rtriangle(n=NSim, min=TPmutton[1], mode=TPmutton[2], max=TPmutton[3])

# Specify mutton supply and demand elasticities
nMreg <- 1.0      # region mutton demand elasticity
nMroa <- 0.8      # ROA mutton demand elasticity
nMaus <- 0.8      # Australian mutton demand elasticity
nMrow <- 2.5      # ROW mutton demand elasticity
eMreg <- 0.25     # region mutton supply elasticity
eMroa <- 0.75     # ROA mutton supply elasticity
eMaus <- 0.75     # Australian mutton supply elasticity
eMrow <- 2.0      # ROW muton supply elasticity

# K and Z parameters
# --------------------
# Wool
TKwool <- cbind(0.00, 0.00, 0.00)
KW <- rtriangle(n=NSim, min=TKwool[1], mode=TKwool[2], max=TKwool[3])
ZWreg <- eWreg*KW/(eWreg+nWreg)

# Lamb
TKlamb <- cbind(0.005, 0.016, 0.030)
KL <- rtriangle(n=NSim, min=TKlamb[1], mode=TKlamb[2], max=TKlamb[3])
ZLreg <- eLreg*KL/(eLreg+nLreg)

# Mutton
TKmutton <- cbind(0.0, 0.0, 0.0)
KM <- rtriangle(n=NSim, min=TKmutton[1], mode=TKmutton[2], max=TKmutton[3])
ZMreg <- eMreg*KM/(eMreg+nMreg)


# Wool industry economic calculations
# ------------------------------------
# Economic surplus change formulae with a region, Australia and ROW
dWPSreg <-  SWreg*Pwool*(KW-ZWreg)*(1+0.5*ZWreg*eWreg)/1000000
dWPSroa <- -SWroa*Pwool*ZWreg*(1+0.5*ZWreg*eWroa)/1000000
dWPSrow <- -SWrow*Pwool*ZWreg*(1+0.5*ZWreg*eWrow)/1000000
dWCSreg <-  DWreg*Pwool*ZWreg*(1+0.5*ZWreg*nWreg)/1000000
dWCSroa <-  DWroa*Pwool*ZWreg*(1+0.5*ZWreg*nWroa)/1000000
```

```
dWCSrow <-  DWrow*Pwool*ZWreg*(1+0.5*ZWreg*nWrow)/1000000
# Total economic surplus (TES) change
dWTES <- matrix(ncol=1,nrow=NSim)
dWTES <- dWPSreg+dWPSroa+dWPSrow+dWCSreg+dWCSroa+dWCSrow
meansW < cbind(mean(dWTES), mean(dWPSreg), mean(dWPSroa), mean(dWPSrow),
         mean(dWCSreg), mean(dWCSroa), mean(dWCSrow))


# Lamb industry economic calculations
# -----------------------------------
# Economic surplus change formulae with a region, Australia and ROW
dLPSreg <-  SLreg*Plamb*(KL-ZLreg)*(1+0.5*ZLreg*eLreg)/1000000
dLPSroa <- -SLroa*Plamb*ZLreg*(1+0.5*ZLreg*eLroa)/1000000
dLPSrow <- -SLrow*Plamb*ZLreg*(1+0.5*ZLreg*eLrow)/1000000
dLCSreg <-  DLreg*Plamb*ZLreg*(1+0.5*ZLreg*nLreg)/1000000
dLCSroa <-  DLroa*Plamb*ZLreg*(1+0.5*ZLreg*nLroa)/1000000
dLCSrow <-  DLrow*Plamb*ZLreg*(1+0.5*ZLreg*nLrow)/1000000
# Total economic surplus (TES) change
dLTES <- matrix(ncol=1,nrow=NSim)
dLTES <- dLPSreg+dLPSroa+dLPSrow+dLCSreg+dLCSroa+dLCSrow
meansL <- cbind(mean(dLTES), mean(dLPSreg), mean(dLPSroa), mean(dLPSrow),
          mean(dLCSreg), mean(dLCSroa), mean(dLCSrow))

# Mutton industry economic calculations
# -------------------------------------
# Economic surplus change formulae with a region, Australia and ROW
dMPSreg <-  SMreg*Pmutton*(KM-ZMreg)*(1+0.5*ZMreg*eMreg)/1000000
dMPSroa <- -SMroa*Pmutton*ZMreg*(1+0.5*ZMreg*eMroa)/1000000
dMPSrow <- -SMrow*Pmutton*ZMreg*(1+0.5*ZMreg*eMrow)/1000000
dMCSreg <-  DMreg*Pmutton*ZMreg*(1+0.5*ZMreg*nMreg)/1000000
dMCSroa <-  DMroa*Pmutton*ZMreg*(1+0.5*ZMreg*nMroa)/1000000
dMCSrow <-  DMrow*Pmutton*ZMreg*(1+0.5*ZMreg*nMrow)/1000000
# Total economic surplus (TES) change
dMTES <- matrix(ncol=1,nrow=NSim)
dMTES <- dMPSreg+dMPSroa+dMPSrow+dMCSreg+dMCSroa+dMCSrow

# Sum of total economic surplus'
# ------------------------------
dPSreg <- dWPSreg+dLPSreg+dMPSreg
dCSreg <- dWCSreg+dLCSreg+dMCSreg
dPSroa <- dWPSroa+dLPSroa+dMPSroa
dCSroa <- dWCSroa+dLCSroa+dMCSroa
dPSrow <- dWPSrow+dLPSrow+dMPSrow
dCSrow <- dWCSrow+dLCSrow+dMCSrow
dTES   <- dWTES+dLTES+dMTES

# Calculate summary statistics using a temporary variable (temp)
# --------------------------------------------------------------
temp <- dPSreg
stat1 <- rbind(mean(temp))
stat2 <- rbind(sqrt(var(temp)))
stat3 <- rbind(min(temp))
stat4 <- rbind(max(temp))
statsPSreg <- cbind(stat1, stat2, stat3, stat4)
temp <- dCSreg
stat1 <- rbind(mean(temp))
stat2 <- rbind(sqrt(var(temp)))
stat3 <- rbind(min(temp))
stat4 <- rbind(max(temp))
statsCSreg <- cbind(stat1, stat2, stat3, stat4)
temp <- dPSroa
stat1 <- rbind(mean(temp))
stat2 <- rbind(sqrt(var(temp)))
stat3 <- rbind(min(temp))
stat4 <- rbind(max(temp))
statsPSroa <- cbind(stat1, stat2, stat3, stat4)
temp <- dCSroa
stat1 <- rbind(mean(temp))
```

```
stat2 <- rbind(sqrt(var(temp)))
stat3 <- rbind(min(temp))
stat4 <- rbind(max(temp))
statsCSroa <- cbind(stat1, stat2, stat3, stat4)
temp <- dPSrow
stat1 <- rbind(mean(temp))
stat2 <- rbind(sqrt(var(temp)))
stat3 <- rbind(min(temp))
stat4 <- rbind(max(temp))
statsPSrow <- cbind(stat1, stat2, stat3, stat4)
temp <- dCSrow
stat1 <- rbind(mean(temp))
stat2 <- rbind(sqrt(var(temp)))
stat3 <- rbind(min(temp))
stat4 <- rbind(max(temp))
statsCSrow <- cbind(stat1, stat2, stat3, stat4)
temp <- dTES
stat1 <- rbind(mean(temp))
stat2 <- rbind(sqrt(var(temp)))
stat3 <- rbind(min(temp))
stat4 <- rbind(max(temp))
statsTES <- cbind(stat1, stat2, stat3, stat4)


################################################################################

# BENEFIT-COST ANALYSIS OF RESEARCH PROGRAM
# ----------------------------------------

# The total surplus estimates are used as the annual measure of
# benefit for each scenario; this will apply the probability distributions to the
# benefit estimates based on the ranges defined in the triangular function

# number of years in BCA
NYear <- 20

# define the discount rate
drate <- 0.04

# define the bcr procedure
time <- (1:NYear)

# define discount factor
dfactor <- matrix(data=(1/(1+drate)^time), nrow=NSim, ncol=NYear, byrow=T)

# Define adoption - a trapezoidal model is used
a1   <- 0.1                              # initial adoption (year 1)
La   <- 2                                # years until maximum adoption
Amax <- cbind(0.20, 0.40, 0.50)          # triang dist for ceiling adoption
L    <- cbind(3, 5, 10)                  # triang dist of years of max adoption
A    <- matrix(data=0, nrow=NSim, ncol=NYear)
C    <- rtriangle(n=NSim, min=Amax[1], mode=Amax[2], max=Amax[3])
Lm   <- rtriangle(n=NSim, min=L[1], mode=L[2], max=L[3])
Lm   <- trunc(Lm)                        # this converts real values to integers
Lp   <- NYear - (La+Lm)

# Derive the annual adoption values
A[,1] = a1
for (i in 1:NSim) {
  for (t in 1:NYear) {
    {if((t > 1) & (t < La)) A[i,t] <- min(C[i], A[i,t-1] + (C[i]-a1)/(La-1) )   }
    {if((t >= La) & (t <= (La+Lm[i]))) A[i,t] <- C[i]                          }
    {if(t > (La+Lm[i]))                A[i,t] <- max(0, A[i,t-1]-(C[i]/Lp[i]) ) }
  } # ends the t (year) for loop
} # ends the i (iteration) for loop

# define costs ($million)
KCost <- 0.10                            # Capital cost
```

```
OCost  <- 0.05                            # Operating cost
Costs  <- matrix(data=0, nrow=NSim, ncol=NYear, byrow=t)
Costs[,1:5] <- KCost + OCost
Costs[,6:10] <- OCost

# discount annual benefits
mycalc <- bca (amount=dTES, df=dfactor, adopt=A, cost=Costs)
npv <- mycalc$npv
bcr <- mycalc$bcr

TmeanNPV <- rbind(mean(npv))
TsdevNPV <- rbind(sqrt(var(npv)))
TminNPV  <- rbind(min(npv))
TmaxNPV  <- rbind(max(npv))
statsNPV <- cbind(TmeanNPV, TsdevNPV, TminNPV, TmaxNPV)
TmeanBCR <- rbind(mean(bcr))
TsdevBCR <- rbind(sqrt(var(bcr)))
TminBCR  <- rbind(min(bcr))
TmaxBCR  <- rbind(max(bcr))
statsBCR <- cbind(TmeanBCR, TsdevBCR, TminBCR, TmaxBCR)

# Calculate CDF's for BCA results
probs <- seq(0.0, 1.0, 0.05)

# percentiles for NPV CDF for regional model
cdf <- c(quantile(npv,prob=probs))
CDFnpv <- data.frame(cdf)

par(mfrow=c(1,2))
plot( c(0,TmaxNPV), c(0,1), type="n", xlab="NPV ($m)", ylab="Cumulative
Probability")
lines(cdf, seq(0, 1, 0.05), "l" )

# Calculate percentiles for BCR CDF for regional model
cdf <- c(quantile(bcr,prob=probs))
CDFbcr <- data.frame(cdf)

plot( c(0,TmaxBCR), c(0,1), type="n", xlab="BCR", ylab="Cumulative Probability")
lines(cdf, seq(0, 1, 0.05), "l" )

# Calculate percentiles for economic surplus results for regional model
cdf <- c(quantile(dTES,prob=probs))
CDFdTES <- data.frame(cdf)

cdf1 <- c(quantile(dPSreg,prob=probs))
CDFdPSreg <- data.frame(cdf)
cdf2 <- c(quantile(dPSroa,prob=probs))
CDFdPSroa <- data.frame(cdf)
cdf3 <- c(quantile(dCSreg,prob=probs))
CDFdCSreg <- data.frame(cdf)
cdf4 <- c(quantile(dCSroa,prob=probs))
CDFdCSroa <- data.frame(cdf)

# Plot CDF for PS and CS for region and Australia
par(mfrow=c(2,2))
# 1. PS for region
cdf <- c(quantile(dPSreg,prob=probs))
maxval <- rbind(max(dPSreg))
plot( c(0,maxval), c(0,1), type="n", main = "Producer surplus - region", xlab="$m",
ylab="Cumulative Probability")
lines(cdf, seq(0, 1, 0.05), "l" )
# 2. PS for Australia
cdf <- c(quantile(dPSroa,prob=probs))
maxval <- rbind(max(dPSroa))
minval <- rbind(min(dPSroa))
plot( c(minval,maxval), c(0,1), type="n", main = "Producer surplus - Australia",
xlab="$m", ylab="Cumulative Probability")
lines(cdf, seq(0, 1, 0.05), "l" )
```

```
# 3. CS for region
cdf <- c(quantile(dCSreg,prob=probs))
maxval <- rbind(max(dCSreg))
plot( c(0,maxval), c(0,1), type="n", main = "Consumer surplus - region", xlab="$m",
ylab="Cumulative Probability")
lines(cdf, seq(0, 1, 0.05), "l" )
#4. CS for Australia
cdf <- c(quantile(dCSroa,prob=probs))
maxval <- rbind(max(dCSroa))
plot( c(0,maxval), c(0,1), type="n", main = "Consumer surplus - Australia",
xlab="$m", ylab="Cumulative Probability")
lines(cdf, seq(0, 1, 0.05), "l" )


# Plot CDF for total economic surplus
par(mfrow=c(1,1))
cdf <- c(quantile(dTES,prob=probs))
maxval <- rbind(max(dTES))
plot( c(0,maxval), c(0,1), type="n", xlab="$m", ylab="Cumulative Probability")
lines(cdf, seq(0, 1, 0.05), "l" )
```

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