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by

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Abstract

Agroforestry can help prevent land degradation while allowing continuing use of land to produce crops and livestock. A problem with the evaluation of agroforestry using long-run static models and traditional discounting techniques is that the present value of the forestry enterprise is generally much lower than that of other production activities. This problem is common with Australian native species which tend to have a high environmental value but a low market value.

This paper presents an economic analysis of an agroforestry operation in land prone to degradation and in the presence of positive externalities provided by trees. The value of the land is estimated based on the present value of expected returns in perpetuity under optimal management. Simulation analysis is used to evaluate the loss in land value caused by dryland salinity. A nonlinear programming model is developed and used to study the effects of timber prices and forest planting costs on optimal forest area and the level of salinity. Elasticities of relevant variables with respect to prices and costs are derived and policy implications of results are discussed.

Key Words: agroforestry; land degradation; externalities; dryland salinity

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Valuing Agroforestry in the Presence of Land Degradation

Introduction

Land degradation is the lowering of the productive capacity of the land through processes such as soil erosion, loss of soil fertility and soil salinity (Young, 1997). Land degradation can be temporary but may become permanent if left unchecked. Severe land degradation is widespread in developing countries and fairly common in developed countries, the current interest in agricultural sustainability is an attempt at arresting and, if possible, reversing current trends in land degradation.

Trees can be effective tools for land restoration, and agroforestry is emerging as an important alternative to conventional cropping systems that tend to cause land degradation. Agroforestry may take many forms, common examples include trees intercropped with pasture in an extensive system, trees planted in bands or belts that provide shelter to crops and livestock, and separate areas of forest and crops or pastures in the same property (Young, 1997). The benefits provided by tress include prevention of soil erosion, restoration of soil fertility and soil organic matter, and reduction of dryland salinity emergence.

An economic understanding of land degradation and the identification of efficient strategies to deal with it must be based on dynamic models. Static or long-run equilibrium models do not deal properly with the complex interactions that occur in the production system. Three sets of literature are relevant to the issue of agroforestry and land degradation. The first set deals with the problem of non-timber values of forests, as first described by Hartman (1976) based on the forestry rotation model of Faustman. This work has been built upon by authors such as Englin and Klan (1990), Ehui *et al.* (1990) and Swallow *et al.* (1990). The second set of literature deals with deforestation; authors such as McConnell (1989), Lopez et al. (1994), Barbier and Burgess (1997) and Deacon (1995) have studied the optimal mix of land uses and the effects of government policy. The third set of literature follows from the seminal work of McConnell (1983) who concluded than, under most institutional arrangements, the private and social rates of soil erosion are the same. This research has been extended by authors such as Barbier (1990), Barrett (1991), Milham (1994) and Goetz (1997).

This paper presents a simple model of an agroforestry system consisting of an annual crop and a tree crop. The model is dynamic and accounts for the positive externalities provided by trees in the form of improvements in land productivity. The model is used to estimate the optimal mix of forestry and agriculture for a private landholder confronted with dryland salinity emergence. The analysis leads to a discussion of possible effectiveness of alternative policies to encourage the adoption of farm forestry.

Theoretical Foundations

The problem of the socially optimal forest rotation in the presence of amenity or other non-timber values was first studied by Hartman (1976). Hartman's work resulted in a modified version of the classical Faustman formula which accounted for non-timber benefits as well as timber value. With a single harvest and no forest maintenance costs the present value of a single-rotation forest, starting with bare land, is:

$$V_1 = \int_{t=0}^{T} n(t)e^{-rt}\,dt + f(T)e^{-rT} \tag{1}$$

where n is the flow of non-timber benefits from the forest (these include amenity and environmental services), f is the value of the timber net of harvesting and establishment costs. If the trees are planted at $t=0$ and harvested a $t=T$, then t represents the age of the forest and non-timber benefits are a function of forest age. A value of $dn/dt > 0$ is generally assumed, indicating that a well established forest provides more non-timber benefits than a young forest. However, this simple assumption has been challenged by authors such as Englin and Klan (1990) and Swallow et al. (1990) who argue that non-timber benefits may follow any time path, depending on the externalities considered. Thus, $n(t)$ may be a composite function with several inflection points.

The value of the forest over an infinite time horizon is:

$$V_\infty = V_1 + V_2 e^{-rT} + V_3 e^{-2rT} + \ldots + V_\infty e^{-\infty rT} \tag{2}$$

which can be simplified to:

$$V_\infty = \frac{1}{1-e^{rT}}\left[\int_{t=0}^{T} n(t)e^{-rt}\,dt + f(T)e^{-rT}\right] \tag{3}$$

The socially-optimal rotation length (T) is that which maximises function (3). Hartman shows that the first order condition for maximisation of this function is:

$$\frac{f'(T)}{f(T)} = r\left[\frac{1}{1-e^{-rT}} + \frac{\int_0^T n(t)e^{-rt}\,dt}{f(T)\left[1-e^{-rT}\right]}\right] - \frac{n(T)}{f(T)} \tag{4}$$

Hartman refers to the term in brackets as an ‘adjustment factor’ for the interest rate, it is a measure of the value of non-timber benefits relative to timber benefits. The optimal value of T is that at which the growth rate of the forest (left hand side) equals the discounted stream of non-timber benefits (relative to timber benefits) up to the time of harvest. The second term on the right hand side is a measure of the amenity value given up by harvesting at time T – eg. the opportunity cost of harvesting the forest at time T rather than delaying the harvest. Englin and Klan rearrange (4) to derive a function that provides further insight into the optimal rotation rule:

$$\frac{f'(T)}{f(T)} = \frac{r}{1-e^{-rT}} + \frac{\frac{r}{1-e^{-rT}}\int_0^T n(t)e^{-rt}\,dt - n(T)}{f(T)} \tag{5}$$

Here the second term on the right hand side is the modification caused by externalities. The numerator of this term is the "externalities balance" (Englin and Klan), it represents the balance between the stream of forest externalities up to harvest time and current externalities (at time *T*)

This analysis assumes that the land will be planted to forest in perpetuity and deals only with the optimal rotation length. On the issue of conversion of forest land to agriculture, Barbier an Burgess (1997) point out that an evaluation of the social opportunity costs of converting forest land to agriculture must include the value of production as well as non-market environmental values. They derive a “critical decision rule” for conversion of tropical forest land to agriculture; where the optimal area allocated to each use is that at which the benefits obtained form agriculture are equal to the sum of production and environmental benefits provided by the remaining forest. The optimal allocation of land between the two completing uses determines the price of land. The emphasis in the study of Barbier and Burgess and others has been on clearing land for agricultural purposes from a social standpoint. This paper deals with the converse problem of converting agricultural land to forestry for land restoration purposes and from the standpoint of an individual producer.

The Agroforestry Model

Timber production and non-timber benefits may occur in different areas of land within a catchment; such is the case of land planted to either trees or annual crops where trees provide land conservation services. Non-timber benefits can be measured as increases in the flow of yields of annual crops caused by forestry. The benefit obtained from a given area $\bar{k}$ of land over a single-rotation of length *T* is:

$$V_1 = \left(\bar{k} - k\right)\int_{t=1}^{T} a(t,k)\, e^{-rt} dt + k\int_{t=1}^{T} f(t,k)\, e^{-rt} dt \tag{6}$$

with $0 \le k \le \bar{k}$.

Where *k* is the area planted to forest. The discounted flow of profit obtained over a single forest rotation consists of the non-timber benefit provided by an annual agricultural crop (*a*) and the timber benefit provided by a forestry operation (*f*). This specification is more flexible than (1) in its treatment of timber benefits, as it allows for the inclusion of forest maintenance costs and thinning in addition to planting costs and final harvest. The effects of *k* on *a* and *f* depend, among other factors, on the initial state of the land as defined by its productive capacity. This analysis can be extended to a group of crops and/or livestock enterprises by adjusting the definition of *a* to represent a vector of crops, a single crop is considered here for simplicity of exposition.

To derive the first order conditions (FOC) for maximisation of (6) we simplify the notation by letting the net present value of a hectare of land devoted to agriculture or forestry be denoted by:

$$V^a(T,k) = \int_{t=1}^{T} a(t,k)\, e^{-rt} dt \tag{7}$$

and

$$V^f(T,k) = \int_{t=1}^{T} f(t,k)\, e^{-rt}\, dt \,. \qquad (8)$$

For a given rotation length T and maximising (6) with respect to *k* we obtain the first order condition[1]:

$$V_1' = \frac{dV_1}{dk} = (\bar{k} - k)V_k^a + kV_k^f - V^a + V^f = 0 \qquad (9)$$

Where $V_k^f = {dV^f}/{dk}$ and $V_k^a = {dV^a}/{dk}$; rearranging we obtain the condition for an interior solution of (9):

$$V^f = V^a - \left[(\bar{k} - k)V_k^a + kV_k^f\right] \qquad (10)$$

This condition states that, over a single forest cycle, the optimal forest area is that which makes the average per-hectare monetary benefit obtained from harvesting timber equal to the average per-hectare monetary benefit obtained from agriculture less the opportunity cost of converting agricultural land to forest. The opportunity cost (the term in brackets) is the sum of the marginal benefit of an increase in the area of land planted to forest (*k*) and the marginal benefit of the $(\bar{k} - k)$ area remaining in agriculture. The first component of the opportunity cost term is the value of the forest externality. The sign of the externality depends on the value of additional agricultural production per hectare (V_k^a) as *k* increases. When the land is partially degraded additional land planted to forest (lost to agriculture) causes an increase in land productivity and $V_k^a > 0$; when the land has been restored to a point where additional tree plantings have no effect on land productivity, $V_k^a = 0$. It is possible to have $V_k^a < 0$ when the presence of forest hinders cropland productivity (through competition for light and nutrients).

Following Samuelson (1976), Hartman (1976), Comolli (1981) and others, the value of the land is estimated as the flow of benefits in perpetuity under the most profitable use:

$$V = V_1(k_1^*, T) + V_2(k_2^*, T)e^{-rT} + V_3(k_3^*, T)e^{-2rT} + \ldots + V_\infty(k_\infty^*, T)e^{-(\infty-1)rT} \qquad (11)$$

with $0 \le k_i^* \le \bar{k}$.

Where k_i* represents the optimal area planted to trees in cycle *i* as required for global maximisation of (11). The first term on the right hand side of (11) is the optimal value of

[1] The problem of optimising simultaneously with respect to *T* and *k* is not discussed here. *T* is kept constant according to accepted forestry practices, this simplifies the solution of the numerical problem.

equation (6), the present value of the profit obtained from the first timber harvest plus the discounted stream of annual crop benefits during the first forest cycle; the sum of all remaining terms represents the opportunity cost of tying up the land in forestry for an additional time period. This equation differs from the common definition of land value in that the optimisation is performed with respect to forest area (k) rather than rotation length (T).

Yield Dynamics

A feature of this model is that the decision variable (k) is fixed throughout a forestry cycle of T years – i.e. the land is tied up in the forestry operation for a period of T years and therefore the value of k remains constant from $t=1$ to $t=T$. However, important changes in land productivity take place over a forestry cycle. Annual changes in land productivity are influenced by climatic events, land use patterns and the age of the forest. The benefits obtained from agriculture in any given year t are:

$$a_t = p^a y_t^a - c^a \tag{12}$$

where p^a is the price of agricultural output y_t^a is agricultural yield obtained in year t and c^a is the cost per hectare of agriculture. Actual yield is affected by the productivity of the land:

$$y_t^a = \bar{y}^a q_t(S_t) \tag{13}$$

Where $\bar{y}^a$ is expected output under 'normal' land productivity and q_t is a measure of land productivity which depends on the state of the land (S_t). Land improvements may increase the value of q_t and land degradation will cause q_t to decrease. When $q_t = 0$ the land is so degraded that no crop will grow on it. The benefits obtained in the forestry operation are defined in a similar manner, except that now expected yields and costs depend on the age of the forest:

$$f_t = p^f y_t^f - c_t^f \tag{14}$$

$$y_t^f = \bar{y}_t^f q_t(S_t) \tag{15}$$

in discrete time $\bar{y}_t^f$ and c_t^f can be conveniently represented as vectors of known values rather than as explicit function of time. Finally, the dynamic nature of land degradation is represented by the difference equation:

$$S_t = S_{t-1} + \Delta S_t(S_{t-1}, k, t) \tag{16}$$

The state of the land at any time depends on its previous state, the area planted to forest and the age of the forest.

Salinity and the Water Table

Dryland salinity is an important problem in Australia. Salt has a number of negative effects on plants: it hinders their ability to absorb water and causes 'drought symptoms', it may reduce the availability of plant nutrients and, at high levels, salt can cause ion toxicity and kill the plant (Greiner, 1997). For a given type of plant there is a critical level of salinity beyond which crop yields are reduced. Dryland salinity may emerge in response to changes in the vegetation cover of a catchment. Extensive land clearing for conventional agriculture causes excess rain water to recharge the groundwater system at a faster rate than before. In catchments with poor groundwater drainage the additional recharge causes water tables to rise. The rising water may carry salts from the bedrock into the root zone, thereby reducing crop yields (Greiner, 1997, 1998). Where dryland salinity emergence is a problem, trees can be strategically placed in recharge areas to reverse trends in rising water tables.

Let land quality (S_t) be represented by the depth of the water table (w_t) measured in meters below the surface. The land productivity function is defined as:

$$q_t = 1 - b\, e^{-j\, w_t} \tag{17}$$

Where the parameters b and j vary depending on land characteristics. The depth of the water table is inversely related to the level of salinity; thus, for a given set of soil characteristics, w_t can be used as a proxy for land quality which is directly related to yields (Fig. 1). High values of w have no impact on land quality, but as w approaches the critical level w_{crit} from the right, rising groundwater containing salt has a negative effect on land productivity. This effect is initially mild but becomes stronger as w moves from w_{crit} towards w_{min}. If w is allowed to go below w_{min} the land has no value – the damage is irreversible.

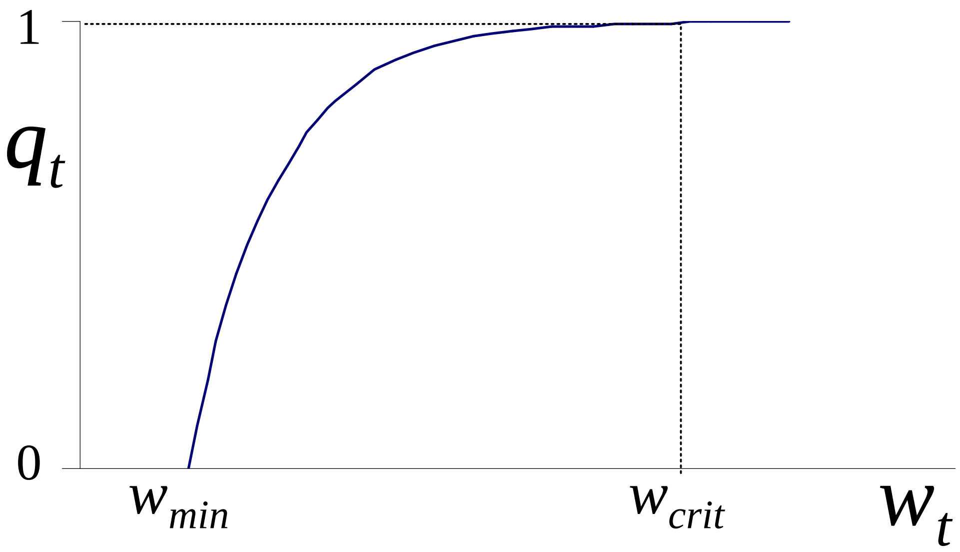

Figure 1. The land degradation function.

The dynamics of the water table are captured by the equation:

$$w_t = w_{t-1} + \Delta w_{t-1}(k, w_{t-1}) \tag{18}$$

For a given rainfall pattern, the change in the depth of the water table over a year is given by the net recharge rate of the crops present on the property.

$$\Delta w_t = -\frac{(\bar{k} - k)R^a + k\, R_t^f}{\bar{k}\, g} \tag{19}$$

Where R^j represents the amount of recharge associated with crop j and g converts total recharge (in mm/m^2) to water table depth changes (in m) over the property. The value of g depends on characteristics of the aquifer and can be adjusted to represent areas with different levels of propensity to dryland salinity emergence. As w_t decreases below w_{crit} and towards w_{min}, it becomes increasingly important to make $Dw_t > 0$ to restore land quality – i.e. either R^a or R^f must be negative. A value of $R^a > 0$ is assumed here, as it represents a crop with short roots which stimulates the emergence of soil salinity. The value of R_t^f, on the other hand, changes from positive for young trees to negative for well-established trees. This is because young trees do not absorb deep water ($R^f > 0$), but as they grow larger their roots reach deeper into the water table and eliminate large volumes of water through evapotranspiration ($R^f < 0$). With mature trees, w will increase whenever $\left|kR_f\right| > (\bar{k} - k)R_a$, thus decreasing the rate of salinity emergence. The model assumes that land is homogeneous and therefore the effect of a tree is the same independently of where it is planted. Note that, although this discussion is cast in terms of an individual producer, it would apply equally to a decision maker with control over the whole catchment.

Table 1. Parameter values used in the numerical model

Parameter	Value	Units	Parameter	Value	Units
Assumptions:			*Biophysical:*		
$\bar{k}$	100	ha	$\bar{y}^a$	2.0	tonne/ha
T	30	yr	$\bar{y}^f_{30}$	140	m^3/ha
w_0	4	m	R^a	40	mm
Economic:			a	55.56	mm
r	0.06	*	$\bar{y}^f_{10}$	60	m^3/ha
p^a	140	A$/tonne	h	35.56	mm/yr
p^f_{10}	21	A$/$m^3$	R^f_{min}	-300	mm
p^f_{30}	70	A$/$m^3$	g	160	mm/m
c^a	140	A$/ha	w_{crit}	2	m
c^f_1	1920	A$/ha	w_{min}	0.5	m
c^f_5	175	A$/ha	β	3.684	*
c^f_{10}	95	A$/ha	φ	2.608	*
c^f_{30}	210	A$/ha			

*coefficient has dimension 1.

The numerical model

The nature of the externalities flowing from the forest to the crop is an empirical question. Swallow *et al.* (1990) present a set of alternative functional forms to represent the effect of forest age on various types of non-timber benefits. Here, rather than using a specific functional form, the time trajectory of externalities is generated through numerical integration of the model. The only form of land degradation considered in the numerical model is dryland salinity and the positive externality provided by trees is an increase the depth of the water table. Amenity and other environmental values provided by trees are not considered.

In estimating R_t^f it was assumed that the rate of recharge per hectare ranges from 20 mm/year for newly planted trees to -300 mm/year for well-established trees. A linear function with a lower bound was assumed, thus:

$$R_t^f = \min(a - h \cdot t, R^f_{\min}) \qquad (20)$$

Parameter values used in the numerical model (Table 1) are based on estimates for the Liverpool Plains of NSW. The land is assumed to be fairly productive, with the annual crop yielding 2.0 tonnes per hectare in the absence of land degradation, and the forestry operation yielding 60 m^3/ha in year 10 from thinning and 140 m^3/ha in year 30 from final harvest. Expected yields and recharge rates for agriculture are similar to those reported for sorghum on red-brown earth in the Liverpool plains during an average season (Greiner, 1998). Expected yields and recharge rates for forestry are based on values expected for a eucalyptus woodlot planted at a density of 1600 trees/ha (Fulloon, 1996). These parameters can be adjusted to represent other crops and locations.

The optimisation problem was implemented as a nonlinear programming model and solved for six forest cycles of 30 years each, for a total of 180 years. This provided a good approximation to the infinite time-horizon problem (11). Model solution yielded the optimal area planted to forest over six cycles (k_i^*, i = 1,...,6), the optimal level of the water table overtime (w_t^*) and the value of the land (V).

Results

Effect of forest area on land value

The beneficial effect of trees on land productivity translates into a larger present value of the flow of benefits obtained from both the agriculture and the forestry operations. Under the given assumptions, the benefits obtained from both enterprises (as measured by the discounted value of net revenue over a rotation cycle of 30 years) increases in a sigmoidal fashion (Fig. 2). Although V^f is small relative to V^a, the indirect benefits of the forestry operation $\left((\bar{k}-k)V_k^a + kV_k^f\right)$ in equation (10) may exceed the value of timber harvested. The largest forest externality occurs in the interval k=(10,15) when the initial water table (w_0) is at 2 m and in the interval k=(5,10) when w_0 = 4 m. Within these intervals, a dramatic effect is observed on the value of both the forestry and the agriculture enterprises. Increases in the value of agricultural production caused by forestry are more pronounced in degraded land (compare Fig. 2A and 2B). When w_0 = 2 m, V^a increases from -\$199/ha to \$1,604/ha as k increases from 10.2 ha to 14.8 ha, the equivalent increase in V^f is from -\$1,1877/ha to \$140/ha. When w_0 = 4 m, V^a increases from \$1,671/ha to \$1,964/ha as k increases from 7.1 ha to 9.1 ha, the equivalent increase in V^f is from -\$1,421/ha to \$163/ha. The patterns shown in figure 2 result from changes in w_t relative to the critical values w_{min} and w_{crit} (as depicted in Fig. 1). When $w_t > w_{crit}$, the water table is not constraining, yields occur at their normal values and the forest provides no benefits to agriculture, this corresponds to the flat areas on the right side of the plots (Fig. 2 A and B). When the externality is present ($w_{min}<w_t<w_{crit}$), trees have a dramatic effect on the benefits obtained from the land.

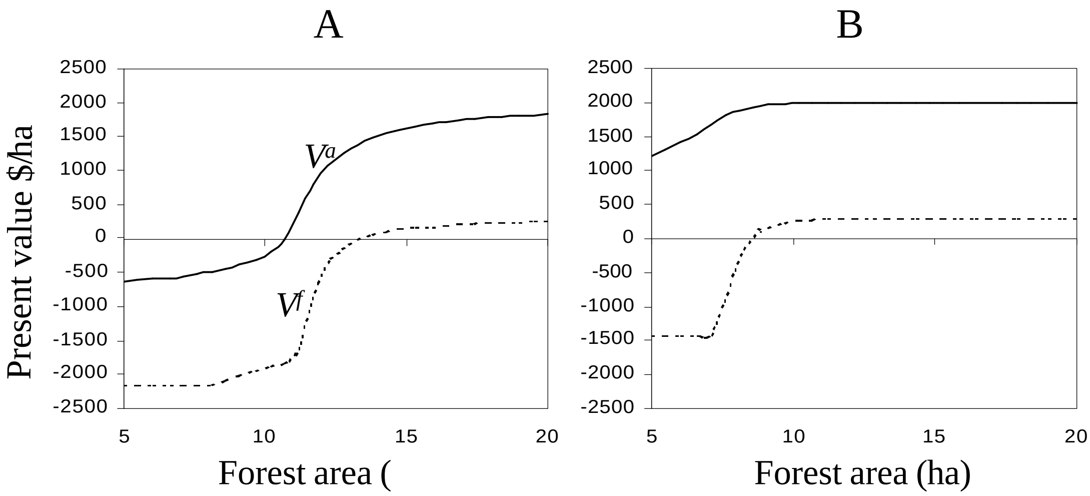

Figure 2. Effect of forest area on the present value of agriculture (solid line) and forestry (dotted line) at initial water table depths of 2 meters (A) and 4 meters (B).

Table 2. Marginal benefits of forest land with a single forestry cycle at two different initial water table depths (w_0).

	w_0 = 2m	w_0 = 4m
$\Delta V^a / \Delta k$	392	146
$\Delta V^f / \Delta k$	438	792

The slopes of these functions are the marginal benefits of forest land, the derivatives V_k^a and V_k^f can be approximated as DV^j/Dk ($j=a,f$) over a discrete interval in k (Table 2). The maximum values of the externalities from forestry to agriculture are approximately \$392/ha with w_0 = 2 m and k = (10.2,14.8), and \$146/ha with w_0 = 4 m and k = (7.1,9.1). At larger forest areas the marginal value of the externality approaches zero as k continues to increase.

Analysis of First Order Conditions

For a single forestry cycle, the optimal area of forest, k^*, is that at which the benefits from forestry equal the benefits from agriculture. This is expressed mathematically by rearranging condition (10) as:

$$V^f + (\bar{k} - k)V_k^a + kV_k^f = V^a \tag{21}$$

Figure 3 A presents a plot of both sides of this condition for base parameter values (r=0.06, w_0=4). The total benefits from forestry (LHS) exceed the benefits of agriculture (RHS) by a considerable margin at forest areas between 6 ha and 9 ha . At a forest area of 10.2 ha benefits obtained from forestry and agriculture are equal, this is the optimal point. To the right of the optimal point benefits from forestry decrease rapidly, to approach zero as k approaches 14 ha.

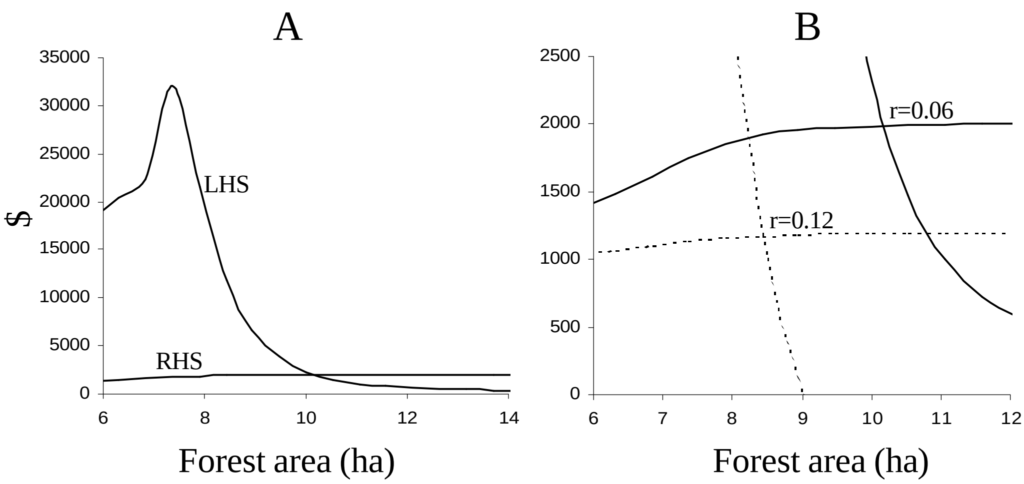

Figure 3. First order condition for profit maximisation with a single forestry cycle. LHS and RHS represent the benefits of forestry and agriculture respectively as defined in equation (21). Figure B presents a detailed view of the intersection point of figure A (r=0.06) and the results at a higher discount rate (r=0.12).

A detailed view of this relationship is presented in figure 3 B for two different discount rates. The effect of doubling the discount rate from 0.06 to 0.12 is to decrease optimal area planted (k*) from 10.2 ha to 8.4 ha, a 17.6 percent reduction. Recall that forest cycle length is fixed at 30 years and results may change if this variable is allowed to change.

This analysis of optimality conditions is limited to the single-cycle case. For an *m*-cycle optimisation problem there would be *m* conditions such as (21) to be satisfied simultaneously. The results of the normative model with six forestry cycles and for a range of assumptions are discussed in the following sections.

The Cost of Land Degradation

As seen above, the initial depth of the water table (w_0) afects the productivity of the land and therefore its value. The value of the land (V) under base assumptions increases from $1,667/ha to $2,376/ha as w_0 increases from 1.5 m to 14 m (Fig. 4 A). These estimates are consistent with actual values of farms in the Liverpool Plains, Greiner (1998, p. 235) reports land values ranging between $853/ha and $2,083/ha under current land-use practices.

The marginal cost of land degradation can be approximated by the slope of figure 4 A (the value of the land) as w_0 decreases. There are three fairly distinct intervals in w_0 over which the marginal cost of land degradation changes (Fig. 4 A): between 1.5 and 3 m, between 5 and 10 m and between 10 and 15 m. The slope of V over each of these intervals was approximated by calculating DV/Dw_0.

The marginal cost of land degradation is considerable at water table depths under 3 m ($632.5/m) and decreases rapidly to approximately $5.53/m at water table depths over 10 m (Table 3). These changes in V are accompanied by adjustments in the area planted to forest (Fig. 4B). During the first forestry cycle, k* ranges from 30 ha planted at w_0 = 1.5 to no forest planted at w_0 = 10. In contrast, the optimal area of forest planted during the sixth cycle is only slightly affected by w_0, ranging from 10.6 ha to 13.3 ha, this indicates that the land has been restored to its optimal state after 150 years.

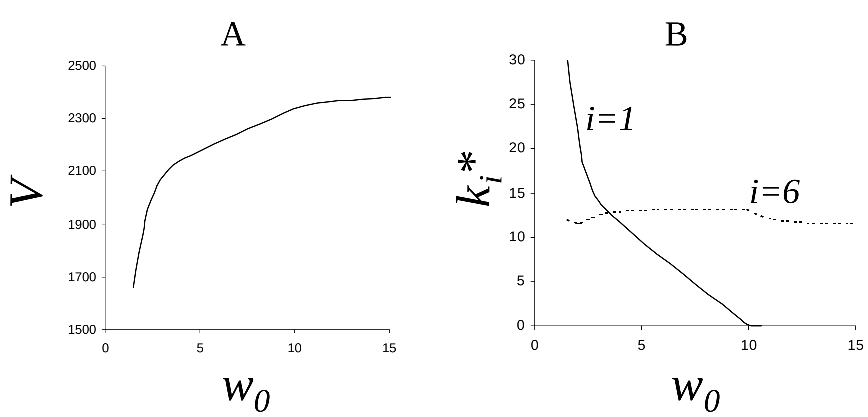

Figure 4. Land value (A) and optimal forest area (B) at various initial water table depths.

Table 3. Marginal cost of land degradation at various initial depths of the water table (w_0).

w_0 range (m)	Marginal cost of rising water table ($/m)
1.5-3	632.50
5-10	31.51
10-15	5.53

The Optimal Depth of the Water Table

More insight into the dynamics of the water table from a normative standpoint can be obtained by selecting a few points in w_0 space from Fig. 4 and analysing their behaviour through time (Fig. 5). Because of the dynamic behaviour of w_t and the lag between planting trees and their effect on w_t, no optimal long-run equilibrium is obtained over a 180-year period. Rather, a cyclical pattern of optimal w_t values emerges.

The w_t* trajectories generated at initial water table depths of 6m and 8m 'converge' to the same cycle by the end of the first timber harvest in year 30 and continue along the same trajectory for the remaining 150 years (Fig. 5). At an initial water table depth of 2 m, w_t* follows a different trajectory, although it settles into a similar pattern as described above. After the second forestry cycle (year 60) w_t* values fluctuate between 1.86 and 3.45 m. Extensive land degradation occurs during the first forestry cycle with initially high levels of land quality, whereas initially low land quality encourages land conservation during the first cycle (Fig. 5)

If the decision interval is shortened to allow different age classes of trees to be present simultaneously, it would be possible to establish a long-run equilibrium in w_t (in the context of the deterministic model presented here), but this question is out of the scope of the paper.

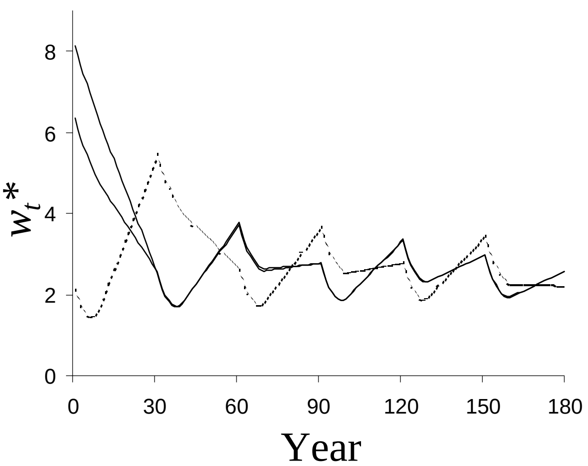

Figure 5. Optimal water table depth trajectory through time.

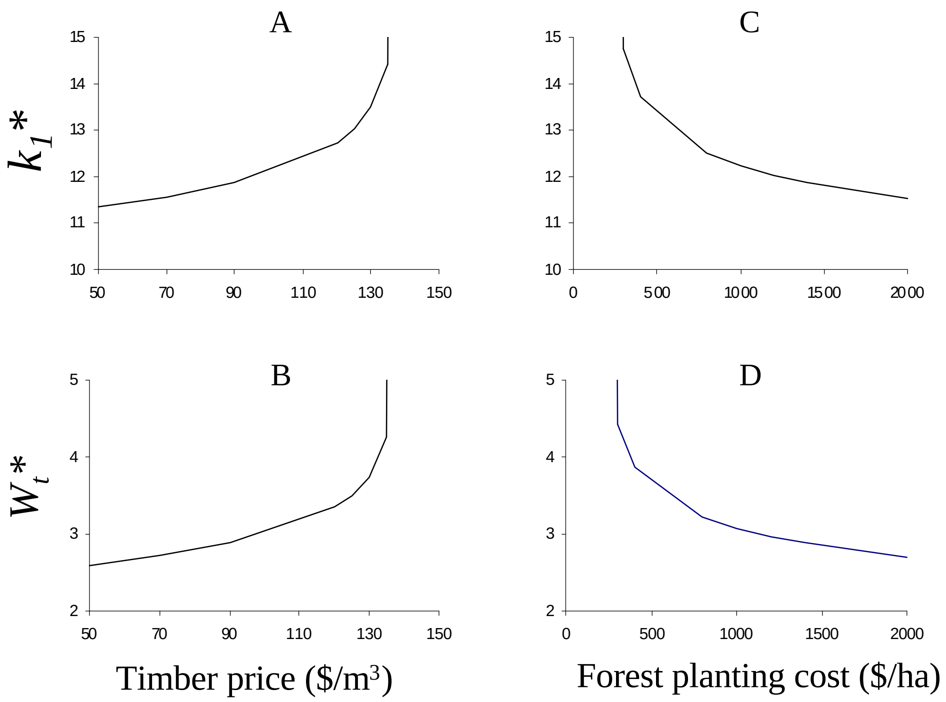

Figure 6. Effect of timber price and forest planting costs on the optimal area of forest (A and C) and water table depth (B and D).

Policy Analysis

From the above analysis it would appear that no incentives are required to prevent salinity emergence, so long as the recharge zone and the salinity-emergence zone belong to the same landholder, and assuming that the producer is aware of the intertemporal trade-offs. These findings are consistent with those of McConnell (1983) for soil erosion. When the recharge and salinity-emergence zones belong to different landholders the problem becomes more complex. The private optimal solution for the individual producers will differ from the socially optimal solution and government intervention will be required to encourage forest planting. A tradeable permit system may be used here or various forms of salinity taxes and forestry subsidies may help eliminate externality costs.

The socially optimal solution derived here does not take into account possible amenity values or other benefits such as prevention of soil erosion and maintenance of water quality. If these benefits were included in the externality function we would expect the optimal forest area (and water table depth) to be higher than estimated above. Although the model does not deal explicitly with these externalities, it can be used to explore the problem to some extent. Assume that the 'ultimate' socially optimal area of forest (or salinity level) has been estimated for a given catchment, the question then arises: "what would it take to encourage producers to plant the socially-optimal area of forest?". Economic incentives for agroforestry adoption could take the form of price or cost subsidies, to explore the effect of these policies on land degradation the model was solved for a range of timber prices (from 50 to 250 $/m^3$) and planting costs (from 50 to 2,000 $/ha). The results are presented in figures 6 and 7.

The effect of timber prices on the optimal area of forest planted in the first cycle of 30 years (k_1^*) increases slowly from 11.3 ha at $50/m^3$ to 11.87 ha at $90/m^3$, the rate of increase then increases rapidly from 13 ha at $125/m^3$ to 14.4 ha at $135/m^3$ (Fig. 6 A), beyond this price timber becomes more profitable than agriculture and the whole area (100 ha) is planted to forest. The effect of timber price on the optimal water table depth at the end of the first 30-year cycle (w_T^*) closely follows forest area with the value of w_T^* increasing from 2.6 m at \$50/m^3 to 4.25 m at \$135/m^3. The effects of tree planting costs are mirror images of the effects of prices; with a cost of \$200/ha it becomes profitable to plant the whole area to forestry.

To put these results in perspective recall that the base price of timber is \$70/m^3 and the planting cost is \$1,920/ha. To encourage producers to increase their base optimal forest area of 11.6 ha by 24 percent (to 14.4 ha) it would be necessary to increase timber price by 85 percent, which suggests that the elasticity of forest area to timber price is 0.28. In the case of cost subsidies, to produce a 26 percent increase in area planted (to 14.7 ha) cost would have to decrease to 16 percent of its original value, thus the elasticity of forest area to forest planting cost is 0.31. It appears that cost subsidies would fare slightly better than price subsidies in encouraging agroforestry adoption; however, cost subsidies are provided in the present period while price subsidies do not have to be paid until 30 years from now. These are rough estimates of arc elasticities based on highly nonlinear functions, it would be more appropriate to estimate elasticities over shorter intervals. ter policy tool.

Table 4. Elasticities of *V*, w_T* and k_1* with respect to timber price at final harvest, and forest planting cost.

Price range (\$/m^3)	Elasticities		
	E_{VP}	E_{WP}	E_{KP}
50-120	0.14	0.31	0.14
120-130	0.21	1.42	0.71
130-135	0.23	3.36	1.79
135-140	0.48	46.41	41.13
Cost range (\$/ha)	E_{VC}	E_{WC}	E_{KC}
50-300	-0.06	-1.17	-1.04
300-400	-0.02	-0.48	-0.26
400-800	-0.04	-0.27	-0.14
800-1400	-0.07	-0.20	-0.09
1400-2000	-0.11	-0.19	-0.08

Let the elasticities of land value (*V*), optimal water table depth at the end of the first rotation (w_T^*) and optimal forest area in the first production cycle (k_1^*) with respect to timber price (P_f) and forest planting cost (C_f) be defined as:

$$E_{VP} = \frac{\Delta V}{\Delta P_f}\frac{P_f}{V}, \quad E_{WP} = \frac{\Delta w_T^*}{\Delta P_f}\frac{P_f}{w_T^*}, \quad E_{KP} = \frac{\Delta k_1^*}{\Delta P_f}\frac{P_f}{k_1^*},$$
$$E_{VC} = \frac{\Delta V}{\Delta C_f}\frac{C_f}{V}, \quad E_{WC} = \frac{\Delta w_T^*}{\Delta C_f}\frac{C_f}{w_T^*}, \quad E_{KC} = \frac{\Delta k_1^*}{\Delta C_f}\frac{C_f}{k_1^*}. \tag{22}$$

Using these definitions and estimating elasticities over limited ranges, based on figures 6 and 7, we obtain a more clear picture of the responsiveness of optimal water table depth and forest area to policy variables (Table 4). Within the range of base prices and costs ($70/m^3 and $1,920/ha) the relevant elasticities are: E_{WP} = 0.31, E_{KP} = 0.14, E_{WC} = -0.19 and E_{KC} = -0.08. Thus it appears that timber price subsidies are a bet

Timber price and planting cost affect the value of the land, the relevant elasticities are: E_{VP} = 0.14 and E_{VC} = -0.11. The switch from 15 ha to 100 ha of forest planted as timber price or forest planting cost reach a critical level ($140/m^3 and $200/ha respectively) cause a sudden increase in the value of the land (Fig. 7).

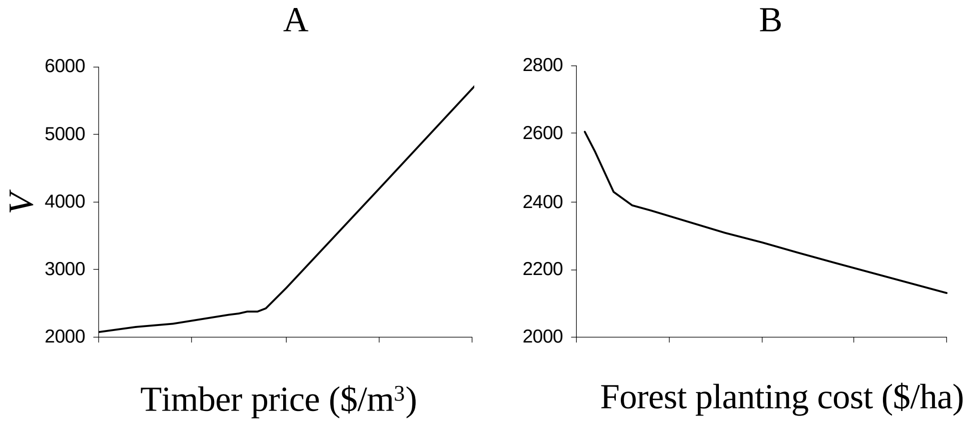

Figure 7. Effect of timber price and forest planting cost on land value.

Conclusion

The analysis assumes that producers are profit maximisers, this may be a good approximation provided that producers are aware of the inter-temporal trade-offs of land use. If they are not, education would be a desirable policy.

Trees are by no means the only solution to dryland salinity emergence, but in the long term they are perhaps the most effective option (although not necessarily the most economically efficient). Other crops, such as lucerne and native pastures can be used, along with rotations, to achieve a negative water balance, Greiner (1997) discusses some of these.

The estimation of forest externalities in this paper is limited to the beneficial effect of treeson the quality of cropland. Other externalities such as soil conservation, water quality control and amenity value were not considered. These externalities would apply to trees but not to other crops and pastures and, therefore, farm forestry should be a worthy contender in the race to control dryland salinity, provided that the problem of missing markets can be at least partially solved. Currently, not enough information is available to test this hypothesis, but current research on amenity and environmental values of forests may eventually yield the data required to study these issues empirically. Finally, the recent introduction by the NSW Government of a scheme to encourage farm forestry by providing a stream of annual payments, based on the value of the land, may hold promise. The evaluation of such a scheme is possible with the model developed here.

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