Modelling socially optimal land allocations for sugar cane growing in North Queensland: a linked mathematical programming and choice modelling study[#]

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ABSTRACT

A modelling framework is developed to determine the joint economic and environmental net benefits of alternative land allocation strategies. Estimates of community preferences for preservation of natural land, derived from a Choice Modelling study, are integrated with a model of agricultural production in an optimisation framework. The trade-offs between agricultural production and environmental protection are analysed using the sugar industry of the Herbert River district of north Queensland as an example. Spatially differentiated resource attributes and the opportunity costs of natural land determine the optimal trade-offs between production and conservation for a range of sugar prices.

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1. Introduction

Sugar-cane growing is the dominant economic land-use in many tropical catchments along the north-eastern Australian seaboard. While cane growing provides direct economic benefits, environmental values are becoming increasingly important. Rising community pressure for reform in natural resource management poses a major challenge to the Australian sugar industry to reduce environmental risks. Regional planners must manage the trade-offs between economic and environmental objectives in cane growing (Mallawaarachchi 1998). Land-use planning is seen by the sugar industry as a management tool to mitigate the negative environmental consequences of sugar production. This study seeks to provide a method of analysing economic–environmental trade-offs in land allocation.

The sugar industry has several vertically integrated sectors, where the growers who produce sugar cane, and millers who process raw sugar from milled cane, are the two primary links. Raw sugar marketing and a small raw sugar-processing sector comprise the rest of the industry. Historically, sugar production in Queensland has been closely regulated. The relationship between growers and millers is managed through a system of cane area assignment that restricts production to designated land, and a cane pricing formula to distribute returns from sugar between millers and growers (Bartley and Connell 1991; Industry Commission 1992; Mallawaarachchi 1998).

A combination of high prices, partial relaxation of regulations, and most notably, the move to local control over land assignment since 1991, encouraged the industry to expand rapidly from 360 000 hectares in 1990 to 520 000 hectares in 1999. Industry expansion has raised environmental concerns about the effects of land clearing and about non-point source pollution from an expanding cane area. Concerns about present policies stem from the perception that existing institutional and regulatory arrangements have led to an excessive allocation of resources to sugar production and inadequate conservation of the natural environment.

The increase in environmental concerns, in conjunction with rising costs and variable prices means that productivity improvements and area expansion must be both financially viable, and environmentally responsible. The decision problem faced by the industry is one of maximising the net social benefits of land management. The choice between production and environmental conservation is complicated by the spatial heterogeneity of land that alters the production benefits by affecting the potential yield and the environmental value associated with current uses. These complex value trade-offs are often overlooked in local area planning.

This paper addresses issues of land allocation in cane growing regions, with particular reference to a major sugar-cane production region – the Herbert River district of north Queensland. We present an analytical framework suitable for application to the Queensland sugar industry. The broader framework, however, is applicable to a wide range of regional resource assessment problems.

It is argued that the Krutilla–Fisher (1985) framework for total economic valuation can be used to model efficient allocation of land using a programming approach. The modelling approach and the results of a case study reveal the advantages of an integrated economic–environmental model in capturing the significance of spatially heterogeneous resource attributes in determining the intertemporal allocation of land units between production and conservation.

2. Background

The cane land assignment system, single-desk selling of Queensland sugar, and the cane pricing formula for determining payments to growers are the key institutional arrangements that underpin sugar-cane production in Queensland. The legal basis for these arrangements was provided by the Queensland *Sugar Industry Act 1991*, which has been superseded by the *Sugar Industry Act 1999* since 1 January 2000. These industry regulations have been in place for many years, and the new legislation preserves these arrangements with only slight modifications. The provision in the new Act for individual negotiation of cane supply agreements between growers and millers is unlikely to

change the pre-1999 status, because of a 'no disadvantage' clause inserted to protect the interests of other growers. These developments are consistent with the Sugar Industry Review Working Party Report (1996), which provided the policy blueprint for the new Act.

While the sugar industry legislation assigns environmental responsibility to local industry within Cane Supply and Processing Agreements, over the past decade, the State and Commonwealth governments have responded to environmental concerns in a variety of ways. These include policies designed to provide access restrictions, vegetation protection, and the promotion of voluntary restraints and resource stewardship through community partnership arrangements, such as Land Care and Integrated Catchment Management initiatives, and the Natural Heritage Trust (Johnson et al. 1998). Producer responses to these initiatives have been largely positive, but the *ad hoc* nature of many policies makes their economic effects harder to assess.

One important difficulty is that of valuing the benefits of environmental preservation in a way that is useful for land use planning. Although there has been extensive development of methods for eliciting environmental values, commonly referred to as contingent valuation methods, most attention has focused on dichotomous choices, such as the decision on whether or not to proceed with a given development. Cameron and Quiggin (1994) discuss estimation difficulties in this context. Alternative approaches based on suitability scores have also been developed to address valuation difficulties (Hanink and Cromley 1998).

More recent developments such as Choice Modelling (Morrison, Bennett and Blamey 1998; Blamey et al. 1998; Blamey, Gordon and Chapman 1999) are better suited to land management problems since they are concerned with modelling choices that vary over a range of characteristics, rather than, as in older versions of contingent valuation, with the estimation of demand curves for a given good. The object of this paper is to show how Choice Modelling results may be integrated with modelling of optimal land allocation, within a theoretical framework based on private and common property rights.

2.1 Environmental issues facing the sugar industry

The Australian sugar industry is located adjacent to environmental regions of national and international significance: the Great Barrier Reef Marine Park and the Wet Tropics World Heritage Area. This, coupled with the growing trend in tourism and in urban growth along the Queensland coast, has brought the sugar industry under close public scrutiny for its environmental management. In particular, the industry's rapid expansion in Queensland over the past decade has been associated with a growing number of environmental disputes. Mary Maher and Associates (1996) and Johnson et al. (1997) identify a number of environmental issues that are relevant to the sugar industry. The most pressing issues arise from an expansion of the area of assigned land on which cane may be grown. In the absence of careful planning, expansion can create problems such as: altering the existing drainage regime, including wetlands, poorly drained coastal plains and coastal waterways; clearing of critical habitat and significant vegetation communities; disruption to aquatic life, water quality and fish breeding grounds; and fragmentation of previous integral native habitat.

Additional environmental problems, also shared with other intensive agricultural industries, include the diffuse source pollution arising from run-off of pesticides, fertilisers and mill effluents, and problems associated with the demand for irrigation water (Mary Maher and Associates 1996; Rayment and Neil 1997; Johnson et al. 1997). These environmental concerns have been the source of conflict between economic and environmental objectives of land use within the cane growing regions of Australia. The industry has responded to community concerns by adopting a voluntary Code of Practice for Canegrowing (Canegrowers 1998), aimed at mitigating the adverse environmental effects of on-farm practices.

2.2 Impacts of industry regulation on resource allocation

The system of industry regulation developed in Australia in the early twentieth century involved restrictions on where cane could be grown, on where the cane grown on any given piece of land could be processed, and on the terms and conditions under which growers and processors negotiated

prices. The object of the assignment system is to allocate land to match existing mill capacity. However, the system is based on an implicit assumption that yields are constant, both spatially across lands and over time periods. In practice, growers are free to vary their production levels on assigned land by altering agronomic management, notably through the application of nitrogen fertiliser to augment land quality.

The regulatory system as a whole was designed to limit the total area used for cane production and to restrict the reallocation of land from cane production to other agricultural activities and vice versa. Moreover, the combination of high prices and restricted areas of land meant that intensive production techniques were more profitable under regulation than would have been the case otherwise. In environmental terms, there is a trade-off between increases in area and increases in production intensity. Incentives for intensive production tend to increase the severity of problems such as soil erosion and nutrient run-off. However, more intensive production techniques reduce the need for land clearing. Hence, the gradual relaxation of regulation since 1991 has yielded both environmental benefits and environmental costs.

Studies of the land assignment policy have generally been carried out at the national level, in association with inquiries into the operation of the Australian sugar industry (ABARE 1991; Industry Commission 1992, see also Mallawaarachchi 1998). Bartley and Connell (1991) used a farm-level linear programming model to investigate the impact of regulatory changes on the profitability of canegrowers. Beard and Wegener (1998) used an econometric model to investigate the effects of deregulating the assignment system on the distribution of profits between canegrowers and millers. They used constant unit costs for cane growing and did not account for production differentials between land classes. They concluded that the dismantling of the assignment system would be beneficial to both growers and millers. However, none of these studies analyse the trade-offs between the economic and environmental objectives of land management and the equity and efficiency implications of such trade-offs.

3. Analytical approach

3.1 Resource Management Strategies

Multiple-use and dominant-use management are two broad options available for resource management at a regional level. These alternatives are conceptually similar to diversification and specialisation, and may be analysed in terms of the convexity and divisibility of the production technology.

Under dominant-use management, each unit of land is allocated to the single use that provides the greatest economic return. This was first mooted as an alternative approach to resource allocation in managed forests. Dominant-use management follows the theory of comparative advantage and is preferable when joint production is less efficient than specialisation (Helfand and Whitney 1994). Conversely, multiple-use systems involve using each unit of land to generate multiple outputs and are therefore preferable in the presence of complementarities in production.

Multiple-use management will be preferable where the technology is convex and divisible, while dominant-use management will be preferable in the presence of indivisibilities. Hence the choice between dominant-use and multiple-use management depends on the scale at which management units are defined. Dominant-use management applied to small units within larger systems may be regarded as a form of multiple-use management applied to the entire system, and may yield higher levels of all outputs than a system where all units are devoted to multiple uses (Pearson 1943; Glascock 1972).

The nature of the production technology is also relevant. Ward and Lynch (1997) investigate whether resource management for dominant use provides greater economic benefits than multiple-use management. Following an empirical trade-off model incorporating competitive and complementary options, Ward and Lynch compare dominant-use and multiple-use management strategies to allocate water between consumptive and non-consumptive uses in the New Mexico Rio

Chama basin. Using a basin-wide programming model, they conclude that in basins where non-consumptive uses are dominant, multiple-use management can meet economic efficiency objectives. In general, the more intensive the consumptive use, the less the capacity for multiple-use management.

Given the intensive and regionally concentrated nature of land-use for cane growing, it appears appropriate to employ a dominant-use framework to examine resource allocation issues in the sugar industry. Dominant-use management clearly involves numerous difficulties. However, it is possible to manage dominant uses, while allowing for other uses within a region. It requires careful planning and agreement between competing users, in particular to identify important, but non-dominant, uses (Johnson et al. 1998). Management of mahogany glider habitats in canegrowing areas of North Queensland is an example (Queensland Department of Environment and Heritage 1995).

3.2 Linking production and environmental values

Resource allocation decisions that ignore the sources of utility of the resource in its natural state may be inefficient. In particular, if future changes in technology or preferences that will make the unspoilt resource more valuable are ignored in resource allocation decisions, excessive amounts of the resource may be irreversibly converted to commercial use (Antle and McGuckin 1993). Capturing the interplay between the private benefits of the production alternative and its externality impacts on the environment is vital to ensure allocative efficiency (Ayres and Kneese 1969). Antle and McGurckin (1993) suggest the use of an optimisation model to integrate economic and environmental systems. Such applications however, are uncommon because of the difficulty in measuring environmental values in a manner useful for inclusion in allocation models.

The framework adapted in this paper follows Rygnestad and Fraser (1996) and Ward and Lynch (1997). Rygnestad and Fraser use an integrated agronomic and economic model to analyse set-aside policies in the European Union. Their model contains a production function for determining optimal nitrogen use in farms with heterogeneous land. The associated profit function determines the pay-

offs from alternative management options, including set-aside options. Ward and Lynch apply a mathematical programming model at a regional level to compare the pay-offs from alternative water allocations, subject to reservoir capacity and water demand constraints for electricity generation and consumptive uses.

Neither of these models incorporates the social costs of the loss of environmental amenity associated with production. We attempt to incorporate these costs into our analysis by estimating the willingness to pay for environmental protection based on a Choice Modelling study (Mallawaarachchi et al. 1999). The total economic valuation framework adopted in the model is derived from the Krutilla–Fisher algorithm for evaluating irreversible investment options (Krutilla and Fisher 1985). The integrated regional programming model offers a robust theoretical basis to determine the trade-offs between environmental and economic objectives of resource use. We use the model to investigate efficient land allocation strategies for a catchment in response to changes in mill capacity and the price of raw sugar.

3.3 Choice Modelling

To compare monetary benefits with environmental costs, it is necessary to estimate environmental values. Attempts at direct elicitation of monetary values for environmental goods, using the family of approaches commonly referred to as the 'contingent valuation method', have proved problematic (Quiggin 1998). A more promising approach is that of 'Choice Modelling' where respondents are asked to choose between policy outcomes that vary with respect to a number of monetary and environmental attributes. Econometric procedures may then be used to estimate a utility function, leading to predictions of choices between policy outcomes that may be characterised in terms of these attributes (Blamey, Gordon and Chapman 1999).

Mallawaarachchi et al. (1999) conducted such a study in the Herbert River district. The alternatives in each choice set were described by four attributes: levels of protection for two land types; regional income from cane production; and an environmental levy. Given a representation of the feasible

environmental and economic attributes, the choice model is used to estimate individual willingness to pay for a given level of environmental protection. Given the public good nature of the environmental values, the marginal value of the social benefit of protection is estimated by summing the individual values across the target population.

Mallawaarachchi et al. (1999) examined preservation of two types of land in the Lower Herbert river district: wetlands, which currently occupy an area of 2300 hectares, and tea-tree woodlands which currently occupy an area of 21000 hectares. The area of both land types is declining at present, primarily because of expansion in the area allocated to sugar-cane production. The marginal value elicited for wetlands was $2800 per hectare, considerably more than the maximum value that can be generated using the land for agricultural production ($1500 per hectare for sugar cane). Hence, optimal land use management should, as far as possible, prevent any further diversion of wetlands to agricultural production. In the model presented in this paper, it is assumed that such constraints are imposed and that allocation of land for agricultural uses incorporates requirements for preservation of wetlands.

The marginal value elicited for tea-tree woodlands by Mallawaarachchi et al. (1999) was $18 per hectare, with a 95% confidence interval of $3.20 to $36.90 per hectare. At the margin, this is less than the value of land in sugar production, but comparable to the value of beef production under extensive grazing ($34 per hectare) . As a result, in the modelling solutions presented below, we investigate the effect of site characteristics such as slope and elevation on the suitability of different land parcels for conversion to sugar cane. Alternative simulations are conducted with different marginal values for tea-tree woodlands, reflecting higher opportunity costs on the assumption that further contraction of natural woodland areas would lead to an increase in the value of remaining areas. The values of the opportunity costs of different types of land that would make preservation a viable option is investigated in successive model simulations.

3.4 Model integration

The modelling framework presented in this paper includes many features that are often ignored in existing analyses of natural resource allocation (Deacon et al. 1998). In particular, the model integrates the on-site environmental benefits of existing natural resource stocks with an optimising model of land use. The production and environmental components of the model simultaneously recognise the important dynamics in spatial and temporal resource allocation. The spatial characteristics of natural resource stocks are first modelled using Geographic Information System (GIS) tools to prepare a data set that captures the spatial resource variability that affects the flow of benefits from environmental preservation and economic production by providing an implicit ranking of land units in terms of their suitability for sugar production.

Definition of the objective function to measure regional benefits from land use enables the integration of economic and environmental values. On the one hand, the environmental attributes of land units influence production possibilities and welfare. On the other hand, agricultural production diminishes the quantity of environmental resources in their natural state and may diminish the quality of the environment through pollution (Hofkes 1996). In the model used in this paper, we do not capture reduction in environmental quality due to pollution. However, interrelationships between the economic and environmental systems are modelled as an integrated system. To achieve this integration, we combine choice modelling (Mallawaarachchi et al. forthcoming), geo-spatial analysis, and economic optimisation. The economic optimisation model is presented below.

4. Cane Land Allocation Model – Herbert (CLAM–Herbert)

The purpose of developing this model is to investigate the socially optimal strategy for allocating land at a regional level between sugar production, other production activities, and conservation. The choice problem includes the trade-off between the pecuniary benefits of cane production and the social costs of expansion in terms of forgone environmental values in land converted to sugar-cane. CLAM–Herbert is specified as a multiperiod, deterministic, non-linear programming model of the

Lower Herbert catchment. The model solution is the land allocation that maximises net social returns. The objective function maximises the regional value added in cane production, cattle farming and natural area conservation consistent with available land, site characteristics such as slope and elevation, and the opportunity costs of using that land.

Production objectives for cane supply are met in two ways: intensification of the existing cane area (intensive margin) and expansion of the current cane production area (extensive margin). Decisions at the intensive margins are management decisions, such as the level of fertiliser used for a block of land. Decisions at the extensive margin are investment decisions, and involve the determination of the level of new land to come into production. Optimal investment decisions are guided by the environmental and economic characteristics of land, which jointly determine the long-term profitability of land in production (Antle, Capalbo and Crissman 1998).

4.1 The conceptual model

The distribution of farm and environmental characteristics across the catchment induces a distribution of management practices and environmental attributes for land units in production. Farm characteristics are defined broadly to include both prices and policies that affect land and environmental allocations. Environmental characteristics are represented in terms of site characteristics and the opportunity costs of land in the preserved state.

Therefore; $Y = f(E, M)$,

where Y is regional income, and E and M are environmental and farm management characteristics respectively.

The total land available in the catchment is S_0. The current area under cane production is K_0 and the area remaining under natural use is E_0, where,

$$E_0 = S_0 - K_0. \qquad (1)$$

4.3 The basic model

In the basic model formulation, the cane area is fixed. The production system is represented through a simple production function incorporating land quality[1] and crop management. A generic yield response function of the Mitscherlich form determines the farm yields and optimal fertiliser combinations for different soil quality classes (Paris 1992; Rygnestad and Fraser 1996).

$$w(N) = \kappa \ (1 - d \ e^{-b\,N}) \qquad (2)$$

For different values of the parameters κ , d and b, this function determines the corresponding values for nitrogen, N, and the cane yield, w . This response function displays diminishing marginal returns to fertiliser applications. The parameter κ corresponds to the quality of the land and indicates the maximum attainable yield. Parameters d and b together determine the deviation from the asymptotic maximum, reflecting the level of fertiliser applied.

Cane production is the sole income generating activity[2] and the profit function includes a single income variable. The profitability achieved per hectare is determined by production costs, cane yield and the commercial content of sugar (CCS). Total revenue, R, represents income from selling cane to the local mill m ($m=1,2$).

$$R = \sum_{m=1}^{2} L_m \ (1-\alpha) \ w \ PP \qquad (3)$$

where:

L_m = area of assigned land in mill area m (ha);

α = fallowing rate (land left without a crop in that year, %);

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[1] For simplicity, the ensuing algebraic formulation ignores land quality and site characteristics.

[3] During simulations this is relaxed to incorporate a cattle-grazing activity, although the sugar industry has no effective competitor in the region for consumptive land use.

w = average cane yield (plant, ratoon-1 and ratoon-2) (t/ha); and

PP = average price for cane ($/t).

The average price for cane was estimated in the model, based on the cane payment formula,

$$PP = 0.009\ PPS\ (CCS - 4) + 0.578.$$

The price of raw sugar, *PPS*, is the average price paid to the miller by the Queensland Sugar Corporation in 1996.

Total costs, TC, are divided into four parts: fertiliser costs derived from the use of nitrogen fertiliser, VC_F; other agronomic costs such as planting and maintenance, VC_A; cane harvesting costs, VC_H; and fixed costs, FC, apportioned over the assigned area.

$$TC = \sum_{m=1}^{2} \left(L_m \cdot (1-\alpha) \cdot (VC_F + VC_A + VC_H) + L_M \cdot FC \right) \qquad (4)$$

where:

$$VC_F = c_F \ \ N \ ;$$

c_F = cost of nitrogen fertiliser ($/t);

N = optimal use of nitrogen fertiliser (t/ha)

and

$$VC_H = w \ \ h,$$

where,

h = harvest cost ($/t).

The profit relationship for various combinations of land allocation and fertiliser management is obtained by using equations (3) and (4) to construct the annual profit function, π_t:

$$\pi_t = \sum_{m=1}^{2} L_m \cdot (1-\alpha) \cdot w(N_t) \cdot PP - \sum_{m=1}^{2} \left(L_m \cdot (1-\alpha) \cdot (VC_F + VC_A + VC_H) + L_M \cdot FC \right), \quad (5)$$

where t = 1996 to 2011.

The discounted net present value, *NPV*, of the farm profits over the planning horizon is given by:

$$NPV = \sum_{t=1}^{T} \left[\pi_t \cdot (1+r)^{-(t-1)} \right], \quad (6)$$

where, r is the annual discount rate.

It is assumed that technology displays constant returns to scale, and that the optimal nitrogen decision in one period does not affect the optimal decision in a subsequent period. This means that the carry-over effects of nitrogen and the managerial differences between farms are excluded.

The first order condition for maximising the NPV of regional profit is:

$$\delta NPV / \delta N = 0 . \quad (7)$$

The first order condition indicates that optimal nitrogen use is a function of the cost of nitrogen fertiliser and the price of cane, as stated in (8).

$$N = -1/b \cdot \ln\left[c_F / (PP \cdot k \cdot d \cdot b) \right] . \quad (8)$$

Model implementation

This model is implemented and solved as a constrained non-linear programming problem, subject to total production in each mill area *m*, a function of available land L_m, and potential yield *w*,

satisfying milling capacity $\overline{M}_m$.

The model solution yields shadow prices for various land parcels under alternative price assumptions. The extent of trade-offs between economic and environmental objectives is explored by solving the model with different levels of land availability, and by varying cane prices. The shadow prices derived from the programming analysis are then combined with the environmental valuations based on Choice Modelling to rank alternative land use strategies.

4.4 An extended model

In an extended form of the model, new land may be brought into cane production through investment in land clearing. In addition to the physical costs of clearing, land clearing for cane production has an opportunity cost associated with the loss of natural amenity. By linking economic and environmental costs and benefits in a dynamic model of production, investment and conservation, CLAM permits the assessment of policy alternatives.

Following equation (1), and adopting the notation used by Zilberman,Wetzstein and Marra (1993), let the environmental and recreational benefits from land currently in a natural state be denoted by $V(E_0)$. At the initial period, the consumption benefits of land use are equivalent to π_t in (5). To simplify the notation, assume that the benefits of production from land allocated to cane can be denoted as $B(\gamma K_0) - cK_0$, where γ and c are the unit area yield, and unit cost of production respectively for cane produced on land K in period 1. Assuming conservation benefits

$$V(E_0) = V(S_0 - K_0),$$

the net benefit from land use in the catchment in period 1 is:

$$B(\gamma K_0) - cK_0 + V(S_0 - K_0). \qquad (9)$$

Similarly, the investment in land clearing for converting land from its natural state to cane

production can be represented as an annual increment to K_0, where $K_1 - K_0 > 0$. Then the net benefit of land use in period 2 is:

$$B(\gamma K_1) - cK_1 + V(S_0 - K_1). \quad (9a)$$

If the cost of transforming land from its natural state to cane production is *Z* ($/ha), and both farming technology and preferences for environmental conservation do not change over time, the solution to the intertemporal investment and production problem can be obtained as:

$$\underset{K_o, K_1 \ldots K_T}{Max} \sum_{t=1}^{T} (1+r)^{-t} [B(\gamma K_t) - cK_t - Z\,?(K_t - K_{t-1}) + V(S_0 - K_t)]. \quad (10)$$

Optimisation involves a series of annual production and investment activities over the length of the planning horizon *T*. Ignoring for the moment the investment costs, *Z* $/ha, of converting land from its natural state to cane production, it is possible to write the first-order condition for the relationship in equation (9a) for an ongoing cane growing activity as:

$$\gamma B_y(\gamma K_0) - c - V_E(S_0 - K_0) = 0. \quad (11)$$

Equation (11) states that, for an optimal allocation, the marginal benefits of resource use in cane production $\gamma B_y(\gamma K_0) - c$ (the product of the unit yield of cane and price of cane less the unit cost of production), should be equal to the marginal benefits from environmental and recreational uses, $V_E(S_0 - K_0)$. The optimality condition means that, in each period, the price obtained for cane must be greater than or equal to the sum of the marginal costs of cane production and the environmental opportunity cost of cane production in each time period *t*.

$$P_0\,?\,B_y(\gamma K_0) = c + \frac{V_E(S_0 - K_0)}{\gamma}. \quad (11a)$$

If P_0 is smaller than $c + \frac{V_E(S_0 - K_0)}{\gamma}$, the area of land in cane production is greater than would

be socially optimal. For a given price of sugar P_0, and a given unit cost of production c, the environmental cost per tonne of sugar produced is higher for cane land with lower yields.

In evaluating the multiperiod investment decision, the capital cost, Z \$/ha, of converting land from its current use to cane farming enters the decision calculus. For the investment to be socially desirable, the discounted sum of marginal agricultural benefits from cane growing must be greater than or equal to the discounted sum of marginal agricultural and environmental costs of resource use and conversion costs over the planning horizon (T-t). The marginal optimality condition is:

$$P_0 \, ? \, B_y(\gamma K_0) = c + \frac{V_E(S_0 - K_0)}{\gamma} + rZ \, . \qquad (12)$$

This criterion is embedded in the multiperiod optimisation problem in (10). Using this model, we investigate the implications of different assumptions about cane prices, technology and preferences for environmental conservation for socially optimal land allocations.

4.5 Model Simulations

The model was developed in GAMS (Brooke, Kendrick and Meeraus 1999) and solved using GAMS/Conopt2 non-linear optimisation solver (GAMS 1999). Data for the regional analysis was obtained from the CSIRO land use database for base year 1996 (Johnson and Murray 1997). The study area was grouped into 109 composite mapping units using GIS analysis. Land units within each group represented one of four classes (good, average, marginal and poor) based on agricultural land suitability maps (1:50,000) for the Ingham area (Wilson and Baker 1990). Additional soils information collected at a finer scale (1:10,000) were used to model yield potential within the good, average and marginal land suitability classes, based on detailed soil mapping conducted by CSR (Andrew Wood, CSR Herbert River Mills, personal communication, August 1999). The land suitability class ‘poor’ was excluded from the analysis because local assignment criteria prevent cane production on this class of land. In the final data set the study region was spatially disaggregated into 99 unique mapping units (hereafter referred to as mapping units) on the basis of

land suitability, soil variability, elevation and current land use.

Spatial interpolation techniques were used to relate data collected at different spatial scales, and cluster analysis and regression modelling techniques were used to identify statistical associations between soil characteristics and the observed yield of sugar-cane. The soil data included 35 soil groups reflecting the variability associated with location (river beds, banks, river overflow), particle size composition (silt loam, clay, sand and so on), and soil colour indicating physico-chemical variability (grey-brown loam, black sandy loam, red sandy loam and so on). The 35 soils were grouped into eight homogeneous groups using cluster analysis. Relating these eight groups to observed yields, four clusters of soils were identified for the determination of yield response to fertiliser application.

Simulations conducted using the APSIM cane growth simulator (McCown et al. 1996) were used as a guide to model fertiliser response (Paris 1992). The modelled response represents average management conditions for the green-cane-harvesting and trash-blanket farming system as applied in the Lower Herbert River catchment area. Within the optimisation, optimal yield in a given mapping unit is modelled as a function of soil type, elevation and fertiliser application.

Three land uses were considered – cane, grazing and natural. Suitable areas of both grazing and natural land are available for conversion to cane.

The model was calibrated to reflect the situation in 1996. The following parameter values were used:

PPS	- average pool price of raw sugar	= \$342/tonne
c_F	- cost of nitrogen fertiliser	= \$870/tonne
CA	- total cost of other inputs	= \$340/hectare
h	- cost of harvesting	= \$6/tonne

FC	- fixed costs	= $676/hectare
NVPcat	- net value of grazing production	= $34/hectare
AVNA	- annual value of natural area	= $18/hectare
r	- discount rate	= 0.04
α	- annual ratio of fallowed cane area to total area	= 0.20
Z	- capital costs of conversion to cane	= $1500/hectare (natural) $300/hectare (grazing).

The net value of grazing production ($34/hectare) represents the opportunity cost of converting grazing areas to cane (ABARE 1997).

5. Results

5.1 Base simulation

In the base simulation, a ceiling is imposed at 1996 levels on the assigned cane area. Marginal land values and shadow prices are calculated under the assumption that fertiliser inputs are chosen optimally. Under a base price of $342 per tonne for raw sugar, marginal values of cane land varied from -$110 to $4380 per hectare, reflecting differences in site characteristics. Mapping units L37, L42 and L98 recorded negative shadow prices indicating that cane production in those locations was unprofitable. Consequently, 3605 hectares of cane land are not used for cane growing in subsequent years in the optimal solution.

Table 1 reports the results of parametric reduction of the price of raw sugar from $342 per tonne to $272 per tonne. As sugar prices drop, the area allocated to cane declines and cane production is restricted to more productive sites, mainly within the good and average land classes. Land withdrawn from cane production is used for grazing. Such transitions in land use are not common in

most cane growing areas at present, because of restrictions on changes in land use arising from the assignment system. Since withdrawal of land from cane production may result in the loss of assignment rights, farmers may choose to continue cane production even when the return from cane is temporarily below the marginal opportunity cost of cane production.

(Table 1 near here)

Withdrawal of land from cane production is also constrained by the existence of fixed costs. Most canegrowers have several cane blocks with differing levels of productivity. In some cases, although the revenue per hectare obtained from some blocks is less than the average cost of sugar-cane production, the pooling of returns from all blocks in a single farm enterprise yields profitable returns from the business as a whole. This form of cross-subsidisation between blocks of land with different productivity levels within an enterprise cannot be modelled in a regional formulation of the type used in this study. Models that include fixed costs, personal taxation constraints and private profit objective functions are better suited to analyse such microeconomic effects (Vandeputte and Baker 1970; Mallawaarachchi, Hall and Phillips 1992).

Use of fertiliser is not reported, but is inelastic over the entire price range. This is due to the asymptotic nature of the fertiliser response function and the comparatively low cost of nitrogen. These responses are compatible with actual experience in the Lower Herbert River catchment.

At a base price of $342 per tonne of raw sugar, the shadow price of mill capacity was around $10.00. That is, each additional tonne of cane crushed would yield $10.00 to the cane growing sector. This is evident in subsequent simulations, where relaxation of the milling constraint leads to increases in the area allocated to sugar-cane until the available land is fully used up in each suitable site[3].

The model yields a negative net surplus when the price of raw sugar is $262 per tonne or less. This

[3] The model assumes that marginal increases in mill capacity can be achieved profitably within the price range simulated. However, the rate of return on mill investment under current pricing structure needs further investigation.

'break-even' sugar price is equivalent to $21.80 per tonne of cane (at a CCS level of 13 per cent). At prices below this level, cane production is unprofitable in most sites, leading to infeasible model solutions. The expected return to Queensland cane growers of $250 per tonne of raw sugar for the 1999-2000 crop is less than this 'break-even' price. Such low prices, coupled with a production downturn is threatening the viability of some cane enterprises, particularly those in marginal areas. If such low prices were to be sustained, over one third of existing cane land in the Lower Herbert would be withdrawn from cane production in an optimal solution, in the absence of reductions in costs or other adjustments to farming systems.

5.2 Unconstrained solution

General response

In the unconstrained solution, the constraints on land allocation and mill capacity are relaxed, and landowners are free to allocate land to the most profitable use, taking account of conversion costs and the environmental costs of converting natural areas. The environmental costs of converting tea-tree woodlands are set at $18/hectare, the value derived in the Choice Modelling study of Mallawaarachchi et al. (1999). Since the environmental costs of converting wetlands to agricultural production always exceed the value-added in agriculture, a constraint is imposed to prevent any such conversions taking place.

The results are presented in Table 2. The first two columns of Table 2 contain a comparison between the base solution and the unconstrained solution, using a base price of $342 per tonne for raw sugar. As would be expected, the relaxation of the allocation constraint causes total value-added for the region to increase. The present value of regional value-added rises from $260 million in the base solution to $337 million in the unconstrained solution.

(Table 2 near here)

In particular, conversion of grazing and natural land to cane production in sites that are more suited

to cane results in an expansion of area under cane. In all simulations, this adjustment is complete by 2000, which is used as a reporting year in this paper.

In the unconstrained solution, the total area under cane increases from the base level of 57 617 hectares in 1996 to 83 397 hectares in 2000. The growth of the cane area is the result of the conversion of 15 886 hectares of natural land and 9894 hectares of grazing land to cane. All tea-tree woodland and grazing land units in the good category and all grazing land units in the average category are converted to cane. The necessary condition (12) is not satisfied for some land units in the marginal category, because of the relatively low value-added in sugar production on land in this class. Hence, some, but not all, tea-tree woodland land units in the marginal category are converted to cane.

The annual value-added in cane production increases from $22.3 million in 1996 to $32.4 million in 2000 as a result of the conversion of natural and grazing land. The increase in value-added in cane production is partially offset by a reduction of $0.2 million in value-added for the grazing sector and environmental opportunity costs of $0.3 million per year arising from the conversion of tea-tree woodlands to cane production. After taking into account the costs of converting land to cane production, this reallocation results in a net gain in regional value-added of $77 million in net present value, over the 15 years modelled period, from $260 million in the constrained solution to $337 million in the unconstrained solution. The analysis excludes returns to the milling sector, which may increase as a result of greater throughput.

Sensitivity to the price of sugar

Given the volatility in world sugar prices, it is important to examine the sensitivity of the optimal allocation to price levels. Table 2 shows the change in the unconstrained solution as the price of raw sugar is parametrically varied from $342 per tonne to $272 per tonne.

The optimality conditions (12) implies that returns from canegrowing must be sufficient to meet the unit costs of production c, environmental opportunity costs, and the interest costs of capital

employed to convert land from current uses to cane production. The price of sugar, and the yield measured in tonnes per hectare, jointly determine the attractiveness of cane production on land with given characteristics.

At prices above $302 per tonne, all natural land in the good category (other than wetland) is converted to cane. As the sugar price drops below $302 per tonne, the proportion of natural land converted to cane declines. Conversion to cane in the average category declines slightly as the price falls from $342 per tonne to $322 per tonne, and more rapidly thereafter.

Conversion of natural land to cane in the marginal category is sensitive to changes in the price of sugar. The area converted can be obtained by comparing the area of natural land in the base simulation (Column 1 in Table 2) to the area in the unconstrained solution for the relevant price. The area of marginal land converted from natural areas to sugar-cane declines from 9272 hectares when the price of sugar is at $342 per tonne to zero when the price is $292 per tonne. At prices below $292 per tonne, the returns from sugar-cane are not sufficient to offset the cost of converting marginal natural land to cane.

Disaggregated analysis

The basic unit of analysis in the modelling presented here is the mapping unit, derived from the GIS discussed in Section 4.5. The decision on whether to convert land in a given mapping unit from natural use to grazing will depend on whether the optimality condition (12) is satisfied, at given sugar prices for the yield obtainable in that mapping unit, which is determined by the site characteristics of the mapping unit. The relationship between site characteristics, the price of sugar and the decision on whether to convert natural land to cane may be illustrated by an analysis

focusing on natural land in the marginal category, disaggregated into mapping units.[4]

(Table 3 near here)

The comparative statics of the model may be illustrated by considering two mapping units, L20 and L28 (Table 3). Mapping unit L20 has a clay soil type, but has a good yield potential as evident from an average yield of 90 tonnes/hectare. Mapping unit L20 has an area of 21 810 hectares, of which 14 010 hectares are currently under cane, 5446 hectares are under grazing, and 2354 hectares are in the natural state. At the base price of $342 per tonne, the entire area of 21 810 hectares is allocated to cane production in the optimal solution. When the price of sugar falls to $292 per tonne or less, conversion of natural land to cane production becomes unprofitable, so the cane area declines to 19 456 hectares. Conversion of grazing areas to cane production becomes unprofitable at prices of $272 per tonne or less, and the optimal allocation of land to cane is the same as in the base solution (14 010 hectares).

Mapping unit L28 has sandy clay soil and the average cane yield in the existing cane area is 80 tonne/ hectare The mapping unit has an area of 5491 hectares of which 1762 hectares are currently allocated to cane and 864 hectares to grazing, while 2865 hectares remain in the natural state. At the base price of $342 per tonne, the entire area of 5491 hectares is allocated to cane production in the optimal solution. Conversion of natural and grazing land to cane becomes unprofitable when the price of sugar is $332 per tonne or below. Hence for prices above $302 per tonne, but less than or equal to $332 per tonne the optimal cane area is the same as in the base solution (1762 hectares). At prices of $302 per tonne or less, the optimal solution is to withdraw all land from cane production.

[4] A similar analysis could be undertaken for the average land category. Some sites classified as 'average' for cane are unprofitable when other factors such as elevation and other soil characteristics make returns from cane unattractive at lower prices. Locations 36, 89 and 97 are not converted to cane when the sugar price is $292 per tonne or less. Elevated sites often have high level of soil erosivity and dry up more rapidly during dry periods, leading to yield stresses. Preliminary analysis of yield data in the Herbert River district indicates a declining trend in cane yields as elevation increases above 2–3 metres.

Effect of environmental opportunity costs

Environmental opportunity costs are incurred because of the loss of amenity when natural land is converted to cane production. When environmental opportunity costs are taken into account, the conversion of marginal land from its natural state to cane production becomes less attractive. The cost of converting sites from grazing to sugar-cane is unaffected, since grazing land is assumed to yield no environmental amenity (or the same amenity as land used for cane production). It is useful to consider the impact on the optimal land allocation of variations in the opportunity cost of natural land. The Choice Modelling study reported above yielded a confidence interval from $0-$36 per hectare for the opportunity cost of tea-tree woodland. However, higher values might be derived if the concerns of nonresidents were taken into account, or if continued clearing made tea-tree woodland scarcer and therefore more valuable. For illustrative purposes we consider a range of opportunity costs from $0-$108 per hectare.

(Table 4 near here)

Increasing the opportunity costs of natural land in successive simulations led to fewer sites becoming suitable for converting to cane at any given price for sugar (Table 4). This response was non-linear, reflecting the non-uniform distribution of site characteristics. An increase in opportunity costs from $18 per hectare to $36 per hectare had only a small effect on the aggregate area of retained natural woodlands and even this effect was evident only at sugar prices below $302 per tonne. However, at higher values such as $72 per hectare, the changes in land allocation are significant at a sugar price of $302, which is more likely to represent medium term price expectations.

Trade-offs between expansion and intensification

The current version of the model does not account for the environmental consequences of increased fertiliser use. Simulations, conducted with the APSIM crop growth simulator, indicate that there are

increasing levels of leaching losses at higher levels of fertiliser use (Keating et al. 1997). The long-term environmental impact of fertiliser leaching is not well understood, and further agronomic research is necessary to accommodate the environmental effects of fertiliser use in the model.

6. Conclusions

Much of the land converted to cane over the past ten years in the Lower Herbert River District has been in the 'marginal' category. A large proportion of new cane land has been converted from grazing use, rather than directly from natural use to cane (Johnson et al. 1998). The model results reported in this paper imply that, on average, expansion of the area allocated to sugar-cane yields positive net social benefits at sugar prices higher than $292 per tonne, assuming that the opportunity cost of natural tea-tree woodland can be measured by the stated preferences of residents of the Herbert River district. At sugar prices of $292 per tonne or less, conversion of natural land to cane production is socially optimal only for limited areas of land in the average and good categories. As noted in Section 3.1, the stated preferences derived from the Choice Modelling study of Mallawaarachchi et al. (1999) imply that land management policies should prevent further diversions of natural wetlands, regardless of the sugar price.

The analysis presented above indicates that the conversion of 'marginal' natural land to cane may be socially undesirable when environmental costs are taken into account. Inclusion of more disaggregated spatial data in the analysis would enable marginal land to be characterised with greater precision. In addition, a more detailed analysis of environmental values would help to identify sites of above-average value within the broad category of 'tea-tree woodlands', including habitats for endangered species such as the mahogany glider.

The results must be qualified by the observation that negative externalities arising from intensive cane growing, such as the damage to the Herbert River system from run-off of fertiliser and other effluent, have not been accounted for in the model, which has dealt solely with the opportunity cost

of converting land from its natural state or from grazing. Current profit-maximising levels of fertiliser use may be higher than the socially optimal level. More agronomic and ecological research is needed to confirm or refute this belief.

The profitability of cane area expansion is highly responsive to changes in the price of sugar. In particular, prices similar to those that prevailed in the 1999 season would not only make conversion of marginal land to cane unprofitable, but would imply that some existing cane land should be converted back to grazing. The model also indicates that a finer disaggregation of land types enables greater efficiencies in land allocation. This applies to both production and conservation. In this model, however, more disaggregated values for environmental attributes were not available. Availability of such information will improve the accuracy of model results. This is particularly true for specific uses of the environment, such as that of providing unique habitats for threatened species, for which the opportunity cost would be higher.

In this paper, we have taken a first step towards the integration of choice modelling and land allocation modelling to assist in problems of land management that involve trade-offs between economic and environmental values. The results show some of the potential benefits of this approach, but more detailed modelling of both agronomic systems and environmental values is required to guide efficient allocation decisions for individual canegrowers.

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