Exploring environmental-economic benefits from agri-industrial diversification in the sugar industry: an integrated land use and value chain approach

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Abstract

The sugar industry in Queensland (Australia) is confronted with increasing economic pressure and environmental constraints. To explore whether agri-industrial diversification of the sugar industry provides a sustainable development pathway for the region, we develop a spatial environmental-economic approach that integrates a land use and value chain model with a hydrological model. Results indicate that agri-industrial diversification can lead to substantial increases in regional income, while at the same time increasing the resilience of a sugar industry facing decreasing sugar prices. Agri-industrial diversification drives land use diversification, which under current sugar prices does not lead to a reduction in sugarcane production. Water quality benefits from this land use diversification are mixed, and depend on the economic viability and erosion characteristics of the concerned production systems.

Key words: spatial economics; environmental economics; value chains; agri-industries; water quality.

JEL codes: C6; O18; Q13; Q53.

1. Introduction

Sugarcane production and processing were pioneering industries in Queensland that have made profitable use of natural resources to create wealth in the region. Protection of the sugar industry ceased in 1995 and it has since been fully-exposed to world markets (Smith et al, 2005). Declining sugar prices outpace improvements in production efficiency, creating a 'cost-price squeeze' and, thus, resulting in considerable pressure on the industry and the region to adapt and respond to globalisation (Keating et al., 2002).

Protection of the environment is an additional issue facing the region. Landscapes in Queensland have been transformed by agriculture, causing loss of biodiversity and changes in the flow regimes of the major rivers. Sediment and nutrient runoff from farms has caused water quality to deteriorate in the Great

Barrier Reef (GBR) region, impacting the health of aquatic and marine ecosystems as well as the prosperity of the fishery and tourism industries.

Agri-industrial diversification of the sugar industry, based on changes in the growing and milling sectors of the industry, is perceived as a sustainable development pathway for the region as it opens opportunities for growing crops that complement the sugarcane system (Smith et al, 2005). Commercial Agroforestry Production Systems (CAPS) is a concept for an integrated sugar-fibre-timber production and processing system that uses diversification to: i) increase regional income from production and processing, ii) increase the resilience of the sugar industry, and iii) restore environmental services in the landscape.

The objective of this paper is to develop an approach that allows for the spatial exploration of these economic potentials and environmental implications of agri-industrial diversification in the sugar industry. In contrast to earlier spatially explicit explorative approaches in agricultural and environmental economics (Nelson, 2002; Khanna et al., 2003; Rounsevell et al., 2003; Hajkowicz et al., 2005; Jansen et al., 2005), we develop a spatial environmental-economic approach that integrates a land use and value chain model with a hydrological model in which we relate land use choice and sediment delivery to land use location, distance to the market and agri-industrial processing options. An application of the model is provided for the case of the Tully-Murray catchment in Queensland, Australia.

The remainder of this paper is structured as follows. Section 2 provides an overview of the rational behind agri-industrial farming and processing systems. In Section 3 a spatial environmental-economic approach is developed that allows for the exploration of agri-industrial diversification. In Section 4, we parameterize the model for the Tully-Murray catchment to explore, in Section 5, the economic potentials and environmental implications for specific scenarios of CAPS agri-industrial diversification options. Finally, Section 6 offers concluding remarks and observations.

2.   Conceptual framework: integrated agri-industrial farming and processing systems

Under current industry arrangements, sugar mills rely on throughput of sugarcane to survive. Mills receive the value of the first 4 units of CCS as payment for crushing of cane (Smith et al., 2005), meaning that they

are paid a flat rate for milling the cane. Loss of area of cane production from a mill district, regardless of the effects on the growing sector, will reduce profitability of the mill. In an era when sugar prices are low and the cost-price squeeze is tightening, diversification which shrinks cane supply therefore threatens the viability of the mill. Collapse of a sugar mill could cause collapse of an entire local industry – at least in districts with only one mill. As a result, in its traditional guise, the industry is vulnerable to land use diversification that reduces cane supply. The industry is effectively 'locked-in' to the current monoculture of sugarcane that covers much of the GBR catchments in Queensland.

Breaking the 'lock-in' afflicting the sugar industry would reduce the vulnerability of the industry to change, bringing flexibility to future business strategies. Also, breaking the 'lock-in' may bring options to restore environmental functions on the floodplains that have been degraded by 100 years of clearing and agricultural intensification. Under the sugar-fibre-timber concept, the 'lock-in' is removed by making the sugar mill the centre-piece of an agri-industrial cluster that in addition to processing sugarcane, processes fibre and timber crops and adds value through manufacturing. Under this scheme the mill crushes sugarcane and fibre crops, but does not perform all of the other processing and manufacturing functions. The mill is involved in supplying energy and transport services to other enterprises in the cluster through partnership agreements. The mill can share fixed costs with and sell services and by-products to its partners, while it can also invest in other processing options.

CAPS (for Commercial Agroforestry Production Systems) is a concept for an integrated sugar-fibre-timber production and processing system in Queensland. Diversification of processing options at the mill drives change in land use, with sugarcane, fibre and timber crops allocated to land according to profitability and, in some possible scenarios, environmental benefits. Diversified land use under CAPS would lead to supply of diversified raw materials at the processing cluster and corresponding processing functions would add value to these raw materials.

The framework behind CAPS has parallels in other industries and regions that demonstrate that systems innovation in agriculture, to create multiple benefits, is emerging as a key strategic R&D activity in support of regional development. Internationally, there is growing momentum behind the concept of 'eco-

agriculture', which aims to integrate innovation in farming systems into the management of landscapes which sustain livelihoods, wildlife and ecosystem services (McNeely and Scherr, 2003).

3.   Methodology: a spatially explicit land use and value chain approach

Agricultural and environmental economic approaches that are spatially explicit have recently gained increasing interest, as it is recognized that production choice is related to production location and distance to the market (Nelson, 2002). Von Thunen (1826) was the first to develop an analytical model of this relationship, and showed that land rents decline with distance from the central market despite uniform productive characteristics of the land.

There are numerous spatially explicit explorative approaches in agricultural and environmental economics that relate land use location to economic opportunities and environmental consequences (Nelson, 2002; Khanna et al., 2003; Rounsevell et al., 2003; Hajkowicz et al., 2005; Jansen et al., 2005). These studies are, however, either relatively weak from an economic point of view (plot level economic indicators aggregated to the regional level) or relatively weak from an environmental point of view (plot level environmental indicators aggregated to the regional level). In contrast, we develop a spatial environmental-economic approach that integrates a land use and value chain model with a hydrological model to explore the economic potentials and environmental implications of agri-industrial diversification.

The approach developed recognizes that: i) bio-physical characteristics of the land vary widely according to location and, in turn, determine agricultural production potentials, ii) climatic and geomorphologic conditions differ according to location and, in combination with land use and management, determine diffuse source water pollution, and iii) farmers make use of existing (non-straight line) infrastructure to transport their produce to the processing plant or market. Moreover, differences in fixed and variable costs and potential benefits from alternative agri-industrial processing options are considered.

Land use is allocated at the regional scale on the basis of which land use on a particular land unit contributes most to regional income, where regional income is estimated as (per hectare) production value

(based on final products) less corresponding fixed and variable production, transport and processing costs. The mathematical model, which is solved using GAMS 2.50 (Brooke at al., 1998), is structured as follows.

The total agricultural area a in the region is divided into uniform blocks of land $L_{i,j}$, where each block of land is: i) geographically referenced by a site specific identification tag (i), and ii) used to grow a specific crop (j). Each land use site $L_{i,j}$ is characterized by a specific distance to the processing plant or market by road $d_{i,j}^{road}$ or rail $d_{i,j}^{rail}$ (in km), specific soil characteristics and yields $y_{i,j}$ (in t/ha), and specific production costs $k_{i,j}$ (in \$/ha). It is assumed that the region maximizes regional income π

$$
\begin{aligned}
\pi = {} & \sum_{i,j}\left(p_j h_j y_{i,j} L_{i,j} - k_{i,j} L_{i,j}\right) \\
& -\left[\sum_{i,j}\left(v^{road} d_{i,j}^{road} y_{i,j} L_{i,j}\right)\right]_{j=1..n} -\left[\sum_{i,j}\left(v^{rail} d_{i,j}^{rail} y_{i,j} L_{i,j}\right)\right]_{j=n+1..N} \\
& -\sum_{i,j}\left(v^{proc} y_{i,j} L_{i,j}\right) - f^{rail} - f^{proc}
\end{aligned}
\tag{1}
$$

where p_j is the price of final product j (market price in \$/t), h_j is the fraction of final product per unit of crop, v^{road} and v^{rail} are the variable transport costs by road and rail (in \$/t/km), and where f^{rail} and f^{proc} are total fixed costs associated to rail and processing infrastructure (in \$). Note that for each product j the mode of transport is pre-defined to be either road (j = 1..n) or rail (j = $n+1$..N). The objective function is maximized subject to an *ID* block size and regional area constraint, which are respectively given by:

$$
\sum_j L_{i,j} \le a_i
\tag{2}
$$

$$
\sum_i L_{i,j} \le a_j
\tag{3}
$$

with a_i the maximum block size over all crops (in ha), and a_j the maximum crop area over all blocks (in ha).[4]

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[4] The maximum crop area a_j usually corresponds to the total agricultural area in the region, i.e.: $a_j \le \sum_{ID} a_{ID}$.

Sediment loads, originating from different land uses and locations in the region, are estimated using SedNet (Prosser et al., 2001). SedNet (for Sediment River Network Model), estimates river sediment loads by constructing material budgets that account for the main sources and stores of sediment. Sediment sources, stream loads, and areas of deposition in the system are simulated, and the contribution to the river mouth (i.e. sediment delivery) from each sub-catchment can be traced back through the system thereby allowing downstream impacts to be put into a regional perspective (Bartley et al., 2004).

To estimate sediment delivery from a particular block with a specific land use, we use SedNet information on total sediment delivery per sub-catchment, total area per sub-catchment, land use per sub-catchment and cover factors per land use. Hillslope erosion related to land use in a sub-catchment is in SedNet estimated using the Revised Soil loss Equation (RUSLE), which is given by (Renard et $al.$, 1997):

$$Y = RKLSCP \qquad (4)$$

where Y is the mean annual soil loss Y (in t ha^{-1} yr^{-1}), R is rainfall erosivity, K is soil erodibility, L is hillslope length, S is hillslope gradient, C is ground cover, and P is the practice factor. For a particular sub-catchment, SedNet calculates the fraction α of the mean annual soil loss Y that ends up at the river mouth – i.e. sub-catchment sediment delivery D. As R, K, L and S are constant when considering land use change, sub-catchment sediment delivery to the coast D is given by

$$D = \beta(c_j) \qquad \text{with } \beta = \alpha RKLS \qquad (5)$$

where β is a constant and c_j is the cover and practice factor for a specific crop associated land use j. As β is homogenous for a sub-catchment, we can calculate β_i for each block i. In turn, sediment delivery to the coast D_i as a function of land use $L_{i,j}$ for block i is given by

$$D_i = \sum_j \beta_i c_j L_{i,j} \qquad (6)$$

Total sediment delivery to the coast from all land uses in the catchment is given by the sum of sediment deliveries for all blocks *i* in that catchment.

4.   Application: an example of CAPS in the Tully-Murray catchment

The model described in the previous section is applied to the Tully-Murray catchment in Queensland, Australia. We perform an assessment of land resource, production systems and processing options as well as an estimation of a transport distances and sediment delivery to explore, in Section 5, the economic potentials and environmental implications for specific scenarios of CAPS agri-industrial diversification options in the Tully-Murray catchment.

4.1   Land resource assessment

The study area is defined as the agricultural area of the Tully-Murray floodplain, plus the farmland surrounding El-Arish and the cleared area inland from Cardwell (based on QLUMP, 1999). The study area is separated into dynamic and fixed land uses, where the dynamic land uses (pasture, sugarcane and forestry) make up the land analysis units for the assessment. This dynamic land use area is converted into 10219 grid cells of 250m by 250m or 6.25 ha. Soil types for the region are mapped (using SALI, 2002) and a soil type is assigned to each land analysis unit. Soil types are then related to four soil suitability classes (S1 to S4) based on a categorisation from Murtha and Smith (1994) developed by Roebeling et al. (2004). In turn, these suitability classes are related to agricultural production (see Table 1).

4.2   Production systems assessment

The most important (in terms of current land use) and potential (for agri-industrial processing) production systems assessed in this study include sugarcane, beef cattle fattening, forestry and bamboo. Sugarcane and beef production data are based on Roebeling et al. (2004), who used a specialised crop growth model APSIM (Keating et al., 2003) and beef cattle production model PASTOR (Bouman et al., 1998) to

determine the relationship between input use and yield. Timber and bamboo production data are based on secondary data (see Smith et al., 2005).

Table 1:   Annuity input costs and yields for sugarcane, beef, timber and bamboo production

	Sugarcane		Beef		Timber		Bamboo	
Soil	Inputs	Yield	Inputs	Yield	Inputs	Yield	Inputs	Yield
Class	($/ha)	(t/ha)	($/ha)	(t/ha)	($/ha)	(m^3/ha)	($/ha)	(t/ha)
S1	1,144	88.3	859	0.44	2,275	17.5	155	37.0
S2	1,123	86.2	802	0.41	2,275	16.3	155	36.0
S3	1,166	90.9	811	0.41	2,275	12.5	155	34.0
S4	1,140	87.9	664	0.32	2,275	11.3	155	31.0

Product prices p_j for sugarcane ($29/t), beef ($2,500/t), timber ($167/t) and bamboo ($15/t) are obtained from Smith et al. (2005). Note that all prices are 2002 export prices.

4.3   Processing options assessment

Agri-industrial processing options assessed in this study include the existing sugar mill processing facility (SU) and two examples of CAPS investment options: a 50,000 m^3 (PB50) and 500,000 m^3 (PB500) capacity particle board plant (based on Smith et al., 2005). Note that in this case bamboo fibre is used in the production of particle boards. Characteristics of the SU and PB investment options are given in Table 2.

For illustrative purposes, we assume that the sugar mill's (SU) transport and processing costs are exactly covered by the 4 CCS paid by the growers and, as a consequence, the sugar mill just breaks even. The particle board (PB) investment options have a production capacity of 50,000 m^3 and 500,000 m^3 of final product per year for PB50 and PB500, respectively. Although an IRR of 11% for the PB50 plant is not outstanding, economies of scale in particle board production allow for an IRR of 24% for the PB500 plant.

Table 2:   Characteristics of SU and PB agri-industrial processing options

Item	Unit	SU	PB50	PB500
Production capacity (final)	t/yr or m3/yr	375,000 t	50,000 m3	500,000 m3
Lifespan	Yrs	30	20	20
Investment costs	$m	330.9	30.0	187.5
Variable processing costs	$/t or $/m3	21.35	126.52	112.37
Price (final)	$/t or $/m3	230.00	220.00	220.00
IRR project (full capacity)	%	0.00	11.44	24.13

Source: Based on Smith et al. (2005).

4.4   Transport distance estimation

To estimate the distance from each grid cell to the market or mill (Tully), the study area is divided into 32 areas using concentric circles drawn at increments of 25 km and eight radial divisions. The centre-most land unit is selected as the centroid point for each area, and distance from this point to Tully by rail or road calculated using GIS software (ArcGIS). This distance is then adjusted for each grid cell in an area, by subtracting or adding the straight-line distance between cell and centroid for points closer or further from Tully, respectively. Fixed transport costs (in $/t) and variable transport costs (in $/km/t) by road and rail are based on confidential data from the Maryborough and Mourilyan mills, respectively.

4.5   Sediment delivery estimation

Levels of sediment delivery to the coast D_i as a function of land use $L_{i,j}$ for block i (see Eq. 6), are determined on the basis of unpublished SedNet estimates for the GBR region (DNR&M, 2005). Given cover and practice factors c_j for sugarcane (0.056), grazing (0.016), timber (0.016) and bamboo (0.036) productions systems (based on DNR&M, 2005; Bartley et al., 2004), the R, K, L and S constant β_i is calculated for each block i. Given β_i and using Eq. 6, we can now determine land use dependent sediment delivery D_i for each block i.

5.   Model results

To explore whether diversification of the sugar industry through CAPS leads to an increase in regional income, an increase in the resilience of the sugar industry and restoration of environmental services in the landscape, we assess model results for the current situation with sugar mill (SU) and in combination with the 50,000 m³ and 500,000 m³ particle board processing facility (PB50 and PB500, respectively) under current and reduced sugar prices (p_{sugar} = $230/t and p_{sugar} = $161/t, respectively). The baseline situation (SU; p_{sugar} = $230/t) is representative of the current situation and provides a reference for comparison against each of the scenarios. Model results for annual regional income, land use and sediment delivery are shown in Table 3. Figure 1 provides a spatial visualization of regional land use and sediment delivery for the baseline situation (SU; p_{sugar} = $230/t).

Table 3:   Environmental-economic effects from the establishment of integrated agri-industrial processing options under current and decreased sugar prices

	Unit	SU		SU & PB50		SU & PB500	
Indicator		p_{sugar} = $230/t	p_{sugar} = $161/t	p_{sugar} = $230/t	p_{sugar} = $161/t	p_{sugar} = $230/t	p_{sugar} = $161/t
Regional income	million $	30.6	4.0	33.1	6.5	67.6	41.6
Sugarcane area	1000 ha	35.5	18.3	35.5	17.5	35.5	12.7
Grazing area	1000 ha	21.3	26.8	20.1	26.1	12.1	23.4
Timber area	1000 ha	5.5	18.6	5.3	18.6	0.0	12.6
Bamboo area	1000 ha	0.0	0.0	1.5	1.5	14.8	15.0
Sediment delivery	1000 t	74.4	58.3	75.2	58.1	84.5	60.9

In the baseline situation (SU; p_{sugar} = $230/t), sugarcane is the dominant land use while the sugarcane area is constrained to the sugarcane assignment area of about 35,000 ha. Grazing is the second most important land use with just over 21,000 ha. Timber production is relatively small at 5,500 ha, while bamboo is

currently not commercially grown in the region as there is no market for fibre products. Associated total sediment delivery to the coast is about 75,000 t/yr and total annual regional income from agriculture and processing is about $31 million.

A 30% decrease in the price of sugar has severe economic consequences for the sugar industry, in the absence of CAPS agri-industrial diversification options. The sugarcane area is halved, in favour of grazing and timber production. Total sediment delivery decreases by about 20%, as erosion from grazing is lower than erosion from arable cropping (Bartley et al., 2004). Annual regional income decreases by over 85%, due to the combined effect of a decrease in sugar production and the lower sugar price.
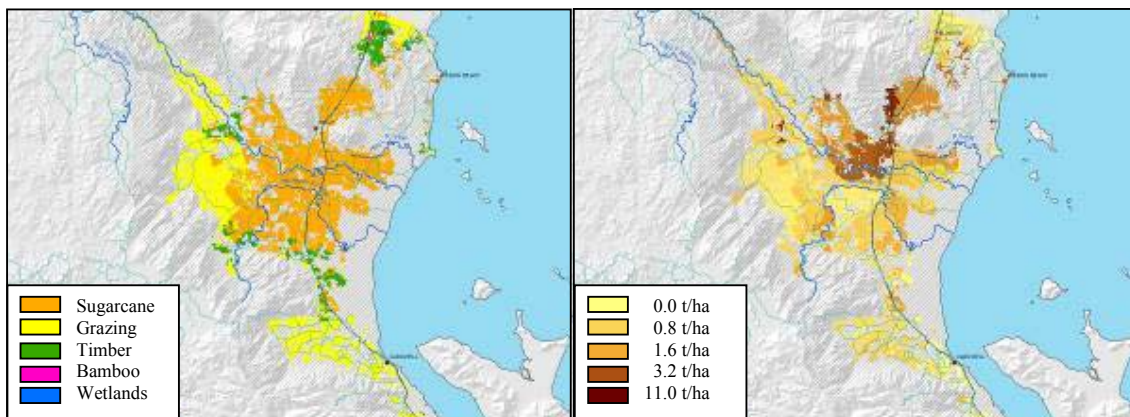

Figure 1: Land use and sediment delivery for the baseline situation (SU; p_{sugar} = $230/t)

Agri-industrial diversification through CAPS, in this case the establishment of a particle board plant (PB), allows for the production and processing of bamboo in the region. Given the favourable gross margins of bamboo production at the plot level (see Section 4.2) in combination with the viability of the particle board plant (see Section 4.3), it becomes feasible to produce and process bamboo in the region.

Under current sugar prices, agri-industrial diversification allows for the establishment about 1,500 ha (PB50) and 15,000 ha (PB500) of bamboo at the expense of grazing and timber production – further expansion of the bamboo area being limited by the size of the PB processing plant. Levels of sediment delivery increase by about 1% and 10% for PB50 and PB500, respectively, due to the higher levels of

erosion for bamboo as compared to those for grazing and timber production. Yet, annual regional income increases by 10% and 120% for PB50 and PB500, respectively.

The economic consequences of a 30% decrease in the price of sugar are dampened by the presence of CAPS agri-industrial diversification options. Despite the larger reduction in the sugarcane area in favour of bamboo production, the decrease in annual regional income is reduced to 80% and 38% for PB50 and PB500, respectively, as compared to the decrease of more than 85% in the situation without the PB processing plant. Total sediment delivery decreases with about 25% for both PB50 and PB500, due to the decrease in sugarcane area in favour of bamboo, grazing and timber production.

6.   Conclusions

In this paper we developed a spatial environmental-economic approach that integrates a land use and value chain model with a hydrological model and that allows for the exploration of the economic potentials and environmental implications from agri-industrial diversification in the sugar industry. In contrast to leading studies in Europe, North and Central America, and Australia (Khanna et al., 2003; Rounsevell et al., 2003; Hajkowicz et al., 2005; Jansen et al., 2005), we not only relate land use choice and sediment delivery to land use location and market distance but also to agri-industrial processing options.

Our results indicate that agri-industrial diversification of the sugar industry can lead to substantial increases in regional income – potential benefits being dependent on the size of the processing facility. Contrary to what is feared by some, model results show that agri-industrial diversification will not lead to a reduction in sugarcane production under current sugar prices. Furthermore, it is shown that the economic consequences from a decrease in sugar prices are dampened by the presence of CAPS agri-industrial diversification options – thus increasing the resilience of the sugar industry.

Environmental benefits from agri-industrial diversification are mixed. Model results indicate that agri-industrial diversification will lead to an increase in sediment delivery to the coast under current sugar prices, as the pasture and timber area are reduced in favour of fibre crop production. Under a 30%

decrease in sugar prices, however, agri-industrial diversification leads to a decrease sediment delivery to the coast, as the sugarcane area is reduced in favour of fibre crop, grazing and timber production.

Future research needs to address a number of limitations associated to this study. First, a more detailed land resource and production systems assessment, based on production systems simulation models (see Bouman et al., 1998; Keating et al., 2003), would improve the sensitivity of the model to changes in parameter values. Second, downstream costs of water pollution associated to GBR degradation are not taken into account. Inclusion of these costs in regional income calculations will lead to a decrease in optimal rates of agricultural water pollution (see Roebeling, 2005). Finally, environmental services considered (but not valued) in this study are restricted to those related to water quality. A comprehensive assessment of agri-industrial diversification options requires the valuation and inclusion of environmental services from terrestrial, aquatic and marine ecosystems.

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