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# Economic incentive-based instruments for the adoption of management options for water quality improvement in heterogeneous sugarcane farming communities

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## Abstract

There is growing recognition that coastal water quality is interdependent with agricultural management in coastal catchments. Economic incentive-based instruments can be used to internalize the negative externalities from coastal water pollution. In this paper we assess a performance-based instrument for promoting the adoption of management practices for water quality improvement in heterogeneous sugarcane farming communities in the Great Barrier Reef (GBR) region, with emphasis on regional income and dissolved inorganic nitrogen (DIN) delivery impacts. We combine financial and environmental analyses of farming systems at the paddock scale with a mathematical modelling approach at the farm scale, differentiating for three farm typologies, aggregated to the catchment scale. Management practice adoption rates are assessed by exploring how different types of farmers are likely to respond to economic incentive-based instruments, using a nutrient accounting system to institute both levies and bonuses that, respectively, penalise pollution and provide incentives for reducing DIN export.

## Keywords

Adoption; land use; land management; water quality improvement; heterogeneity; farming community; natural resource policy; Great Barrier Reef

## 1 INTRODUCTION

Coastal and marine ecosystems around the world are threatened by disturbances (e.g. climate change and water pollution) caused by human activity (Brodie et al., 2012; Burke et al., 2011). Estuarine and coastal water quality is adversely impacted by extensive eutrophication caused by the agricultural sector (Canfield et al., 2010; Smith and Schindler, 2009). For example, (nonpoint source) pollution from agricultural activity is linked to the degradation of coastal ecosystems in the Great Barrier Reef (GBR), Australia (Kroon 2011; Kroon et al., 2011). Population growth, climate change and the intensification of industrial and agricultural activity are likely to increase eutrophication of estuarine and coastal waters (Rabalais et al., 2009). To address this issue, improved management of resources in coastal catchments is needed (Doney, 2010; Smith and Schindler, 2009).

In this study we explore the implications of landholder heterogeneity based on a specified landholder classification, i.e. farm enterprise typology, by accounting for differences in property size, labour availability, learning costs and transition costs, to explore the potential consequences of economic incentive-based instruments for water quality improvement. We model how different types of farmers respond to an economic incentives-based approach where pollution beyond a specified level is taxed, whereas improvement beyond this level is subsidised. This conceptual approach provides information regarding the cost-effectiveness of the instrument, but also on likely socio-economic indicators, such as farm enterprise typology specific adoption rates.

The remainder of the paper is structured as follows; in the next section we provide background information for the research presented in this paper. In the following section we describe the methods used in this research followed by a section where we describe the modelling framework used to investigate the problem. We then present the results in a final section, followed by a discussion and conclusion.

## 2 BACKGROUND

The World Heritage listed Great barrier Reef (GBR), adjacent to the Queensland coast in Australia, is the largest reef system in the world with over 3,000 reefs covering an area of approximately 350,000 square kilometres, (Haynes and Michalek-Wagner, 2000). Degradation of GBR ecosystems has been linked with increases in land-based pollutant runoff since European settlement (Kroon et al. 2011). Pollutant sources have been identified and include suspended sediment from erosion in cattle grazing areas; nitrate from fertiliser application on crop lands; and herbicides from various land uses (Brodie et al. 2012). Sugarcane dominates agricultural production in the high risk GBR catchment of the Tully-Murray (Armour et al. 2009; Kroon 2009).

### 2.1 Nitrogen losses from sugarcane cultivation

The majority of sugarcane grown in GBR catchments is located on floodplains, close to the end of catchments. This proximity to the end of catchments means water draining from sugarcane farms can reach the GBR lagoon quickly, leaving little opportunity for in-river processes to remove pollutants from the flow (Furnas and Mitchell, 2001). N losses in water from sugarcane production occur through two pathways, leaching via deep drainage below the root zone, or in surface runoff. Webster et al. (2011) reported N losses to both surface water and via deep drainage are reduced when lower nitrogen application rates are applied. They propose that nitrogen rate is the most important determinant of N losses, being more important than other management practices such as surface versus sub-surface fertiliser application.

For the load estimations of N at the end of catchments (Kroon et al. 2011) to be achieved, Webster et al. (2011) hypothesis that greater than 60% of the N lost through deep drainage is reaching surface water via lateral flow, supporting the work of Rasiyah et al. (2005) that N losses via deep drainage are the most important to manage to reduce anthropogenic N contributions to the Great Barrier Reef.

### 2.2 Government intervention

In 2003, the Queensland state and the Australian Governments jointly launched a voluntary policy instrument, a 10-year commitment to address diffuse source pollution from agriculture to *halt and reverse the decline in water quality entering the GBR*, named the Reef Water Quality Protection Plan (Reef Plan; RWQPP 2003). In 2008, the Reef Plan was reviewed, and updated in 2009 (Reef Water Quality Protection Plan Secretariat, 2009; RWQPP 2009). In addition, in 2008, the Federal Government announced its Reef Rescue Program, including the Water Quality Grants Scheme (\$146 million over 5 years) that provides land managers with matching funding to implement land management activities that will improve water quality run-off from properties. Furthermore, on January 2010 the Queensland Government introduced the Great Barrier Reef Protection Amendment Act 2009 (GBRPAA 2009) to regulate a number of specified activities on cattle grazing and sugar cane properties in catchments in the Wet Tropics, Burdekin and Mackay–Whitsunday regions.

## 3 METHODS

In this paper we use a bio-economic approach that explores the cost-effectiveness of improving catchment water quality via the adoption of prioritized land management practice changes in a heterogeneous farming community. We model how different types of farmers respond to an economic incentives-based approach where pollution beyond a specified level is taxed, whereas improvement beyond this level is subsidised. Adoption rates are estimated by predicting how different farm types are likely to respond to different levels of the levy/bonus system. In addition, farm level profit and environmental consequences of implementing this system are modelled.

### 3.1 Farm enterprise typology

The research presented in this paper concentrates on the sugarcane growing sector in the Tully-Murray catchment. To develop a classification of sugarcane farmers in the Tully -Murray catchment, qualitative interviews with the widest possible range of sugarcane farmers and land managers were carried out during 2006. The resultant landholder profile comprised three types of sugarcane farming agents, broadly based on farm size (Bohnet, 2008).

In the Tully-Murray case study area, the landholder profile is matched with geographical information, through intersection of farm property information from the Digital Cadastral Data Base (DCDB) of Queensland (2006), land use from Queensland Land Use Mapping Program (QLUMP 2004) and soil type data layers (from Roebeling et al. 2009), using the geographical information system software ArcGIS by ESRI. This allows for the identification and characterisation of agents according to their specific objectives, their agricultural production system and socio-economic features and their spatially explicit agro-ecological conditions (e.g. soil typology).

### 3.2 Management practices for water quality improvement

A range of agricultural management practices have been developed to address water pollutant exports from sugarcane farms while maintaining production (Roebeling et al. 2009; Schroeder et al. 2009; Thorburn et al. 2010). The management practices we use in this research have been adopted from the 'ABCD' framework of farming system classification used by natural resource management (NRM) regions for Reef Rescue (Higham et al. 2008). The 'ABCD' framework describes management practices that range from *degrading* (D), *common* (C), and *best* or industry recommended (B), through to *aspirational*, cutting edge (A) farming systems that would provide the greatest water quality improvement.

### 3.3 Transition costs

Information on required capital investments and changes in farm gross margins has been adopted from financial economic research in various GBR catchments by Van Grieken et al. (2010). To account for variation in farm sizes while faced with investments, the investment quantities provided by Van Grieken et al. (2010) are adjusted. This analysis uses a 6 year investment horizon, representing the full crop cycle of the sugarcane planting in the Wet Tropics. Hence the future revenues are discounted at a 7% real rate to represent these cash flows in present values (Zerbe and Dively 1994).

Each farm type has a specific per hectare requirement for labour. In this analysis we assume economies of scale for labour requirements. Furthermore, management practices for water quality improvement tend to require less operational hours. Counterbalancing the labour savings are the transition costs (e.g. time spent on learning about a new practice).

Expert consultation suggests that farmers face once-off as well as re-occurring time investments when faced with changing land management practices. Examples given for once-off time investments are the time spent purchasing new equipment, the time learning to operate new equipment and the time learning about new management practices. Examples for re-occurring time investments are the time spent on record keeping. These transition costs are used to estimate changes in labour requirements when changes in land management take place. In line with Pannell and Wilkinson (2009) we found that small and medium sugarcane farmers experience higher transition costs than the large sugarcane farmers.

### 3.4 Production system simulation

Sugarcane input-output data for different management practices were generated using the APSIM (version 7.0) cropping systems model (Keating et al. 2003). The APSIM model was used because it is capable of modelling N cycling in sugarcane production systems (e.g. Thorburn et al. 2011), and has been used previously in bio-economic modelling in the Tully region (Roebeling et al. 2009; Van Grieken et al. 2011). APSIM was used to predict regional soil type specific productivity (sugarcane yield) and environmental indicators (available DIN; Van Grieken et al. 2011).

### 3.5 Paddock to end of river delivery of pollutants

The APSIM cropping system simulator provides plot scale DIN in runoff and DIN leached below the root zone for each scenario. In our framework we assume 100% of DIN in runoff reaches the GBR lagoon (Furnas and Mitchell 2001) and 60% of N in deep drainage reaches the GBR lagoon (Webster et al. 2011).

### 3.6 Nutrient accounting system

In this paper we assess the cost-effectiveness of an economic incentive-based policy instrument in promoting the adoption of best management practices to achieve DIN water quality improvement. When landholders pollute beyond a specified performance standard level of DIN exported from the farm (runoff and deep drainage leaching), a tax is charged for each corresponding kg of DIN. However if landholders adopt management that reduces pollution beyond this baseline level, a subsidy will be granted for each corresponding kg of DIN. This may also occur if landholders decide to take their land out of production.

This conceptual approach is based on the Mineral Accounting System (MINAS) introduced in 1998 by the Dutch Government, to reduce farm gate nutrient surpluses. MINAS is a nutrient bookkeeping system in which nitrogen and phosphate outputs are subtracted from the inputs. The resulting surpluses are taxed if they exceed a predetermined surplus standard (Ondersteijn et al. 2003). We extend on this approach by, in addition to taxing surpluses; exploring the provision of incentive subsidies for negative surpluses (i.e. outputs are lower than the predetermined standard).

## 4 FRAMEWORK

To estimate the level of adoption of farming systems by farmers in the Tully-Murray catchment under the levy-bonus system, we use a linear constrained optimisation model. It assesses how different types of sugarcane producers in the Tully-Murray catchment are likely to respond to changes in their decision environment. The

model uses production functions to explore the farmers' decision making process. The farm enterprise will try to maximize their (gross) income, which is defined as the gross value from sugarcane production and on- and off-farm employment, minus the costs related to the use of labour and agricultural inputs, and corrected for private costs and or benefits from policy interventions. The most important constraints faced by each producer or farm type are related to the use of production systems, land, labour and agricultural output. As we estimate short term responses to instruments (1 full crop cycle; 6 years), land use is constrained to the currently available agricultural area. Available farm household labour can be used for on- and off-farm employment, where each farm profile has a specified proportion of off-farm employment. Also, labour can be hired-in for on-farm agricultural production.

For the Tully-Murray case study, the model estimates production, income, resource use and employment at the farm and regional level for identified sugarcane farms in the study area. The mathematical optimisation model is solved using GAMS 22.7 (Brooke et al. 1998).

## **5 RESULTS**

In this section, the results are presented. After presenting the base scenario, against which all scenario results are compared, details will be provided with regards to the regional as well as farm type specific net abatement costs, the changes of area under land use and land management, and regional productivity.

### **5.1 Base scenario**

To determine the base scenario, an initial or pre-base model run was performed where all farms in the region start off operating under C Class management. After this initial run, accounting for farm type specific characteristics such as farm size, gross margins per hectare, investment costs and labour availability, the results determine the base distribution of management across the landscape. The base distribution of management Classes is presented in Table 1. These result have been validated with local experts to ensure a realistic distribution is presented.

### **5.2 Abatement costs**

Net (private costs/benefits net of public earnings/spendings) abatement costs are calculated for all farm types, and aggregated to the region. The abatement achieved is presented for a levy/bonus of up to \$40 per kg of DIN polluted/abated by farms. For large farm, at a levy/bonus level of \$40, the maximum abatement achieved is likely to be just under 15%. This would results to a net cost to the region of just over \$9M over the whole crop cycle. For the medium sized farms, the abatement at this levy/bonus level would be just over 19%. The net cost to the region equals just over \$10M. At the highest levy/bonus level the potential for abatement for small farms is just under 43%, with associated net costs of just over \$24M. For the whole region, this equates to a potential decrease in DIN exports of almost 77%, at a net cost to the region of just under \$44M over the whole crop cycle.

Cost-efficiency of the mineral accounting system for water quality improvement is presented in Table 1. For example, at a levy/bonus of \$8 per kg DIN polluted/abated, the total reduction in DIN delivery that can be achieved is 19% compared to the base scenario. The cost-efficiency at this level of levy/bonus is \$4.58. In other words, the net cost to the region of a levy/bonus of \$8/kg DIN polluted/abated is just under \$5 per kg reduction of DIN exported. At a levy/bonus of \$40 per kg DIN polluted/abated, the total reduction in DIN delivery that can be achieved is 77% compared to the base scenario. The cost-efficiency at this level of levy/bonus is \$19.82.

### **5.3 Land use and management distribution**

Table 1 furthermore shows the distribution of land use and management for increasing levy-bonus values from AU\$0 (base scenario) to AU\$40, in steps of AU\$8. In the base scenario, 44% of the land under sugarcane is cultivated using B class management. C Class management is represented by 42% of the sugarcane land, with sugarcane land cultivated using A Class management only at 14%. With increased levy/bonus levels, management practices shift from C and B Class dominated, to A Class dominated. At a levy/bonus of \$8/kg DIN polluted/abated beyond the standard, A Class management is now adopted on 41% of the sugarcane land; however the majority of sugarcane land is still cultivated using B- and C Class management (59%). At the highest levy/bonus level (\$40/kg DIN), almost all sugarcane land is cultivated using A Class management

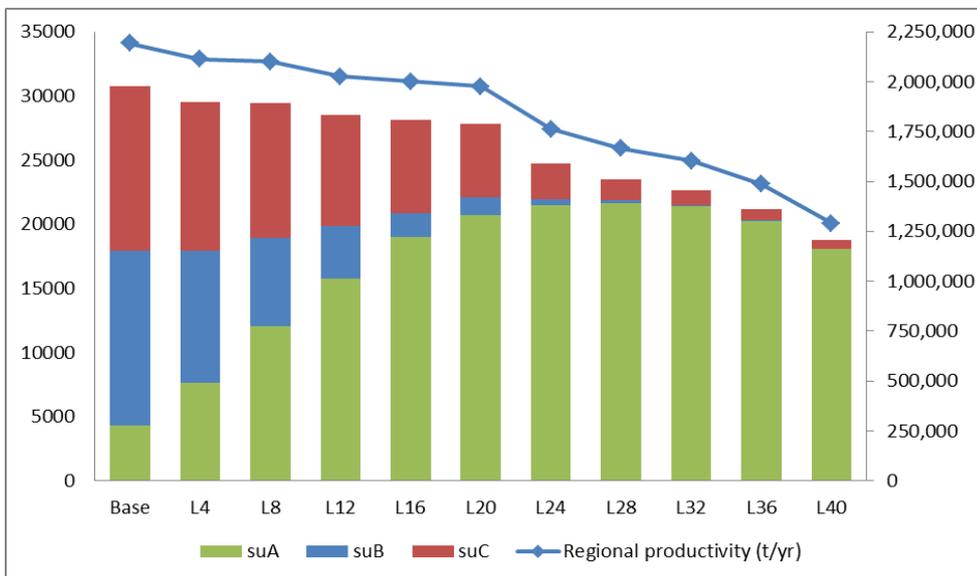
(97%), where only very little of the land is under C Class management (3%). This is made up by landholders with very small land, where initial investments to change to B- and A Class management is not offset by the increased per hectare gross margins.

Scenario	Cost-efficiency (\$/kg)	DIN delivery (% reduction)	Management Class A (%)	Management Class B (%)	Management Class C (%)
Base	-	-	14%	44%	42%
Levy \$8	\$4.58	19%	41%	23%	36%
Levy \$16	\$9.14	38%	67%	7%	26%
Levy \$24	\$13.57	57%	86%	3%	11%
Levy \$32	\$15.75	66%	94%	1%	5%
Levy \$40	\$19.82	77%	97%	0%	3%

**Table 1** Cost-efficiency of a mineral accounting system; Management class distribution as a percentage of total land under sugarcane cultivation

The area of land use and specific management for each farm type is calculated separately, as well as aggregated to the region (see Figure 1). With a levy/bonus of \$12 all the sugarcane land operated by large farms is operated using A Class management. At a levy/bonus level of \$4 the medium sized farms start adopting A Class management, and at a level of \$24 all the land is operated using A Class management. At a levy/bonus level of \$4, landholders owning small farms start adopting B Class management, and at the level of \$12, they commence the adoption of A Class management. At the highest level of levy/bonus (\$40) the majority of sugarcane land is managed using A Class practices. A few farms remain under C Class management, and many farms take land out of production.

Figure 1 shows how land use and management as well as sugarcane production changes in the catchment with increased levy/bonus levels. From the first levy/bonus level (\$4), limited sugarcane land is taken out of production (4%; Farm type 3). At the highest levy/bonus level, 39% of sugarcane land is taken out of production. With decreased land under cultivation, regional productivity drops in the region. At \$40/kg polluted/abated, regional productivity drops with more than 41%.



**Figure 1** Total regional area under cane production and management with increasing levy-bonus values (X-axis), including regional cane productivity. The left Y-axis represents area (ha) whereas the right Y-axis regional productivity (t/yr)

## **6 CONCLUSION AND DISCUSSION**

In this paper we presented a bio-economic approach that explores the cost-effectiveness of improving catchment water quality via the adoption of prioritized land management practice changes in a heterogeneous farming community. We modelled how different types of farmers respond to an economic incentives-based approach where pollution beyond a predetermined surplus standard is taxed, whereas improvement beyond this level is subsidised. Adoption rates were estimated by predicting how different farm types are likely to respond to different levels of the levy/bonus system. Furthermore, regional socio-economic and environmental consequences of implementing the policy were estimated, such as changes in local income, employment and nitrogen run-off.

Net abatement costs are calculated for all farm types, and aggregated to the region. In the base scenario, the large commercial farms (farm type 1), are already largely operating in management Class B and A. This means their margin for improvement (reducing DIN exports) by changing management is small (given current available technology) in comparison with farm type 2 and farm type 3. The small farms (farm type 3) on the contrary, are largely still operating under management C, leaving substantial margin for water quality improvement by changing management to Class A and B.

With regards to land use and management distribution, in the base scenario, C and B Class management dominate in the region, with some sugarcane land cultivated using A Class management. With increased levy/bonus levels, management practices shift from C and B Class dominated, to A Class dominated. At the highest levy/bonus level almost all sugarcane land is cultivated using A Class management. More specifically, large farms initially operate in a mix of B and A Class management and shift rapidly to A Class management. With a levy/bonus of \$12 all the sugarcane land operated by large farms is operated using A Class management. The medium sized farms operate in B Class management and slowly change towards A Class management. At a level of \$24 all the land is operated using A Class management. Small farms operate mainly in C Class management, shift to combined A and B Class management, before shifting to mainly A Class management. At a levy/bonus level of \$40 the majority of sugarcane land is managed using A Class practices. A few farms remain under C Class management, and many farms take land out of production.

At the highest levy/bonus level, 39% of sugarcane land is taken out of production. Intuitively, with decreased land under cultivation, sugarcane production drops in the region. At \$40/kg polluted/abated, regional productivity drops with more than 41%. This raises additional questions not addressed in this research, such as the viability of regional sugarcane mills (see for example Van Grieken et al. 2011).

A number of biophysical and cost related caveats of this study must be mentioned. First, industry water pollution abatement costs are based on the management practices assessed and, thus, do not include any alternative technologies, some of which are currently under development, that may prove cost effective in the future. Second, related to the previous point, industry water pollution abatement costs are based on current land-use patterns and, consequently, gains from land-use change between industries are not taken into account. Third, equivalent production functions are used for all farm types, but this could potentially differ and needs to be investigated further. Small farmers may not be as productive per hectare as their bigger colleagues or they may face differing cost functions or production constraints that we did not explore in this paper. Fourth, in this study it is assumed that labour is freely available for hire – which is not always the case in small towns or during peak labour periods. Fifth, instrument transaction costs are not included in the analyses which could have implications on cost-effectiveness, especially on the adoption and delivery process. Pannell and Wilkinson (2009) for example, found that transaction costs are likely to be higher for small scale (lifestyle) farmers than for larger scale (commercial) farmers. Sixth, it is important to note that a nutrient accounting system as explored in this study may prove difficult in practice as it relies on adequate and proven modelling. It is both difficult and costly to monitor nonpoint emissions with current technology because their diffuse nature. Furthermore, they are impacted by random events such as weather and depend on many site specific factors (Ribaudo 1999). Last, the approach used here is deterministic and is, as a result, does not account for uncertainty. Consequently and self-evidently, care should be taken when using the figures presented in this study for policy and planning purposes.

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