Assessing Policy Options in Response to Climate Change in the GBR Catchments

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EXTENDED ABSTRACT

Climatic parameters like rainfall or mean temperature define an important foundation for anthropogenic decisions regarding land use and land management. Changes in climatic parameters are likely to trigger land use change as conditions for current crops might deteriorate. Land managers and regional decision makers might adapt to such changes by changing crops, irrigation infrastructure or incentive schemes linked to the use of natural resources such as water. Adaptation dynamics of, for instance, agricultural sectors have the potential to increase pressure on important regional variables such as employment, water quality or biodiversity. Policy that attempts to define incentives in an adaptive way in order to avoid unnecessary losses in societal, economic or environmental values can be supported by effective decision support tools that integrate a range of relevant indicators such as sectoral production, employment, water quantity and water quality and ecological variables.

This paper develops a catchment scale approach for the Great Barrier Reef region using hybrid Computable General Equilibrium modelling. The Policy Impact Assessment model presented here explicitly links water quantity and water quality aspects to: (1) the economic production process and (2) ecological variables such as fish populations. Scenarios are examined in a two dimensional way by testing how a range of policy options, such as a cap and trade system for water or fertiliser, impact on sectoral production, price changes, employment, and environmental variables such as fish population sizes. Results show how environmental pressure shifts between catchments if policy instruments that respond to (expected) climate change are applied differently across the region.

1. INTRODUCTION

Impacts of climate change can be analysed from a bio-physical as well as from a socio-economic perspective. This paper aims for an integrated assessment that genuinely links key physical and economic variables. It is not aiming for developing a holistic assessment that considers the complexity of the real world, which would include various ecological and social aspects of climate change impacts. Instead, Computable General Equilibrium (CGE) modelling is trialled for incorporating physically realistic dynamics of water quality and quantity.

This methodological choice results from the important role CGE models play in helping climate change related decision making. Economists have often analysed climate policy by developing CGE models that quantify the costs of mitigation strategies (Bernstein et al., 1999; Hillebrand et al. 2003; McKibbin and Wilcoxen, 2002). The dominate method for this kind of analysis is CGE modelling, because it allows the cross sectoral implications of price changes for commodities or production factors to be captured (Dixon and Parmenter, 1996; Ginsburgh and Keyser, 1997).

As discussed by Bergman (2005), the vast majority of these climate change related CGE models do not include environmental dynamics and even less include environmental feedbacks on the market driven processes. It seems obvious that such modelling capacity would be beneficial and defines a deficit in the capacity of researchers to advise macro political decision makers.

Even the few existing CGE models that are focused on water quantity (Briand, 2004; Decaluwé et al., 1997; Goldin and Roland-Holst, 1995; Horridge et al., 1993; Seung et al., 2000) or water quality (Cassells and Meister, 2001; van der Mensbrugghe et al., 1998; Xie and Saltzman, 2000) exclude mostly ecological variables that are of potential use in an integrated assessment. The only examples for environmental feedback links in CGE models exist for the assessment of mitigation strategies for greenhouse gas emissions (Harrison et al., 1989; Vennemo, 1995).

Additionally, the majority of climate change policy assessment models are focused on mitigation while a significant part of the political discussion (particularly in Australia) is focused on adaptation. Arguably, the most relevant environmental variable for adaptation dynamics is water and its relevance for food production. Existing agricultural practices in most regions around the world generate pressure on the environmental needs for water, which provides ecosystem services that are fundamental for a multitude of market-based and non market values.

This paper aims for developing a CGE model that allows simulating the impact of changes in rainfall patterns in the Great Barrier Reef (GBR) region on the regional economies including feedback effects from environmental processes. The physical dimensions of a water cycle is incorporated that provides water as a production factor for economic production processes. Additionally, the Policy Impact Assessment (PIA) model accounts for environmental needs for water. This opens the option of quantifying ecological indicators and values such as fish population.

The context of this model development is declining water quality in the catchments adjacent to the Great Barrier Reef (GBR) and projections of changing rainfall patterns that are dominated by longer dry periods. Section 2 provides background for the model's development. Section 3 provides the model design, scenario definition and model results. Section 4 reflects critically on the integrated CGE model and discusses the process of model development in the context of integrated climate change driven policy assessments.

2. THE ENVIRONMENTAL CONTEXT OF THE GREAT BARRIER REEF

The GBR marine ecosystem has a complex interdependent relationship with the adjacent river systems. Some 30 major rivers and hundreds of small streams drain into the GBR lagoon. Declining water quality, principally from agricultural land use, threatens the viability of downstream marine based activities in the GBR. This complex and interconnected ecosystem is managed through an equally complex array of legislation and policy spanning both State and Commonwealth jurisdictions. The GBR is also identified as a World Heritage Area with international obligations for management.

Regional Natural Resource Management Bodies form an important tier of governance. The Great Barrier Reef region is divided into six areas, each governed by such a NRM agency. These regional bodies are crucial for the implementation of the Reef Water Quality Protection Plan as their mandate includes the change of incentive schemes for resource users. Resource users represent another crucial decision-making level as their adaptations to changes in incentive schemes determine triple-bottom-line outcomes.

Policy makers identified market-based incentives as the most relevant tool for policy scenarios, especially the implementation of markets for tradable rights for water and fertiliser. Policy makers discussed instruments like water markets, not in isolation but in the context of climate change and international markets. Section 3 models a scenario based on a combination of a water market, fertiliser restrictions and climate change driven rainfall reductions.

3. MODEL STRUCTURE AND RESULTS

3.1. Design

The aforementioned regional context reflects a situation in which system processes will be increasingly driven by market-based price signals, while other dynamics are determined and constrained by bio-physical processes.

Stakeholders were involved at an early stage of model design. They were asked to list indicators they perceived as relevant for evaluating outcomes of their decision making. Among the most relevant ones were water quality indicators, unemployment, abundance of various species (mainly fish species), sectoral production and regional gross domestic product. An important debate in the GBR region is focused on the potential trade-off between the tourism sector and agricultural activities, which are linked by ecological and geo-hydrological processes. Thus, model development linked the impact of market based instruments on economic, ecological and social indicators. These include:

- Economic processes – demand and supply of goods are driven by price, including the capacity for policy to alter incentives via markets for tradable quotas for water and fertilizer.

- Biophysical processes that are often represented poorly in economic models, including ecological population dynamics and water quantity and water quality aspects.

- Regional structure (i.e. five regions mentioned below).

Smajgl (2006) explains the general approach and results of a static version of the model. This paper is based on a full-dynamic version of the PIA model and focuses on the implementation of dynamic ecological and hydrological system components. In order to capture cross-sectoral

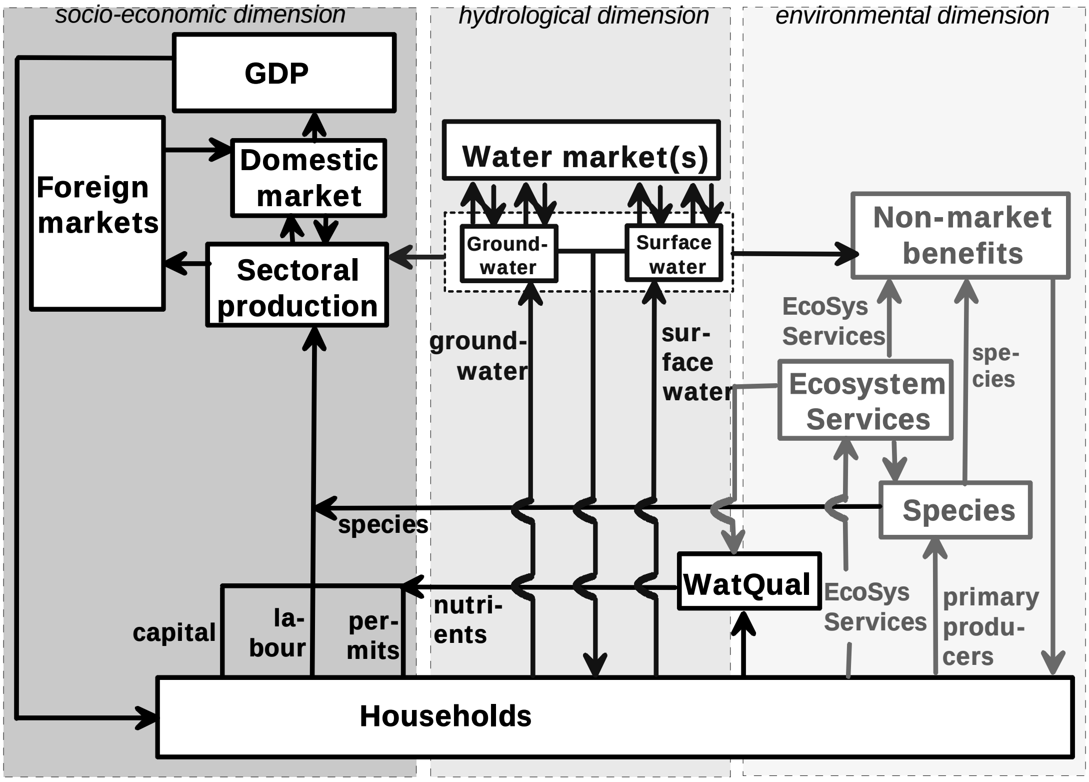

Figure 1. Flow diagram for the PIA model specification.

effects and trade-offs between market-based and non-market benefits, the PIA model links three main dimensions, the socio-economic, the hydrological, and the ecological dimension. Figure 1 shows a conceptual diagram of the PIA model and how variables from the socio-economic, the hydrological, and the environmental dimensions are linked. The left part of the flow diagram contains the socio-economic component with the sectoral production as the central element. The box labelled “sectoral production” represents 34 sectors. The PIA model quantifies trade-offs between these economic sectors in order to allow stakeholders to quantify sectoral trade-offs associated with adjustments to changing market incentives (Smajgl, 2006). Like traditional CGE models, economic activities from different sectors are linked through intermediate uses of production, trade flows and price effects (for water, land, etc.) from one sector to others. On the top of this dimension are the indicators of market based benefits which determine Gross Regional Product (GRP).

As mentioned above the focus of the PIA model is the assessment of policy instruments in the context of water quantity and water quality. PIA is aggregated to a catchment scale and divides the GBR region according to the Natural Resource Management agencies into five catchments. This model inter-regional characteristic allows quantifying trade-offs between regions along the GBR. Restrictions in one area can lead to increasing production in other areas. While the model reports on chosen indicators for all five catchments, this paper is focused on the Wet Tropics and the Burdekin catchments.

Trade-offs based on changes in the quantity or quality of economic water use can be quantified as non-market benefits of water are incorporated. In order to incorporate non-market benefits a Multi-Criteria Analysis (MCA) was conducted (Hajkowicz, 2006; Smajgl and Hajkowicz, 2005). Non-market attributes were defined and ranked for water use benefits in the GBR region. The MCA revealed that after indicators reflecting the quality of drinking water, biodiversity indicators (especially in regard to fish species) are the most relevant to the 1,000 people that took part in the MCA. Policy changes impact these non-market benefits.

In this approach, the ecological components of the model are calibrated by the mass–balance model Ecopath with Ecosim software, which is described in Gehrke (2007) and Smajgl and Gehrke (2007). This delivers a benchmark situation and constraints for response functions of these ecological variables. The links between economic production functions and ecological variables were drawn from expert knowledge elicited in workshop situations. This includes impacts from economic activities on ecological indicators (like irrigation and fertiliser application in agriculture) and *vice versa*, impacts of ecological changes on economic activities (like tourism). The linking domain between economic and environmental variables is defined by hydrological functions, which are modelled as a water cycle on a catchment scale.

In summary, two aspects are critical for the environmental module of the CGE model for capturing the questions that are of interest for the policy and management domain: the incorporation of relevant ecological variables; and a water cycle that represents catchment hydrology. Details regarding these two components are further discussed below.

3.2. Ecological Variables

The MCA identified fish populations as the most relevant environmental variables. Smajgl and Gehrke (2007) explain in detail how EcoPath modelling was used for developing and calibrating a catchment-scale foodweb model that allowed adequate representation of fish populations. The incorporation of Ecopath results into the PIA model is based on CES (Constant Elasticity of Substitution) functions. The total biomass (and their responses to changes in nutrient loading) estimated by Gehrke (2007) for each discussed species is taken into account as the output side of the ecological production function. This approach makes a Leontief assumption with an elasticity of nil. For the population of detritivores (in terms of biomass) the foodweb approach leads to the following ecological production function:

$$PopulationDetritivores_r = \begin{pmatrix} BenthicInvertebrates_r^{\rho_{Leontief}} \\ + MacroAlgae_r^{\rho_{Leontief}} \\ + MicroPhytoBenthos_r^{\rho_{Leontief}} \\ + Detritus_r^{\rho_{Leontief}} \end{pmatrix}^{1/\rho_{Leontief}} \quad (1)$$

PIA implements 12 ecological production functions that define food-webs for each catchment. Primary producers are modelled as outputs of a generic environmental service. Lowering water quality decreases the potential of the environment to provide these primary producers, which affects the whole food-web. An important mechanism for closing the link to the economic component is to incorporate, where necessary, environmental variables as inputs for economic production functions. For instance, the tourism sector is modelled with the following production function:

$$py_{TOU,r} = \begin{pmatrix} \left(pk_{TOU,r}^{\rho_{KL}} + pl_{TOU,r}^{\rho_{KL}} \right)^{\rho_Y / \rho_{KL}} \\ + pa_{ss,r}^{\rho_Y} + fspe_r^{\rho_Y} \end{pmatrix}^{1/\rho_Y} \quad (2)$$

The production level (output *py*) is a function of capital (*pk*), labour (*pl*), intermediates (*pa*), and species (*fspe*) as natural assets. The rationale is that tourists visit GBR catchments in order to experience a certain environment, which includes biodiversity values. A reduction in such natural assets is likely to impact tourist numbers and therefore the production level of the tourism industry. As environmental variables depend on, for instance, levels of pollution, water quality issues have to form a link between the economic and the environmental domains. Fertiliser use is part of the agricultural production function. The model defines a consumptive behaviour of nutrients as well as a productive impact.

3.3. Water cycle

Water needs for economic production purposes, such as irrigated agriculture, respond to price changes that are often triggered by changing demands. Such market dynamics can lead to increasing pressure on water resources available in a catchment, which is regularly observed in Australia. These increasing use levels restrict the environmental need for water, reduce the ecosystem services that require water and, as shown above, feed back into the economic system in the form of iconic species for tourism activities and fish for fishing.

Integrating water in a CGE model and linking it into the economic as well as into the environmental production functions is critical. In the PIA model two Leontief production functions approximate catchment hydrology. Surface water is based on rainfall, which is modelled as an input factor. The output of this ‘hydrological production function’ is the recharge of the groundwater aquifer and the amount of water that can be either used for irrigation purposes or left for environmental needs. Water that runs off satisfies such environmental needs but can be pumped out of the stream, which creates a second input next to rainfall.

Groundwater is modelled such that last period aquifer plus recharge from rainfall and from additional irrigation (based on pumped stream water or pumped groundwater) ‘produces’ the next periods groundwater table. This can be used for irrigation which reduces next period’s aquifer by the amount pumped minus recharge.

3.4. Scenario results

As described above, the stakeholders identified policy changes in the context of climate change and international markets. This paper shows model results based upon a policy scenario where water restrictions are imposed in response to reductions in rainfall and additional fertiliser restrictions are imposed in order to improve water quality. The following table is based on multi-faceted scenario assumptions. It is assumed that rainfall decreases by 5% as an annual average for all years between 2007 and 2013 compared with the average for 2001–2005. Further it is assumed that just one catchment imposes policy instruments. In this case it is assumed that for the Burdekin catchment surface water use is put under licences and restricted by 10% in order to protect environmental flows. Additionally, it is assumed that the use of fertilisers in agricultural sectors is restricted by 10%. While the model calculates results for all five catchments, we restrict our comparison to the Wet Tropics and the Burdekin catchment. The Wet Tropics experiences just drought driven restrictions, not policy based constraints.

The results show the strength of a CGE approach. While just one sector applies policy instruments the distortions lead, together with the drought, to cross-sectoral impacts across catchments. Sectoral adaptation processes due to production adjustments impact other sectors as they compete for labour and capital. Together with price changes, these effects lead to an increase in GDP of 6% in the Burdekin and a GDP reduction of 5% in the Wet Tropics. A strong assumption behind the model results is mobility of labour. The sectoral examples in Table 1 show how diverse adaptations are. The examples of responses of different species demonstrate that impacts can be seen across trophic levels.

Table 1. Scenario results for the Wet tropics and the Burdekin catchment.

Years	Regional GDP (%)	Sum of fish populations (%)	Dugong population (%)	Beef production (%)	Dairy production (%)	Horticulture (%)	Sugarcane (%)
Wet Tropics							
2007	95	95	95	94	94	91	92
2008	95	95	95	94	94	91	92
2009	95	95	95	94	94	91	92
2010	95	95	95	94	94	91	92
2011	95	95	95	94	94	91	92
2012	95	95	95	94	94	91	92
2013	95	95	95	94	94	91	92
Burdekin							
2007	106	105	102	94	108	103	104
2008	106	105	102	94	111	106	106
2009	106	105	102	94	113	108	107
2010	106	105	102	94	114	109	108
2011	106	105	102	94	115	109	109
2012	106	105	102	94	114	110	109
2013	106	105	102	94	116	110	109

4. CRITICAL MODEL DISCUSSION

What is important from a modelling perspective is the limitations of such aggregated simulation results. The PIA model does not allow the analysis of policy options in a disaggregated manner or to simulate the spatial distribution of effects at sub-catchment scales. While highly aggregated approaches such as CGE modelling allow a better understanding of cross-sectoral and cross-regional consequences, real world complexities at sub-catchment scales are profoundly reduced. In particular, spatially relevant dynamics within catchments cannot be captured, such as the direction of water flow with its consequences for available water quantity and water quality.

An additional modelling limitation is that human decisions cannot be captured adequately. While in traditional CGE models highly aggregated decision makers face just price signals, such an integrated CGE model adds non-market variables. These non-market variables are perceived by households but the demand side continues to respond solely to price signals. This shows that if the strengths of CGE models are relevant for any given context and non-market variables have to be integrated, the theoretical underpinnings have to be improved to better capture the manner in which non-market values influence human decision-making. In other words, more research effort has to be invested in integrating environmental variables and their feedback links in CGE modelling frameworks.

An alternative strategy to improving integration is the parallel development of an additional model that operates at a lower scale and that improves the modelling capacity of spatial dynamics and human decisions. Such a multi-scale approach is realised for the GBR context. Parallel to the development of the PIA model, an agent-based model was developed (Smajgl et al., 2007), which covers the farm scale as the second important level of decision making. Both the catchment and farm level decisions determine sustainability. Such a multi-scale approach improves the capacity for analysing triple bottom line outcomes of policy responses to climate change.

However, improved CGE methodology for integrating environmental variables with feedback links would significantly benefit catchment management. Critical for assessing policy options in a climate change context is the integration of economic, environmental and hydrological variables. The PIA model is an example for how to respond to this modelling challenge in the applied policy context.

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