MODELLING THE ECONOMIC, SOCIAL AND ECOLOGICAL LINKS IN THE MURRAY-DARLING BASIN: A CONCEPTUAL FRAMEWORK

Maheshwar Rao
Research Fellow, Institute of Governance and Policy Analysis (IGPA), University of Canberra, Bruce, ACT, 2601, Australia.
Email: mraofiji@hotmail.com

Robert Tanton
Professor, Institute of Governance and Policy Analysis (IGPA), University of Canberra, Bruce, ACT, 2601, Australia.

Yogi Vidyattama
Senior Research Fellow, Institute of Governance and Policy Analysis (IGPA), University of Canberra, Bruce, ACT, 2601, Australia.

ABSTRACT: The water policy reform in the Murray-Darling Basin (MDB) will have a range of implications on the social-ecological system (SES) of the Basin. We propose an analytical framework that may be useful in analysing how policy changes or external shocks, which originate in one part of a SES can be traced transparently throughout the SES by sequentially linking a series of models, where each model has demonstrated strength in explaining a part of the whole system. This framework is suitable to analyse the national, regional and spatial socio-economic and distributional effects of regional-specific policy reforms or external shocks.

KEY WORDS: Systems approach, water policy reform, computable general equilibrium, microsimulation, distributional analysis.

1. INTRODUCTION: WATER POLICY REFORM UNDER THE MURRAY DARLING BASIN PLAN

The Murray-Darling Basin (MDB) is an important regional economy for Australia in terms of its economic, social and environmental significance. It can be treated as a social-ecological system (SES) encompassing the ecology, the economy and the community or the social system, all of which are intricately interdependent, thus capturing the interactions of humans with their physical and ecological environment (Chapin *et al*., 2009). The Basin's ecological system, including its irrigated agricultural economy and its abundant wildlife and natural environment, is largely dependent on water from the Basin's river network. The community, in turn is significantly dependent on the agricultural economy and the natural environment in the Basin.

At least in the last two decades, the sustainability of the Basin's ecosystem (due to combined impacts of severe and prolonged drought and past water management decisions such as water over-allocation to irrigation (MDBA, 2010)) have brought to the forefront, the public policy debate on the competing demands for water for the environment/ecology and the economy. These competing demands are largely the requirement for environmental flows for the long-term health of the river system in the MDB on the one hand and the sustainability of irrigated agricultural production in the Basin on the other. For example, as early as mid-1992, the then Murray-Darling Basin Ministerial Council initiated the development of an irrigation management strategy with the aim "to achieve an ecologically and environmentally sustainable and self-sufficient irrigation system in the SMDB by 2010" (Hall, *et al*., 1994, p. iv; SMDB is the Southern Murray-Darling Basin). This water management strategy, articulated two decades ago, remains the overall aim of the Basin Plan (discussed below), which is now under the responsibility of the Murray-Darling Basin Authority (MDBA).

The water policy reform under the MDB Plan aims to achieve two broad objectives: first, to improve and restore the health of the river system in the Basin and second, to encourage farmers to adapt to reduced inputs of water for farming activities. The implementation of the MDB Plan falls under the responsibility of the MDBA specifically created under the Australian Water Act 2007 (Commonwealth of Australia, 2014a) to manage the water resources in the Basin. In fact, in 2004, the Commonwealth had secured an agreement with the states for a national framework for water reform that paved the way for the enactment of the

Water Act 2007 (Commonwealth of Australia, 2014b). The Basin Plan thus is a legislative requirement under the Water Act 2007. The core of the Basin Plan is the attainment of Sustainable Diversion Limits (SDLs), that is, limiting the amount of water that can be diverted to consumptive use (MDBA, 2010). SDLs are upper limits on the volume of water that can be taken on a sustainable basis from the Basin's river system. Under the Basin Plan, the SDLs can be achieved in two ways. First, through the Commonwealth buying back permanent water rights from farmers under the water buyback scheme and second, through water-saving infrastructural investment under the infrastructure investment scheme. Under the water buyback scheme, the Commonwealth buys back water entitlements (permanent water rights) from farmers who are willing to sell them on a voluntary basis. This reduces water available for consumptive use (including irrigation), thus contributing to an overall SDL target.

The Basin Plan has evolved since first formulated in terms of the SDL target and the ways in which this target could be achieved. The latest version of the Basin Plan incorporating the current Commonwealth government's policy on water reform is given in Commonwealth of Australia (2014b). However, the overall aim of the Basin Plan remains the same, which is limiting the amount water diverted to consumptive use.

Farms are commercial enterprises, and are likely to respond to the reduced inputs of water (and the consequent increase in its price) by, for instance, switching some irrigation activities to dry-land activities, substituting between factors of production, investing in water-saving infrastructure and technology, and so forth (Dixon *et al*., 2012a). To assist the farmers to adapt to the new economic conditions, the second component of the Basin Plan involves the Commonwealth and States investing in water-saving infrastructure aimed at increasing the efficiency in water use and technological improvements in farming activities, that is, adopting technologies (input-mix) that minimise water usage per unit of output. One of the important developments initiated in the mid-90s, which may assist farmers in the Basin to adapt more quickly to reduced water availability, is the disentangling of water rights from land rights. Assigning and legally recognising property rights to water facilitated the creation of water markets, thus giving farmers the possibility of trading water intra- and inter-regionally. Since 1998 water trading has been possible between States as well. Assigning property rights to water also made it possible to permanently buy or sell water entitlements/rights. Australian evidence shows that water markets help reallocate water to more productive uses (Turral *et al*., 2005). In addition, the possibility of trading water provides farmers an additional option when determining the optimal allocation of resources in adapting to reduced inputs of water (Dixon *et al*, 2012a). For more details of the role and development of water markets in the MDB see Crase *et al*. (2004) and Qureshi *et al*. (2009).

In addition, the Basin Plan has further implications. Underlying the health of the MDB river system is the sustainability of the Basin's ecosystem, and thus, the current and future supply of ecosystem services, including the future flow of water for irrigation and other consumptive uses. Similarly, underlying the sustainability of agricultural production in the MDB is the livelihood and well-being of the Basin communities. In this regard, for analytical purposes, the MDB region can be conceptualised as comprising of three broad systems: the economic, the ecological and the social systems. These systems are evidently interdependent and linked in complex ways. In other words, for analytical purposes, the MDB can be treated as a SES. A perturbation in one system, say caused via an external shock or a policy change, can directly and/or indirectly affect the other two systems. These effects can be transmitted throughout the SES through various channels and in complex ways. In this regard, given the interdependent and interconnectedness of a SES, it can be difficult for any single model to adequately capture the complexity of integrated systems such as a SES. In this paper, we propose a conceptual and analytical framework, which may be useful in analysing how policy changes and external shocks (such as climatic events) that originate in one part of a SES can be transparently traced throughout the SES. This can be achieved by linking a series of models, each model informing other models, thus drawing on the strengths of each model designed to explain a part of the whole system.

The main aims of the paper are twofold: first, to frame the water policy in the context of the three interdependent and interconnected systems and, second, to propose an integrative modelling and analytical framework to analyse the socio-economic and distributional analyses of policy reforms and external shocks. Note the rationale for a systems and integrated approach to model the ecological, economic and social interactions is well established in sustainable development literature (see for instance: Barbier, 1987; Barbier and Markandya, 2013; Buchholz, 2007; Fiksel, 2003; 2006 and Chapin *et al*., 2009), and therefore will not be reviewed in this paper. The rest of the paper is organised as follows. The next section describes the MDB as a SES and how a series of models can be linked to explain the interdependences within a SES. This is followed by a section on literature review of the Computable General Equilibrium (CGE)-Microsimulation linkages to provide a background on how these models can be linked in the context of the water policy reform in the MDB. The penultimate section discusses in detail how CGE and Microsimulation models are linked in a top-down manner. This section also includes how the output of CGE-Microsimulation linkages could inform additional models to further enrich the analyses of the water policy reform in the MDB. The final section concludes the paper.

2. A CONCEPTUAL AND ANALYTICAL MODEL OF THE MDB AS A SOCIO ECOLOGICAL SYSTEM (SES)

Ecosystems are increasingly being recognised and treated as an environmental or natural asset or capital, which perform vital environmental functions (de Groot, 1992) for the welfare of the human society (Chiesura and de Groot, 2003). In the literature, these environmental functions are often defined as the provision of ecosystem goods and services important to human wellbeing (Ehrlich and Mooney, 1983; Daily, 1997). Like physical capital, ecosystems deplete with use. However, unlike physical capital, ecosystems are harder to replace (and in some cases impossible to replace once depleted) and maintain. It is therefore imperative that, for the ecosystems to perform their environmental functions in a sustainable manner, this critical natural capital asset be well maintained (Ekins, *et al*., 2003). The public goods nature of ecosystems and the associated market failures in the provision of ecosystem services (Turner and Daily, 2008; Ostrom, *et al*., 1999) offers additional challenges for achieving optimal balance among the three main systems: the ecological, the economic and the social. Conceptually, the optimal balance in terms of sustainable development is attainable where the goals of the three systems intersect (Barbier, 1987; Barbier and Markandya, 2013). Each of the systems has the desired or 'human ascribed' goals (Barbier, 1987). The main goals of the economic system are economic growth and efficiency, equity and reduced poverty. The key goals of the social system are social justice, good governance and social stability. The key goals of the ecological system are biological productivity, resilience and bio-diversity. Barbier (1987) points out that maximising all the goals may not be possible all the time. For example, increasing economic productivity achievable in an efficient and equitable way may still impose some costs on the environment in terms of resource depletion and environmental degradation (thereby adversely affecting bio-diversity and resilience of the ecological system). On the other hand, maximising the goals of biological productivity and diversity has the potential to impose costs on the economic and social systems in terms of reduced economic growth and increase in unemployment and associated social problems.

It is difficult to envisage economic growth without imposing any costs to the ecosystem. In this situation, sustainable economic and ecological systems would imply an ecological-economic trade off. However, maximising the goals of one system without accounting for costs it may impose on other systems will produce less than socially optimal outcomes. Thus, in recognising the interdependence of all the three systems, sustainable development would involve maximising the "goals across all these three systems through an adaptive process of trade-offs...." (Barbier, 1987, p. 104). The process of adaptive trade-offs implies that for the systems to exist and thrive in a changing environment, they must have the capacity and capabilities to adapt and evolve. In other words, "agents within adaptive systems interact, react, learn, and co-evolve with their environment" (Buchholz *et al*., 2007, p. 6088). This is closely related to the *resilience-based ecosystem stewardship* approach, which emphasises the importance of the "functional properties of systems that are important to society under conditions where the system itself is changing" (Chapin *et al*., p5, 2009). Underlying this approach is the management of resources that "responds to and shape change in ways that benefit society (Chapin *et al*., p5, 2009). This integrative and adaptive approach is explicitly recognized in the Basin Plan.

> "*The Basin Plan provides a platform for an integrated and adaptive approach to water management that balances social, economic and environmental needs in the Basin*" (MDBA, 2012a).

Thus, this interdependence of and the need to maximise goals across the three systems has influenced the approach outlined in this paper to modelling the MDB as a complete system, bringing together a number of models to analyse the policy reforms and external shocks. Recognising these interdependencies in the MDB, it is worth noting that the MDBA has invested a considerable amount of time analysing the potential ecological and socio-economic impacts of water policy reform under a number of Basin Plan modelling scenarios. In coming up with various modelling scenarios, the MDBA has consulted widely with the stakeholders at the business and community levels, including various levels of government and the scientific community (see for instance MDBA, 2012a, 2012b and 2012c). The key purpose of this extensive consultation and modelling work is to get the ‘right amount’ of trade-off, which in the long run can restore the health of the river system and at the same time have minimal adverse socio-economic impacts.

For the economic analysis of the national and regional impacts of various SDL scenarios, the MDBA rightly relied largely on “bottom-up” regional CGE models, where each SDL scenario is modelled as an external shock (see for instance Wittwer, 2010 and 2011 and ABARES, 2011). For the social and community impacts of the water policy reform, a major qualitative study was undertaken by EBC, *et al*. (2011). Other social impact assessments include ABARES (2010, 2011). However, none of the studies use microsimulation models, which are standard models for distribution analyses at the national, regional, small area, community, household and individual levels. More importantly, none of the social and community impact studies systematically link the flow-on economic impact to the regions, small areas, community and household/individual levels. In this paper, we present a framework that traces the impact of the water policy reform from the economy to the community in regions and small areas to the ecology. The framework is described below.

The analytical framework (shown in Figure 1) would be useful in simulating a number of policy or external shock scenarios to inform best policy options. While the analytical framework has been developed in the context of the water policy reform (in the MDB), it can be equally used to analyse policy and external shocks that originate from and affect the ecological, economic and social systems. Using the example of the water policy reform in the MDB, the rest of this paper explains the workings of the analytical framework in Figure 1.

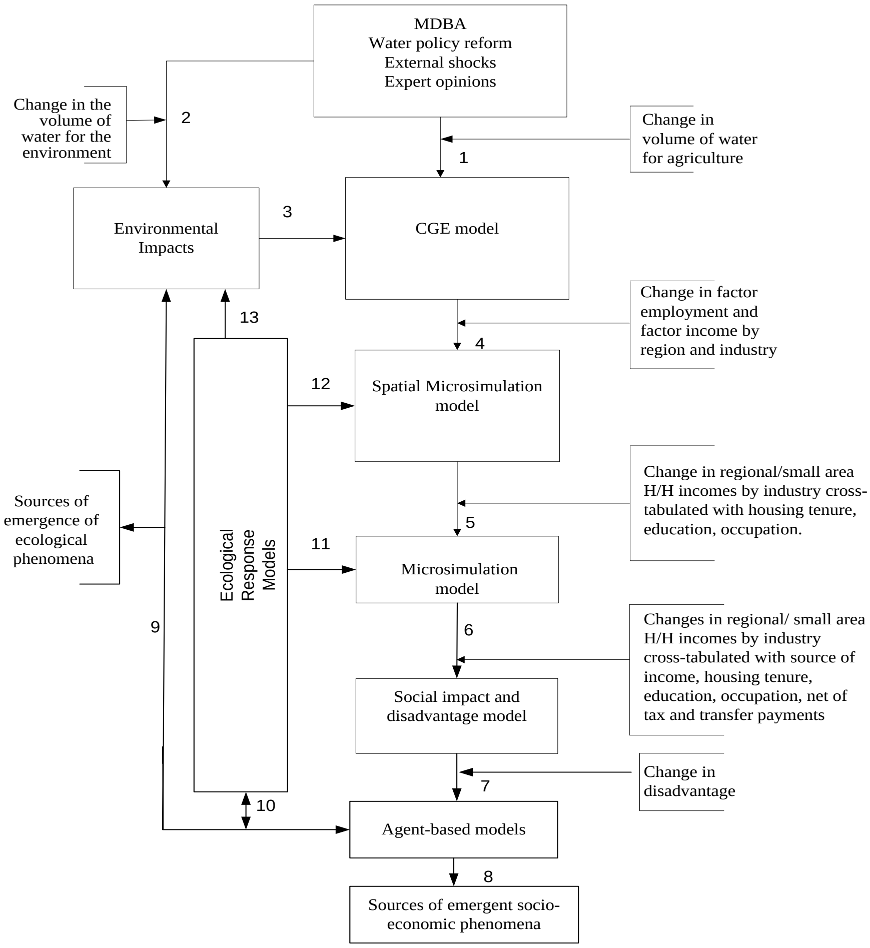

Figure 1. Details of the Interfaces between the Environment/Ecology and the Socio-economic Models. Source: the Authors.

The water policy reform enters the economy via link 1 in Figure 1. As mentioned in the Introduction, the water policy reform includes the water buyback scheme and water-saving infrastructure investments (targeting a SDL), both of which translate into reduced amounts of water available for irrigation (link 1) and increased water flows to the environment (link 2). Increased water flow to the environment may boost the supply of ecosystem system services. This is captured by link 3, which depicts supply of ecosystem services to the economy. In this modelling framework, the economy-wide, sectoral and regional impacts (including the MDB) of the water policy reform are captured by a Computable General Equilibrium (CGE) model. The output of the CGE model, largely the changes in factor employment and incomes, that affect the social outcomes across a number of household characteristics/variables nationally and regionally, including small areas are analysed with microsimulation models. First, the CGE model is linked to a spatial microsimulation model to interface with the regional detail of the CGE model (link 4). The spatial microsimulation model could be further modified and extended to include smaller geographical areas than the regions specified in the CGE model, if a smaller area analysis is desired. This brings the change in incomes and employment by industry from the CGE model to the regional/smaller area household level. The output of the spatial microsimulation model is then fed into a national microsimulation model via link 5 to compute the regional/small area level change in household incomes (cross-tabulated by household characteristics/variables) net of federal taxes and transfer payments. The changes in household characteristics are linked to changes in social disadvantage by a social impact model (link 6). Agent-based models can take as inputs the output of a social impact model (such as psychological or financial stress) via link 7 to investigate emergent socio-economic phenomena such as resilient or vulnerable communities. Finally, the social system (human decisions and interactions) is linked to the ecosystem via agent-based models (link 9) and ecological response models (links 10, 11, 12 and 13) to explain the emergent social-ecological outcomes. The relevant features of each of these models are outlined below; including a discussion on how each of these models is sequentially linked. We begin by first explaining the rational for linking CGE and Microsimulation models, given that these models form the core structure of the conceptual and analytical framework.

3. CGE-MICROSIMULATION LINKAGES AND THE DISTRIBUTIONAL EFFECTS

CGE models provide a rigorous way to quantitatively measure and evaluate the impact of policy reforms (such as the water policy reform under the Basin Plan) in the economy as a whole (Johansen, 1974). The CGE modelling, based on the input-output linkages of the economy, models the structure of the whole economy and therefore the details of all existing interactions among economic agents (producers, consumers, investors, government and the rest of the world). Because of this interconnectedness of markets and agents in a CGE model, the CGE analysis captures a wider range of economic impacts of an external shock or a policy reform, compared to other available techniques (such as the partial equilibrium models). In this regard, CGE models are better equipped to evaluate policy and external shocks whose impacts are expected to be complex, transmitted by different channels, and materializing not only in one but in various rounds through feedback loops via interconnected markets. Moreover, given that the CGE models are designed to evaluate the economy-wide impacts, it not only captures the structural changes in the economy as a whole but also clearly identifies the winners and losers (sectors, regions, occupations, and so forth) of a policy reform or an external shock.

However, the inadequacy of the use of CGE models for distributional analysis is well recognised in the income distribution literature (for instance see Savard, 2005). This is because, traditionally, CGE models include only a limited number of representative households, so do not account for the diversity of individual or household characteristics required for a detailed distributional analysis. In this regard, a companion microsimulation model can be combined with a CGE model to analyse income distributional issues of policy change or an external shock. The strength of the microsimulation models is that they account for individual heterogeneity by making use of nationally representative household surveys of the population (Harding and Gupta, 2007). The effects of a macro policy captured by a CGE model can be passed down to a microsimulation model for detailed distributional analysis. The benefit of combining CGE and microsimulation models is that it overcomes the problem of a lack of general equilibrium effects in microsimulation models and the limitations of the restrictive assumption of representative households in the CGE model (Hérault, 2006).

In the CGE-microsimulation linkage literature, there are four main approaches to linking a CGE model to a microsimulation model for distributional analysis of policy reforms and external shocks. The first approach is the integrated approach (Cockburn *et al.*, 2010). The other three approaches involve sequentially linking the CGE model to the microsimulation model in a top down (Ribilliard *et al.*, 2008, Buddelmeyer *et al.*, 2012) bottom up (Brown *et al.*, 2007) and top down-bottom up (Bourguignon and Savard, 2008) fashion. Sequentially linking CGE and microsimulation models is also called the layered approach to distributional analysis. A layered approach to macro-micro link is considered less complex than an integrated approach as the former involves only sharing information between two standalone models.

4. THE DISTRIBUTIONAL IMPACTS OF THE BASIN PLAN

As discussed earlier, the CGE-microsimulation link overcomes the lack of general equilibrium effects in a microsimulation model on one-hand and the restrictive representative household assumptions of CGE models on the other. It is also clear that drawing on the strengths of both models allows a richer understanding of the micro impacts of (macro) policy reforms.

The irrigation and environmental water policy reform under the Commonwealth's Basin Plan will affect the economy and the community in different ways as a result of structural changes in the economy. In the long-term, some individuals and households may come out winners and some as losers. In this regard, the micro (distributional) impacts of policy reforms help identify the winners, losers and the vulnerable in the communities. It therefore provides policy makers with a basis on which to arrive at measures that will best assist the losers and the vulnerable in the community.

As a starting point to operationalize the conceptual framework, the rest of this paper discusses the top down approach to linking a CGE and microsimulation model to analyse the distributional impacts of water policy reform under the MDB plan. The relatively simpler top down approach will lay a strong foundation to further develop the framework, including adding bi-directional links between the models.

We begin by discussing the desirable features of a CGE model to analyse a regional specific shock such as the Basin Plan.

Desirable Features of a CGE Model

For analytical purposes, the MDB spread over four Australian states and one territory is treated as a single regional economy. However, up to 40 sub-regions within the Basin are distinguished in studies of the Basin Plan capturing the irrigated (and non-irrigated) agricultural detail and water markets in each of the sub-regions of the Basin (ABARES, 2011; Dixon *et al*., 2012b). To capture the economy-wide impact of the water policy reform, a computable general equilibrium (CGE) model would be an appropriate model to capture the flow-on economic impacts in a single analytical framework. Note that the water policy reform under the Basin Plan directly affects the MDB region. In this regard, the implementation of the SDLs is a regional-specific policy shock, originating from the MDB. From the socio-economic impact perspective, policy makers are likely to be interested in:

1) How the policy affects the agricultural industries in the Basin, including the changes in the production/crop mix, the use of factors of production such as land and water, consumption, employment and so forth;

2) The impact that this regional-specific shock may have on the rest of the Australian economy, including the impact of any feedback from changes in the rest of the economy back to the Basin regional economy; and

3) The welfare implications of the policy on households in the Basin and the rest of the economy.

Thus, it is desirable that a CGE model for estimating the economic impact of the Basin Plan have the following key features:

1) It is a "bottom-up" regional model containing the required regional and sectoral detail, in particular small region (area) representation.

2) It should be dynamic: dynamic models capture both the short-run and the long-run effects of the model simulations. In addition, with regards to the Basin Plan, the dynamic nature of a CGE model allows the modeller to take into account the baseline forecasts in the variability of water availability over the simulation period. They are also useful for policy simulations. For instance, the model can take into account a policy implementation (such as a SDL scenario) which is spread over several years or seasons.

3) It should contain sectoral and regional details, including the water markets, all incorporated in a single analytical framework. Having one integrated model with interaction between different systems (economic and water) is preferable to having two separate models joined exogenously by the output of one model feeding as input into another model.

4) The model needs to incorporate inputs and factors of production that are relevant to the MDB. This will allow relevant and realistic scenarios to be derived, and will add to the flexibility of the model.

5) The model must also be designed to handle the impacts of revenues and expenditures that flow into the economy through the water buyback scheme, water trading and water-saving infrastructure investment respectively.

A Top Down CGE-Microsimulation Link to Analyse Water Reform or External Shocks

In the top-down approach, the water policy shock enters the CGE model via link 1 (Figure 1). The results from the CGE model would capture the macro and structural/sectoral changes in the Australian economy and the regional economy of the MDB. Given the regional nature of the water policy shock, the immediate impact of the shock would be on the regional economy of the MDB and thus, the distributional impact of the structural changes in the MDB economy would directly affect the individuals and households in the specific MDB region. As pointed out earlier, the appropriate CGE model to analyse the water policy reform must capture the regional details of the MDB. As link 4 in Figure 1 shows, the output of the CGE model, being the linking aggregate variables (LAVs), is passed down to a Spatial Microsimulation model (see Tanton and Edwards, 2013).

The Spatial microsimulation in this linked model is used to provide the various households that populate the region. These households are represented by unit records taken from a national survey, which are then reweighted to benchmarks for the region from the population census. So each household record has a weight which represents the number of households in each small area that the record represents. The link from the CGE to the spatial microsimulation model is through the LAVs (changes in the factor incomes by industry, employment by industry and occupation) via Link 4. The spatial microsimulation model used for this analysis was SpatialMSM, a spatial microsimulation model of the Australian economy (Chin and Harding, 2007; Tanton *et al*., 2011). SpatialMSM then estimates the impact of changes in the factor incomes and employment by industry and occupation on household income in different family or household types, housing tenure, education level and other characteristics of the employee and income earners in the MDB regions and/or smaller areas within the MDB regions.

By providing data for households in the region, SpatialMSM translates the macro impact from the CGE to the micro impact at the household level. It is important to note that the microsimulation here is applied at the household level. Therefore, the capital stock, production input, and output are all still based on the CGE model. Another important note is that SpatialMSM is a static model so provides only the 'day after' effects of the modelled change. The top down approach means that the household would then adjust according to the changes shown by the CGE model. This includes adjusting to the population growth implemented in the CGE scenario by adjusting the weights of the household unit.

Changing the income in the SpatialMSM model is straightforward (adjust the income for each household record in the SpatialMSM based on the change from the CGE model), the implementation of the employment effect in SpatialMSM is more challenging. One method that can be used is to assign a probability that the person is no longer in the same job based on the reduction in employment in a certain industry and occupation and then simulate whether the person in the SpatialMSM moved to another job or became unemployed. However, this method will only work well if the number of person records in the SpatialMSM is very large.

Reweighting is an alternative solution. Using this technique the observation weight of those who are working in the declining industry and occupation can be decreased while increasing the weight of those working in the industries and occupations that are estimated to be increasing. The reweighting technique can address this issue while keeping other characteristics such as education and family composition in the region unchanged as suggested by Buddelmeyer *et al*. (2012).

Another important note about this CGE-SpatialMSM link is regarding the various databases used in this linked model. Both the CGE and SpatialMSM models are mainly based on ABS data including input-output tables, the survey of income and housing and the population census. These data came from different sources within the ABS, but they essentially represent the same people at a region or national level. The census plays the most important role as most of the regional data are benchmarked so that the modelled results match the regional estimates from the census. Nevertheless, this does not mean that all the differences between the datasets will be resolved, even within a single model as shown in Vidyattama *et al*. (2013). Therefore, one of the important steps in the modelling is validation and if necessary, realignment.

Linking the Microsimulation Models (SpatialMSM-STINMOD)

The changes in income and employment status are likely to affect a household's tax payment to the government and transfer payments from the government according to their family characteristics. In order to calculate the changes in the Commonwealth's tax and transfer payments, the output of the SpatialMSM (the LAVs) would be passed to a national microsimulation model, the STINMOD (Lambert *et al*., 1994), a static (and non-behavioural) federal tax and transfer payments model of the Australian economy. STINMOD estimates the changes in household income of federal tax and transfer payments for each different family observed in the microdata in the regions and/or smaller areas of interest in the MDB. These results allow the estimation of a number of social indicators arising from the changes in income distribution such as poverty rates (Tanton *et al*., 2009) and housing stress (Nepal *et al*., 2010). This method could also be used to measure the dependency on federal government transfer programs and what these programs are likely to cost. The social indicators after the impact of the tax and transfer system give a comparison between the socio-economic status of individuals and households in the base case (or business as usual) scenario and after water policy reform scenario.

A STINMOD-Social Impact and Disadvantage Model (SIDMOD) Link

It may be desirable to know the impact that the water policy reforms have on the social disadvantage of the communities in the Basin, especially wellbeing indicators such as financial stress, subjective wellbeing and mental health. To calculate these indicators, additional data is required beyond the output of the microsimulation models. Link 6 in Figure 1 shows the microsimulation model (STINMOD) is linked to a Social Impact and Disadvantage Model (SIDMOD). SIDMOD, largely a series of econometric models, takes inputs from microsimulation models, together with additional data from surveys such as the Household, Income and Labour Dynamics in Australia (HILDA) Survey, to estimate a range indicators of social disadvantage (such as financial stress, subjective wellbeing and mental health) that could be affected by the water policy reform.

Moreover, the microsimulation models used in the framework are static and non-behavioural. Behavioural responses, like retraining after becoming unemployed to get employment in another occupation, can also be introduced in the framework through an Agent-based model (ABM). These models operate at the individual level, and allow modelling of individual decisions. This can then be used to explain, for instance, emergent socio-economic phenomena such the emergence of resilient or non-resilient communities (Stokals *et al.*, 2013) – those communities that are exposed to prolonged climatic events such as droughts. The goal is to use ABMs to uncover and analyse the main drivers or sources of emergence (such as individual behaviours and interactions, social support networks and institutions) embedded in resilient and adaptive communities or identify those that are absent in vulnerable communities in the MDB.

Social-Ecology Nexus

To complete the links between the systems/models in the overall analytical framework, it is then necessary to link the microsimulation models and social impact models (via link 9 in Figure 1) to the ecological system. This has been done in other literature using Agent-based model (ABMs) or Multi-Agent simulations (MAS) (An *et al*., 2005; Bousquet and Page, 2004). These models incorporate how individual human decisions and interactions among themselves and with the ecology simulate observed emergent macro-scale social-ecological outcomes (Heckbert, *et al*., 2010). These outcomes can include observed phenomena such as depletion of ecosystems, the emergence of land-use systems (Matthews *et al*., 2007), and deforestation and reforestation (Manson and Evans, 2007).

The ABMs are well suited to study emergent phenomena as they allow modelling of individual behaviours and their (non-linear) interactions between themselves and their environment. While this interaction between humans and environment can be modelled using ABM, they can also be used to simulate different animal populations (Abbot *et al*., 1995). This system could include modelling of a number of different animal populations using ABMs.

Link 7 in Figure 1 shows that ABMs can potentially take as inputs the outputs of the social impact model, SIDMOD (such as measures of psychological stress and subjective well-being), together with variables not included in SIDMOD such as institutions, social networks, governance and so forth (Folke, 2006) to investigate how all these factors explain emergence of resilient and adaptive or vulnerable communities. To further enrich the modelling framework, the feedback from the ecological system (modelled through ABM or MAS) can be linked to economic and agent-based models via ecological response models (links 10, 11, 12 and 13). The output of the ecological response models (such as the movements in the socio-economic variables resulting from the changes in the distribution of species) can be passed on to economic and agent-based models to capture the impacts on the social-ecological outcomes.

5. CONCLUSION

From a policy perspective, it is important to increase our understanding of how external shocks and policy interventions are transmitted throughout interdependent social-ecological systems (SES). In this regard, the paper attempts to develop a conceptual integrative analytical framework to analyse the national, regional and spatial social-economic and distributional effects of external shocks (e.g. droughts) and policy interventions (e.g. the water policy reform in the MDB), which originate from an important regional economy such as the MDB. This is achieved by sequentially linking a series of models in a top-down fashion, each model informing the subsequent model, thus drawing on the strengths of each model designed to explain a part of a SES. It is recognised that a bottom-up regional CGE model was the appropriate model to capture the macro, sectoral and regional (including the MDB) effects of shocks that are regional-specific.

However, given the limitations of CGE models for distributional analysis, the output of the CGE can be passed down to microsimulation models for distributional analysis at the household level. It is worth noting the emphasis of this paper on the effects of shocks on small areas, both in the MDB and the rest of the economy. Thus, the output of the CGE model is first passed down to a spatial microsimulation model to capture small area detail at a household level.

The linking of these models is not without any issue. Although the microsimulation model is mainly being used to translate the macro impact of the CGE to the more micro impact and response at the household level, there are differences in the scale and timing of the data sources. Initially, all the data can be benchmarked to small area published data mainly from the census, but the output from the microsimulation model may then have to be aligned to the results and assumptions used by the CGE model.

To analyse the distributional impacts net of federal tax and transfer payments, the output of the spatial microsimulation is passed down to a national microsimulation model. To further enrich the distributional analysis at the household level, the framework proposes linking the microsimulation models to a Social Impact Model, which can use additional data from surveys such as HILDA to provide further estimation of a number of key household variables to calculate the social disadvantage indicators for households in the MDB. The framework further posits that the output from the social impact and microsimulation models, together with other variables, can potentially explain, via agent-based models, the emergence of resilient and adaptive or vulnerable communities exposed to external shocks such as droughts and subsequent policy interventions such as the water policy reform under the Basin Plan. Finally, to complete the interconnection between the systems in a SES such as the MDB (albeit in a top-down fashion), the framework proposes linking the social system (human decisions and interactions) with the ecosystem via agent-based models and ecological response models to explain the emergent social-ecological outcomes.

Though the modelling framework has been developed in the context of the water policy reform in the MDB, it potentially has wide applicability, particularly if external shocks and policy interventions are region-specific and the interest is in analysing their national, regional and spatial socio-economic, ecological and distributional effects.

REFERENCES

ABARES (2010). Indicators of Community Vulnerability and Adaptive Capacity Across Murray-Darling Basin – a Focus on Irrigation in Agriculture. Report prepared for the Murray-Darling Basin Authority, Canberra: Commonwealth of Australia.

ABARES (2011). Modelling the Economic Effects of the Murray Darling Basin Plan. Report prepared for the Murray-Darling Basin Authority, Canberra: Commonwealth of Australia.

Abbott, C.A., Berry, M.W., Dempsey, J.C., Comiskey, E.J., Gross, L.J. and Luh, H-K. (1995). Computational Models of White-Tailed Deer in the Florida Everglades. UTK-CS Technical Report No. CS-95-296.

An, L., Linderman, M., Qi, J., Shortridge, A. and Liu. J. (2005) Exploring Complexity in a Human–Environment System: An Agent-Based Spatial Model for Multidisciplinary and Multiscale Integration. *Annals of the Association of American Geographers*, 95(1), (March), pp. 54–79.

Barbier, E.B. and Markandya, A. (2013). *A New Blueprint for a Green Economy*. New York: Routledge.

Barbier, E.B. (1987). The Concept of Sustainable Economic Development. *Environmental Conservation*, 14, pp. 101-110.

Bourguignon, F. and Savard, L. (2008). Distributional Effects of Trade Reform: An Integrated Macro-Micro Model Applied to the Phillipines. In F. Bourguignon, L. da Silva and M. Bussolo (Eds), *The Impact of Macroeconomic Policies on Poverty and Income Distribution: Macro-micro Evaluation Techniques and Tools*. Houndmills: Palgrave-Macmillan, pp. (Chapter 6), pp. 177-212.

Bousquet, F. and Le Page C. (2004). Multi-Agent Simulations and Ecosystem Management: A Review. *Ecological Modelling*, 176 (3-4) (September), pp. 313–332.

Brown, L.J., Harris, A., Picton, M., Thurecht, L., Yap, M., Harding, A., Dixon, P. and Richardson J. (2007). Linking Microsimulation and Macro-Economic Models to Estimate the Economic Impact of Chronic Disease Prevention. In A. Zaidi, A. Harding and P. Williamson (Eds) *New Frontiers in Microsimulation Modelling*. Farnham: Ashgate, pp. 527-555.

Buchholz, T.S., Volk , T.A. and Luadis, V.A. (2007). A Participatory Systems Approach to Modeling Social, Economic, and Ecological Components of Bioenergy. *Energy Policy*, 35, pp. 6084-6094.

Buddelmeyer, H., Hérault, N., Kalb, G., and de Jong, M.V.Z. (2012). Linking a Microsimulation Model to a Dynamic CGE Model: Climate Change Mitigation Policies and Income Distribution in Australia, *International Journal of Microsimulation*, 5(2), pp. 40-58.

Chapin, F.S., Folke, C. and Kofinas, G.P (2009). A Framework for Understanding Change. In F. S. Chapin, C. Folke and G. P Kofinas (Eds) *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing World*, Springer Science + Business Media, LLC (Chapter 1).

Chiesura, A. and de Groot, R. (2003). Critical Natural Capital: a Socio-Cultural Perspective, *Ecological Economics*, 44(1-2), pp. 219-231.

Chin, S. and Harding, A. (2007). SpatialMSM – NATSEM's Small Area Household Model for Australia. In A. Gupta and A. Harding (Eds) *Modelling Our Future: Population Ageing Health and Aged Care*. Amsterdam: Elsevier, pp. 563-566.

Cockburn, J., Corong, E. and Cororation, C. (2010). Integrated Computable General Equilibrium (CGE) Micro-Simulation Approach. *International Journal of Microsimulation*, 3, pp. 60-71.

Commonwealth of Australia (2014a). Water Act 2007, Act No. 137. Commonwealth of Australia, Canberra. Online version accessed on 10 November 2013, www.comlaw.gov.au.

Commonwealth of Australia (2014b). *Water Recovery Strategy for the Murray-Darling Basin*. Commonwealth of Australia, Canberra,

Crase, L., Pagan, P. and Dollery, B. (2004). Water Markets as a Vehicle for Reforming Water Resource Allocation in the Murray-Darling Basin of Australia. *Water Resources Research*, 40, pp. 1-10.

Daily, G. (Ed.) (1997). *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC.

de Groot, R.S. (1992). *Functions of Nature*. Wolters-Noordhoff, Amsterdam.

Dixon, P.B., Rimmer, M.T. and Wittwer, G. (2012a). Buybacks to Restore the Southern Murray-Darling Basin. In G. Wittwer (Ed) *Economic Modeling of Water: The Australian CGE Experience*. Dordrecht: Springer Science + Business Media, pp. 99-118.

Dixon, P.B., Rimmer, M.T. and Wittwer, G. (2012b). Theory of TERM-H20. In G. Wittwer (Ed) *Economic Modeling of Water: The Australian CGE Experience*. Dordrecht: Springer Science + Business Media, pp. 79-98.

EBC, RMCG, MJA, EconSearch, McLeod, G., Cummins, T., Roth, G. and Cornish, D. (2011). Community impacts of the Guide to the proposed Murray-Darling Basin Plan. Report prepared for the Murray-Darling Basin Authority, Canberra: Commonwealth of Australia.

Ehrlich, P.R and Mooney, H.A (1983). Extinction, Substitution and Ecosystem Services, *BioScience*, 33, pp. 248-254.

Ekins, P., Simon, S., Deutsch, L., Folke, C. and de Groot, R. (2003). A Framework for the Practical Application of the Concepts of Critical Natural Capital and Strong Sustainability. *Ecological Economics*, 44(1-2), pp. 165-185.

Fiksel, J. (2003). Designing Resilient, Sustainable Systems. *Environmental Science and Technology*, 37, pp. 5330-5339.

Fiksel, J. (2006). Sustainability and resilience: Toward a systems approach. *Sustainability: Science, Practice, & Policy*, 2, pp. 14-21.

Folke, C. (2006). Resilience: The emergence of a perspective for socio-ecological systems analyses. *Global Environment Change*, 16, pp. 253-267.

Hall, N., Poulter, D. and Curtotti, R. (1994). ABARE Model of Irrigation Farming in the Southern Murray-Darling Basin. ABARES Research report 94.4, Commonwealth of Australia, Canberra.

Harding, A. and Gupta, A. (2007). Introduction and Overview. In A. Gupta and A. Harding (Eds) *Modelling Our Future: Population Ageing Health and Aged Care*. Amsterdam: Elsevier, pp. 1-29.

Heckbert, S., Baynes, T. and Reeson, A. (2010). Agent-Based Modeling in Ecological Economics. *Annals of the New York Academy of Sciences*, 1185, pp. 39-53.

Hérault, N. (2006). Building and Linking a Microsimulation Model to a CGE Model for South Africa. *South African Journal of Economics*, 74, pp. 34-58.

Johansen, L. (1974). *A Multi-Sectoral Study of Economic Growth*, 2^{nd} edition. Amsterdam: North-Holland.

Lambert, S., Percival, R., Schofield, D. and Paul, S. (1994). An Introduction to STINMOD: A Static Microsimulation Model. STINMOD Technical paper no. 1, NATSEM, University of Canberra, Australia.

MDBA (2010). *Guide to the proposed Basin Plan, Volume 1: Overview*, Murray-Darling Basin Authority (MDBA), Commonwealth of Australia.

MDBA (2012a). Socioeconomic Analysis and the Draft Basin Plan: Part A – Overview and Analysis. MDBA Publication No 52/12, Murray-Darling Basin Authority (MDBA), Commonwealth of Australia.

MDBA (2012b). Socioeconomic Analysis and the Draft Basin Plan: Part B – Commissioned and Non-commissioned Reports which Informed the MDBA's Socioeconomic Analysis. MDBA Publication No 52/12, Murray-Darling Basin Authority (MDBA), Commonwealth of Australia.

MDBA (2012c). Proposed Basin Plan Consultation Report. MDBA Publication No 59/12, Murray-Darling Basin Authority (MDBA), Commonwealth of Australia.

Matthews, R.B., Gilbert, N.G., Roach, A., Polhill, J.G. and Gotts. N.M. (2007). Agent-Based Land-Use Models: A Review of Applications. *Landscape Ecology*, 22, pp. 1447-1459.

Manson, S.M. and Evans, T. (2007). Agent-Based Modeling of Deforestation in Southern Yucatan, Mexico, and Reforestation in Midwest United States, *PNAS*, 104(52), pp. 20678–20683.

Nepal, B., Tanton, R. and Harding, A. (2010) .Measuring Housing Stress: How Much Do Definitions Matter? *Urban Policy and Research*, 28, pp. 211-224.

Ostrom, E., Burger, J., Field, C.B., Norgaard, R.B. and Polikansky, D. (1999). Revisiting Commons, Local Lessons, Global Challenges. *Science*, 284(5412), pp. 278-282.

Qureshi, M.E., Shi, T. Qureshi, S.E. and Proctor, W. (2009). Removing Barriers to Facilitate Efficient Water Markets in the Murray-Darling Basin of Australia. *Agricultural Water Management*, 96, pp. 1641-1651.

Ribilliard, A-S., Bourguignon, F. and Robinson, S. (2008). Examining the Social Impact of the Indonesian Financial Crisis Using a Macro-Micro Model. In F. Bourguignon, M. Bussolo and L.A. Pereira da Silva (Eds) *The Impact of Macroeconomic Policies on Poverty and Income Distribution: Macro-Micro Evaluation Techniques and Tools*. Houndmills: Palgrave-Macmillan, pp. 93-117.

Savard, L. (2005). Poverty and Inequality Analysis Within a CGE Framework: A Comparative Analysis of the Representative Agent and Microsimulation Approaches. *Development Policy Review*, 23, pp. 313-331.

Stokals, D., Lejano, R.P. and Hipp, J. (2013). Enhancing the Resilience of Human-Environment Systems: a Social Ecological Perspective. *Ecology and Society*, 18(1): 7.

Tanton, R. and Edwards, K.L. (2013). *Spatial Microsimulation: A Reference Guide for Users*, Dordrecht: Springer Science + Business Media.

Tanton, R., Vidyattama, Y., Nepal, B. and McNamara, J. (2011). Small Area Estimation Using a Reweighting Algorithm. *Journal of the Royal Statistical Society: Series A*, 174, pp. 931-951.

Tanton, R., Vidyattama, Y., McNamara, J., Vu, Q.N. and Harding, A. (2009). Old, Single and Poor: Using Microsimulation and Microdata to Analyse Poverty and the Impact of Policy Change Among Older Australians. *Economic Papers*, 28, pp. 102-120.

Turner, R.K and Daily, G.C. (2008). The Ecosystem Services Framework and Natural Capital Conservation. *Environment and Resource Economics,* 39, pp. 25-35.

Turral, H.N., Etchells, H., Malano, H.M.M., Wijedasa, H.A., Taylor, P., McNahon, T.A. and Austin, N. (2005). Water Trading at the Margin: The Evolution of Water Markets in the Murray-Darling Basin. *Water Resources Research*, 41, pp. 1-8.

Wittwer, G. (2010). The regional economic impacts of Sustainable Diversion Limits. Centre of Policy Studies, Monash University, Report prepared for the Murray-Darling Basin Authority, Commonwealth of Australia, Canberra.

Wittwer, G. (2011.) Basin Plan CGE Modelling Using TERM-H2O', Centre of Policy Studies. Monash University, Report prepared for the Murray-Darling Basin Authority, Commonwealth of Australia, Canberra.

Vidyattama, Y., Miranti, R., McNamara, J., Tanton, R., and Harding, A. (2013). The Challenges of Combining Two Databases in Small Area Estimation: an Example Using Spatial Microsimulation of Child Poverty, *Environment and Planning A*, 45(2), pp. 344–361

World Commission on Environment and Development (WCED) (1987). *Our Common Future*. Oxford and New York: Oxford University Press.