

PREDICTING REGIONAL AND LANDSCAPE DYNAMICS IN AUSTRALIAN SAVANNAS¹

– ECONOMIC DIMENSIONS

Summary of Project Report

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¹ Map available at the TS CRC web-site: <http://Savannas.ntu.edu.au/information/Savannasexplorer.html>

BACKGROUND

This document summarises key findings from research that was undertaken by the authors as part of a much larger study. The aim of the larger study was to develop a regional dynamic modelling capacity for the Australian Savannas that can simulate the effect (on the environment, on regional communities and on the Savannas economy) of specific changes or shocks to the system.

The task would be non-trivial even if the aim of the larger project was less ambitious (eg developing regional dynamic modelling capacity for the economy only). At least part of the reason for this is because the social and economic structure of the Australian Savannas differs so substantially from the more densely populated, southern and/or coastal areas of Australia, that one cannot simply ‘transfer’ methods or results from urban areas to these.

For example, a large proportion of the Savannas population is composed of Indigenous people (Table 1).

Table 1: Population across the Australian Savannas²

	Proportion of land area in Savannas (estimated %)	Estimated Population	Indigenous persons (number)	Indigenous persons (% of Pop)
North East Qld		339,363	17,435	5
Cape York		20,430	10,892	53
Mitchell Grass Lands	≈ 72%	10,446	856	8
Gulf Country Qld	≈ 80%	31,047	7,917	26
QLD total		401,286	37,100	9%
Mitchell Grass Lands	≈ 28%	4,062	307	8
Gulf Country NT	≈ 20%	7,762	1,979	25
Arnhem land		17,249	11,464	66
VRD Stuart	≈ 90%	7,034	3,115	44
Darwin Kakadu		126,019	15,538	12
NT total		162,126	32,403	20%
VRD Stuart	≈10%	782	346	44
Kimberley		39,252	13,157	34
WA total		40,034	13,503	34%
Savanna Total		603,446	83,006	14%

There are a number of medium to small towns in the area, whose population is predominantly non-Indigenous, though the non-Indigenous people stay in the Savannas for only relatively short periods of time. A number of Indigenous communities are growing so rapidly that they will soon become large in the context of the Savannas,

²Population figures were taken from TS CRC web site. These were compared to ABS 2001 Census data by area on map (% of overlap between states estimated, taking into consideration towns and land mass.)
<http://www.Savannas.ntu.edu.au>, <http://www.abs.gov.au>

although the economy's of these communities is vastly different from those of the mainstream towns with relatively little economic contact between the communities and neighbouring towns.

Further to that, the Indigenous economy is only weakly linked to the rest of the Savannas economy. Indigenous communities exist largely as islands of population and activity with little contact with the surrounding towns. The result of this is that even a large development project (such as the construction of the Tindell Air Base in Katherine, NT) will generally lead to no or little increase in employment and incomes of the Indigenous people in the region. The local non-Indigenous community is much more likely to gain a benefit.

There is also considerable variation in the economic structure of regions within, and across the Savannas. This is clearly shown in Figure 1, which graphs the proportion of persons employed in different industries for three shires in Queensland and for all of Queensland.

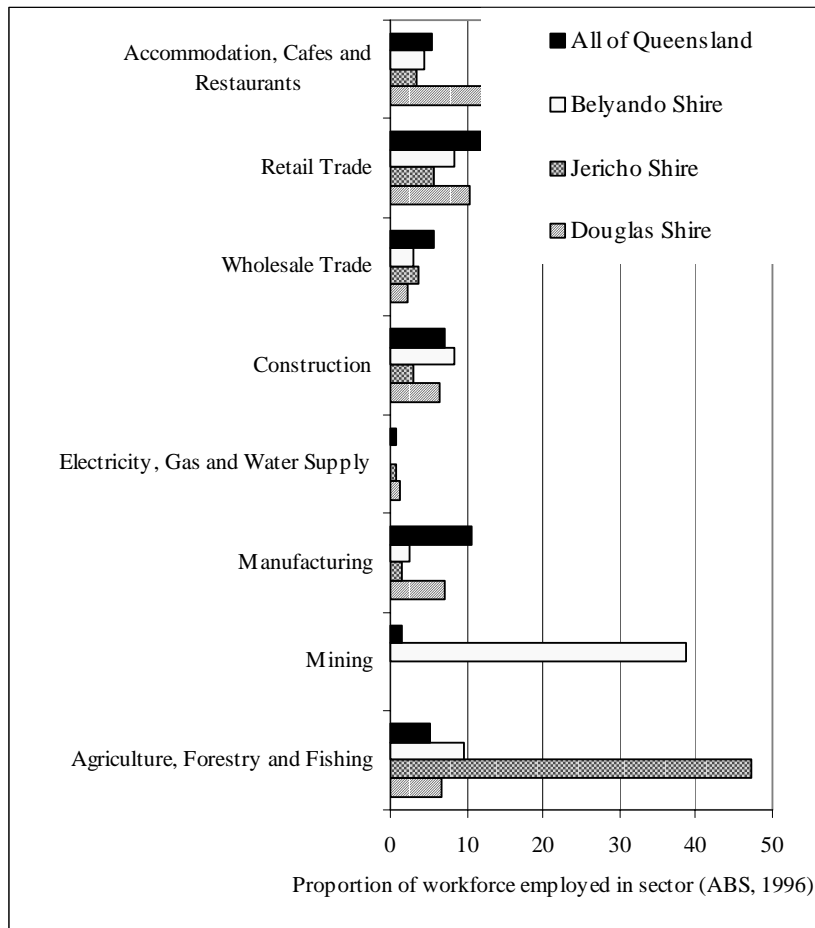


Figure 1: The proportion of workforce employed in different sectors of the economy for a selection of regions within Australia (ABS, 1996)

In the shire of Jericho, the most important industry is Agriculture – with more than 40% of all workers engaged in that Industry. In neighbouring Belyando, mining is the ‘key’ industry; whilst in Douglas, the sectors associated with tourism employ most people. Not surprisingly, the figures for Queensland show a more even distribution of employment across different industries:

If a man stands with one foot on a hot stove, and one foot in a freezer, the statistician will report that he is – on average – comfortable.

These regional differences mean that individuals living in the Australian Savannas need information about what is happening locally: aggregate economic information (eg. about employment in Australia, or in Queensland) is not generally transferable to these smaller, remote areas, and may often be irrelevant.

In short, the complex social and economic structure of the Australian Savannas means that job of modelling the economy (even without interdisciplinary links) is non-trivial. Clearly, one cannot simply take a model from another region and apply it to the Savannas, and the task of building a ‘tailor made’ model is substantial. Hence the importance to dividing the large project into a series of smaller sub-projects.

In 2003/04, the project was divided into three separate disciplinary investigations: economic, biophysical and demographic – the justification for this being that the overarching aims of such an ambitious project might be best worked towards in a series of small, incremental yet related steps. This document relates specifically, to the economic component of the 2003/04 project.

The primary task of the economic investigation was to conduct a stock-take of currently available methods, approaches and models, analysing them in the Savannas context, with a view towards determining which (if any) may be able to:

- a) Simulate changes in the Savannas, generating predictions about the effect of different types of change on regional economies; and
- b) Integrate with other disciplinary approaches also generating predictions about the effect of changes on a broad range of social, demographic, environmental and economic issues; and
- c) Answer questions that stakeholders are interested in;

or

- d) Be adapted so as to achieve all of the above.

The ultimate aim of the economic investigation was to generate a short-list of promising approaches to developing an integrative, dynamic, predictive model of Australian Savannas.

METHODS

There is an extensive body of research focusing on issues of dynamic modelling – indeed entire journals are devoted to the topic (the *Review of Economic Dynamics, Structural Change and Economic Dynamics*; the *Journal of Economic Dynamics and Control* to name just three). Development of new methods to predict regional

dynamics in the Savannas is thus inappropriate if one can use and/or adapt one or more of the many methods that are currently available. Before doing so, however, it is important to assess whether such methods or models are suitable in this context.

The first stage of work therefore involved a stock-take of currently available methods, approaches and models. This review built on the regional dynamics scoping study conducted by Stafford-Smith and others in 2002-03. It collected information on existing regional economic models / approaches, noting: data requirements; underlying assumptions (regarding data, structure and processes); level of integration with other disciplinary perspectives; and final ‘outputs’ (variables, timescales, geographic scales, etc).

For those interested in developing a regional dynamic modelling capacity in the Australian Savannas, the key point to be made from the stock-take is that there are many different economic models and modelling approaches – approaches that can make quite different predictions about the impact of change. This is not to say that such differences mean that some approaches are ‘right’ and some are ‘wrong’ – one expects differences to arise for several legitimate reasons:

1. Different models seek to answer different questions about different variables/issues;
2. Different models often consider different temporal scales;
3. Different models use different spatial scales;
4. Different models consider different sectoral scales;
5. Different models consider different feedbacks (environmental, social, and/or economic);
6. Different models use different types of data;
7. Different models make different assumptions about the structure of the relevant economy (eg. about the proportion of extra income re-spent within the local economy, about production technologies, about the price and availability of imports, about the existence of a global equilibrium, etc); and
8. Different models use different estimation techniques.

Researchers can comment on the theoretical soundness of the different modelling approaches, and on whether or not there is enough data to run them (providing information to others that will allow them to assess the desirability of different modelling approaches according to points 6 – 8). But they are not always well placed to determine which issues are most important to those who must make regular decisions that affect the environment, the economy, and/or the community of the Australian Tropical Savannas (hereafter called stakeholders). That is, researchers, alone, may not always be able to determine which questions stakeholders would like to be able to ask about which variables, over which time frames in which geographic scale, for which sectors (points 1 – 5). Hence the importance of identifying stakeholder priorities, and of taking such issues into consideration when assessing the ‘desirability’ (or otherwise) of different modelling approaches.

The authors of this document therefore undertook a two-pronged assessment of existing modelling approaches – conducting a survey of stakeholders to collect information that

allows one to assess the relevance of different modelling approaches vis-à-vis their ability to provide information that is relevant to different groups; and conducting a desktop analysis of practical, and theoretical issues associated with different modelling approaches.

Insights from the stakeholder survey and the researcher assessment were subsequently synthesised in the final section, allowing for the identification of broad classes of models and modelling approaches that are well suited to the task of developing an integrated predictive dynamic model of the Australian Savannas (i.e. they are theoretically robust, operationally feasible and likely to be able to answer questions/address issues that stakeholders are interested in).

FINDINGS

Based on responses to the stakeholder survey, the basic requirements for the economic component of a suitable model are the following. It would:

1. Allow for shocks and produce results at the LGA region
2. Have a time horizon of 2-5 years.
3. Include at least the following sectors: government administration, health, education, tourism, agriculture, mining, non-residential construction and defence.
4. Enable shocks and produce results for the following: outputs, costs of production and profits for each of the above sectors, employment overall and by sector, the level of unemployment; welfare payments, (of secondary importance to stakeholders was the ability to enable shocks and produce results for wages, interest rates, prices and inflation rates, exchange rates and taxes).
5. Model the interaction between the economy and the environmental, demographic and social characteristics of the region.
6. Separately model the Indigenous section of the economy.
7. Be generally accepted in the research and policy communities, which means, among other things, that all of its specifications, equations and data should be in the public domain. That is, the model should be “open and contestable”.
8. Be capable of extensions and developments so that it can be adapted to address new research questions.

NB: Items 7 and 8 do not explicitly arise from the questionnaire but follow from the need to ensure confidence in model results and adaptability to new data, information and perspectives.

Importantly, the focus of stakeholder interest in their LGA and short time frames (2-5 years), does not mean that there is no accepted role for longer-term or larger-scale predictions. Many stakeholders were interested in longer-term predictions and/or predictions over a larger scale. What this narrow focus of interest does mean is that LGA's and 2-5 year time frames were the most popular.

That said, the LGA focus is probably a sensible one from an economic perspective. As highlighted earlier, there are vast differences in the economic structure of small areas in the Savannas, even those that are adjacent to each other. A region that is almost entirely dependent upon tourism for its income, will need quite different information than one which is almost entirely dependent upon mining, or agriculture, or defence. Evidently, stakeholders in the top-end do not find economic information that has been ‘averaged’ across a larger area to be particularly useful. This poses some non-trivial modelling challenges, not the least of which is scarcity of data – data (and models) covering the entire Australian economy are readily available, but to the best of our knowledge there are no currently available regional economic models (or related data sets) across the top end at the LGA level.

As regards the relatively short time frame so popular amongst stakeholders – we suspect that it probably reflects the planning horizons of those interviewed (that imposed by electoral cycles and/or strategic plans, etc). This is not to say that models with longer time-frames have little to offer; they may be used by fewer people, but those that do use them could extract some particularly useful information from them.

As recently as 20 years ago, the CRC may have been forced to ‘choose’ between a short-term or a long-term model, since economic models were not generally capable of handling both short-term and long-term issues. But recent advances in information technology have allowed for the development of techniques that allow one to follow ‘transition paths’, in essence mapping the impact of change over time. No longer, need one choose between one timeframe and another. That said, it is more challenging to develop such models, primarily because:

- Models which ONLY deal with the very short-term (e.g. less than one year) allow one to make some simplifying assumptions (e.g. fixed prices and wages) that make the computing/equations easier to write.
- Models that ONLY look further into the future (e.g. at least 10-20 years) also allow one to make some simplifying assumptions (e.g. that prices and wages ‘adapt’ to the situation). Here too, these equations can be relatively simple to write.
- Models that are able to deal with the 2-5 year time frame are more difficult to construct since they need to be able to handle transitions/dynamics as both prices and quantities adjust to changes.

Hence the need for careful scrutiny of modelling options, before beginning work on what could be a long-term, large-scale project.

As noted earlier, there are many different types of economic models and modelling approaches – and much theoretical work has been done on issues relevant to small and/or sparsely populated economies. The desk-top analysis highlighted the fact that from a theoretical perspective, there are several economic modelling approaches that are worthy of consideration. These include a range of economic growth models (Mateos-Planas 2002), computable general equilibrium models, systems dynamics models (Radzicki 2002), game theoretic, and agent-based models (Stafford-Smith 2003). While these all have theoretical appeal, the most promising candidates from a data and stage-of-development viewpoint are computable general equilibrium models (which are also capable of providing information at the temporal, regional and sectoral

levels identified as being most relevant to stakeholders). Agent-based modeling approaches show promise when combining interdisciplinary approaches.

To many, this ‘list’ of promising approaches may seem a little short – but for those looking for examples of applied models, a key issue is that remote areas have typically fewer people and smaller economies. This poses several, problems.

First: modelling is more difficult with small numbers, where standard deviations are typically large and market distortions may be the norm rather than the exception. This poses some ‘interesting’ – but not insurmountable – modelling challenges. Many of the currently available applied economic models that are reasonably complex (in terms of their ability to deal with market failures and other related problems) began as simplistic models of ‘large’ economies with little market failure. As researchers became adept at manipulating such models – and as substantial improvements were made in information technology – interest began to turn towards more complex problems. Nowadays, a substantial proportion of the modelling literature, focuses on problems, issues and methods of dealing with smallness, market failure, etc. Not all problems are solved – but many methods are under development and rapid advances in IT make the application of complex models a realistic goal.

Second: small regions tend to attract smaller amounts of research funds – the inevitable consequence being that there are fewer, high-quality, applied models of ‘small’ economies than there are of large economies. This does not mean that there are fewer techniques; just fewer applications, on which to base new research. Hence the relatively short ‘short-list’ of promising modelling approaches.

PROMISING MODELLING APPROACHES

An assessment of the overall usefulness of modelling approaches needs to be done at two levels: one needs to consider their ability to be used as an operationally practical, theoretically sound, economic model that is capable of satisfying the requirements of stakeholders; and one needs to consider their ability to be incorporated / included within a fully-integrated dynamic predictive model of the Australian Savannas that considers economic, demographic and biophysical issues.

To address the last issue first. There appear to be two broad approaches to the problem of developing an integrative model:

OPTION 1: Build a truly integrative model from scratch using techniques from game-theory, agent-based modelling and/ or evolutionary economics to structure the actions/behaviour of the economic components (and using other techniques from other disciplines to frame the actions/behaviour of other parts of the system).

OPTION 2: Build separate, dynamic ‘modules’ (economic, biophysical, and/or demographic) using discipline-specific information and/or techniques, and then link the modules within a ‘systems’ framework – sharing mutually important variables at appropriate time-steps – to develop the integrated model.

The chief drawback with Option 1 is that there is little current applied research – particularly in Northern Australia – on which to build such models, and it could be

relatively resource intensive to develop them. Game-theoretic / agent based models basically start from the bottom, and build up. Hence, they need logically consistent micro data and behavioural equations. To the extent that behaviour varies across regions, the data and behavioural assumptions may need to be collected/developed on a region by region basis (although one could probably start with a generic set, designing the overall model in a manner that would allow for the subsequent amendments that formally acknowledge regional differences).

Option 2 would require those working on separate modules to identify common variables (in common geographic units), and to ensure that their modules could pass those variables back and forth with other modules – suspending calculations whilst each module does its work, and recommencing as required (with the updated variable list). This would probably require less inter-disciplinary co-operation than Option 1, where most researchers would need to have some sort of input into the development of most equations. In short, option 1 has considerable potential, but may be riskier and may take longer to develop than option 2.

Before continuing, it is worth noting that the idea of ‘linking’ separate modules in a systems framework that has each model ‘share’ common variables, is similar in approach to that taken by agent-based modellers. One starts by modelling the known behaviour of individual agents, the aim being to see what will emerge overall when agents act simultaneously, yet interactively. So in some sense, option 2 can be viewed as an agent-based approach to the integrated system – it is just that the agents are highly aggregated (eg. using an entire regional economy as an agent, instead of an individual or a group of individuals).

This begs the question of how best to do the economic module – or ‘agent’ (we leave the specifications for the other discipline-specific modules to researchers in those fields). Some sub-options exist:

OPTION 2.1: Build the economic module from scratch using game-theoretic and/or agent based methods, including mechanisms to link it to other disciplinary modules

OPTION 2.2: Build the economic module from scratch using a CGE approach, including mechanisms to link it to other disciplinary modules

OPTION 2.3: Develop the economic module from an existing CGE model, including mechanisms to link it to other disciplinary modules.

Notice, that the potential *Option 2.4* – to build an economic module using an existing Agent based or game theoretic model – is not listed as an option: the authors of this report could not find any currently available applied models of this type in the Australian Savannas.

Option 2.1 has considerable appeal, although – like option 1 – its chief draw back is that there is little current research on which to build such models. They have considerable potential, but may be riskier and may take longer to develop than other modelling approaches.

From many points of view, Options 2.2 and 2.3 have real advantages. CGE models are capable of conducting the types of simulations which stakeholders want (ie they can provide regional and sectoral data at the levels noted as important by stakeholders – and

over the timeframes highlighted), they are generally theoretically sound and have great flexibility, so that developers can tailor the assumptions/specifications to suit the region of interest. As illustrated by Figure 1, the ability to tailor assumptions to suit specific regions is particularly important in the Savannas.

Nonetheless, these features come at a price: good quality CGEs, with regional and sectoral detail are very costly to develop. While it is technically feasible to build a high quality CGE model to the specifications of stakeholders, to do so from ‘scratch’ could take many years. Option 2.3 may therefore be the quickest (if not necessarily the most theoretically ‘pure’) way to complete a fully operational model.

FUTURE RESEARCH THAT MAY PROGRESS MODELLING CAPACITY

The time path to a fully integrated model is likely to be long. For example, it took 9 years to develop an Australian CGE model that was built using ideas, code and background from other models – and that model did not contain separate, interactive, predictive, dynamic modules of the environment and/or the community! Other modelling approaches (eg those using game theory, agent based models, evolutionary economics etc) may well take longer, since there is less local expertise on which to build. Part of the problem is that it is very time consuming to code such complex simulation programs. Another significant part of the problem is that data of the type required by such models is not readily available in the Savannas.

This is not particularly good news for a CRC charged with showing progress within much shorter time frames – but we note that it may be possible to take steps towards the ultimate goal, generating information that is useful in a piecemeal way, as illustrated in some of the examples below.

First: models require data. The authors of this report are unaware of any, currently available data set that is capable of supporting any of the models identified above. Researchers interested in developing a fully integrated dynamic predictive model of the Australian Savannas, would therefore need to compile an appropriate data set. This could be done by survey, but there are also other techniques for generating fine-scale data – including the creation of ‘synthetic’ data sets (NATSEM, 2003)³. One does, however, need to be careful not to ‘stretch’ data beyond its limits (Woollett et al, 2003: 7), and we note that researchers may also need to look at various tools for detecting and removing data inconsistencies, like those currently being developed by ABARE (Buetre et al, 2003).

Importantly, a geographically fine-scaled socio-economic database that could support a dynamic predictive model has the potential – on its own – to bring great benefit to stakeholders in the Australian Savannas. In other words, the process of collecting regional data could generate immediate benefit while also allowing one to work towards the larger goal of developing a full-scale model.

Second: it may be possible to start with an existing CGE model (option 2.3), and look at ways of making modifications to enhance its suitability to the task at hand, while also

³ We do, however, caution against the tendency to ‘stretch’ data beyond its limits (Woollett et al, 2003: 7), and note that those pursuing such an approach may need to consider using tools for detecting and removing data inconsistencies, like those currently being developed by ABARE (Buetre et al, 2003).

generating some short-term benefits. Figure 2 provides a stylised representation of the way in which some modifications could, ultimately, be linked into a larger model. The discussion that follows it, aims to explain the way in which each step ('modification') could be used to generate a short-term benefit whilst working towards the longer-term goal of developing a fully integrated predictive dynamic model across the Savannas.

NB: the discussion identifies some researchers and/or institutions that have expertise in these areas. This 'list' is neither exhaustive nor definitive. Others would be equally capable of exploring such options - we merely mention the names of these researchers/institutions to illustrate the point that the suggested techniques/approaches are current, realistic options. As for the 'modifications': we note that each of the following have been done (or are currently under way), and are, therefore, technically feasible. They also address key issues identified in the stakeholder survey, and would, therefore, allow a fuller, more integrative model to develop along the lines identified there.

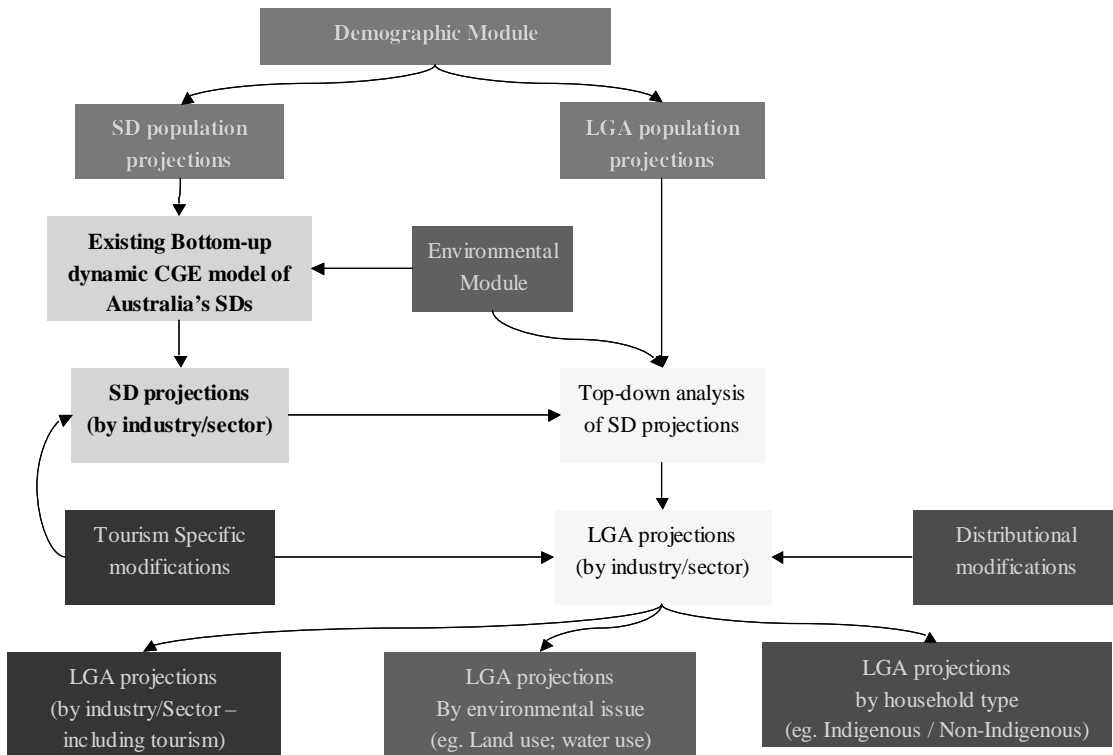


Figure 2: Building a model using existing models and approaches

Modification A: Do a top-down analysis of (existing) SD predictions.

Eg. Compile data (or create 'synthetic' data using insights from NATSEM's research) at a relatively small regional scale (LGA), and use that data in a top-

down re-distribution of information from an existing CGE that uses larger regions.

If one wishes to begin with an existing CGE model and make modifications to enhance its suitability to the task at hand, then either Monash's 57 region dynamic TERM model (currently under development – see Centre for Policy Studies, Monash University, 2004) or Murphy's 32 region static MMR model (Murphy, 2002) offer themselves as reasonable starting points. Both models include all of the Australian Savannas, and have some level of regional detail.

In the short-medium term, one could develop a hybrid model, by doing a top-down re-distribution of 'results' from either of these models to the LGA level across the Savannas. This would allow one to do a limited amount of regional modelling (although the 'top-down' models require one to average some predictions – mostly those relating to prices – across relatively large areas). CoPS (2004) notes that in practice, the number of regions *plus* the number of sectors must not exceed 100. In the short term, this may prove to be a problem if aiming to develop a model with many more regions, yet technological advances are likely to occur in the near future, so that this constraint may not be binding by the time the CRC is ready to compile a model that exceeds this limit.

Importantly, this step – of developing a 'hybrid' model of the Australian Savannas – would require researchers to start compiling information that is essential to the development of a genuine 'bottom-up' CGE (which would allow one to incorporate many regional differences within the model). This 'modification', would therefore, allow one to generate some short-term benefits (eg creating a top-down predictive model at the LGA level and a geographically fine-scale dataset) while allowing one to work towards the larger goal of developing a more relevant (bottom-up) model.

Modification B: Consider ways of linking demographic and/or other socio-economic information into a CGE.

Eg. Use insights from the Murphy (forecasting) suit of models, from some of the currently available European CGEs that allow for over-lapping generations (INGUENE Team, 2002), and from research into endogenous growth theory (much of which focuses on the relationship between health, education, population and economic growth) to develop links between the CGE and another, relevant demographic model.

Stakeholders expressed a great deal of interest in the problems of health and education, and the way in which these impacted upon local communities. Research on these issues thus has the potential to bring immediate benefit to those in the local area, while simultaneously generating information that could be usefully incorporated into a larger predictive model. Here again, the first step – of compiling and analysing data on health and education using insights from endogenous growth theory – has the potential to generate immediate benefits, but could also generate information useful to a larger, longer-term goal.

Modification C: Consider ways of allowing for the tourism sector.

Eg. Use insights from Woollett et al (2003) to make the CGE explicitly model important aspects of the Tourism Industry (as per QGEM-T, but at a small scale across the Savannas).

Tourism is an extremely important industry in many regions across the Savannas – but few CGE’s explicitly model that sector (in most cases, those interested in tourism must ‘cobble together’ information from other more commonly used sectors such as accommodation, retail trade, etc). However, there is relatively little publicly available data on tourism in the Savannas. Consequently, any research that could collect data on regional tourism could generate immediate benefit to those in the Savannas. If that data were collected or stored in a format that could be used in a CGE, then the research could also contribute towards the development of a more relevant, larger, predictive model.

Modification D: Consider ways of explicitly allowing for Indigenous issues.

Eg. Use insights from NATSEM’s work with the Centre for Policy Studies at Monash University to look at the way in which changes in the larger economy affect Indigenous persons and at the way changes in Indigenous communities affect the larger economy.

The Australian Research Council is funding Researchers from NATSEM and from CoPs to look at ways of linking one of the Monash’s applied CGEs with NATSEM’s microsimulation models. They have already used ‘top-down’ approaches to the links (using the Monash model to generate aggregate predictions about income and relative prices, and then feeding those into STINMOD to consider the distributional impacts of the changes) and are looking towards developing ‘bottom-up’ linkages (where predictions from the microsimulation models re, for example, the income effect of tax changes, are fed into the CGE, to look at the flow-on effect that such a change might have upon the demand for products in particular sectors).

If it is possible to do that which is described above, then it should also be possible to develop similar ‘top-down’ and ‘bottom-up’ approaches that will allow one to consider the distributional impact of different policies across different regions, and/or across Indigenous and Non-Indigenous households. Although still in its embryonic stages, research like this clearly has much to offer and rapid progress is to be expected.

As noted earlier Indigenous issues are of central importance in the Savannas – in many areas Indigenous persons comprise the majority of the population, and many Indigenous communities are economically ‘disconnected’ from other parts of society. Many stakeholders stressed the need for good-quality data on Indigenous persons, particularly in remote areas. As for previous ‘modifications’, researchers could generate short-term benefits to many by simply compiling relevant data. Ultimately, such data could be incorporated into a larger model – looking at the way in which changes in Indigenous communities affect other parts of the model (eg. the ‘non-indigenous economy and/or the environment) and at the way in which external changes affect Indigenous persons and communities.

Modification E: Consider ways of integrating economic and environmental models.

Eg. Use insights from previous work on ‘green’ CGEs and on systems-frameworks to either add a ‘green’ component to the CGE, or to forge links between a separate environmental module, and the CGE.

There are many different ways of trying to explicitly model economy/environment reactions. For example, CGEs can be readily customised to include physical interactions with the environment – although to date much of this is done by looking at ‘energy use’ per sector – a variable which may be less relevant in the Savannas than in urban areas. Nonetheless, the methodology may be useful; one could, for example, look at water use per sector. Here again the data itself would be useful to those working in water-scare environments – and it might also be useful within a broader model. It is also possible to link economic ‘modules’ with environmental ‘modules’ using a systems type framework (where the modules run independently, but stop and ‘swap’ common variables at specific points in time). Research that is able to identify these common variables, and to develop ways of ‘scaling’ them in a way that satisfies both types of models could generate information that is useful in the short term, but could also be used as input into a larger fully integrated model, thus progressing work towards the larger, longer-term goal.

A final, important point to be made here, is that the system we are attempting to model (the Australian Savannas) may be inherently chaotic. A network of well-built modules (each of which can be updated and improved upon as new data and/or knowledge becomes available) may therefore be a sensible way of exploring trajectories of change over time. Researchers can concentrate on trying to describe the small parts that they know best, and let the (possibly chaotic) model show them what might emerge at the aggregate level as the parts interact and evolve.

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