Modelling Climate Change Impacts using CGE Models: a Literature Review

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Executive summary

To facilitate studies of climate-change policy that include the benefits as well as the costs of policy, it is necessary to start from a base case in which the effects of climate change are identified. There are numerous published CGE-based Australian studies of the costs of policies aimed at restricting Australia's greenhouse-gas emissions but only the ABARE GIAM project has modelled the economic impact of climate change occurring.

Several international studies using CGE models have attempted to estimate the economic costs of climate change. The range of climate change effects covered includes effects on agricultural productivity, energy demand, seal-level, human health and tourism. These studies provide some guidance as to how similar exercises might be undertaken using Australian CGE models. Other parts of the international literature on the integrated assessment of climate change work at an aggregate level and lack the regional or structural detail that will be necessary to inform the debate about climate-change policy in Australia.

1 Introduction

The project specification (Garnaut Review, 2008) sets out the purpose of the project as follows.

> *"The purpose of this project is to discuss and critique the methodologies and results of key CGE analyses on the economic impacts of climate change.*
>
> *The focus of the project will be on key published Australian impact studies. However, where relevant and significant international studies have been identified they should also be included."*

Narrowly interpreted, this leaves the reviewer with very little scope because:

- although there are numerous published CGE-based Australian studies of the costs of policies aimed at restricting Australia's greenhouse-gas emissions, there are very few published CGE-based Australian studies of the impact of climate change on the Australian economy. Indeed, the only such study that we have identified is the recent work by the Australian Bureau of Agricultural and Resource Economics using its GIAM model (ABARE, 2008). A corollary is that the Australian greenhouse-policy studies address the costs of greenhouse policy, but not the benefits[1].
- only a few of the significant international studies of the impact of climate change rely seriously on CGE modelling to map from physical effects of climate change to economic effects. Moreover, the international studies that project the economic effects in a regionally disaggregated way rarely identify the effects on the Australian economy alone. More often, Australia is included in a regional group such as CANZ (Canada, Australia, New Zealand) (Kemfert, 2002), Oceania (Mendelsohn, 2000), Pacific Asia OECD (Deke et al, 2001), Other OECD (Hope, 2006) or Other high income (Nordhaus and Boyer, 2000 and Bussolo et al, 2008).

This suggests that a wider interpretation of the purpose of the project might be appropriate. Our understanding is that the Garnaut Climate Change Review (the Review) intends to include in its final report results of new CGE modelling of the effects of climate change on the Australian economy and of the benefits of climate-change mitigation (Garnaut, 2008).

To model these issues convincingly, the modelling framework will require the following properties.

- It should be capable of generating time paths of the effects on economic variables of interest of shocks over quite long time periods, not just a snapshot for a particular point in time. Climate models indicate that climate change depends on the global accumulation of greenhouse gasses

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[1] For a small country, the direct benefits of reducing its own greenhouse-gas emissions might, in any case, be negligible, even though the country might have much to gain from the attenuation of climate change that might follow from a significant global reduction in emissions.

in the atmosphere, which depends on global emissions and their time profiles. Climate changes sufficient to generate significant economic effects will occur well into the future. Correspondingly, the benefits of preventing climate change will be experienced much later than the costs of the policies that will be required to prevent the change. Consequently, modelling designed to inform cost-benefit judgements about climate-change policy must be able to facilitate the comparison of costs and benefits occurring in widely separated time periods.

- It should have a global, not just a national, focus. One reason is that climate change and its direct effects on any country depend on global emissions and their accumulation in the atmosphere, not just on that country's own emissions. Another reason is that the indirect effects of climate change on a country's economy, or the effects of climate-change policy, might be more important than the direct effects. The paper of Godden and Adams (1992) provides an early example. Using the ORANI-F model, they studied the effects on Australian agriculture of two possible consequences of global warming: a *direct* negative effect on agricultural productivity and a reduction in the demand for Australia's coal exports. Because of the foreign-debt constraint that is a feature of the model's base case, the latter consequence has an *indirect* positive effect on the agricultural sector via an induced depreciation of the real exchange rate. For the authors' calibration of shocks, which is purely illustrative, the positive indirect effect dominates.
- It should be able to take some account of the numerous uncertainties attached to the science and economics of climate change. For practical purposes, this will probably mean that extensive sensitivity analysis will be required to test the robustness of policy conclusions drawn from the modelling framework. More ambitious approaches, unlikely to be feasible within the timeframe of the Review, would include using the model to project formal probability distributions of outcomes on the basis of probabilistic assumptions about key inputs (model parameters or exogenous variables.

We, we have attempted to construct the rest of this project report in a way that is supportive of the Review's intention to augment the currently available stock of Australian CGE-based greenhouse modelling. In particular, we have:

- critiqued the currently available output from the ABARE GIAM project (Section 2). We spend some time on GIAM, firstly because it is the primary example of an integrated assessment model developed in Australia and secondly because it allows us to explain the underlying structure of integrated assessment models in general.
- reviewed some of the major international studies of the physical and economic effects of climate change (Section 3), with a view to identifying:
  - what (if anything) they have had to say about the effects on Australia; and

    - how their results could be used as input to the new Australian CGE modelling of the effects of climate change that the Review intends to include in its final report.

- reviewed the major Australian CGE models that have been used to analyse the costs of greenhouse policy (Section 4), with a view to identifying:

    - what (if anything) about the effects of climate change is implicit in the base cases underlying the relevant policy studies; and

    - their suitability for generating the climate-change results that the Review intends to include in its final report.

Section 5 of the project report summarises our conclusions.

2 The ABARE GIAM project[2]

2.1 AIMS AND STRUCTURE

The development of GAIM is a joint endeavour between ABARE and the CSIRO, with ABARE supplying the economic modelling and CSIRO supplying the physical climate modelling. The main aims of the GIAM project are to allow ABARE to project:

- a base-case scenario for growth in the global (and Australian) economies that includes greenhouse-gas emissions and a consistent picture of their consequences for the global climate. This contrasts with the base cases underlying most Australian modelling of greenhouse-gas policy, which include emissions but nothing explicit about their climate consequences (see Section 4, below).
- the economic effects of greenhouse-gas policy accounting for the benefits in terms of the mitigation of climate change as well as the costs of adopting the policies. This contrasts with most Australian modelling of greenhouse-gas policy, which, as noted above, accounts only for the costs.

Figure 1 outlines the basic structure of GIAM.

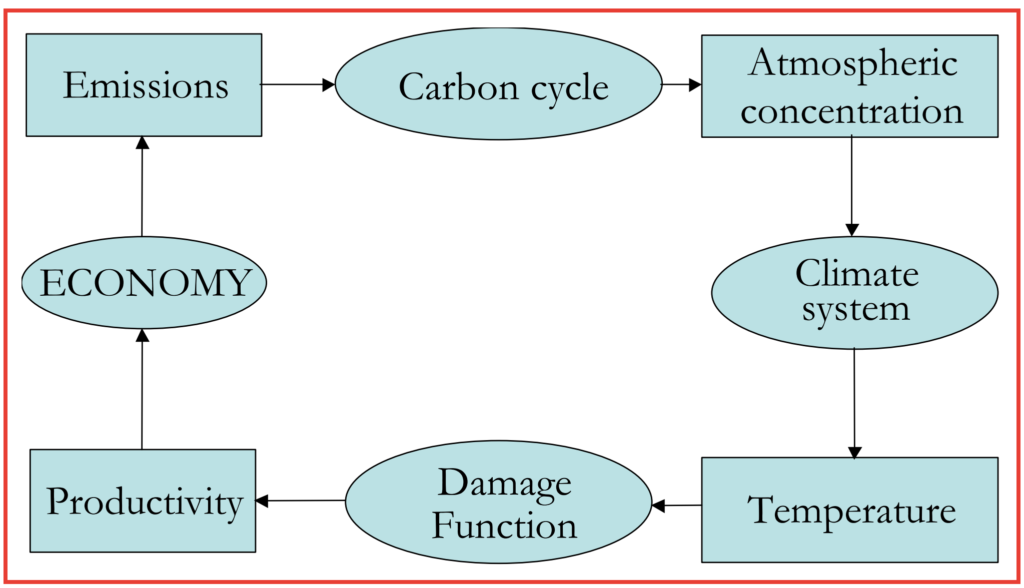

Figure 1: Structure of GIAM

In Figure 1, the ovals represent sub-models and the rectangles represent the variables that connect the models. To project a base case with GIAM, an iterative procedure is used. We start with a preliminary economic scenario for the period of interest, generated in the Economy sub-model. This sub-model includes a

[2] Descriptive material in this section and in Appendix 1 is taken from ABARE (2008) and Pant (2007).

facility for projecting the path of greenhouse-gas emissions associated with economic activity: principally the use of fossil fuels in the generation of stationary energy and in transport. The emissions path from the preliminary economic scenario is fed into two climate sub-modules: a Carbon-cycle sub-model that projects the accumulation of greenhouse gasses in the atmosphere and a Climate-system sub-model projects the development of the global climate on the basis of these atmospheric concentrations. Finally, a system of Damage Functions translates the projected climate change into changes in variables that are relevant to economic development, agricultural productivity, for example. As indicated in Figure 1, the output of the Damage Functions is fed back into the Economy sub-model and the sequence is repeated until satisfactory convergence is achieved. The Economy sub-model will allow agents to adapt to the economic effects of climate change (e.g., to react to changes in relative prices induced by the damage effects) but in generating the base case no policy reactions would be assumed.

Further details on the sub-models of GIAM are given in Appendix 1.

2.2 ILLUSTRATIVE BASE CASE WITH CLIMATE EFFECTS

Using exogenous scenarios on population growth, productivity growth and technological developments with respect to energy usage and the emissions characteristics of energy-using and other production processes, the ABARE authors use GTEM to project a base-case profile of regionally disaggregated economic development and greenhouse-gas emissions for the period 2001-2100. They then allow iteration through the other sub-models of GIAM to modify the base case to include climate effects.

In the ABARE base case without climate damages, Australia's rate of growth is lower than the global average. Allowing for climate effects reduces growth globally and for Australia, with the effect on Australia's growth rate being smaller than the global effect. Global and Australian emissions of greenhouse gases are correspondingly lower. The ABARE authors emphasise that these are preliminary results, produced to illustrate the operation of GIAM rather than as a carefully considered estimate of the actual likely global or Australian effects of climate change.

2.3 APPRAISAL

GIAM provides an impressive example of how an Australia-focussed integrated assessment model can be constructed using readily available components, in particular drawing on computable general economic modelling techniques that have a long history in policy analysis in Australia. The GIAM results that have been published to date are preliminary and just illustrative of the capability of the model. In particular, the range of climate-change effects included is not yet wide enough to provide a base case for assessment of the benefits and costs of greenhouse policy. As indicated in Section 3, the international literature provides a good starting point for the inclusion of several additional potential effects of climate change. Nor have they been reported in enough detail to permit judgements about whether or not they are detailed enough and convincing enough to support the ambitions of the Review for new modelling results. But the GIAM project is innovative in the Australian context, is well documented (at least as far as its GTEM sub-model is concerned) and certainly represents the type of structure that is appropriate for the modelling analysis that the Review requires.

3 International studies

The international literature includes many examples of studies that attempt to evaluate the economic effects of human-induced climate change and of the costs and benefits of policies designed to mitigate those effects. They all involve structures that combine economic models with models of the effects of greenhouse-gas emissions on the global climate and damage functions that project the effects of various dimensions of climate change on various economic variables. But not all of them rely on computable general equilibrium modelling for their economic content and few of them report results for Australia on its own. In this section, we first examine four published international projects that do use CGE modelling, two of which rely on versions of the GTAP model. Then we look at the major projects that rely on more aggregated economic modelling.

3.1 MODELS INCORPORATING CGE ECONOMIC COMPONENTS

3.1.1 Models associated with the Fondazione Eni Enrico Mettei (FEEM) and Roberto Roson of the Ca' Foscari University in Venice.

In a series of papers, Roson and co-authors have analysed the effects of climate change on several dimensions of the global economy, including tourism (Berrittella et al, 2006), coastal inundation (Bosello et al, 2007) and human health (Bosello et al, 2006). We provide some details about how the relevant climate-change shocks are formulated in a sub-section below.

The FEEM models use versions of GTAP-E, i.e., the basic GTAP model expanded to include greenhouse-gas emissions (Burniaux and Truong 2002). The papers cited above use a comparative-static methodology with GTAP-EF, an enhanced version of GTAP-E. The methodology involves generating snapshots of the global economy for points of time sufficiently far into the future to be of interest in the context of climate change (typically 2010, 2030 and 2050). The modellers first calibrate the model to base snapshots generated using database-projection techniques developed by the CoPS team and including no climate-change impacts. They then shock the calibrated models with climate change impacts taken from the FUND model[3]. Under this methodology, the economic effects of the relevant dimensions of climate change are shown deviations of the values of economic variables from their base-case values at the selected snapshot dates. There are no complete time paths for the global economy, either with or without climate-change effects. Hence, neither is there a time path of the effects of climate change. This restricts the usefulness of the results for assessing the overall costs and benefits of climate-change mitigation, which requires a weighting of costs and benefits occurring at different points in time.

3 FUND is an integrated assessment model developed at the University of Hamburg and incorporating damage functions due to Tol (2002).

In a more recent paper (Eboli et al, 2008), the FEEM modellers describe a new, dynamic version of their model, called ICES. ICES has recursive dynamics focussing on capital and debt accumulation, just as in GTEM. Using an 8-region, 17-sector version of ICES, the modellers first project an annual base profile for the global economy without climate-change impacts for the period 2001-50. They then superimpose time paths of climate-change effects on the base profile. The dimensions of climate effects covered are: effects on agricultural productivity; effects on energy demand; effects on human health; sea-level effects and effects on tourism.

This study provides an interesting example of how a great deal of detail about the effects of climate change can be accommodated in a recursive-dynamic CGE model. The results demonstrate that at both the regional and sectoral levels there will be winners as well as losers from climate change. In a general-equilibrium setting, there are winners as well as losers even from predominantly negative shocks: across-the-board reductions in agricultural productivity, for example.

As is the case for GTEM, the outputs of the ICES model include projections of the effects of climate change on greenhouse-gas emissions. In the discussion ABARE's GIAM in section 2 above, we noted that this feature of GTEM requires iteration between the economic and climate sub-models to produce projections with climate-change effects. Results from the ICES study, however, indicate that the emissions effects are predominantly distributional: emissions in some regions and sectors fall but in others they increase. The aggregate level of emissions does not change much, suggesting that in practice it will not make much difference whether an iterative procedure is used or not.

Methods for formulating climate-change shocks

Agricultural productivity

This is the most widely studied of the economic effects of climate change. There are numerous studies (domestic and international) of the direct effects of climate change on agricultural variables such as crop and pasture yields[4]. In applying the results of such studies as shocks for general-equilibrium analysis of the effects of climate change, the physical shocks are first calibrated to be consistent with the climate-change scenario under study and then transformed into shocks to parameters of the agricultural-industry production functions in the CGE models. Many of the CGE models have specifications of their agricultural sectors that are detailed enough to allow the production-function shocks to be input-specific (e.g., land-using or fertilizer-using technical change). In other cases, the shocks are applied to total-factor productivity in agriculture.

Another dimension of the general-equilibrium effects on a given economy of the impact of climate change on agriculture is the impact on the world prices of agricultural commodities. In multi-country CGE models such as the GTAP-based models, these price changes are endogenous. In single-country models

4 Examples are ABARE (2007) and Adams et al (2004).

such as the Monash-based models or IGEM (Section 3.1.4), shocks to the positions of agricultural export-demand or import-supply curves will be required.

Energy demand

Procedures for including energy-demand effects in CGE assessments of the economic effects of climate change are described in Bosello et al (2007)[5]. Shocks for the CGE model are based on econometric estimates of the elasticity of demand for various forms of energy with respect to temperature, taking account of nonlinearities implied by the competing effects of heating and cooling uses of energy and of the effects of base climate conditions. The econometric estimates translate climate change into changes in the demand for energy (at given prices and income). These demand shocks are then mapped to shifts in parameters of the household-demand or production-function equations included in the CGE model.

Human health

As reported in Bosello et al (2006) there are many studies of the effects of climate change on mortality and morbidity due to disease. Results of these studies are used to map climate-change scenarios into mortality/morbidity scenarios formulated at the level of regional disaggregation of the CGE model. The implications of these scenarios for regional labour supplies are applied as shocks to the CGE model. Also included are shocks to household-demand parameters and to the structure of public consumption to represent the effects on private and public demand for health services that are implied by the changes in morbidity.

Sea-level rise

A good example of the approach taken to estimating shocks appropriate for use in CGE simulations of the effects of climate-change-induced rises in sea levels is given in Darwin and Tol (2001); this study combines the use of Tol's FUND integrated assessment model and Darwin's agriculturally oriented FARM CGE model.

The first step is to use FUND to estimate the amount of dry land lost to sea-level rise in each region for given climate-change scenarios, assuming no coastal protection. Lost land is allocated to land type (defined by climate) and land use, using data from FARM. Lost land and the associated lost capital are then valued using data on the returns to land and capital by land type and use. Next, incorporating data on the costs of coastal protection (including the value of wet land lost in the process of protecting dry land) FUND is used to estimate the optimal level of coastal protection. These calculations give the researchers the option of analysing the effects of climate-change-induced sea-level rise either under the assumption of no coastal-protection response or with optimal protection. The general-equilibrium effects of seal-level rise (including general-equilibrium measures of welfare costs) are simulated in the CGE model via sector-specific shocks to the availability of land and capital and via diversion of

5 Another example is Jorgenson et al (2004); see section 3.1.4.

the economy's investment spending from productive uses to coastal protection (assumed to be unproductive)[6].

Tourism

Econometric estimates of the effects of climate on bilateral tourist flows are available from the Hamburg University Tourism Model (Hamilton, 2003). The FEEM modellers use these data to formulate region-specific shocks the structure of household spending and to consumers' income. An increase (decrease) in tourism increases (decreases) the share of household spending allocated to tourism services and increases (decreases) income available for consumption spending in the region. An alternative (more intuitive) approach would be to define a dummy sector (international tourism) and to shock the position of the relevant export-demand schedule.

A country-specific study

Another paper from this stable (Carraro and Scobbi, 2008) demonstrates how modelling of this type can be used in conjunction with detailed information about the effects of climate change on a particular national economy: in this case, the Italian economy. The authors assess the direct economic costs of climate change on four areas in Italy: alpine regions, regions prone to floods and landslides; coastal zones; and arid zones. In assessing the costs, they take account of the costs of adaptation measures that are likely to be undertaken (e.g., the costs of artificially enhancing snow cover in alpine areas and the costs of protecting against sea-level rises in Venice). To compute the overall implications of these direct effects for the Italian economy, they are fed into the FEEM global CGE model. The model accounts for the autonomous adaptation that results from the responses of agents in the economy to climate-change-induced changes in relative prices, including responses of the economy's trade flows.

It is detailed information of this type that it is required to inform domestic debate about climate change ad the merits of pursuing climate-change policy. Given its extensive experience with CGE modelling, Australia is well placed to produce studies that include fine structural detail about the Australian economy (see Section 4, below).

3.1.2 DART

Deke et al (2001) report results generated from an integrated assessment model developed at the Kiel Institute for the World Economy based on the DART computable CGE model. DART is a recursive-dynamic multi-regional CGE model, much like the energy/emissions-enhanced versions of the GTAP model, e.g., GTEM (Section 2) or ICES (Section 3.1.1). To translate emissions projections derived from DART into climate changes, the authors use simplified "impulse-response" representations of standard carbon-cycle and three-

6 This last effect can be modelled as an additional depreciation term in the model's capital-accumulation relationships.

dimensional global climate circulation models[7]. They concentrate on just two effects of climate change: effects on agricultural productivity and effects on investment required to protect against sea-level rise. They impose the latter on the economic model by introducing quasi-depreciation terms into the model's capital-accumulation equations. Their experience, like that of Eboli et al (see Section 3.1.1, above) is that, in generating economic scenarios that include climate-change effects, it is unnecessary to complete the loop accounting for the effect on emissions of climate change.

The DART project as described in Deke et al (2001) is now a little dated; certainly it is not as ambitious as the ABARE GIAM or FEEM projects. We were unable to find any substantial updating of the model or its application on the Kiel Institute website. Nevertheless, the Deke paper does provide a careful example of how CGE models can be used in conjunction with other climate inputs to analyse the effects of climate change.

3.1.3 ENVISAGE

Bussolo et al (2008) describe a new model global recursive-dynamic CGE model (called ENVISAGE) that is being developed at the World Bank. ENVISAGE is based on the Bank's LINKAGE global trade model but has a more detailed energy specification a vintage-capital specification that allow various forms of energy substitution, including the idea that it may be easier to substitute capital for energy when new capital is being installed than with the existing capital stock. Like other integrated assessment models, ENVISAGE also includes modules describing emissions generation, the translation of emissions into atmospheric concentrations of greenhouse gases and the implications of greenhouse concentrations for global temperature. Finally, damage functions transform projections of global temperature change into shocks to agricultural productivity.

Typical of integrated assessment studies using CGE models, Bussolo et al report the results of three scenarios projected out to 2050: one (BaU) in which climate-change effects on agriculture are included; a second scenario (BaUND) in which the climate change effects are excluded; and a policy scenario (GBL) that includes a global carbon tax. What distinguishes the ENVISAGE project from other integrated assessment projects is it focus on personal income distribution within and between regions. To effect this, the modellers run ENVISAGE in conjunction with the Bank's GIDD micro-simulation model of income distribution.

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7 The impulse-response functions aim to capture the relationships between emissions of greenhouse gases, atmospheric concentrations of the gases and climate change that would be captured in a fully articulated integrated assessment model by components such as the Carbon-cycle and Climate-system sub-models included in Figure 1. Full runs of such sub-models explicitly, typically entail substantial inputs of time and computer power. To economise on these inputs, simplified impulse-response approaches are common. It is claimed that they provide good approximations to the climate models represented, at least for changes in emissions that keep atmospheric concentrations well below the catastrophic threshold.

3.1.4 IGEM

The models described in the previous three sections are all global models. Another approach is to simulate the effects of climate change on a single economy by shocking a stand-alone model of that economy. Jorgenson et al (2004) provides an example for the US economy, using the IGEM model. IGEM is a dynamic 35-sector model of the US economy. Unlike the models dealt with above, IGEM includes forward-looking behaviour for investors and consumers; hence, its dynamics are not recursive[8].

The authors use regression techniques to estimate the effects of changes in temperature and/or precipitation on unit costs for crop and livestock agriculture, forestry, fishing, the provision of space heating and cooling, and water supply. The estimates are used to specify sector-specific unit-cost shocks implied by a number of climate-change scenarios[9]. Also included are shocks to investment, representing the diversion of capital from other uses to protection against sea-level rise, and shocks to the labour supply, reflecting the effects of climate change on human health[10]. The results of the IGEM simulations indicate that climate change might produce short-term benefits for the US economy but that these are offset by longer-term costs. The agricultural effects are the dominant factor.

3.2 OTHER INTEGRATED ASSESSMENT MODELS

The literature includes several well-known integrated assessment models that include all the relationships covered by the sub-models illustrated in Figure 1 but without structural detail. In particular, their economic models have less sectoral or regional disaggregation than the CGE models covered in sections 2 and 3.1. Key examples are the pioneering DICE model due to Nordhaus (2008), MERGE (Manne and Richels, 2004) and the UK PAGE2002 (Hope, 2006) that featured heavily in the Stern review. These models are essentially reduced-form structures in which the reduced-form equations are calibrated so that their "results approximate those of the most complex climate simulations" (Hope, 2006).

DICE has no regional or sectoral disaggregation[11]. Its economic core is a neoclassical growth model in which gross output is produced by capital and labour via a Cobb-Douglas production function but temperature-change-induced damages and investment in emissions abatement are deducted in computing the "net output" that is available for consumption and investment. The model

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8 The question of whether or not to include forward-looking behaviour in CGE models depends on issues of computational convenience and judgement about whether adding such behaviour enhances significantly the analysis being undertaken. The models maintained at CoPS, for example, can be run with forward looking behaviour, although this increases computing time to the extent that compromises in terms of sectoral detail are often required. For this reason, the models are more often run with myopic behaviour.

9 In the case of space heating and cooling, the shocks are applied as changes in the demand for the fuels used in the production of heating and cooling.

10 The same approach to including health impacts in CGE simulations is adopted in a study of Brazil by Patanayek et al (2007)

11 A regionalised version of DICE (RICE) is currently under development.

includes equations that relate emissions to gross output and abatement, temperature to emissions and damages to temperature.

PAGE2002 distinguishes eight regions but has no sectoral disaggregation. Global emissions drive regional temperature via a reduced-form representation of the greenhouse effect, with account also taken of the cooling effect of sulphate aerosols. It accounts for market and non-market damages of climate change – all temperature driven, including the catastrophic effects that could occur if global temperature exceeds a catastrophe threshold. A Monte-Carlo approach is adopted for simulations with PAGE2002, each simulation being run 1000 times with random draws of the model's parameters to generate probability distributions of results rather than point estimates.

Like PAGE, MERGE has regional disaggregation but it also distinguishes between energy and non-energy production. The production functions include inputs of capital, labour and energy, with substitution allowed between capital and labour, electric and non-electric energy and Capital/labour and energy. The model distinguishes between market and non-market damages both of which are temperature driven. Market damages reduce the amount of gross output that is available for consumption, investment or net exports. Emissions from energy production and non-energy sources drive global temperature changes, with account taken of carbon sinks.

The emphasis of these models is on analysis of aggregate welfare costs and benefits of climate-change policy rather than on the structural effects of climate change and climate-change policy. Because of the long time frames over which the effects of climate change are spread, a particular concern with normative issues of time discounting has emerged

4 Australian CGE models

Apart from ABARE and its GIAM, GTEM and AUSREGION models, Australia is host to two internationally known CGE modelling projects: the MONASH-based models of CoPS and McKibbin's G-cubed model, both of which have figured prominently in debates about policies to limit Australia's greenhouse-gas emissions. But to date neither have addressed explicitly the economic effects of the occurrence of global warming. In their studies of greenhouse policy, neither has estimated the benefits of avoiding global warming, just the costs of the policies.

One interesting issue that we consider is what (if anything) is assumed about global warming in the economic-development scenarios that these models project as base cases against which to evaluate the costs of greenhouse policy. If the policy studies are to be extended to cover the benefits as well as the costs of greenhouse policy, base cases including the effects of climate change will be required. The second issue that we address is what role the models are suited to play in evaluating the economic effects of climate change.

4.1 MONASH MODELS

4.1.1 Current MMRF-GREEN base case

For its greenhouse-policy modelling, the CoPS team generally uses MMRF-GREEN (e.g., Allen Consulting Group, 2006). MMRF-GREEN is a stand-alone dynamic CGE model of Australia with regional disaggregation to the State/Territory level and with a detailed treatment of stationary energy and transport and of the associated greenhouse-gas emissions. The time horizon for the publicly available MMRF-GREEN greenhouse-policy studies is 2030.

An important feature of the base cases that the CoPS team generate for these studies is that, rather than attempting to forecast all variables internally, they make extensive use of forecasts from other expert groups. In particular, they use:

- macroeconomic forecasts from Access Economics, at least for the first part of the forecast period;
- forecasts of volumes and prices of commodity exports from ABARE;
- forecasts for world oil prices and gas supplies from the International Energy Agency; and
- forecasts of the effects of existing greenhouse policies (MEPS, GGAP, MRET) from Australian government sources.

Also included are detailed scenarios on changes in technology and household preferences that are formulated on the basis of CoPS historical studies of the development of these variables. Finally, McLennan Magasanik Associates (MMA) supplies projections of changes in the structure of the electricity-generation sector. The MMA electricity model is run iteratively with MMRF-GREEN to ensure that the MMA structural projections are consistent with the MMRF-GREEN projections for electricity demand.

None of these inputs appear to be based on explicit assumptions about the effects of global warming, although there may be implicit assumptions that are not articulated. We note, however, that the most comprehensive of the studies reviewed in sections 2 and 3 above (Eboli et al, 2008) suggests that the effects of global warming on aggregate regional output and global sectoral output would be quite small out to 2030 (generally less than 0.4%).

4.1.2 Suitability of CoPS models for use in the evaluation of the economic effects of climate change

Of the available models, MMRF-GREEN provides the most detail about the Australian economy, including detailed specifications of the energy and transport sectors all at the State/territory level. The CoPS team has also developed top-down facilities to map results to even higher levels of detail about sub-state regions, income distribution and the occupational structure of the labour force. Hence, the CoPS models can identify the potential winners and losers from climate change and climate-change policy at the fine level of detail required to support public debates about Australia's response to the threat of climate change. On the other hand, MMRF-GREEN is not a global model. This means that information about global aspects of climate change and response to it have to be fed into MMRF-GREEN as exogenous shocks. The international literature provides several examples of how this can be done to assess the single-country effects of climate change (e.g., Jorgenson et al, 2004). Similarly, policy studies with MMRF-GREEN of the costs and benefits of internationally coordinated climate-change policy will require scenarios describing the effects of international policy on key variables such as the positions of the demand schedules for Australia's exports and the its import-supply schedules.

4.2 G-CUBED

4.2.1 Current G-Cubed base case

McKibbin et al (2004) discuss at length issues relevant to projecting base cases for the global economy and greenhouse-gas emissions for climate-change studies using G-Cubed[12]. The time horizon envisaged is 2100. The main issue upon which they dwell is convergence: what are the economic variables with respect to which we should assume convergence between regions over the forecast period and how should those variables be compared across regions. There is no discussion of the role of global warming.

12 G-Cubed is a 14-region, 13-sector dynamic CGE model, emphasising inter-temporal optimisation and financial assets.

4.2.2 Suitability of G-Cubed for use in the evaluation of the economic effects of climate change

G-Cubed is a global model capable of projecting future time paths of greenhouse gases, although its representation of the key stationary-energy and transport sectors are not as detailed as available in some other models. We are not aware of any attempts to date to use G-Cubed as the economic sub-model in an integrated-assessment framework. It would be interesting to see what value would be added in this context by the additional dynamic features that G-Cubed offers relative to the more-common recursive-dynamic models, e.g., GTEM or ICES. In any case, it is clear that to provide analysis of the benefits as well as the costs of climate-change policy, G-Cubed would require a base case that includes the effects of climate change and an ability to include the effects on climate change of local and international policy. Unless G-Cubed is to be set in an integrated-assessment framework, this would require the imposition of shocks derived from models that do capture the effects of climate change on key exogenous economic variables.

From the point of view of the Australian debate about climate change, G-Cubed should be regarded as complementary to the other available models. Being a global model, it has significant overlap with GTEM. A key issue (noted above) is the practical significance of its dynamic structure relative to recursive approach adopted for GTEM. It certainly lacks the detail about the structure of the Australian economy that the CoPS models offer.

5 Conclusion

In Australia to date, the issue of how climate change would affect the economy has been studied much less than the issue of what costs climate-change policies would impose on the economy. To facilitate studies of climate-change policy that include the benefits as well as the costs of policy, it is necessary to start from a base case in which the effects of climate change are identified. The ABARE GIAM project is attempting to do this for Australia but the other well known Australian CGE models (MONASH and G-CUBED) have not yet done so.

The international literature on integrated assessment models includes examples that use CGE models for their economic content. Our survey of this literature discusses the range of climate effects that has been included and offers guidance about how the necessary additions to the major Australian models might be made.

Appendix 1: Sub-modules in GIAM

A1.1 ECONOMY SUB-MODEL

The Economy sub-model in GIAM is GTEM. GTEM is a variant of the GTAP model that ABARE has been developing for some time now; an earlier incarnation was MEGABARE. The GTAP model is a multi-country CGE model developed at Purdue University using the techniques pioneered by the team currently located at the Centre of Policy Studies (CoPS) at Monash University[13].

GTEM divides the global economy into nine regions, one of which is Australia, distinguished as a separate region. In each region, production is divided into 28 sectors, with key energy-using sectors (electricity and iron & steel) allowed to substitute between technologies in response to changes in their relative costs. Fourteen technologies for generating electricity are distinguished. The sub-model allows for learning by doing in the introduction of new technologies and for decreasing returns in natural-resource extraction.

GTEM is a dynamic model, capable of projecting time paths of economic variables. The main dynamic relationships are capital accumulation, foreign-debt accumulation and accumulation of the population/labour force. The assumption of static expectations in equations relating investment to expected rates of return, ensures that the solution of the model for any period depend is independent of information about solutions for future periods, i.e., it ensures that the model can be solved recursively.

As noted in Section 2.1, GTEM includes a facility for tracking greenhouse-gas emissions. For the three main greenhouse gases (Carbon dioxide, methane and nitrous oxide), emissions are related on a detailed sector- and region-specific basis to the economic activities that are responsible for them (e.g., the combustion of fossil fuels, agricultural output or the use of key emitting inputs such as fertilizer, the outputs of other sectors responsible for fugitive emissions and the generation of solid waste)[14].

A1.2 CLIMATE SUB-MODULES

The Climate-system sub-model included in GIAM is the CSIRO's Mk3L model. Mk3L deals explicitly only with carbon dioxide. Hence, the atmospheric

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13 The GTAP project is led by Tom Hertel who developed his interest and expertise in CGE modelling during his Fulbright Fellowship at the University of Melbourne, where the current CoPS team was then located. GTAP is best known in the economic-modelling community for the multi-country input-output databases that it has developed and maintained to support multi-country models. These data are used extensively by modellers, even those whose modelling techniques differ from the techniques preferred by the CoPS team and Hertel. Several of the international studies discussed in Section 3 use versions of the GTAP model. Further information about GTAP can be found at https://www.gtap.agecon.purdue.edu/.

14 The model also includes a treatment of "high global-warming potential" gases (hydroflourocarbons, perflourocarbons and sulphur hexafluoride) but these are not currently fed through to the climate submodules.

concentrations of other greenhouse gases projected by the Carbon-cycle sub-model have to be converted to CO_2-equivalents. Mk3L models the functioning of the atmosphere, the oceans and land surface, and projects a range of regional climate outcomes, including temperature, precipitation, soil moisture, snow and ice thickness, surface runoff and ocean currents. The current implementation of GIAM, however, exploits only the temperature projections.

A1.3 DAMAGE FUNCTIONS

The loss-function approach currently taken in GIAM follows the approach taken in the MERGE integrated assessment model (see Section 3, below). For each region and time period, an economic loss factor is defined. For region r in period t, the value of the loss factor depends on the change in average surface temperature relative to the reference year (2000) and on the region's per-capita real income relative to the per-capita real income of the reference region (the USA). In the current version of GIAM, the economic-loss factors are applied to the Economy sub-model as negative shocks to total-factor productivity. Together with the parameterisation described in ABARE (2008), this structure implies that the economic damage associated with climate change depends only on temperature rise and increases more than proportionally to the rise in temperature up to some threshold temperature that is catastrophic from an economic point of view. In the sub-catastrophic range, damage is more serious for developing than for developed countries.

The ABARE authors stress that this is only a preliminary specification of the economic impact of climate change. The international literature on integrated assessment models (see Section 3) provides plenty of ideas about how the specification could be generalised. These include allowing economic impacts to be driven by climate variables other than temperature, allowing climate variables to affect economic variables other than total-factor productivity and allowing climate change to trigger positive as well as negative economic shocks.

Appendix 2: Notes on GCCR Reference list

ABARE (2008)	• GIAM documentation • **Dealt with at length in Section 2**
ABARE (2007a)	• CSIRO/BoM estimates of change in Australian temperature, rainfall and extreme weather events. • ABARE/CSIRO estimates of direct effects on agriculture • Stand-alone GTEM/AUSREGION simulations of declines in regional activity plus changes in agricultural productivity – no emissions/climate change feedback as is allowed by GIAM
ABARE (2007b)	• Case studies of effects on two regions (WA, NSW) of agricultural-productivity effects of climate change • Based on stand-alone simulations with AUSREGION
Gunesekera et al (2007)	This is the same as ABARE (2007a)
Howden et al (2006))	• Canvasses options for agricultural industries to adapt to climate change. • No economic modelling.
Nelson et al (2005)	• Constructing an index of vulnerability from farm-survey data. • Not about climate-change modelling.
Jorgenson et al (2004)	• Sector-specific damage shocks imposed on a stand-alone, dynamic CGE model of the US economy (IGEM) • **Covered in Section 3.1.4**
Wittwer (2008)	• Not on topic.
Roson (2004) Bosello et al (2005&2007) Berrittella et al (2004)	• FEEM models • **Dealt with at length in Section 3.1.1**
Patanayek et al (2007)	• Simulations with Brazil/Rest of South America/Rest of World version of US EPA ADAGE dynamic CGE model • Health effects using the same methods as Jorgenson et al (2004) • **Brief reference in footnote in Section 3.1.4**
Preston and Jones (2006)	This deals only with the direct physical effects of global warming, not the economic effects.
AGO (2002)	This is s "glossy", dealing mainly with the physical effects of climate change; it includes no economic modelling.
AGO (2004)	This is a fairly lightweight discussion of some of the issues and methods relevant to the economic analysis of climate change. It includes no original economic modelling.

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