From input-output to computable general equilibrium modelling of water use in the Canterbury region

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Abstract

Current systems of water allocation and use in New Zealand reflect its relative historical abundance. In many parts of the Canterbury region though, massive growth of irrigated agriculture and other water uses has led to problems of water scarcity, nitrate contamination of groundwater and ecological impacts in streams and riparian ecosystems. New allocations of water are increasingly contested by different users and by community and environmental groups. While existing allocations are presently relatively secure, their equity and economic efficiency are increasingly questioned. These issues present major policy challenges to the regional authority, Environment Canterbury.

In this paper we describe initial development of a regional CGE model suitable for analysis of water policy issues, and development of an environmental and social accounting matrix for Canterbury that can be used to calibrate this model. We build on previous work in which we applied environmental input-output techniques to examine the role of water in Canterbury's economy. We focus on the particularities of the Canterbury case, as well as the practical challenges of applying a data-intensive modelling approach in a country where regional economic and environmental statistics are very limited.

Introduction

In the region of Canterbury, extractive, in-stream and passive uses of water play vital economic, social and cultural roles. Extractive use is dominated by pastoral irrigation on the coastal plains. In New Zealand, water has historically been relatively abundant and current systems of allocation – essentially, first-come, first served – reflect this (Ministry for the Environment, 2004b). However, over the last decades, population and economic growth, particularly of irrigated agriculture and hydroelectricity generation, have led to many water resources becoming scarce and contested in many areas. In many areas of Canterbury, groundwater resources are at or beyond sustainable limits, as is extraction from many rivers and streams (Environment Canterbury, 2006a, b). The combined pressures of water extraction and nitrate pollution from fertilisers and livestock have led to serious water quality problems in many lowland streams and increasingly in shallow aquifers (Environment Canterbury, 2006b).

Both decision-making processes for and outcomes of water allocation have become highly contested. This applies both to a number of specific high-profile administrative or judicial decisions (e.g. Environment Court, 2005), and to the more general situation of the region and its major catchments and groundwater zones. One important dimension of the contested issues about water allocation is whether, first, the current allocations are economically efficient, and second, how water can best be allocated – or even reallocated – to increase the economic benefits flowing from its use. An example of this is the limited additional water rights accessible to the rapidly expanding vineyards of the Waipara district.

Regional and district councils have a strong interest in understanding the economic costs and benefits of their decisions in relation to water allocation, the economic potential of reallocating water, and the potential of economic policy instruments in the allocation and management of water. Lennox and Andrew (2005) have previously used environmental input-output (EIO) analysis to examine backward- and forward-linked water use of regional industries in Canterbury. These links provide measures of the upstream and downstream economic activity associated with the direct water use of each industry. However, while EIO provides useful descriptive information that facilitates understanding of the role water plays in economic production, it is not well suited to prospective analyses of changes in economic drivers, the effects of climate change, new water supply infrastructure, or the effects of policies.

These issues can more easily be considered within the more flexible framework of a computable general equilibrium (CGE) model. In this paper we describe the construction of a regional environmental and social accounting matrix (ESAM) for Canterbury and a relatively simple CGE model. The latter will serve as the basis for development of more sophisticated versions of the model, tailored to specific policy questions[1]. The construction of an ESAM at the regional level is often difficult because of a lack of data, and this is certainly the case in New Zealand. For this reason, we describe the sources of data and assumptions in some detail. We also discuss some of the specific issues that are faced in regional CGE modelling of water allocation issues.

Context of water issues in Canterbury

Canterbury is a region in the South Island of New Zealand (Figure 1). The population in 2001 was 481 431, 12.9% of the New Zealand total. The region has one city, Christchurch, with a population of 316 227. The region's climate is temperate, with 648 mm average annual rainfall in Christchurch, 844 mm in Kaikoura (in the north), and only 573 mm in Timaru (in the south). In contrast, the foothills and main dividing ranges on the region's western border receive far more precipitation (often as snow), which feeds the many braided river systems that flow eastward across the coastal plains. Variability of precipitation, as well as variation of permanent snow and ice, contributes to significant inter-annual variation in surface water availability and groundwater levels.

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[1] This is part of a 4-year project 'Old Problems, New Solutions', for which we have recently received funding from the Foundation for Research Science and Technology, New Zealand.

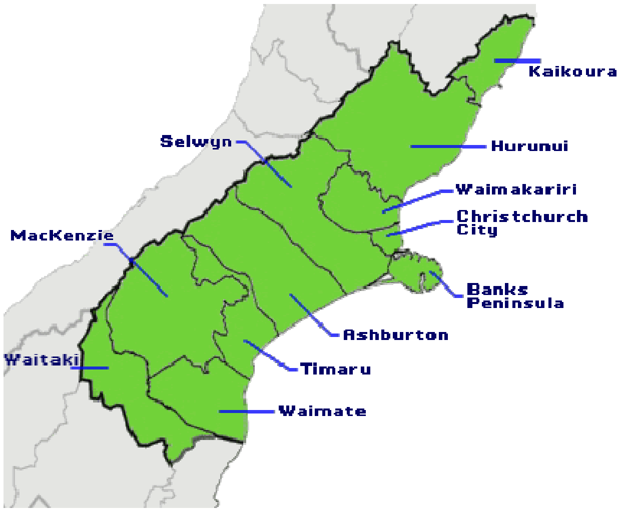

Figure 1 – Map of New Zealand's South Island

The total land area of Canterbury is 2 341 800 ha. Of this, land under irrigation systems increased from 150 000 ha in 1985 (Lincoln Environmental, 2000) to 287 000 ha in 2001/02 (Ministry of Agriculture and Forestry, 2003); 61% of all land under irrigation in New Zealand. In recent years, expanding and intensified dairy farming has dominated rural land use change in Canterbury. In 1999, 34% of irrigated land was used for dairying, most of the remainder being other pasture (36%) and arable crops (27%) (Lincoln Environmental, 2000). South Canterbury, closely followed by North Canterbury, has the largest average farm size and highest intensity of dairy production in New Zealand[2]. Agricultural intensification also involves other inputs[3], including fertilisers implicated in water and groundwater pollution.

In South Canterbury (and neighbouring North Otago) there have been major hydroelectric developments in the upper and middle catchments of the Waitaki, involving large-scale water diversion and storage. In addition, there are many small- and medium-scale diversion and/or storage schemes in Canterbury that meet water supply (mostly irrigation and stock water) needs. There are continuing pressures to increase both hydroelectric generation and water supply storage and diversion in the region. Although this paper focuses on extractive water uses, impacts of water storage and diversion systems should not be forgotten. These are mainly associated with altered stream flows (e.g. impacts on riparian biodiversity and ecosystem services) and artificial reservoirs or lake levels (e.g. recreational and aesthetic benefits, flooding of original habitat). Increasing water storage may also increase surface evaporation.

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[2] In 1998/99, South Canterbury herds averaged 437 cows at 2.9 cows per hectare producing 122 g protein per cow. By 2003/04, these figures had increased to 604 cows, 3.08 cows per hectare and 161 g protein per cow (LIC, various years).

[3] For instance, in an analysis of direct and embodied energy use in the New Zealand dairy industry, Wells ((2001)) found that irrigated farms used an average 12.2 GJ/ha of electricity and applied 135 kg N/ha, while non-irrigated farms used an average 3.4 GJ/ha of electricity and applied 68 kg N/ha.

Households, commercial and secondary industries are also significant water users. Sixty-three percent of Canterbury households are located in Christchurch. These households use 70% of delivered water in the city (p. 29 Lincoln Environmental, 2002). Average household use is relatively high (625 L/day), as large gardens with water-intensive plantings are common, and the penetration of water-efficient devices and appliances is still very poor. Intra-annual variation is significant, with much higher and more variable demands in the summer months (e.g. for irrigation of household and public gardens and sports fields) than in the winter months (p. 30 Lincoln Environmental, 2002).

Finally, Canterbury's water systems generate significant social, cultural and economic values from in-stream and other non-consumptive uses (Sharp et al., 2004) and also have significant option and existence values (Sharp & Kerr, 2005). These values may be threatened by changes to stream flows and lake levels, water pollution, and consequent impacts on aquatic and riparian ecosystems. From an economic perspective, non-consumptive uses are particularly important to the tourism industry (Ministry for the Environment, 2004a).

Literature Review

Environmental input-output (EIO) analysis has been widely used to study water use, and in some cases also pollution at both national and sub-national scales. Seminal works include Hite and Laurent's (1971) study of ecological linkages (including water) in a coastal region of California and Lofting and Davis' (1968) multiregional study of water resources in California. A resurgence of interest in EIO analysis in the 1990s has seen many more applications to water resources (e.g. Dietzenbacher & Velázquez, 2007; Duarte *et al.*, 2002; Hassan, 2003; Lennox & Andrew, 2005, 2006; Lenzen & Foran, 2005; Velazquez, 2006; Wang *et al.*, 2005) and, less frequently, to water pollution (e.g. Duarte Pac & Sánchez-Chóliz, 1999; Okadera *et al.*, 2006).

Most commonly, IO techniques have been used for *ex post* analysis, either of economic structures and water use at a point in time, or of their change between two points in time. IO techniques are less suited to *ex ante* analysis of either hydrological or policy constraints on water resources and their use. The Leontief production functions of economic and resource inputs used in EIO models do not allow for substitution of other inputs as water becomes scarce. Instead, any adjustments must occur via changes in final demands. No automatic mechanism for such an adjustment is inherent within an EIO model, although this can be achieved within a more general linear programming framework (ten Raa, 2005); for instance by changing exports to maximise GDP, given water resource and other constraints. However, this does tend to generate rather extreme solutions due to the linearity of the production system and the on/off nature of the inequality constraints. There are analogous difficulties with the Leontief dual price model. Regional scarcity of water is unlikely to generate a simple cost-push effect, especially when the water is mainly used in agricultural industries that are essentially price-takers in global commodity markets.

Another limitation of EIO multipliers is that they do not capture feedbacks from household income and expenditure of changes in an exogenous account (typically exports). These effects can be captured in accounting multipliers derived from an environmentally extended social accounting matrix (ESAM[4]) (e.g. Lenzen & Schaeffer, 2004; Morilla *et al.*, 2007; Resosudarmo & Thorbecke, 1996; Xie, 2000). With the addition of information on income elasticities, more realistic 'marginal' fixed-price multipliers can be calculated (Khan, 2007). Most other limitations of EIO multipliers (e.g. Leontief production functions) are shared. While ESAM multipliers are now becoming more widely used, we are aware of only one published application to water resources (Morilla et al., 2007).

EIO or ESAM accounting multipliers provide valuable descriptive information in relation to the economic drivers of water use, or conversely, the importance of water in regional or national economies. However, they have limited potential in the analysis of policy or exogenous changes, especially when these have their predominant direct impacts on the supply side. In many areas, availability of water for extractive uses is threatened by climate change and increasing emphasis on maintaining environmental flows (e.g. to maintain biodiversity and provide for in-stream recreational uses). Policy-makers are increasingly turning to economic instruments, and particularly market-based instruments, in their search for ways to reconcile often increasing and competing demands on these scarce resources. These issues can be studied more easily within a partial or general equilibrium framework.

There is now a significant body of literature in which CGE models are used to analyse water resource issues and policies. Earlier contributions include Berck *et al.* (1991), who used a regional CGE model to study reductions in water use as an efficient solution to drainage problems in the San Joaquin Valley, California, and Dixon (1990), who used a CGE model to study public utility pricing of water in Australia. A particular challenge in applying CGE to analysis of water resource issues is that it is often important to represent at least the stylised facts of usually complex, interconnected hydrological systems (e.g. Dixon et al., 2005)[5]. A classic example of this is the CGE model of Morocco of Decalauwé *et al.* (1997), which includes specific production functions for water from both storage sources and rainfall.

Another feature distinguishing the literature on CGE applications to water issues, is its regional focus: multiregional models (Dixon et al., 2005; Roe et al., 2005) or single region sub-national models (see below) dominate. This doubtless reflects the fact that in most countries, both the water resources themselves and the ensuing issues vary considerably between regions. Accordingly, water policies and public investments are also determined at a regional or catchment level in many countries. Single region models also build on a broader trend towards CGE applications at sub-national scales – even down to the city scale (Schwarm & Cutler, 2006).

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[4] 'ESAM' is used by Xie, while 'SAMEA' is used by Morilla *et al.* In this paper we use the former.

[5] This issue does not arise to the same extent in many other natural resource or environmental applications (e.g. energy use, greenhouse gas mitigation), in which for practical purposes, the environment may be modelled as a passive 'source' of resources or 'sink' for emissions.

There are a significant number of recently published studies in which regional CGE models have been used to analyse water resource issues (including here issues of both water quantity and quality). Goodman (2000) study the relative benefits of urban-rural water transfers to increased storage in the Arkansas river basin, Colorado. Seung *et al.* (2000) use a dynamic regional CGE model, which includes recreational demand for wetlands, to study the impacts of water reallocation in Churchill County, Nevada. Gomez *et al.* (2004) show that sale of rural water rights to urban users may be preferable to building new supply infrastructure in the Balearic Islands, while Tirado *et al.* (2006) show that improving technical efficiency of water use in tourism may not actually reduce pressures on water systems. Velázquez *et al.* (2004) show that introducing a water tariff in Andalusia could result in significantly greater economic efficiency, but limited water savings. Smajgl (in press) integrates hydrological and ecological production functions within a regional CGE framework to study the effects of policies aimed at improving water and marine ecosystem quality in the Great Barrier Reef region of Queensland, Australia. From a rather different perspective, Rose and Liao (2005) use a regional CGE model to estimate potential economic impacts of a major water supply disruption in Portland, Oregon.

In this paper we describe the development of an ESAM for Canterbury, New Zealand. The regional SAM is extended with land accounts for the use of irrigated and unirrigated land by agricultural and forestry activities, as well as water accounts for the use of water by other productive activities and by households. Construction of the ESAM is motivated by the need to develop a suitable calibration database for a regional CGE model, which will initially focus on land and water use in agriculture and forestry. Hence we also describe relevant attributes of such a model and discuss its implications for construction of the ESAM. These uses are substantially dominant in all districts of Canterbury except Christchurch City, where household, industrial and commercial uses dominate. Thus, such a model is suited to consideration of two key issues: water reallocation within the agricultural sector, and water reallocation to in-stream or passive uses.

A CGE model of land and water use in Canterbury

Adapting a standard model structure to the regional scale

The publicly available IFPRI 'standard CGE model' (Lofgren et al., 2002) has become a popular starting point for CGE modellers. It is a static (i.e. single period) single-country model implemented in GAMS (GAMS Development Corporation, 2005). The standard implementation provides considerable flexibility in the specification of production functions (CES or Leontief nestings), macro-closures, and even includes less common features like transaction costs. Activities, commodities, household groups, etc., can be defined by the user, provided that they conform to a generic macro-structure. The standard model is implemented in such a way that generic model structure is separate from the implementation-specific definitions and data.

With minimal adaptation, the standard model can also be applied to regions (as has been done for example by San *et al.* (2000) for Sumatra, Benfica *et al.* (2006) for a region of

Mozambique, and Lahr (2006) for New Jersey). Two of the existing standard model closures are used, but a new savings–investment closure is introduced:

1. RoW: standard closure with fixed exchange rate and flexible RoW savings. Note that Canterbury shares a common currency with the rest of New Zealand, which constitutes a significant part of the RoW account.
2. Government: standard closure with fixed tax rates and expenditure, balanced by flexible government savings. This is a simple representation of government that is adequate to our basic purpose.
3. Savings–Investment: non-standard closure with exogenous investment *and* marginal propensity to save, with any difference accruing to RoW savings. This is appropriate, given the openness of the regional to trade and financial flows.

Land and water use in land-based industries

Further changes to the standard model are necessary to adequately account for the use of agricultural land and irrigation water as factors of production. Cororaton (2004) proposes production functions for irrigated agriculture in which land and water are complements, and constraints on their use are formulated as inequalities. This structure allows for a high level of modelling abstraction in our initial model, particularly as concerns the very complex spatial and temporal realities of water use. It also allows that water may be abundant, and hence have a zero price. Irrigated and unirrigated forms of production are distinguished as separate, since their input structures differ considerably. However, since the amount and productive characteristics of land and the availability of water for irrigation vary considerably within Canterbury, we also distinguish the location of agricultural production activities by district.

There are several ways in which spatial aspects can be partially accounted for, while retaining most of the simplicity and lower data requirements of the single-region structure. The best choice depends on the intra-regional integration of markets for agricultural commodities and for productive factors. If agricultural activities are distinguished by district, the their outputs may either be combined additively, or by constant elasticity of substitution (CES) functions. Additive combination is likely to result in dramatic reallocations of activity in response to small changes, while CES functions avoid this. Imperfect substitutability could be justified by differences in composition of aggregate commodities and/or transport costs. Another possibility is to model the distribution of agricultural production between districts implicitly, by making distinguishing a single (possibly composite) factor input by location, with all other inputs assumed fully mobile between these locations. This is illustrated in Figure 2 for an irrigated agricultural activity.

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[7] The fuel and electricity associated with irrigation are therefore excluded from the Leontief nest of othe intermediates. Also, for simplicity, we do not model substitution between these two energy sources. Prices of these goods are essentially determined outside the region, by forces that are not a primary concern in the policy scenarios of interest here.

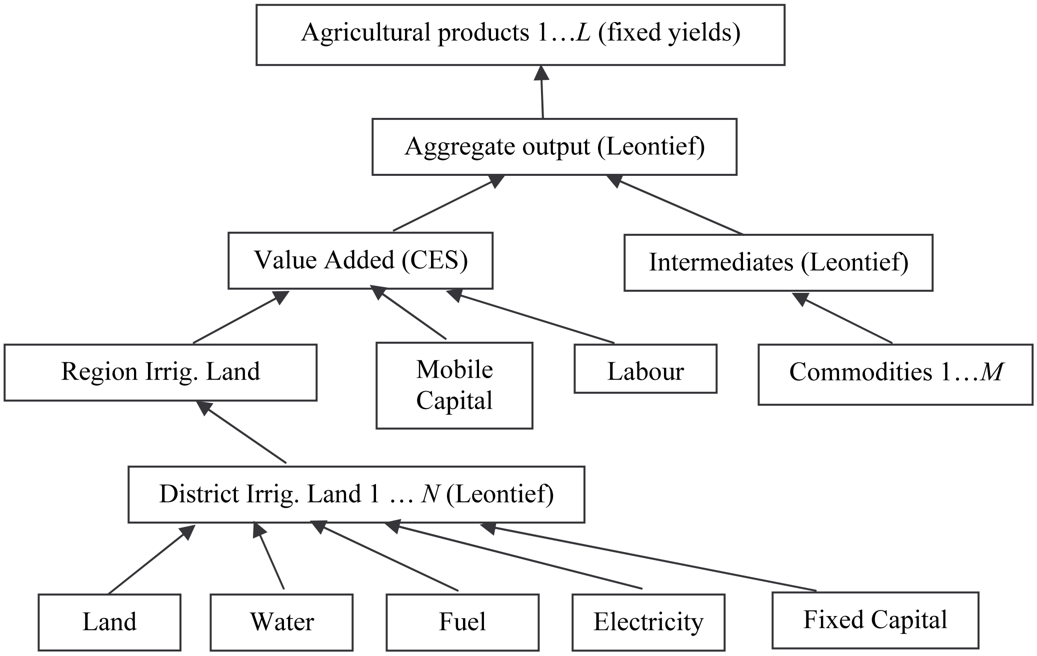

Figure 2 – A production function for irrigated agricultural activities

The top level of each production function is a Leontief combination of value added and an aggregate intermediate input. The latter is a Leontief combination of intermediate commodities. Value added is a CES aggregate of composite irrigated land, mobile capital (farm vehicles, plant and machinery), and labour. Composite irrigated land is a CES composite of district irrigated land, which in turn combines fixed proportions of land, water, fuel, electricity and fixed capital (land improvements, buildings, irrigation works)[7]. Ratios of irrigated water to land can differ to reflect differences in rainfall between districts. Unirrigated agricultural activities and forestry can be modelled similarly, but omitting the water, fuel and electricity inputs from the bottom-level Leontief function.

Inequality constraints ensure that neither the total available water nor the total available agricultural land in each district are exceeded. When either one of these constraints is binding, land or water receive an additional scarcity rent (Cororaton, 2004). The distribution of activities between districts and their propensity to relocate between districts in response to relative input price changes can be specified by choice of the CES parameters. If it is assumed that labour is mobile between industries, or at least between agricultural activities, then the mobility of labour between districts implied by the agricultural production functions should not be an unduly restrictive assumption in most circumstances. The standard model allows for industry-specific factor price distortions, which can be used here to allow for unmodelled factors influencing the current distribution of land-based activities.

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[11] The term 'satellite accounts' refers to the fact that these accounts have only rows, and not matching columns.

Canterbury Environmental and Social Accounting Matrix (ESAM)

A SAM describes current transactions related to production, consumption, trade and transfers between institutions (e.g. households, government, the rest of the world). A symmetric system of accounts shows payments in columns and receipts in rows, such that the *i,j*th entry of the SAM contains the flow of funds from the *i*th to the *j*th account. The number of accounts in a SAM varies widely, depending on both the availability of data and the purposes for which the SAM will be used. For Canterbury we have initially constructed a SAM that represents the production and consumption of goods and services in considerable detail, but provides only an aggregate representation of institutions. This choice reflects our initial modelling focus on agricultural production.

In summary, the initial Canterbury ESAM includes the following economic accounts:

- 45 Activities
- 102 Commodities
- Primary factors: labour, capital (excl. agricultural land), agricultural land, and irrigation water
- Regional households
- Government (an aggregate of local and regional councils, the regional transactions of central government, and non-profit institutions serving households)
- Tax accounts
- Change in inventories (CII)
- Savings and Investment (S–I)
- Rest of New Zealand and the world (RoW).

In addition, the ESAM includes the following environmental satellite[11] accounts:

- Agricultural land use by each industry in each territorial local authority area
- Water use (estimated) by each industry in each territorial local authority area.

For Canterbury, as for New Zealand regions generally, few of the requisite ESAM entries can be derived directly from survey data. Instead, they must be estimated from a variety of sources relating to both national and regional scales. The following sections describe this process and the data sources in detail. The ESAM is constructed for the financial year ending March 2001[12], since when this research began this was the most recent period for which most of the data were readily available. It is planned to update the ESAM to 2003/04.

Supply and Use of Commodities

Supply and Use Tables (SUT) cover several main elements of any disaggregate SAM and are also the basic data used in construction of IO models. Supply table data are used (directly, or more likely, after appropriate aggregation, updating, etc.) to construct the commodity column accounts in the SAM, while the use table data are used to construct the

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[12] Various annual accounting periods are used for different primary data sets, so this definition is inexact in some cases.

commodity row accounts. In New Zealand, the most recent available national SUT is for the year 1995–96 (Statistics New Zealand, 2001b)[13]. At the Regional or District level[14], only a limited range of economic data is generally available. The most important of these in the current context are the Quarterly Employment Survey (Statistics New Zealand, 2007d), the Agricultural Production Census (Ministry of Agriculture and Forestry, 2003), and the Household Economic Survey (Statistics New Zealand, 2001a). Using these and other data, Canterbury SUT for 2001 were estimated by McDonald[15], using the generation of regional input-output tables (GRIT) method (Jensen et al., 1979; West et al., 1980), a gravity model (appendix 1, McDonald & Patterson, 2004), and RAS balancing (Bacharach, 1970). While these are considered to be the best estimates currently available, they must nevertheless be treated with caution.

SAM sub-matrix S was constructed by aggregation of 123 industries and 210 commodities in the supply table to 45 industries and 102 commodities[16]. Regional imports M were also taken from the supply table, aggregating over rest-of-New Zealand (RoNZ) and international origins. The use table gave intermediate and final uses of commodities at basic prices. These were first converted to purchasers' prices, because in the Standard CGE, rates of *per valorem* taxes on commodities are estimated from the SAM as part of the calibration. Given the total tax paid on each commodity and the total commodity taxes paid by each account from the use table, RAS was used to adjust an initial matrix of taxes (which assumed the same rate for every transaction) to match the row and column totals. After this conversion, the sub-matrix U was constructed using the same commodity and industry aggregation. Final consumption F_{HH}, F_{GOV}, F_{GFCF} *and* F_{CII}, were also taken from the use table, aggregating non-profit institutions serving households (NPISH), local and central government into single 'government' account. Inter-regional and international exports were also aggregated to construct sub-matrix E.

Primary factors of production

The majority of CGE models distinguish capital and labour as the two primary factors of production. Estimates of these inputs, in value terms and in full-time-equivalents (FTEs) for labour, are available from the use table. Returns to labour can be taken directly from the table, while returns to capital are taken as the sum of depreciation and gross operating surplus. However, particularly in agriculture and forestry, significant components of the operating surplus should be accounted for by differential and scarcity rents generated by land of different types and locations. Use of water for irrigation also generates rents due to natural or imposed scarcity of water at the times and locations where the water is required. To calibrate the model as described above would require these values. However, neither land nor water rents are explicitly accounted for in official statistics.

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[13] Contrary to the practice of most other OECD countries, Statistics New Zealand does not publish input-output tables on a regular basis, and to our knowledge, no new survey is currently planned.

[14] New Zealand has three main levels of governance: central, regional and local. Canterbury is one of 16 regions in New Zealand, and included 10 Districts in 2001 (two since amalgamated).

[15] Dr Garry McDonald, Market Economics Ltd, personal communication, April 2007.

[16] Details of concordances and other detailed are available from the authors on request.

Accurate estimation of returns to irrigation for individual activities by district is a daunting task. A possible approach is to equate total irrigation rents to the total opportunity cost that would be incurred if currently irrigated activities were replaced by the most profitable alternative unirrigated activities. This approach is taken in a study by the Ministry of Agriculture and Forestry (MAF) (2004), and values relevant to Canterbury are summarised in Table 1.

Table 1 – Assumed returns to irrigation

ESAM activity	Relevant estimated returns to irrigation
Horticulture and fruit growing	Onions \$9,150/ha Viticulture (Marlborough) \$7,600/ha Potatoes \$4,400/ha
Mixed livestock and cropping	Arable \$620/ha Other Pastoral (intensive) \$630/ha
Dairy farming	Dairy \$1,367/ha
Other farming	Other Pastoral (intensive) \$630/ha

Rental prices for land in different areas and uses can in theory be estimated based on land values. Rental prices, at least in theory, should equal user costs, which, following (Statistics New Zealand, 2007c), can be estimated as

User Cost = Land Value x (industry rate of return – rate of appreciation + rate of taxes on land)

The industry rate of return could be chosen to reflect market interest rates, adjusted for industry-specific risk, or directly from observed rates of return to (total) capital, as in (Statistics New Zealand, 2007c). Official land valuation (with and without land improvements) and rates data are available publicly in New Zealand and more systematically, in a commercially operated database (Quotable Value New Zealand Ltd). Land values can fluctuate significantly in the short term, sometimes motivated in part by speculative and other motives that we do not wish to model. Hence, it is important that the above rates are estimated over periods of time representative of periods over which the CGE model will be run. In addition, typical farm budget data (Ministry of Agriculture and Forestry, 2007) could be used to separate the combined value of land and buildings from that of machinery and equipment for different farm types. This suggests a possible division in the ESAM between combined agricultural land and buildings and other capital (possibly specific to agriculture). The former are necessarily immobile between districts, while the latter could be assumed mobile.

Primary and Secondary Distribution of Income

Given the simple structure of factor and institutional accounts in this initial SAM, accounting for the primary distribution of factor income is straight-forward. All labour income accrues to households, all capital income (including returns to agricultural land and forest) to enterprises, and all taxes to the government account. The enterprise account here includes both private and public sector productive activities. Establishing the secondary distribution of income is considerably more difficult at the regional scale.

Entries in the row account for households show income from labour (includes self-employment), government transfers, regional investment income and extra-regional investment income, and other transfers (transfer from RoW account). Initial estimates for all these entries are based on the New Zealand Income Survey (Statistics New Zealand, 2006b). This source gives total average weekly household income in 2001 for Canterbury ($1025pw), and distinguishes income by source for New Zealand as a whole[17]. We apply proportions for the national scale to Canterbury, to split gross income between: wages, salaries and self-employment, government transfers, and investment income. The investment and other transfers income, however, must be split between receipts from Enterprises and RoW, as described below.

Entries in the column account for households show consumption of goods and services, payment of taxes, transfers to other regional institutions and RoW, and savings. Consumption data are taken from the use table at purchasers' prices, as are taxes on products (mainly GST and excise duties on fuel, alcohol and tobacco products). An effective rate of income and other direct taxes on households was estimated from the national household income and outlay account (Statistics New Zealand, 2006a). Similarly, an effective rate of household savings was estimated from the Household Economic Survey (Statistics New Zealand, 2004). In the absence of readily accessible regional data, these national rates were applied to Canterbury household income in the SAM (above). Net transfers from Canterbury households to RoW households are likely to be small, so are assumed to be zero.

The government account in the SAM combines local and regional governments with the 'regional manifestations' of central government. The latter include (i) regional expenditure by central government, and (ii) central taxes collected within the region. Although central taxes do not, in reality, finance central government expenditure in the region directly, this formulation simplifies the SAM and should be satisfactory in our application, in which government finance is not a significant concern. This also makes the aggregate RoW account less heterogeneous, simplifying the formulation of closure rules. Data on government consumption are taken from the use table. Government savings are taken as the aggregate of local and regional councils' savings (Statistics New Zealand, 2007b), implying there is no direct link between central government savings and regional investment. Government transfers to households are as described above. It is assumed that there are no Government transfers to enterprises, the Government having already netted subsidies to activities out of the taxes on production (above). The balance of the Government account is transferred to RoW, representing the net flow of funds to central government from Canterbury. It should be noted that central government expenditure has been regionalised according to the region of supply, which may not always coincide with the region of use (i.e. this component of government expenditure imperfectly accounts for government provision of public goods and transfers in kind within Canterbury).

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[17] Investment income was not included in the survey until 2002, so the figure for that year was used.

The income of enterprises is equated to the total gross operating surplus generated in Canterbury. This is a simplification of the actual structure of capital ownership, in which households and governments may directly hold equity. Accounting for the secondary distribution of this income, however, is more complicated. Very few data can be used to estimate the share of equity in regional enterprises held within the region. First, we assume enterprises save an amount equal to the total capital depreciation. This probably underestimates the true savings of enterprises (given the above definition) in an expanding economy. Second, the total gross operating surplus is split between direct taxes on enterprises, government (for productive activities in the government sector), regional households, and RoW. The effective rate of tax on enterprises was estimated for New Zealand (Statistics New Zealand, 2006a), and this figure is assumed to apply to Canterbury enterprises. The share of operating surplus accruing to the Government account is estimated based on the non-market share in operating surplus by industry calculated from the national use table (Statistics New Zealand, 2001b). The remainder of enterprise income is split between households and RoW accounts 30:70. This ratio is somewhat arbitrary, but is informed by national level data on foreign ownership (14% in 2002, Statistics New Zealand, 2007a), the ratio of population in Canterbury to the rest of New Zealand (12.9%), the size-distribution of Canterbury businesses (Statistics New Zealand, 2007a), and our own assumptions on the bias towards within-regional ownership as a function of business size.

SAM Balancing

To calibrate the parameters of the CGE model, it is essential that the accounting identities underlying both the SAM framework and the model equations hold. In practice, this means that all row and column totals of the SAM must be equal: total income must equal total expenditure plus saving over the accounting period. The supply and use tables had been previously balanced at producers' prices. The conversion of the use table to producers described above again resulted in balanced accounts. Since independent data on factor incomes was not used directly (see above), these accounts, receipts, and payments balance by construction. Similarly, all tax accounts are balanced. This leaves enterprises, households, government, savings–investment and rest-of-world to balance. As at least one entry in each of these accounts can only be estimated as a residual, or by an equally uncertain method (e.g. household income from regional enterprises, as described above), manual balancing of the few remaining non-zero SAM entries is possible.

Land and Water Use Physical Satellite Accounts

Land areas and irrigated areas in 2001 for six primary sectors by ten districts were available from the Agricultural Census[18]. There are currently no comprehensive data on actual water uses in Canterbury. Indeed much self-extraction of water remains unmetered. Estimates must therefore be made based on maximum flowrates stipulated in water 'consents', which are then corrected by applying various empirical factors relating actual to permitted uses in different applications (for more details, see Lennox & Andrew, 2005). Since many consents for agricultural irrigation do not stipulate a particular type of irrigated production, these

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[18] Unpublished data. Several smaller values were suppressed due to confidentiality requirements.

data are insufficient. We therefore use the data on irrigated area to distribute the water use in each district across different sectors. In doing this, it is assumed for simplicity that the irrigation rates are the same for all these activities. A further complication is that the use of water delivered through irrigation schemes (in the sector 'services to agriculture') is unknown. In this case, we assume that the corresponding transactions in the economic use table are proportional to water deliveries. While this may not be a reliable assumption (since many agricultural services other than irrigation are purchased), the relatively small amount of water involved means it should not significantly influence the results. Estimates were made at the district level, and are shown for Canterbury in Table 2.

Table 2 –Land area, irrigable area and water use in Canterbury agriculture and forestry, 2001

	Horticulture & Fruit Growing	Livestock & Cropping	Dairy Cattle Farming	Other Farming	Services to Agriculture	Forestry
Land ('000 ha)	46	2546	173	8	19	11
Irrigable area ('000 ha)	30	144	106	2	3	0
'000 GL/yr	305	1602	1299	26	43	1

Conclusions

In this paper we have discussed the designing and implementation of a regional CGE model suitable for analysing regional land and water policy issues. Key policy issues include the economic potential of water reallocation between the land-based industries of agriculture and forestry, and between this sector and the environment. This would result in a redistribution of activities at regional and district scales. The influence of external economic drivers (e.g. agricultural commodity prices) is also of interest. Our initial model therefore focuses on uses of water and land in this sector, with partial disaggregation to the district level. A standard single-region CGE model can be easily adapted to this task. Necessary modification to the standard model include different macro-closure rules, modification of production functions for agriculture, and modelling inequality constraints on the availability of land and water.

Developing an ESAM that can be used to calibrate such a model is significantly more challenging in the New Zealand context. Most elements of the ESAM must be based on various types of downscaling or transference of national data to the regional scale. Our initial estimates appear sufficiently robust in relation to the supply and use of commodities, although data are not available to confirm the reliability of regional imports and exports in the ESAM. Further development of the ESAM required to calibrate the CGE model will involve the disaggregation of agricultural activities into irrigated and unirrigated versions, and the allocation of gross operating surplus between land, irrigation water and other capital. Methods and data sources for resolving this problem were discussed. Estimating transactions between institutions is particularly difficult. Even given the minimal representation of institutions adopted, gross assumptions must be made in some cases (e.g. secondary distribution of income from enterprises, some transfers to RoW). Sensitivity of simulation results to these calibration data must therefore be tested. In addition to completing the ESAM, it remains to find values for elasticities of CES and CET functions. These will be based on a survey of relevant literature and expert judgement.

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