Modelling regional general equilibrium effects and irrigation in Canterbury

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Abstract

We describe the development of a regional CGE model for the analysis of issues around water supply and (re)allocation in Canterbury, New Zealand. Traditionally, water has been seen as an abundant resource, but growing irrigation demands are now outstripping the supply of water and competing with instream uses (e.g. recreation) and non-use values (e.g. biodiversity). In the longer term, this problem may be exacerbated by climate change, which is predicted to increase water demands and reduce supply from rainfall and snowmelt in parts of Canterbury. It is therefore important to be able to quantify the impacts on the regional economy of changes in water availability and policies and other measures addressing water supply or demand. In addition, we are concerned with the current, relatively inflexible, 'first-come, first-served' system for water allocation. In this paper, we present some preliminary scenarios focusing on a reduction of irrigation supply and the interaction with changes in rainfall. These results are intended only to illustrate the potential of the modelling approach, not least because the provisional data to which the model is currently calibrated are in many cases dated or incomplete. We discuss how the model and its underlying database may be improved and extended to provide results that are qualitatively robust and policy-relevant.

Keywords: general equilibrium, land use change, water allocation, agriculture, irrigation.

JEL: C68, R13, Q15.

1. Introduction

In the Canterbury region, New Zealand, extractive, instream and passive uses of water all play vital economic, social and cultural roles. Water has historically been relatively abundant and current systems of water allocation – essentially, rights are freely allocated on a 'first-come, first-served' basis – reflect this [1]. 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 increasingly contested. In many areas of Canterbury, extraction of groundwater resources is at or beyond sustainable limits, as is extraction from many rivers and streams [2; 3]. The combined pressures of water extraction and nitrate losses from fertilisers and livestock have led to serious water quality problems in many lowland streams and increasingly in shallow aquifers [2]. In the longer term, water issues may be exacerbated by climate change, which is predicted to increase water demands and reduce supply from summer rainfall and snowmelt in parts of Canterbury [4].

Irrigation is the main extractive water use in Canterbury. Land under irrigation systems increased from 150 000 ha in 1985 to 287 000 ha in 2001/02 [5]; 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 2002, 49% of irrigated land was used in sheep and beef farming, 40% in dairy farming, and 10% in horticulture and viticulture[1]. Primary production (with the associated downstream industries), tourism and recreation are central to the region's economy. Increasing water supply for irrigation may have significant economic benefits for the agricultural sector and the region as a whole. However, instream flows are affected by surface water extraction and indirectly by groundwater extraction: there are complex linkages between ground and surface waters in Canterbury's alluvial plains. Increased water extraction may directly impact tourism and recreational activities instream, and more generally might diminish the natural beauty that is one of the region's key attributes and drawcards. (Re)allocation of water within the

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[1] These figures are based on a customised dataset provided by Statistics New Zealand, February 2007. More recent data from the 2007 Agricultural Census should soon be available.

agricultural sector is also of concern. The current ‘first-come, first-served’ allocation system is relatively inflexible. If this causes water to be allocated between alternative uses in an economically inefficient way, the net economic benefits of irrigation to the region may be reduced.

Despite its importance, there is still limited understanding of the economic costs and benefits of irrigation in Canterbury, and more generally throughout New Zealand. Indeed, even basic information on water use is limited, with many water takes still not metered. At the national scale, irrigation was estimated to contribute 11% of farmgate GDP in 2002/03 [6]. A recent econometric study of the Mackenzie Basin, in inland south Canterbury, found that rights to irrigation water could generate a land sale price premium, relative to similar unirrigated properties [7]. Premiums ranged up to 50%, although in many cases were much lower, as indeed, much land in the basin is not well suited to irrigation and is not currently irrigated. As would be expected, irrigation rights were more valuable on flatter land, land with less rainfall, and land closer to the towns. There have also been several *ex post* evaluations of specific irrigation schemes in Canterbury, which found significant on-farm and wider socio-economic benefits [8; 9]. However, none of these studies can provide more than a general indication of the aggregate value of irrigation rents for the whole Canterbury Region.

This paper describes the development of a regional computable general equilibrium (CGE) model to analyse issues around water supply and (re)allocation. This is one of few CGE models that have ever been developed at the regional scale in New Zealand, and to our knowledge the only one to focus on water resources. There is, though, a significant body of international literature on application of CGE models to analyse water resource issues and policies. Early contributions include Berck *et al.* [10], 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 [11], who used a CGE model to study public utility pricing of water in Australia. A particular challenge in applying CGE models to analyse water resource issues is that it is often necessary to represent frequently complex, interconnected hydrological systems [e.g. 12][2]. A classic example of this is the CGE model of Morocco developed by Decalauwé *et al.* [13], which includes specific production functions for water from both storage dams and rainfall.

Another feature distinguishing the literature on CGE applications to water issues, is its regional focus: multiregional models [12; 14] 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. Catchments are also a key analytical scale from a hydrological perspective. Single-region models also build on a more general extension of CGE modelling, to sub-national scales (even down to the city scale [15]).

There is a significant number of recently published studies in which regional CGE models have been used to analyse water resource issues (including both water quantity and quality). Goodman [16] studies the relative benefits of urban–rural water transfers to increased storage in the Arkansas River basin, Colorado. Seung *et al.*[17] 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.* [18] show that the sale of rural water rights to urban users may be preferable to building new supply infrastructure in the Balearic Islands, while Tirado *et al.* [19] show that improving technical efficiency of water use in tourism may not actually reduce pressures on water systems. Velázquez *et al.* [20] show that introducing a water tariff in Andalusia could result in significantly greater economic efficiency, but limited water savings. Smajgl [21] 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 [22] use a regional CGE model to estimate potential economic impacts of a major water supply disruption in Portland, Oregon.

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[2] 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.

In this paper, we focus on modelling the economic impacts of constraints on water supply for irrigation. Using provisional data, we present preliminary results of scenarios concerning a reduction in aggregate irrigation supply. In fact, a claw-back of irrigation water rights currently seems most unlikely. However, this scenario equally well represents growth in all factors of production *other* than water, because the CGE model depends only on *relative* quantities and prices (i.e. doubling all factor inputs doubles all other quantities in the model). In a second scenario, we simulate the impact of a simultaneous reduction in rainfall and in irrigation. Given the paucity of data to support development of a relatively complex model, we also present results that illustrate the sensitivity of the model to key elasticity values, and to different structural specifications. We discuss the implications for further model development; in particular, for the improvement of calibration data and elasticities. We also discuss the potential to explicitly model technologies for water supply (storage, ground and surface-water extraction), and to model instream market and non-market values.

2. CGE Model

General model structure

The CGE model describes production processes in agriculture and other sectors; the supply of labour, capital, land and water rights owned by enterprises and households; households' and government consumption of goods and services; and trade between Canterbury and the rest of New Zealand and the world. We employ the common assumptions of perfect competition and non-increasing returns to scale in production. Key features of the current model concern the supply and use of water for agricultural irrigation, and the differentiation of land and water resources by subregions.

Ten different production activities are distinguished in the model: horticulture and viticulture; sheep and beef farming; dairy farming; other agriculture (which includes other livestock farming and agricultural services); forestry; meat processing; dairy processing; other processing and manufacturing; transport and distribution services; and other services. In the current version of the model, we represent land and water use in the first three of these activities only. Difficulties with data must be resolved before this can be expanded to other agriculture and forestry activities. Commodities in the model correspond approximately to the main outputs of these activities. Land and water resources are differentiated by north and south subregions in this version of the model, but our ultimate intention is to distinguish five subregions in the final model. These should be sufficient to capture key stylised factors of water resource economics in Canterbury. Institutions of households, government and enterprises are modelled very simply.

Primary factors in production are labour, capital and agricultural land. In this paper we focus on long-run effects, and therefore capital and labour are assumed mobile between sectors. We also assume—optimistically, in the case of the scenarios presented here—that the aggregate capital and labour supplies of the region are fixed, with their relative prices adjusting to clear markets. At the opposite extreme, we could assume that these prices are exogenously determined, and inter-regional flows of capital and labour clear capital markets. The reality is most likely somewhere between these extremes. For example we have included urban land in 'capital', as well as buildings and civil works, which are very long lived and may be practically immobile over the timescale of interest. On the other hand, machinery and equipment is less long lived and can also usually be relocated at moderate cost (at least within New Zealand). Research on inter-regional migration in New Zealand [23] suggests that, in the long run, about half the jobs created by a regional employment shock will remain and are mostly accounted for by net in-migration. Impacts on wages are negligible though (even in the short run). While the full development of more realistic 'regional closures' is left for further work, we give some indicative results relating to the effect of an alternative labour market closure.

Households maximise utility from the consumption of final goods, which enter a Cobb–Douglas utility function. Government and investment-good sectors maximise single-level CES utility functions with elasticities of substitution of 0.5, reflecting our assumption that their substitution possibilities are lower than in the household sector. Net household savings and net household transfers are fixed in real terms (i.e. they vary proportionally with price indices for government and investment consumption respectively). Household income is derived from labour, and transfers from enterprises, which own all capital, land and (rents from) water resources. Enterprises are partly owned by extra-regional institutions and are included in the model to provide a crude accounting of the leakage of capital, land, and water rents. Lack of primary data prevents rigorous analysis of these flows.

Agricultural land and water

Agricultural land and water resources are differentiated by two subregions, North and South, but our intention is to increase this to five subregions. As noted above, forest and land used by ‘other agriculture’ are not distinguished in the model. Several problems with the data underlying the model must be overcome before they can be included. For example we must account for the value of standing timber and not only the bare forest land. We do not attempt to differentiate between different qualities of land, primarily to limit data requirements and to simplify the representation of land and water resources. In particular, it is likely that there would be significant net flows of surface and/or groundwater between different land areas. It might then be necessary to model the influence of land cover and upstream water abstraction and use on downstream water resources. While this might be technically possible within the CGE framework, it would be very difficult to establish the credibility of the resulting model.

We assume that the aggregate land of each district is imperfectly mobile between alternative uses. This may reflect the costs of land use change, as well as the relative suitability of land for one use or another. It is modelled with nested CET functions [see e.g. 24]. At the bottom level (Figure 1), transformation of land within each subregion $P_R(d)$, between horticulture/viticulture $P_{RR}(d,htvt)$ and pastoral activities $P_{R\_SRD}(d)$, is relatively inelastic. At the second level, pastoral land is allocated to sheep and beef $P_{RR}(d,shbf)$ or to dairy farming $P_{RR}(d,dairy)$ with a moderately low elasticity of substitution.

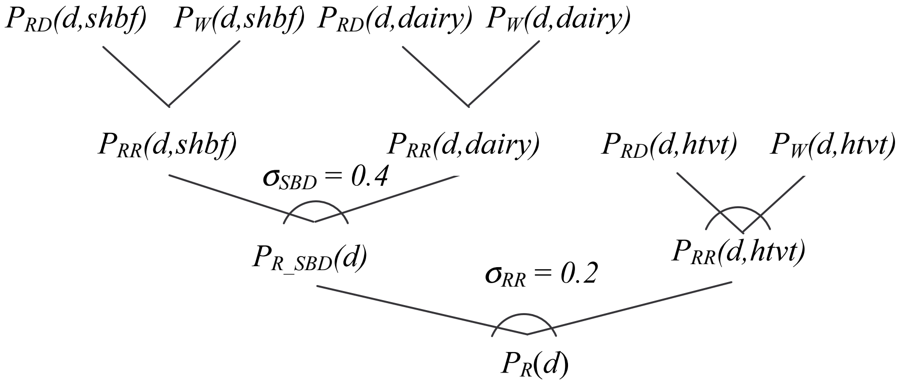

Figure 1 Allocation of land and rainfall between agricultural sectors

A particular feature of this model is that we allow explicitly for variation in rainfall, and the association of rainfall with land, in addition to the supplementing of rainfall with irrigation water. This is useful for simulating the impact of reduced effective annual rainfall, which may be one of the impacts of climate change in much of lowland Canterbury [4]. The term 'effective' refers to the fact that the utility of one millimeter of rainfall in pasture or crop growth depends on the soil moisture content, the stage of pasture/crop growth, and many other factors. This model specification accommodates pasture/crop yield curves with a minimum soil moisture threshold and decreasing returns to soil moisture above this threshold. 'Effective rainfall' then refers to the contribution of rainfall to increasing soil moisture about the threshold level. The separation of sector-specific land and rain in fixed proportions and for each subregion is shown at the top-level nests of Figure 1. We assume that irrigation water and effective rainfall are imperfect substitutes in the aggregate production activities modelled (in particular, each aggregate activity includes both rainfed and irrigated production). For example, unit costs of irrigation application should increase as the fraction of irrigated area increases and less suitable land is brought into irrigation.

The value of rainfall in production should form part of the (observable) land rent. The share of rent attributed to rainfall is likely to vary by subregion, because the annual rainfall and the distribution and intensity of that rainfall varies significantly in different areas of Canterbury. For the purpose of the preliminary simulations presented in this paper though, we have arbitrarily assumed that 25% of the estimated gross land rents are associated with effective rainfall (see also the description of agricultural production functions, below). We also show results of a comparative simulation with a more conventional input structure, in which only irrigation water inputs are included. Water from rainfall is augmented by sector-specific water from irrigation in each district, as described below. With this structure, more irrigation-dependent activities are more severely affected by constraints on irrigation supply and less by reductions in rainfall, and *vice versa* for less irrigation dependent activities.

Agricultural production and irrigation supply

The production structure for agricultural activities is illustrated in Figure 2. Some prices of aggregates in the production structure are omitted for clarity. The first level of the hierarchical production function combines in fixed proportions the aggregate intermediate input (P_{INT}) with the aggregate factor input (P_{KLWR}). At the second level, intermediate inputs ($P_A(c)$) are combined in fixed proportions and labour (P_L) is combined with other factor inputs in a CES function. At the third level, capital (P_K) is combined with an aggregate land and water input in a CES function. At the fourth level, the aggregate land and water input is a CES composite of land–water inputs from different subregions. At the lowest level, sector-specific land ($P_{RD}(d,i)$) and sector-specific evapotranspired water ($P_{ET}(d,i)$) are combined in each subregion. Evapotranspired water comprises effective rainfall plus irrigation for each activity in each district (not shown).

The substitution between land and water within each subregion is moderately inelastic. The substitution of land-water composites from the different subregions is highly elastic. This is a simplification of a model structure with a full representation of each agricultural activity in each district [24]. Aggregation to regional scale would then occur at the level of commodity markets. Commodities produced in each subregion could be combined additively, or else in a CES function, with the finite elasticity of substitution reflecting e.g. transport costs and product heterogeneity. The simplified structure reduces data requirements (on labour and intermediate input costs by subregion) and avoids complexity that is unlikely to be warranted given the types of scenarios we wish to simulate.

For activities that produce multiple outputs $P_D(c)$ (e.g. wool and meat), it is assumed that these are produced in fixed proportions. This assumption may be relaxed in future work, since in some sectors, and considering the high aggregation level of the model, there are certainly possibilities to adjust output proportions to maximise revenues. Multiple outputs of non-agricultural production activities are treated the same way.

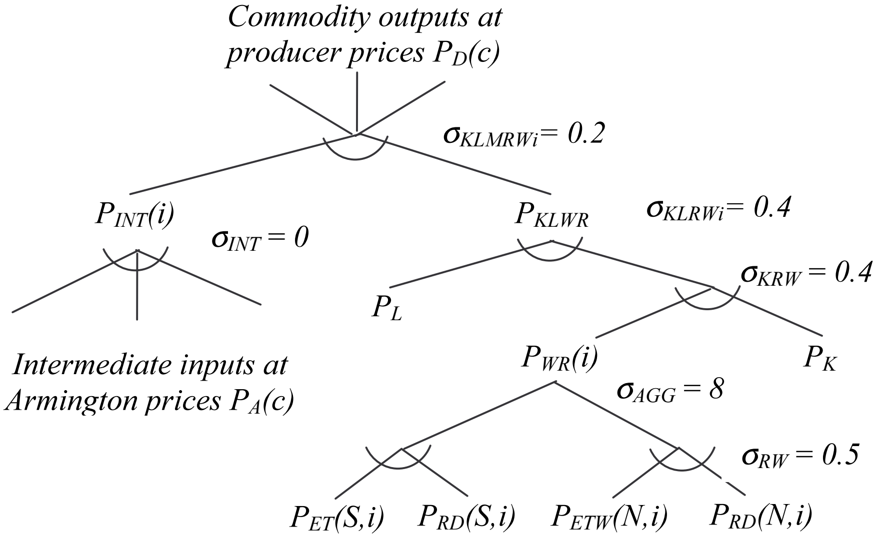

Figure 2 Nested production function for agricultural sectors

As described in the previous section, sector-specific effective water from rainfall can be augmented by irrigation. Sector-specific irrigation activities for each subregion draw on a common irrigation water resource. For all these activities, we assume the same assumed cost structure: 40% capital, 20% labour, and 40% other goods—which represent mainly fuel and electricity. Although existing studies show that in some areas at least shadow prices for irrigation rights are positive, we make a provisional simplifying assumption that they are zero. At the top level of the irrigation production functions Figure 3, the irrigation water resource ($P_W(d)$) is combined with other inputs in fixed proportions. If we assume constant returns to scale in irrigation supply, then a zero elasticity of substitution is a necessary condition for the shadow price of the irrigation water resource in a subregion to be zero. At the second level, substitution between 'other goods' (P_{OTH}), representing mainly electricity and fuels) and the aggregate factor inputs is moderately inelastic. At the third level, substitution between labour (P_L) and capital (P_K) is also moderately inelastic.

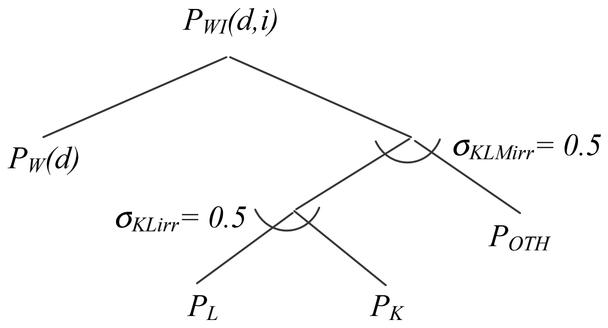

Figure 3 Production functions for irrigation supply

Other production activities

In all other industries, intermediates are combined within a Leontief nest, and capital and labour in a Cobb–Douglas nest. Intermediates ($P_{INT}(i)$) and value added ($P_{KL}(i)$) are then combined in a CES function with low elasticity of substitution. A slight variation on this structure is made for the meat processing and dairy processing industries. These sectors essentially transform a single farm input ($P_A(c=ag)$), animals and raw milk respectively) into processed outputs. We therefore assume there is no practical ability to substitute for these inputs. They are combined directly with the composite of all other inputs (formed as described above) in a top-level Leontief function.

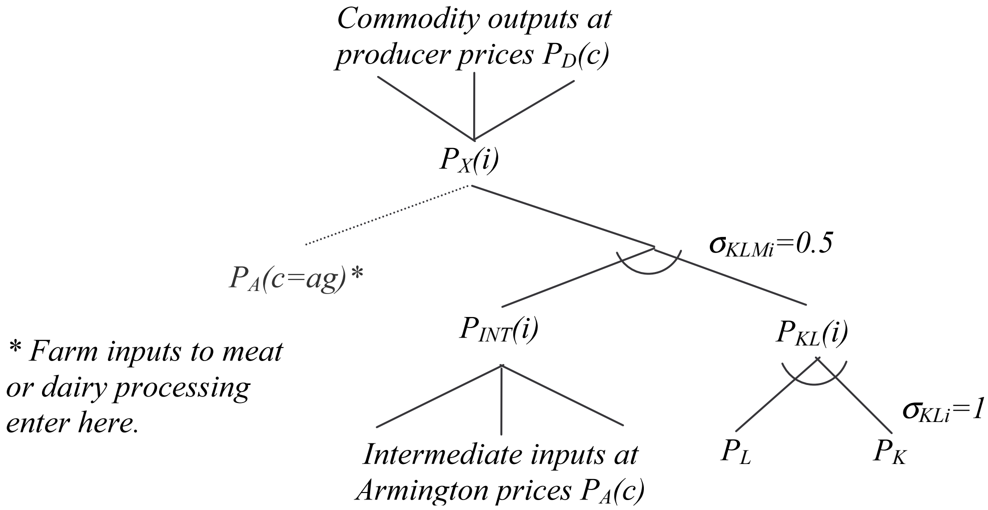

Figure 4 Nested production function for other industries

Trade in commodities

We employ the Armington assumption, that regional commodities and commodities from other regions or countries (the latter are not distinguished in the model) are imperfect substitutes. Regional supply of commodities is therefore a constant elasticity of substitution (CES) aggregate of imported and domestically produced commodities. Regional exports are treated symmetrically to imports, with constant elasticity of transformation (CET) functions describing the allocation of output between regional and extra-regional markets. There is no possibility for trade in water between regions, nor interactions between catchments. This is a good approximation of reality, as the only major shared catchment is that of the Waitaki River (between Canterbury and Otago).

Model calibration:

The model is currently calibrated using an environmental and social accounting matrix (ESAM) for the year ending March 2001, the construction of which is described in [25]. In addition, we have used various *ad hoc* data and assumptions to estimate irrigation supply costs, and to separate land rents, from other returns to manufactured capital and improvements. We have made only crude assumptions about the contributions of irrigation rights and rainfall to gross land rents. The elasticities of substitution are likewise based on typical values found in the literature, or our own judgement. All of these data and parameters require substantial further work. It is our intention to update the benchmark dataset to 2004 in the near future. In this paper we also conduct some sensitivity testing in relation to some of the more uncertain data and parameters.

Some key benchmark (i.e. 2001) values and statistics are shown in Table 1 for those industries on which we focus in this paper (i.e. omitting other agriculture and forestry). Sheep and beef farming (Sheep/Beef) has the largest output and by far the largest land area. However, a significant proportion of that area is accounted for by native pasture in the Canterbury foothills. The dairy sector is slightly larger than the horticulture and viticulture combined (Hort/Vit). The fractions of land under irrigation are highest for Hort/Vit and lowest for Sheep/Beef. However, the sheer size of the sheep/beef sector means that it is the largest water user in absolute terms. At present, we use the physical accounting data mainly to disaggregate economic data to subregional levels. It should be noted that the 'quantities' of land used to calibrate production functions in the CGE model are in fact the land rents. This greatly reduces the problems of assuming a homogenous 'land' factor, since the values should incorporate differences in the primary productivity of land. For example, one average hectare of horticultural land is far more productive than one average hectare of sheep and beef pasture. However, if we consider two areas with the same annual rent, then at least at the margins at which land use changes may occur, such areas should be reasonable substitutes.

Table 1 Land and water consumption data for the agricultural industries

	Hort/Vit	**Sheep/Beef**	**Dairy**
Sector output ($m)	233	971	305
Land area (10^3 ha)	45	2227	169
Percentage of land irrigated	49%	5%	55%
Water used for irrigation (est. $10^6 m^3$)	302	1529	1258
Total rents to dry land ($m)	15	58	83

3. Model results and discussion

We apply the CGE model to analyse scenarios involving shocks to irrigation and rainfall: (Scenario 1) 20% reduction in the total water available for irrigation in north and south Canterbury; and (Scenario 2) the same reduction concomitant with 20% decrease in effective rainfall. It should be noted that these scenarios are purely hypothetical. They are intended to illustrate in a general way the impacts of constraining irrigation water supply relative to growing irrigation demands, and how such constraints might interact with a future drier climate. It should also be noted that we are already aware that wages are essentially exogenously determined (section 2), whereas our simpler assumption of a fixed labour force and variable wage rate may buffer the impacts of the modelled shocks considerably.

We expect that the results are highly contingent on key parameters and assumptions of the model, many of which are currently highly uncertain. We therefore present key results for three variations on the first scenario that employ different parameters and assumptions:

(1A) Increase in the elasticities of substitution in agriculture

(1B) Increase in the elasticities of transformation of land between uses

(1C) Distinguish only land and irrigation water inputs to agriculture, treating rainfall simply as part of the land input.

Note that in Scenario 1C, we use the same elasticity of substitution between land and water in the agricultural production function. However, 'water' is now only irrigation water, and so its value share in the land–water aggregate is significantly less than in the base scenario.

Table 2 shows percentage changes in key economic aggregates for all scenarios. Under Scenario 1, there is minimal impact on gross regional product (GRP) in either the main scenario or variations A–C. In Scenario 2, the decrease in GRP is an order of magnitude larger, but still less than 0.1%. The impacts on the agricultural sectors are almost completely mitigated by reductions in the relative prices of labour and capital (−0.02 to −0.07%) and consequent reallocation of these resources to sectors other than agriculture and food processing. This is confirmed by the small increases of output of these (much larger) sectors, shown in Table 3. The impacts on agriculture are more significant, with declines in the value added (i.e. farm gate contribution to GRP) of (0.27% to 0.66%) in Scenario 1, and declines in total agricultural labour of 0.30% to 1.06%.

Table 2 Changes in key indicators with respect to benchmark values (%)

Scenario:	1	1A	1B	1C	2
Gross regional product	−0.005	−0.003	−0.004	−0.007	−0.087
Labour price	−0.052	−0.023	−0.042	−0.060	−0.230
Capital price	−0.061	−0.029	−0.051	−0.068	−0.242
Agricultural sector value added	−0.586	−0.266	−0.487	−0.661	−2.111
Agricultural labour (quantity)	−0.870	−0.301	−0.722	−1.055	−3.684

Table 3 Percentage changes in sector outputs

Scenario:	1	1A	1B	1C	2
Horticulture/viticulture	−0.60	−0.23	−0.57	−1.06	−2.90
Sheep and beef farming	−0.86	−0.36	−0.58	−0.91	−3.40
Dairy	−1.63	−1.02	−1.82	−1.76	−7.16
Other agriculture	−0.24	0.01	−0.17	−0.27	−0.96
Forestry and logging	0.54	0.23	0.44	0.60	2.25
Meat and wool processing	−0.84	−0.35	−0.59	−0.89	−3.35
Dairy processing	−1.24	−0.76	−1.36	−1.34	−5.47
Manufacturing	0.08	0.04	0.07	0.09	0.34
Transport and distribution	0.04	0.02	0.03	0.04	0.09
Services	0.03	0.02	0.03	0.04	0.09

In Scenarios 1A and 1B the impacts are relatively less than in the base scenario, 1: relatively high elasticities of substitution in agriculture (1A) reduce the impacts on this sector considerably, while doubling the elasticities of land transformation (1B) has a smaller effect. In Scenario 1C, omitting rainwater from the model without increasing the elasticity of substitution between land and water in agricultural production effectively decreases the elasticity of substitution between irrigation water and land. Consequently, the impacts are greater than in the base scenario.

While impacts on GRP and capital and labour prices may be very small, impacts on the agricultural sector and hence on farm households, and by extension, rural townships and businesses, are larger. This is reinforced when we consider the prices and quantities of land (Table 4) and irrigation water (Table 5) for each of the three land-using activities distinguished in this version of the model. In both tables, differences between north and south subregions are rather small. Greater differentiation may be expected once more, smaller subregions are modelled, and the corresponding parameter values are refined to reflect actual climatic and other differences between them.

Land moves mainly from dairy into sheep and beef farming. Land under horticulture and viticulture increases slightly, but in absolute terms this change is very small, since the benchmark area is small (Table 1). Sectoral price impacts are larger than the quantity impacts, reflecting the relatively low elasticities of transformation assumed. This is confirmed by comparison of Scenario 1 with 1B. The impacts of the shock are more directly mitigated by higher elasticities of substitution in agricultural activities

(1A). Conversely, the lower effective elasticity of substitution of irrigation water with land (1C) increases the impacts. For the larger shock under Scenario 2, the patterns are similar, but the impacts much greater.

Table 4 Change in sectors' land input quantities and prices

		Quantity change (%)			Price change (%)		
		Hort/ Vit	Sheep/ Beef	Dairy	Hort/ Vit	Sheep/ Beef	Dairy
1	North	0.13	0.82	−0.61	2.53	3.92	0.27
	South	0.12	0.75	−0.58	2.52	3.77	0.37
1A	North	0.03	0.32	−0.23	0.36	1.29	−0.09
	South	0.00	0.27	−0.20	0.49	1.17	−0.01
1B	North	0.18	1.14	−0.84	1.87	2.85	0.34
	South	0.19	1.03	−0.80	1.81	2.61	0.30
1C	North	0.30	0.85	−0.66	2.83	3.40	−0.43
	South	0.29	0.72	−0.59	2.82	3.11	−0.21
2	North	0.88	2.97	−2.39	10.06	13.06	−1.07
	South	0.86	2.89	−2.44	10.10	13.00	−1.06

Table 5 Change in sectors' irrigation input quantities and prices

		Quantity change (%)			Price change (%)[*]		
		Hort/ Vit	Sheep/ Beef	Dairy	Hort/ Vit	Sheep/ Beef	Dairy
1	North	−6.26	−29.33	−13.61	10.20	28.55	10.53
	South	−5.87	−27.22	−13.27	9.71	27.19	10.03
1A	North	−7.43	−29.76	−12.91	8.56	23.94	8.84
	South	−6.97	−27.66	−12.30	8.01	22.42	8.28
1B	North	−6.48	−29.47	−13.42	9.86	27.59	10.18
	South	−6.08	−27.35	−13.03	9.36	26.20	9.67
1C	North	−11.23	−27.17	−14.68	19.78	55.31	20.42
	South	−10.46	−26.04	−13.70	18.48	51.68	19.08
2	North	−5.54	−27.96	−15.17	10.17	24.48	10.47
	South	−5.22	−26.53	−14.49	10.19	24.67	10.49

[*] Price = cost of irrigation plus shadow value of irrigation water rent (if any)

By far the largest impacts are, quite reasonably, on the (shadow) price and sectoral use of irrigation water. The patterns of change here differ from those of land prices and use. The particularly large price impact for sheep and beef reflects the relatively much lower volumetric costs for this sector in the benchmark. Although we have not verified the unit costs directly, this could be explicable by the use of more basic forms of irrigation (e.g. border-dyke) and a relatively higher share of stock-water use in this sector, compared with the dairy farming sector. The higher share and (assumed) lower elasticity of substitution of irrigation for rainwater, and for land in the horticulture/viticulture sector, means that the sector is less responsive to the price increase than is the dairy sector, which we estimated to have similar volumetric irrigation costs. Increasing the flexibility of land transformation (1B) has only a very slight effect on sectoral irrigation prices and use, but tends to equalise the relative impacts between sectors. In Scenario 1C, the effect of the lower elasticity of substitution for irrigation water is clearly apparent, as the responses are significantly larger for this scenario than any other. Surprisingly, comparison of Scenarios 1 and 2 shows relatively little interaction between rainfall and irrigation, once other adjustments (e.g. substitutions in production, land use change, reductions of output) are accounted for. However, it is possible that there would be significant interactions if significant subregional differences in rainfall and sectoral differences of its value in production were accounted for (see previous section).

With a ‘standard’ closure in which capital and labour stocks are fixed, non-agricultural sectors benefit slightly from reduced prices of labour and capital, and consequently, impacts on GRP are minimal. However, we believe that this result will change once we implement a more realistic regional closure, involving, *inter alia*, an exogenously fixed real wage and clearance of the regional labour market by net migration. Implementing this closure is made difficult by the numerous inter-institutional financial flows and transfers that should be aligned with (implied) changes in population and different sources of income. Further work is required to develop this closure adequately. Nevertheless, preliminary investigations suggest that for Scenario 1, the labour force (and we assume the population) may decrease by approximately 0.02% and

GRP by approximately 0.04%. The alternative closure has minor impacts on the sectoral reallocations of land and minimal impacts on the sectoral reallocations of water.

4. Conclusions and future work

We have described the initial structure of a regional CGE model for Canterbury, focusing on the allocation and use of land and water in agricultural production. Preliminary scenarios concerning the increasing scarcity of water for irrigation suggest that this would be likely to impact negatively on dairy farming, whilst other agricultural sectors would benefit, either because they are much less dependent on irrigation (sheep and beef), or derive much more value per litre of water used (horticulture and viticulture). Our preliminary results are indicative of the model's capabilities, but must be treated with extreme caution, given the limitations of our current benchmark data set and elasticity values, and the issue of regional closure. In addition to completing the development of a more realistic closure (or several plausible variants), we intend to prioritise the improvement of land and water benchmark data, and the corresponding elasticities of substitution in production, as well as the elasticities of land transformation between uses. Further consideration will be given to the benefits and practicality of disaggregating irrigated from unirrigated production activities, and distinguishing several categories of land (e.g. alluvial plains versus hill country).

Beyond the improvements described above, we also intend to extend the model in several directions. The model will be extended to distinguish five subregions within Canterbury, providing more useful detail for local policymakers. Other extensions may include:

- More detailed treatment of irrigation supply, possibly including major water storage
- Non-agricultural consumptive water uses
- Non-consumptive uses of water, particularly for recreation and tourism.

5. References

[1] Ministry for the Environment, and Ministry of Agriculture and Forestry, Testing the water. Report on the sustainable water programme of action written submissions, Ministry for the Environment, Wellington, New Zealand, 2005.

[2] Environment Canterbury, No more easy water, Press Release, Christchurch, New Zealand, 2006.

[3] Environment Canterbury, Groundwater allocation map., Environment Canterbury, 2006.

[4] L. O'Donnell, Canterbury, its people, its resources Climate Change An analysis of the policy considerations for climate change for the Review of the Canterbury Regional Policy Statement, Environment Canterbury, Christchurch, New Zealand, 2007.

[5] Lincoln Environmental, Canterbury strategic water study, Prepared for the Ministry of Agriculture and Forestry, Environment Canterbury and Ministry for the Environment, 2002.

[6] Ministry of Agriculture and Forestry, The economic value of irrigation in New Zealand, 2004.

[7] A. Grimes, and A. Aitken, Water, water somewhere: the value of water in a drought-prone farming region, Motu Economic and Public Policy Research, Wellington, New Zealand, 2008.

[8] S. Ford, Economic and social assessment of community irrigation projects, Ministry of Forestry and Agriculture, Wellington, New Zealand, 2002.

[9] S. Harris, G. Butcher, and W. Smith, The Opuha dam: an *ex post* study of its impacts on the provincial economy and community, Aoraki Development Trust, 2006.

[10] P. Berck, S. Robinson, and G. Goldman, The use of computable general equilibrium models to assess water policies. in: A. Dinar, and D. Zilberman, (Eds.), The economics and management of water and drainage in agriculture, Kluwer Academic Publishing, Norwell, MA, 1991, pp. 489-509.

[11] P.B. Dixon, A general equilibrium approach to public utility pricing: determining prices for a water authority. Journal of Policy Modeling 12 (1990) 745-767.

[12] P.B. Dixon, S.Y. Schreider, and G. Wittwer, Encapsulation of water allocation into a general equilibrium model, MODSIM05 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia & New Zealand, 2005, pp. 999-1006.

[13] B. Decalauwé, A. Patry, and L. Savard, Quand l'eau n'est plus un don du ciel: Un MEGC appliqué au Maroc., Département d'économique, Université de Laval, Canada, 1997.

[14] T. Roe, A. Dinar, Y. Tsur, and X. Diao, Feedback links between economy-wide and farm-level policies: With application to irrigation water management in Morocco. Journal of Policy Modeling 27 (2005) 905-928.

[15] W. Schwarm, and H. Cutler, Building small city and town SAMs and CGE models revisited. in: M. Doi, (Ed.), Computable general equilibrium approaches in urban and regional policy studies, World Scientific Publishing Co., Hackensack, NJ, 2006.

[16] D.J. Goodman, More reservoirs or transfers? A computable general equilibrium analysis of projected water shortages in the Arkansas river basin. Journal of Agricultural and Resources Economics 25 (2000) 698-713.

[17] C.K. Seung, T.R. Harris, J.E. Englin, and N.R. Netusil, Impacts of water reallocation: A combined computable general equilibrium and recreation demand model approach. The Annals of Regional Science 34 (2000) 473-487.

[18] C.M. Gómez, D. Tirado, and R. Rey-Maquieira, Water exchanges versus water works: insights from a computable general equilibrium model of the Balearic Islands. Water Resources Research 40 (2004) W10502.

[19] D. Tirado, C.M. Gómez, and J. Lozano, Efficiency improvements and water policy in the Balearic Islands: a general equilibrium approach. Investigaciones Económicas 30 (2006) 441-463.

[20] E. Velazquez, Water price and water reallocation in Andalucia:a computable general equilibrium approach, Universidad Pablo de Olavide, Seville, Spain, 2004.

[21] A. Smajgl, Quantitative evaluation of water use benefits - an integrative modelling approach for the Great Barrier Reef region. Journal of Natural Resource Modelling (in press).

[22] A. Rose, and S. Liao, Modeling Regional Economic Resilience to Disasters: A Computable General Equilibrium Analysis of Water Service Disruptions. Journal of Regional Science 45 (2005) 75-112.

[23] A. Grimes, D.C. Maré, and M. Morten, Adjustment in Local Labour and Housing Markets, Motu Economic and Public Policy Research, Wellington, New Zealand, 2007.

[24] T.W. Hertel, S. Rose, and R.S.J. Tol, Land use in computable general equilibrium models: an overview, Purdue University, 2008.

[25] J. Lennox, and S. K. Varghese, From input-output to computable general equilibrium modelling of water use in the Canterbury region, International Input-Output Conference, Istanbul, 2007.