Estimating Impacts of Climate Change Policy on Land Use: An Agent Based Modeling Approach

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INTRODUCTION

- This paper uses the Agent-based Rural Land Use New Zealand model (ARLUNZ) to assess the implications of an agricultural GHG emissions reduction policy on farm income, land use and the environment.
- ARLUNZ is linked with the New Zealand Forest and Agriculture Regional Model (NZFARM), an agri-environmental economic optimization model (Daigneault et al. 2012; Greenhalgh et al. 2011), to develop detailed estimates of changes in agricultural output and farm management from implementing various land-based GHG mitigation practices.
- There are various ways to model economic and land use impacts of environmental policy, yet most of these approaches are focused on a particular impact or limited by its model structure.
- Additionally the lack of heterogeneity in how farmers respond to environmental policy, the way environmental mitigation techniques are transferred through their peer networks, and the effect that both have on the resulting effectiveness of environmental policy are under examined in the literature.
- The incorporation of these micro-level perspectives of human behavior through an approach such as an agent-based model can provide a better understanding of land use change processes, and will improve the resulting estimates of how policy could influence changes in land management and land use.
- Policy analysis imposes a GHG price of $0-50 NZ ($0-40 US) per ton CO_2 equivalent on emissions from agricultural output beginning in 2015, as stipulated in the NZ Emissions Trading Scheme.
- The same set of GHG prices are applied to forest carbon sequestration payments.
- the Hurunui-Waiau catchment in the Canterbury region of New Zealand's South Island is used as a case study. This catchment is located in a region with a large and diverse set of land uses and agricultural enterprises..

HURUNUI-WAIAU CATCHMENT, CANTERBURY NEW ZEALAND

Figure 1. Catchment Location

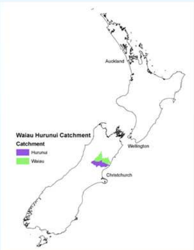


Figure 2. Farm Distribution

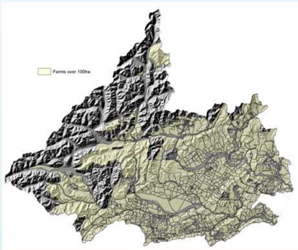
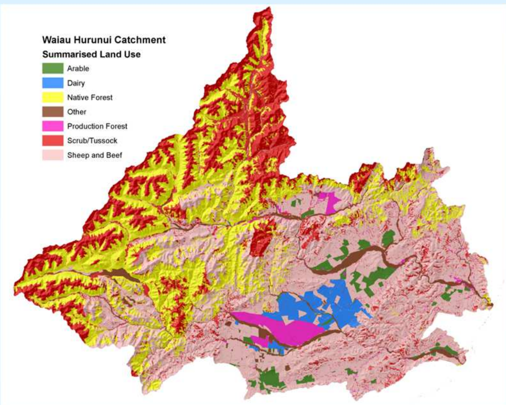


Figure 3. Baseline Land Use



AGENT BASED MODELLING

- Agent-based models (ABM) are a valued technique in representing disaggregated decision making. As their name suggests, agent-based models (sometimes known as an multi-agent systems) attempt to model the behavior of a complex system by representing the behavior of the various agents that make up the system (Klosterman and Pettit 2005)
- LUCC models have been adapting agent based approaches to enable the simulation and analysis of a variety of LUCC scenarios. The benefit for LUCC models in this approach is the explicitly focus on human decision making which is important for examining the role and interactions of the actors which drive LUCC.
- Agents are discrete entities which are defined in terms of both their attributes, behaviors and by what the model is examining (Brown et al. 2005). The selection of the roles the agent (or agents) will simulate is usually anyone who makes decisions or takes actions which affect the underlying system state (Evans et al. 2005, Page 2008).
- It is claimed that agent-based models advance most disciplines it is applied to as it includes more realistic assumptions about behavior, structure and timing than previous methods of modeling (Page 2008).

FARMER TYPOLOGIES

- Farmers are typically assumed to be one of the more important actors when looking at the land use and land cover changes within the rural area. Their importance in this space is magnified when you consider their actions, the size of their farms and the highly concentrated numbers of farmers in certain locations around New Zealand.
- After review there are four distinct typological approaches for farmers which have relevance for implementation within an agent-based LUCC model; Farming sector, Farming attribute, Production process, and Life-stage. Each of these approaches have their advantages and disadvantages, but all improve upon a single rational profit-maximizer perspective which is the homogeneous option for farmer agents, and which is still used in a range of economic and agricultural simulation models.
- The chosen typology is a combination of both a farming sector and life-cycle approach however the life-cycle is for the farm as a social unit rather than a life-cycle for an individual farmer.
- A typology was developed that created farm agents that intersected between a farming sector approach and a farmer's life-cycle approach. The sectors included were Arable, Sheep and Beef, Dairy, and Production Forest. The life cycle stages for the farm can be classed as Succession, Consolidation, Expansion, Transition, and Retirement.

Table 1. Farmer Typologies

Life Stage	Incumbent	Successor	Type of Change
Farm life-stage 1	40-45 years	15-20 years	Succession
Farm life-stage 2	45-50 years	20-25 years	Consolidation
Farm life-stage 3	50-55 years	25-30 years	Expansion
Farm life-stage 4	55-60 years	30-35 years	Transition
Farm life-stage 5	60-65 years	35-40 years	Retirement

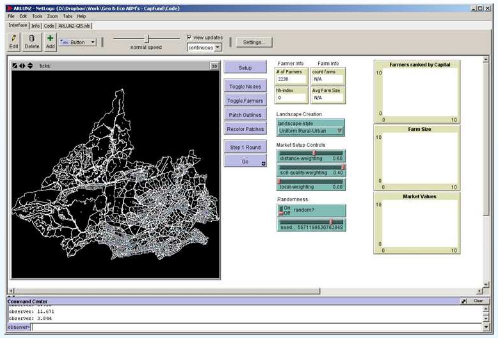
SOCIAL AND GEOGRAPHIC NETWORKS

- When reviewing farmer's social interactions from both a conceptual and theoretical perspective, it is obvious that the farmer's networks are framed around social (usually with farmers who are similar to themselves), and geographical (farmers who might be different but are close in proximity) interactions.
- Distilling each of these two types of networks further they relate to two types of weighting factors which enable their implementation within an agent-based model; endorsements and imitation (Schmit & Rounsevell 2006, Jager et al 2000).
- Endorsements are used in agent-based models to incorporate the transfer of qualitative knowledge. They capture the transfer of information, a process of reasoning, and the establishment of a preferential ordering of behavioural options based on this information.
- In relation to this research, the farmer agents incorporate information from other farmer agents who operate in the same sector or are similar in age mimicking the potential social interaction between farmers in the same sector and/or age.
- Imitation is an evolutionary process which helps agent populations to observe and learn about the consequences of certain actions. Imitation as a process where an actor observes another actor being rewarded for understandable and reproducible behaviour.
- Farming is a very visible land use and activity. Schmit & Rounsevell (2006 – pg. 114) state the practice of farming is visible "to other local inhabitants, to anyone who passes through the countryside and more importantly to other farmers".
- In relation to this research, the farmer agent will incorporate information from the farms that are geographically adjacent to their own farm, mimicking the farmers observation of the successes and failures of the surrounding farms regardless of the farm sector.

AGENT-BASED RURAL LAND USE NEW ZEALAND (ARLUNZ)

- The model was primarily developed using NetLogo. It is linked with an agri-environmental economic optimization model, the New Zealand Forest and Agriculture Regional Model (NZFARM) that is programmed in GAMS. The initial set up is shown in Figure 5.

Figure 4. Initialization of ARLUNZ Model



NEW ZEALAND GHG EMISSIONS POLICY SCENARIO

- We use ALUNZ to assess the economic and LUCC impacts of imposing a GHG reduction policy on New Zealand's forest and agricultural sector.
- Policy imposes a GHG price of $0-50 NZ (approx. $0-40 US) per ton CO2 equivalent on emissions from agricultural output (i.e. point of obligation at the processor level) beginning in 2015, as stipulated in the NZ Emissions Trading Scheme.
- Same GHG price imposed for carbon sequestered in forest growing stock.
- We also measure co-benefits on the catchment's land and water, such as changes in fertilizer and pesticide application, vegetation cover and soil erosion, amongst other things.

BASELINE AND SCENARIO ANALYSIS

Table 2. Key Outputs and Relative Change From Baseline

GHG Price	Farm Profit (Million NZD)	GHG Emissions (Million tCO2e)	Net GHG Emissions (Million tCO2e)	N Leaching (tons)	P Loss (tons)
2015					
$0/tCO_2e$	19.1	1.0	0.8	2445	22.7
$12.50/tCO_2e$	-2%	-8%	-37%	-5%	-8%
$25/tCO_2e$	-3%	-29%	-146%	-14%	-28%
$37.50/tCO_2e$	-5%	-24%	-110%	-13%	-23%
$50/tCO_2e$	-8%	-23%	-91%	-15%	-23%
2035					
$0/tCO_2e$	21.6	1.1	0.8	2944	26.5
$12.50/tCO_2e$	1%	-16%	-111%	-6%	-15%
$25/tCO_2e$	-2%	-43%	-295%	-19%	-42%
$37.50/tCO_2e$	-2%	-57%	-392%	-26%	-56%
$50/tCO_2e$	-1%	-56%	-379%	-23%	-54%
2055					
$0/tCO_2e$	23.6	1.3	0.9	3474	31.1
$12.50/tCO_2e$	14%	-15%	-122%	6%	-10%
$25/tCO_2e$	23%	-37%	-281%	4%	-28%
$37.50/tCO_2e$	26%	-48%	-367%	2%	-38%
$50/tCO_2e$	17%	-61%	-461%	-12%	-54%

ECONOMIC AND ENVIRONMENTAL IMPACTS

Figure 5. Land Use

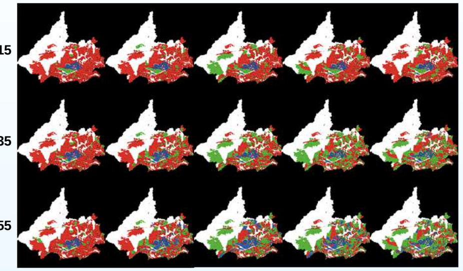


Figure 6. Farm Profit

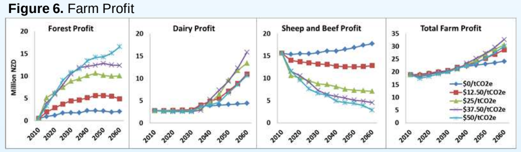
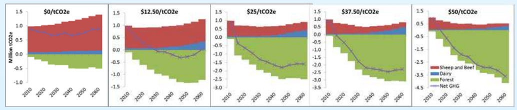


Figure 7. GHG Emissions



CONCLUSIONS AND FUTURE RESEARCH

- GHG price on land-base emissions could lead to large changes in GHGs
  - Combination of emissions reductions and added forest carbon sequestration
- Substantial land-use change likely to occur over next 50 years
  - Dairy expands for all scenarios because of high relative profits
  - Forestry more than doubles by 2055 for all GHG price scenarios
  - Sheep and beef contracts with GHG price because of relatively low profits and high GHG emissions rates
- Farm profits at catchment level could actually increase over simulation period because payments for forest carbon sequestration more than offset costs to sheep and beef and dairy enterprises.
  - Farmers would have to be willing to become at least part-time foresters
- GHG price generally reduces N leaching and P loss levels
  - GHG policy could provide co-benefits to water quality (regulations being considered)
  - Exception is after 2050 when dairy increases under new ownership from farm succession
- Additional research will focus on using farm-level surveys to provide additional insight on defining farmer typologies and willingness to adopt new technologies to adapt to climate change and commodity price risk

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