Analysis of impact on New Zealand's economy of the New Zealand emissions trading scheme

By

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Abstract

Climate change has triggered international concerns and research interests globally. Traditional energy consumption and agricultural fertilizers contribute to a large proportion of greenhouse gas (GHG) emissions in many countries and regions. GHG emissions damage the environment and are a suspected cause of extreme climate change such as droughts and flooding. In order to reduce emissions there are two basic approaches: on the one hand, new technology is being developed to substitute for traditional fossil fuels with low-carbon energy sources; on the other hand, policies are aimed at reducing the negative impact of GHG on climate change by penalizing GHG producers.

The Emissions Trading Scheme (ETS) is a key pillar in New Zealand (NZ)'s approach to climate change. The ETS, as currently designed, is unique because, in principle, it involves most sectors and all GHG. To date, many greenhouse gas emitting sources and sinks have been incorporated into the ETS. However, agriculture, the major emitter of GHG is not involved in this scheme.

In this study, a computable general equilibrium (CGE) model is used to assess the effect of ETS on the NZ economy assuming agriculture is included into the scheme. This model is linked to a partial equilibrium forest growth model, used to derive variables such as rotation age, timber yield, and carbon sequestration. In this thesis, I examine land use change of the forestry and agriculture sectors under four carbon tax rates and derive an equilibrium carbon permit price assuming a closed carbon trading market with respect to international carbon markets. Additionally, based on the results, I compare the impact of a carbon tax and the ETS on land use change, and the macro economy, with aim of deriving implications for policy.

Dedication

I dedicate this thesis to my family. A special feeling of gratitude to my loving parents, Mr. Qun Wang and Ms. Huajuan Qi for their unconditional support and love.

I also dedicate this work to my beloved husband, Dr. Qinwen Hu, who has cheered me on when I was discouraged, and he has most importantly been 100% confident in my ability to get this done. Thank you for always believing in me.

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My genuine gratitude goes to Dr. James Lennox and Professor John Gilbert for sharing their knowledge and insights of CGE modeling. I also wish to thank PhD fellows Mr. Zhenting (Leon) Lin, Ms. Huixian (Helen) Zhang, and Dr. Qiaomin Li from the University of Auckland, for their contribution on constructive group discussions about general equilibrium theory and CGE modeling during my study. Professor Mark Greer, Dr. Eric Tong, Dr. Eilya Torshizian and Dr. Quan Zhou are also acknowledged sincerely for devoting their time and energy to discussions and helping with Latex programming.

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Chapter 1

Introduction

New Zealand (NZ) and other countries are making efforts to reduce greenhouse gas (GHG) emissions. New Zealand has implemented a domestic emissions trading scheme (ETS) with the aim of reducing its GHG emissions. The European Union (EU) has implemented its own ETS. Carbon taxes have been introduced in Sweden and Ireland. These policies are aimed at meeting emission reduction targets within a certain period. At the latest global convention on climate change (COP21), held in Paris at the end of 2015, participants agreed on a global treaty with the aim of reducing emissions and limiting the rise of global warming. Main discussions from the convention were related to the GHG associated with agriculture, forestry, and other land use changes which account for 24% of global emissions (Agency, 2016).

In this thesis, I apply a computable general equilibrium (CGE) model with an endogenous forest growth model (forest-CGE), to evaluate the introduction of a carbon tax and, as an alternative, ETS, on NZ's land use change between forestry and agricultural sectors, and also on NZ's macro economy. By comparing the effect of a carbon tax and the ETS on the macro economy, the thesis provides insights that may assist policy makers to decide which policy results in a better outcome for New Zealand.

1.1 Background

GHG emissions are widely accepted as a cause of extreme weather conditions such as drought and flooding (MFE, 2016). In 2012-2013 NZ experienced the worst drought in nearly 70 years. It substantially reduced agricultural production. According to the latest

GHG emissions report (MFE, 2015c), NZ has a unique emissions profile with the largest proportion (48%) of GHG emissions produced by the agriculture sector in 2013 (as shown in Figure 1.1). In contrast, "land use, land use change and forestry" (LULUCF) is considered a net carbon sink. Carbon can be stored in tree trunks, branches, leaves, roots and soils (carbon sequestration). The net removal of carbon dioxide by forest land from LULUCF sector in 2013 was 11.5% increase from 1990. This implies a need to reduce externalities from emissions, and indicates the importance of afforestation. [1]

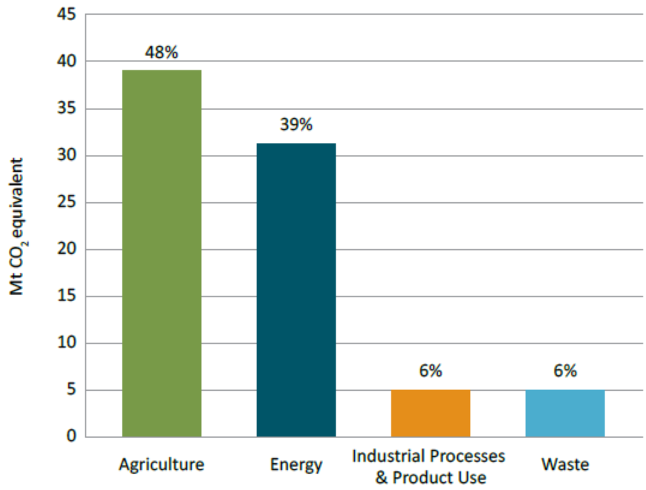

Figure 1.1: New Zealand's greenhouse gas emissions in 2013 by sector

source: MFE (2015c)

NZ implemented its ETS as the main policy tool to price carbon emissions. However, in the absence of agriculture in the ETS, a market-based carbon price is very low (as shown in Figure 1.2). This lowers incentives against afforestation and emissions reductions by other sectors. To date, forestry has financial liability for harvested trees and decayed woods. Energy, industrial processes, waste, refined fuels, and synthetic gases sectors have to pay for their emissions, but agriculture is exempted from the scheme. Given the significant role the agriculture plays in NZ economy, the impact of the ETS with agriculture on carbon prices and economy should be carefully analyzed.

[1] Afforestation is the establishment of a forest or stand of trees in an area where there was no previous tree cover. In contrast, deforestation refers to a removal of a forest or a stand of trees where the land is then converted to a non-forest use.

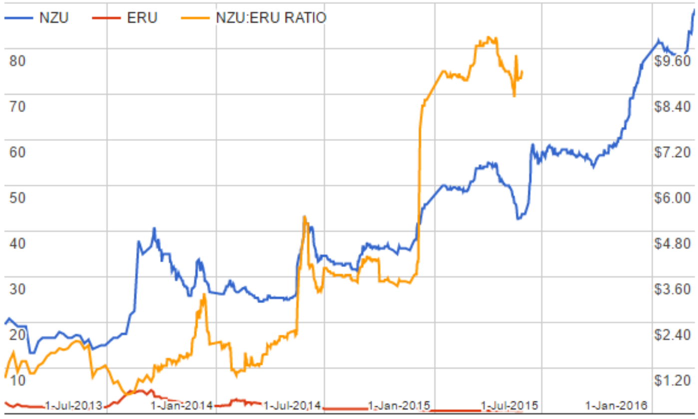

Figure 1.2: New Zealand Unit (NZU) price

source: `http://www.carbonforestservices.co.nz/nzueru-chart.html`

Like the ETS, carbon tax is also used to reduce GHG emissions. Both carbon tax and ETS span a range of regulatory approaches, including emission pricing and quantity control. Others include technology improvements and performance standards. To date, a carbon tax not been introduced in NZ. If a fixed tax is imposed on production inputs, Ramseur and Parker (2009) point out that a carbon tax has a potential advantage by not causing additional volatility in energy prices, and it can lead to investment in efficiency improvements and equipment upgrades. But the disadvantage of implementing carbon tax is the possible uncertain emission control. At a higher carbon tax, emitters respond by shifting away from relatively expensive input to those less expensive ones. As a result, sectoral outputs decrease which lead to a decrease in emissions.

My thesis covers all emission sectors in NZ including agriculture with an endogenous forest sector. This fills the gap in the existing study and shows the impact of an ETS which includes agriculture. An optimal rotation age of trees is estimated and land use change between agriculture and forestry under four carbon tax rates and ETS is assessed. The impact of both policies, at an equilibrium carbon permit price, which is derived by a forest-CGE model, is also examined.

The following sections provide three research questions and outline the methodology.

1.2 Research questions

1.2.1 What is the impact of carbon tax on land use change between forestry and agriculture?

Forestry and land use are important considerations when analyzing policy responses to climate change (MFE, 2009). Although NZ researchers have applied a CGE model to estimate how climate policy impacts the macro economy (NZIER & Infometrics, 2009b), these researches had yet to take land use into account. According to MFE's report in 2010, New Zealand has a total area of 26.9 million hectares, with almost 30% in native forest, 51% in grassland, 2% in new forest land (i.e. land with forest present in 2008 but not in 1990), 2% in cropping and horticulture, and 15% in "other" land use classes.

The agricultural sector was expected to enter into the scheme in 2015 but, to date, it is still exempted from the scheme. However, government has agreed to extend the entry date for agriculture if two conditions are met: firstly, that new technologies are introduced to help reduce emissions; and that international competitors take sufficient action on emissions in general (MFE, 2012). Having agriculture in ETS could generate a large reduction in GHG emissions and a sharp increase in a market-based carbon permit price[2], because agriculture is the largest emission sector in NZ.

In the NZ context, some studies have used a partial equilibrium or a dynamic econometric approach (see Kerr & Sweet, 2008; Kerr & Olssen, 2012; Hendy et al., 2007; Kerr et al., 2012) to focus on land use change between forestry and agriculture. These methods did not reflect the potential drivers for land owners to make land conversion decisions. This is because unlike CGE model, partial equilibrium and econometric analysis do not show the interactions between sectors.

In this thesis, I will apply a CGE model with an endogenous forest growth model to estimate the impact on land use for forestry and agriculture under a carbon tax policy. The model includes agricultural sectors. Carbon tax is assumed to be imposed on sectoral

[2] If there is no international trade for carbon permits

output emissions and I examine the effect under four carbon tax settings from low to high: NZ$0/t, NZ$25/t, NZ$50/t, NZ$100/t. “t” means metric tonne of CO_2e emission.

1.2.2 What is impact of market-based carbon permit price on NZ’s economy under ETS?

In December 1997, the United Nations Framework Convention for Climate Change (UNFCCC) parties signed the Kyoto Protocol, which committed Annex I countries to binding emission reduction obligations (NZIER, 2008). To meet Kyoto Protocol obligations, each participant was allocated an assigned amount of emission rights based on their emission data. Participants could increase their assigned amounts of carbon permit by either reducing domestic emissions or generating new amounts through a carbon sink such as forestry sequestration.

Under the ETS, seven main sectors are covered: Forestry; Liquid fossil fuels; Stationary energy; Industrial processes; Synthetic gases; Waste; and Agriculture. Each sector has a different start date as seen in Table 1.1 (Provost, 2011). Except for the forestry sector, each sector surrenders one unit of carbon permit for every two tonnes of carbon emitted under the scheme. Pre-1990 forest owners do not surrender New Zealand Units (NZUs) if they harvest trees as long as the forest land is replanted. Post-1989 forest owners must surrender carbon permits at deforestation (MFE, 2015a). The agricultural sector has had its entry into the scheme delayed, as mentioned earlier.

Table 1.1: Entry date of sectors in the NZ ETS

Sector	Voluntary reporting of emissions	Mandatory reporting of emissions	Full obligations: payment for emissions
Forestry			1 January 2008
Liquid fossil fuels		1 January 2010	1 July 2010
Stationary energy		1 January 2010	1 July 2010
Industrial processes		1 January 2010	1 July 2010
Synthetic gases	1 January 2011	1 January 2012	1 January 2013
Waste	1 January 2011	1 January 2012	1 January 2013
Agriculture	1 January 2011	1 January 2012	NA

New Zealand also has access to international permits available under the Kyoto Protocol including: NZ assigned amount units (AAUs); Certified emission reduction units (CERs); and Emission reduction units (ERUs).

Diukanova et al. (2008) estimated the equilibrium NZU price under different scenarios. However, their study did not take into account the effect of forest carbon sequestration on the carbon market. Also they did not consider how land use might change across sectors.

In chapter 4, I estimate an endogenous carbon permit price with a closed NZ carbon market including all ETS sectors. Three scenarios are assumed: pure ETS, carbon pool and free allocation of surplus international permits to sectors. In particular, I compare the endogenous carbon permit price under the three scenarios, and analyze land use change between the forestry and agricultural sectors.

1.2.3 What is the implication of carbon tax and the ETS for NZ policy?

Although carbon tax and "cap-and-trade" are two different mechanisms, they share some equivalents. Both policies are aimed at providing incentives to reduce emissions. In particular, Goulder and Schein (2013) claim that both policies have the same effect on subsidizing emission-intensive and trade-exposed industries and use a similar mechanism.

Sachs (2009) held a forum to discuss the merits of a "cap-and-trade" versus a carbon tax. Supporters of "cap-and-trade" believe that the system has the advantage of creating a carbon market which produces a "market-based" carbon permit price, and it rewards companies with an allocation of carbon permits. But supporters of carbon tax claim that the tax system is easily implemented and adjusted. A carbon tax can be levied upstream and cover the entire economy with a stable tax, whereas "cap-and-trade" generates a fluctuating spot price.

The main difference between carbon tax and "cap-and-trade" is that a carbon tax fixes the carbon permit price but quantity can vary, whereas the price is volatile under cap-and-trade. The volatility may result in a risk and uncertainty in carbon-saving investments in capital or R&D. Weitzman (1974) discusses the choice of either price control or quantity control under conditions of uncertainty. He points out that the relative slope of marginal benefit of abatement and marginal cost of abatement are important considerations in the regulator's decision making.

Parry and Pizer (2007) show that carbon tax has advantages over cap-and-trade because the tax can be collected by government as revenue. However, Parry and Pizer (2007) also mention that from the government's perspective, policymakers may want to compensate the industries which are affected by the carbon policy, either by auction or by free allocation of the carbon permits. The problem of permit price volatility can be solved by allowing firms to bank unused carbon permis. Both carbon tax and "cap-and-trade" have merits and weakness. For carbon tax, how to allocate tax revenue is a concern; and for cap-and-trade, how to manage the risk of volatile permit price would need to be considered.

Geoff (2016) discusses three approaches of tackling climate change issues: carbon tax, command and control, and cap and trade. Pricing on carbon gives incentive for individuals to reduce the GHG emissions. However, a carbon tax can be ruled out by the absence of a global authority and it would lead to moral hazard problem; the command and control is inefficient compared with regulation that focuses on all effort on cutting emissions; the cap and trade is the most effective approach as it provides a limited quantity of tradable permits based on initial emission endowment, and also establishes a global permits market that would have to meet requirements of competitiveness and liquidity. A small economy such as New Zealand will meet carbon leakage problem if it has domestic emissions regulation whereas the rest of world has none. Thus, Geoff (2016) proposes an idea called "climate club", where a single country will join an international agreement only if the leading country or countries call for formation of coalition. In addition, imposing a tariff on imported goods is also useful to reduce emissions.

The research focus in chapter 5 is a comparison of the effect of carbon tax and ETS on NZ's macro economy, based on results from the model used in chapter 3 and 4.

1.3 Thesis outline

This thesis consists of 6 chapters. Chapter 1 introduces both the background to the NZ ETS and the research questions. Chapter 2 summarizes existing literature on economic theory, application to the problem, and computable general equilibrium model. Chapter 3 establishes a CGE model with an endogenous forest sector to analyze how NZ's economy and land use responds to four possible carbon taxes. Chapter 4 extends the forest-CGE model to estimate a market-based carbon permit price in a closed NZ carbon market, and compares the permit price under three scenarios. Chapter 5 analyzes and compares the impact of carbon tax and the pure ETS on land use change between forestry and agriculture, macro variables including GDP, factor use and international trade, based on the model results of chapter 3 and 4. Chapter 6 outlines a conclusion and future research.

Chapter 2

Literature Review

In this chapter, I review the existing literature as it relates to forestry, carbon tax and the ETS study. Section 2.1 extends the introduction of NZ's current emissions problem and government initiatives in detail. The following sections explain features of externalities and the choice of carbon tax and ETS based on theory and application. Section 2.2 provides a high-level review of externalities and forest economics. Section 2.3 examines existing studies and their application to forestry, land use and carbon trade. It also summarizes the carbon tax VS ETS debate; section 2.4 introduces methodology used in this thesis (CGE model); section 2.5 draws a conclusion.

2.1 Practical issues

Greenhouse emissions can have a negative impact on both the environment and the economy. For instance, from an environmental perspective, the emissions result in air pollution which harm people's health, and climate change which increase global temperature. From an economic perspective, it causes externalities which can negatively affect consumers' utility. Externalities will be explained in detail in section 2.2.

2.1.1 New Zealand's emission profile

This subsection introduces NZ's emission profiles and indicates the main emission sectors and sources. Current policies for reducing emissions in NZ and other country are introduced in the next section.

The primary carbon dioxide emission from agriculture is methane from the enteric fermentation category and nitrous oxide released from soils (MFE, 2015b). Due to improved productivity, feed, and stock management, agriculture emission intensity declined from 1990 to 2013. Emissions from the energy sector are mainly from road transport and electricity generation. From the year 2008 to 2011, the level of emissions was lower than the period 1990 to 2007, due partly to the increasing use of renewable resources in electricity generation (EECA (2015) reports that in 2013 NZ sourced 38% of its total energy from renewable resources). The main emission sources from the "industrial processes and product use" sector are industry, household refrigeration, and air-conditioning systems. Chemical, mineral, and metal products contribute to the emissions from the industrial sector. The waste sector has lower emissions by 1% compared with year 1990 due to improved landfill management (MFE, 2015c).

MFE (2015b) reports the emission from deforestation activity over the period 1990 to 2013 (Table 2.1). Deforestation included natural forests, pre-1990 planted and post-1989 forests.

Table 2.1: NZ's net emissions in forestry

Activity	Gross hectare (1990-2013)	Net hectare (2013)	Emissions in 2013 (Gg $CO_2 - e$)
Afforestation/reforestation	682,189	659,332	-17,057
Deforestation	168,024	8,453	4,892
Forest management		9,272,279	-9,030
Net emission			-21,195

source:MFE (2015b)

Figure 2.1 shows the change in net removal CO_2-e by the forestry sector. The fall of carbon sequestration before 2008 was caused by deforestation of planted forests before the introduction of the NZ ETS. Specifically, since 2008, the area of deforestation is more than the average of new planted forest area (MFE, 2015c). This is partly because owners of pre-1990 forests have to pay a carbon emission liability at the time of harvest or deforestation under the ETS. Hence, to avoid this cost, many forest owners felled their trees before the introduction of the ETS. Figure 2.1, it shows a sharp fall in net removals between 2007-2008.

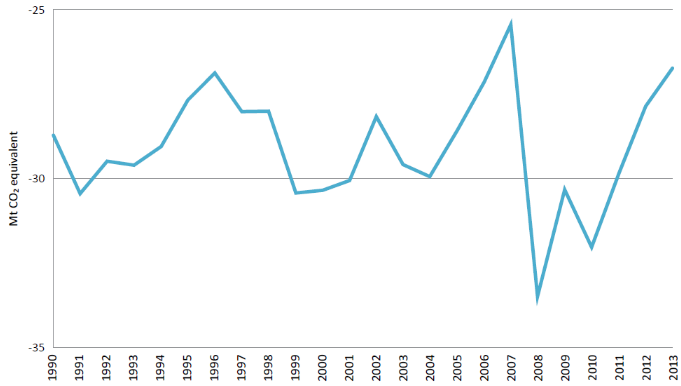

Figure 2.1: Net removals from LULUCF

source: MFE (2015c)

In fact, the net removal of CO_2-e increased during the first commitment period (2008-2012), because the area of planted trees exceeded that deforested. Forest owners obtained benefits from planting trees as they were able to trade carbon permits in the global market. In 2013, net removals from the LULUCF sector were -26.8 Mt CO_2-e. This figure is different from 33.7 Mt which is mentioned above, because 33.7 Mt measures the net removal from the land converted to forest land only. Figure 2.2 shows the change of total emissions and net removals from 1990 to 2013.

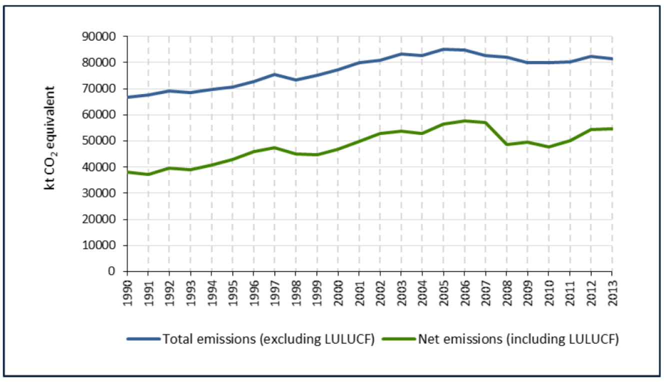

Figure 2.2: NZ's total emissions and net removals

source:MFE (2015b)

Emissions and removals for harvested timbers were first reported in 2013 (MFE, 2015c). In that year, about 8,453 hectares of forest land was converted to grass land and other land use. Land conversion leads to a release of CO_2 from trees to the atmosphere (MFE, 2015b). Table 2.2 shows the change in forest land use over the period 1990 to 2013. The conversion of forest land is due partly to the profitability of dairy farming and sheep-beef farming compared with forestry. However, it is probable that the lower carbon prices also reduced the motivation for afforestation.

Table 2.2: NZ's forest land change

Forest land subcategory	Area of forest in 1990 (hectares)	Deforestation since 1990		Deforestation in 2013	
		Area (hectares)	Proportion of 1990 area (%)	Area (hectares)	Proportion of 1990 area (%)
Pre-1990 natural forest	7,897,109	43,531	0.55	1,453	0.02
Pre-1990 planted forest	1,520,335	101,635	6.69	5,588	0.37
Post-1989 forest	0	22,857	NA	1,412	NA
Total	**9,417,445**	**168,024**	**1.78**	**8,453**	**0.09**

source: MFE (2015b)

Compared with CO_2, CH_4 and N_2O are not as persistent in the atmosphere but they do have a stronger warming effect (MFE, 2015c). GHG emissions from NZ agriculture over the period 1990 to 2012 increased by 14.9% [1], and it remains a very high proportion compared with the rest of Annex I countries [2]. Figure 2.3 compares the CO_2 emission between NZ and other countries.

[1] http://unfccc.int/ghg_data/ghg_data_unfccc/time_series_annex_i/items/3853.php

[2] United Nations Framework Convention on Climate Change (2014) defines that "Annex I Parties include the industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States."

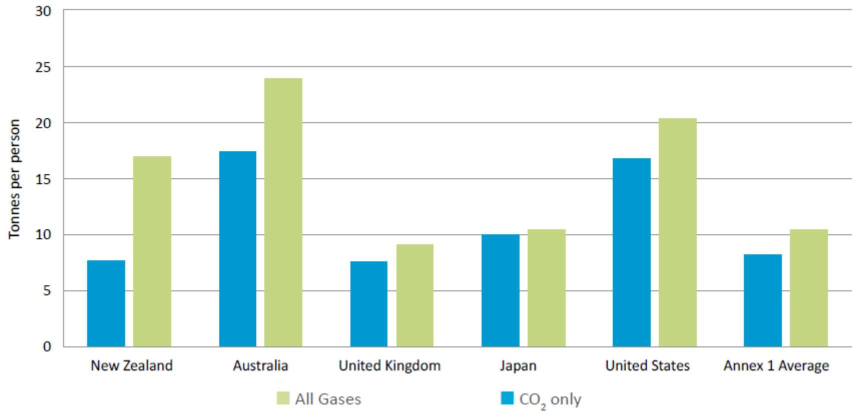

Figure 2.3: Global emission by CO2 comparisons in 2012

source: MFE (2015c)

In order to reduce GHG emissions, NZ and other countries encourage activities across a range of technological innovations, policy regulation, and so on. The next section introduces initiatives taken by NZ, and the international momentum for addressing emissions problems.

2.1.2 International and NZ's effort against climate change

NZ signed the Kyoto Protocol in 1997 and ratified it in 2002 for the first commitment period 2008-2012. From 2008 to 2012, NZ had a target of reducing its emissions to 1990 levels (MFE, 2010).

At the COP 21 conference, delegates from 196 countries agreed to a deal for tackling global climate change. This is the first time in history that all the world's nations have agreed to reduce GHG emissions. The deal endeavours to limit the global average temperature increase to below 1.5°C by the end of this century, and reduce the GHG emissions to the levels at which the natural resources like trees, soil and oceans can absorb carbon naturally, sometime between 2050 and 2100. Renewable energy is encouraged, especially in developing countries. According to the agreement, rich economies are responsible for providing "climate finance" to poorer countries helping them to adapt to the new requirements around climate change. This "climate finance" is treated as a "floor", a base to build upon, and will commence on 2020. Following this, a world review on GHG reductions will be undertaken every five years.

NZ committed to reduce GHG emissions to 30% below 2005 levels by 2030. The reduction covers five main emission sectors: energy, industrial processes and product use, agriculture, forestry and other land use, and waste. All GHGs are included in the target (New Zealand submission to the ADP, 2015).

The two largest economies in the world China and the US, committed to reduce their domestic GHG emissions at the COP 21 conference. China pledged to cut its GHG emission per unit of its GDP by 60-65% from 2005 levels, and increase its share of non-fossil fuel use in energy consumption by 20% by 2030 (Chuli, 2015). In 2014, China and US had agreed to drive bilateral cooperation on climate change, i.e. "US-China commitment to curb carbon emissions". According to this deal, the US will cut emissions up to 28% by 2025, and China promised to establish a national cap-and-trade system on industrial emissions (Sam, 2015).

If agriculture is included in NZ ETS, the scheme would increase production costs for dairy and sheep-beef, and in the short term these industries could lose competitiveness in the global market. However, in the long term, NZ will contribute to reducing GHG emissions compared with countries without emissions regulation policy. This is because in the long term, the polluting sectors in NZ will adjust the sectoral production cost with improved efficiency and technological innovation that will decrease the GHG emissions. Greenhalgh et al. (2007) point out that the climate policy should have competing objectives, such as 1) maximizing environmental effectiveness; 2) minimizing social disruption and adjustment costs; 3) minimizing the fiscal cost to taxpayers; and 4) improving NZ economic efficiency in a carbon-constrained future.

The EU ETS, is the core instrument of EU policy to combat climate change. It operates in 28 EU countries plus Ireland, Liechtenstein and Norway: it is being introduced in 4 phases. The first trading period was between 2005 and 2007; the second trading period was between 2008 and 2012; the third period spans 2013 to 2020; and the last period will run from 2021 to 2028. Around 45% of total EU emissions are regulated by the scheme. Overall emissions have been capped and firms can buy and sell carbon permits as needed. The system accounts for over three-quarters of international carbon trading, and is looking to link with other countries' climate policy. Firms are allocated carbon permits from government in terms of their production, which is called an output-based allocation. Three main GHG emissions are covered: carbon dioxide (CO_2), nitrous oxide (N_2O), and perfluorocarbons (PFC_s). The allocation helps to reduce the risk of the emission leakage.

NZ GHG emissions are mainly from agriculture and energy, therefore, evaluating the negative effects from emissions draws attention. Next section explains the definition of externalities, and summarizes approaches to solve the problem caused by externalities in terms of economic theory.

2.2 Economic theory

This section summarizes the main economic theory on environmental externalities and uncertainty regarding carbon price and quantity control, and three fundamental forest models. I relate each theory to my research questions in each subsection.

2.2.1 Externalities

Externalities are the result of market failure, which if significant can lead to resource misallocation. Baumol and Oates (1988) note that externalities occur when two conditions are met: 1. an individual's utility includes non-monetary variables and is determined by others (government, person, firm) without attention to the effect on the individual's welfare; 2. the individual whose activity affects another person's utility is not being compensated for the activity with an equal value to the resulting benefits or costs to others.

In general, externalities can be categorized as positive and negative. A positive externality generates a benefit on an unrelated third party, but a negative externality imposes a cost on the third party. In a negative externality situation, marginal social cost is greater than the marginal private cost; but a positive externality enables marginal social benefit greater than the marginal private benefit.

Two types of externalities are also relevant. Public good externalities (undepletable) refer to consumption that does not affect the availability of the resource to others, such as air and beautiful view from a garden. In contrast, private good externalities (depletable) are such that every additional unit that is consumed reduces its availability or makes it costly to others. In order to achieve an efficient resource allocation, a tax on emissions without consumer compensation results in an optimal allocation for public good externalities. However, for private externalities, in order to achieve an optimal allocation of resource, imposing a tax on polluters with compensation to consumers is usually required (Baumol & Oates, 1988).

In order to assess the impact of undepletable externalities in NZ, my research focuses on pricing carbon emissions from sectors' output. Undepletable externalities are caused by emissions, released to the atmosphere and they impact consumers' utility (e.g. health). According to Baumol and Oates (1988), a penalty charged to polluters can lead to an efficient allocation of resources. In chapter 3, the effect of four carbon tax rates on sectoral output-based emissions is examined. Land use between forestry and agriculture is also assessed. As expected, sectoral emissions decrease with higher carbon tax rates. This finding conforms Baumol and Oates (1988)' theory.

2.2.2 Optimal pricing

General equilibrium analysis finds an efficient allocation of commodities and services in the economy. Prices play a crucial role in equilibrating demand and supply, such that the same price is faced by buyers and sellers.

A competitive market structure is assumed for NZ economy in this thesis. According to the first theorem of welfare economics, any competitive equilibrium or Walrasian equilibrium leads to a Pareto efficient allocation of resources. The optimal level of tax rate on emission polluters should be equal to the marginal social damage cost for undepletable externalities (Baumol & Oates, 1988). In chapter 4, an equilibrium carbon permit price is derived under three scenarios: 1. pure ETS where only forestry supplies carbon permits, 2. carbon pool where government sells the surplus of international carbon permits along with forestry, 3. free allocation where government subsidizes the surplus of international permits to polluters, forestry still supplies the permits from growing trees. Three scenarios generate three equilibrium carbon permits prices, but the price is equal to the marginal social abatement cost. Total emissions decrease in comparison with a baseline where there is no carbon price.

Coase (1960) states that "when conflicting property rights occur, bargaining between parties involved will lead to an efficient outcome regardless of which party is eventually awarded the property rights, as long as the transaction costs associated with bargaining are negligible". He suggests that transaction costs should not be neglected, and government should create institutions that minimize transaction costs. Without transaction costs, the outcome of production and the outcome in terms of the resource allocation can be efficient in the market, provided private property rights are clearly defined. Policy analysis without considering transaction costs does not represent the real world. However, transaction costs are difficult to measure (Vatn, 2001).

Some literature points out although transaction cost is important, its use could lead to confusion regarding efficiency evaluation (Vatn & Bromley, 1997; Vatn, 1998). For instance, Coase focuses only on the direct abatement cost regardless of the level and distribution of transaction costs. In this thesis there would be costs of government buying carbon permits on the international market and selling them on to domestic industry. By contrast, the Pigovian solution is always reaching the Pareto optimal with tax the polluter at the level where marginal abatement cost equals marginal damage (Bromley, 1989; Vatn, 1998).

2.2.3 Choice of a carbon tax or cap-and-trade

Given the inefficiency caused by significant externalities, policy aims at internalising external costs. Weitzman (1974) analyzed two alternatives under conditions of uncertainty.

Uncertainty refers to a possible mistake made by policy makers choosing either taxes or a quantity cap to minimize the efficiency loss in the economy.

Weitzman (1974) states that an uncertainty or inadequate information is an essential factor in deciding whether price control or quantity control has an advantage over the other. His work specifies abatement cost and abatement benefit for sectors under a partial equilibrium context. The relative slope of the marginal benefit and marginal cost curve determines which policy would be preferred (Grodecka et al., 2015; Weitzman, 1974). If the uncertainty is about sector's emissions abatement cost, then price would be preferred because the deadweight loss under a flat marginal benefit of abatement curve is lower. In contrast, a quantity control might be chosen if the marginal benefit of abatement is relatively steeper than marginal abatement cost curve. Marginal abatement cost depends on input cost, and it increases if emission reduction increases. A steeper marginal abatement cost curve reflects a larger unit abatement costs with respect to abatement. Sin et al. (2005) point out that in NZ's case, the marginal benefit of abatement is determined by the international market, if one exists, hence it is not directly affected by the slope of the international marginal environmental benefit curve. Besides, due to the nature of climate change, environmental benefits are likely to be a small proportion of NZ's marginal benefits, which makes NZ's marginal benefit curve of abatement relatively flat. Agriculture is a significant export sector in the NZ economy, hence, any change in costs to agriculture beyond the current level will be likely more expensive and uncertain. Given uncertainty in NZ's agriculture emissions abatement cost, a carbon tax might be better for abating agriculture emissions in NZ.

In a competitive carbon market, an efficient carbon tax is equivalent to carbon price if the slope of marginal abatement cost and marginal benefit curve is known. In chapter 5, I compare the impacts of a carbon tax and ETS on the NZ economy at a same equilibrium carbon permit price. This equilibrium carbon price is derived from a general equilibrium model. Assessing a choice of two alternatives under the same carbon price provides insights for policy makers.

Weitzman (2015) extending his study from Weitzman (1974), discussed the negotiation of two variants: an international harmonized but national retained carbon tax; and a free distributable emissions permits of global emission quantities to individuals according to an international cap-and-trade system. His work suggests that with uncertainty, carbon taxes have an advantage over tradable permits. In addition, a carbon tax is easier to implement and more transparent than cap-and-trade system.

A carbon tax may not be equal to the optimal carbon price. Figures 2.4 and 2.5 illustrate an individual firm's choice by comparing its marginal abatement cost and marginal benefit under different policies [3].

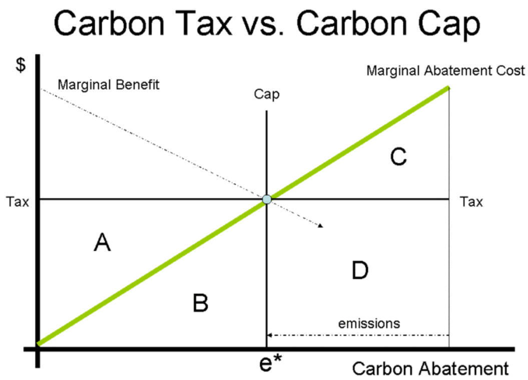

Figure 2.4: Carbon tax and cap

source: `http://www.env-econ.net/carbon_tax_vs_capandtrade.html`

Figure 2.4 presents a situation when the carbon tax is equal to the optimal carbon price under two policies: carbon tax and carbon cap. Carbon tax can be imposed on emissions, and a carbon cap is a limit on the maximum amount of emissions. In Figure 2.4, an efficient level of carbon abatement is determined at point e^*, and the carbon tax is set when marginal abatement cost equals marginal benefit. Under a carbon tax policy, the firm may find that it is advantageous to abate emissions in situation where the marginal abatement cost curve is lower than the tax. This is because the tax payment (A+B) is greater than the abatement cost (B) at the left side of the "cap" line. In contrast, when the abatement cost (C+D) is larger than the tax payment (D) at the right side of "cap" line,

[3] The explanation for each Figure is similar to `http://www.env-econ.net/carbon_tax_vs_capandtrade.html`, as the diagrams are quoted from the website.

the polluting firm will choose to pay tax. Under the carbon cap policy, the abatement cost to the firm is shown as the area B and the firm abates its emission to e^*.

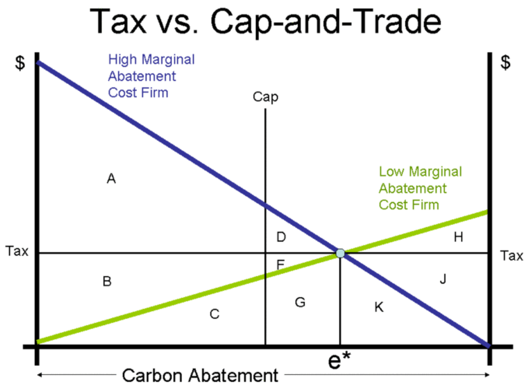

Figure 2.5: Carbon tax VS cap-and-trade

source: `http://www.env-econ.net/carbon_tax_vs_capandtrade.html`

Figure 2.5 shows a case when carbon tax is not equal to an optimal carbon price. Under the carbon tax, a firm with high abatement cost faces the cost at area K (read the graph from right to left for high abatement cost firm), and pays tax as area B+C+F+G. A firm with a low abatement cost has abatement cost C+G and pays tax by area J+K (read the graph from left to right for low abatement cost firm). The efficient carbon tax occurs when the two marginal abatement cost curves equal, and it can be achieved at e^*. However, the emission cap will not lead to an optimal carbon price at a tax level.

In summary, Weitzman (1974) provides insights for choosing either price or quantity control to reduce externalities. His theory sheds light in understanding the effect of central control from either the price (tax) side or the quantity (cap) side. Baumol and Oates (1988)'s theory creates a solid foundation for environmental policy analysis, especially concerning externalities and optimal resources pricing. However, neither Baumol and Oates (1988) nor Weitzman (1974) consider the contribution of renewable resources such as forestry. Trees sequestrate carbon dioxide which contributes to the abatement of emissions from other sectors in the economy.

2.2.4 Forest economics

This section introduces the key literature for finding the optimal harvest age of a wood forest, such as the Faustmann model that focuses on present value of timber's age (Faustmann, 1849), the Hartman model which includes recreational and amenity values (Hartman, 1976), and the Samuelson model which includes some amendments to the maximum sustainable yield (Samuelson, 1976). This section also discusses strengths and weaknesses of each model, indicating the gap my research will address.

Faustmann's model

The Faustmann model maximizes the net present value of timber income to determine the optimal rotation age. Faustmann's model incorporates the discounted value of revenue, and proposes that a stand of timber should be harvested when the opportunity cost of delaying harvesting equals the marginal return of delaying harvesting for a unit of time. Faustmann's formula estimates an optimal level of single rotation and implies that marginal timber growth is equal to investment rent plus land rent. The weakness of using the undiscounted value of land or geometric average interest rate is the tendency to overestimate land value (Amacher et al., 2009).

Amacher et al. (2009) point out that when calculating the optimal rotation age, Faustmann's formula assumes that the forest land owner begins with bare land and the planting technology is fixed. Timber prices and interest rates are constant, assuming forestland markets and financial capital markets are perfect, and the land owner decides when to harvest by maximizing the net present value of harvest revenue over an infinite period of rotations.

"Maximum sustainable yield (MSY)" is one approach to calculating optimal rotation age, where the rotation age is determined by maximizing the average timber volume on a given forest area over time. Harvest should occur when the average timber growth is equal to the marginal timber growth. However, the optimal rotation age is determined by timber growth and MSY does not include economic variables such as price, interest rates, and cost which could have an effect on the time of harvest.

According to Amacher et al. (2009), "the Faustmann and MSY rotation age coincide only when the regeneration cost and real interest rate are zero". By assuming that the opportunity cost of harvesting in Faustmann's formula is higher than in the MSY approach, the Faustmann rotation age will always be shorter than the MSY age. Higher interest rates and timber prices shorten rotation age, whereas higher costs lengthen the age in Faustmann's formula. This thesis selects a timber yield function from Van Kooten et al. (1995) where the Faustmann's rotation age is examined by considering the inclusion of carbon sequestration benefits (Sands & Kim, 2009).

Hartman's model

Hartman (1976) further developed Faustmann's formula by considering recreational and ecological services such as being a carbon sink (these features are called "amenities" by Amacher et al. (2009)) that are provided by forests. He found that the presence of recreational and services features produced by timber may have an important effect on optimal rotation age.

Hartman's theory assumes that all trees are harvested simultaneously, and the timber price remains constant over time. The optimal harvest age of a tree is determined by maximizing the present value of a stand of forest including the discounted value of recreational (amenities) services and timber. This is different from the Faustmann's rotation which maximizes the net present value of timber (Van Kooten et al., 1995). The interest foregone by postponing harvesting the forest for one period should be equal to the gain from postponing the harvest one period, which includes the recreational services value plus the value of timber growth over the period (Hartman, 1976).

Samuelson's model

A "MSY" method is preferred by biologists as it maximizes revenue from renewable resources at sustainable levels, whereas economists use "maximum economics yield" (MEY) which creates the largest surplus between total revenue and costs at sustainable levels.

Samuelson (1976) argues that the MSY approach underestimates profits from planting trees. He suggests that certain assumptions have to be made to solve the problems caused by externalities of harvesting trees. These assumptions include full information about timber price and input price; known interest rates (constant in a steady-state situation); known timber yield; and known transaction of land used in forestry activity. The MEY method is preferable to MSY as it maximizes profits rather than a revenue, appropriately estimates resource stock size as "conservationist", and guarantees a proper resource allocation.

2.3 Applications to forest and carbon trading study

This section outlines existing studies on optimal rotation age of trees, and carbon trading study in NZ and overseas.

2.3.1 Optimal rotation length

Studies that take carbon sequestration into account include Hertel et al. (2009), Lubowski et al. (2006), Gardiner (2009), and Sohngen et al. (2009). Van Kooten et al. (1995) show that carbon benefits are a function of the change in biomass growth, pointing out that growth rate is more important than the tree's age. "Pickle", indicates the percentage of carbon stock in the wood that has been harvested, is an important factor in describing to describe carbon sequestration in timber products.

The steady-state of forestry

Dee (1991) used a CGE model to analyze the economic impact on saving of Indonesia's forests, in which the forestry sector is represented by a steady-state solution. The model distinguished agriculture, forestry and minerals, and allows land movement between forestry and agriculture. Sectors other than forestry were treated by conventional single-period production functions. However, forestry production in this model only refers to natural timber yield, and does not consider the wood processing sector which falls under more comprehensive climate policies such as the ETS.

2.3.2 Carbon trading study in New Zealand

Diukanova et al. (2008) apply a CGE model to study the impact of the NZ ETS on NZ's macroeconomy. The model covers all sectors under the ETS. By simulating four policy scenarios, their study finds that agricultural output is reduced, especially the dairy sector. Sheep-beef production is reduced by about half. However, sectors that are relevant to forestry and the rest of the economy increase their output. Auctioning of permits gives the lowest marginal abatement cost (MAC) (NZD \$13.2 /t CO_{2e}) whereas output-based grandfathering generates the highest MAC (\$14.67 /t CO_{2e}). Hybrid allocation leads to a large reduction in the aggregate output but results in a smaller MAC than the pure grandfathering policy. However, the study does not consider the role of carbon sequestration from the forestry sector, and land use conversion between forestry, agriculture and permanent forest sinks.

NZIER and Infometrics (2011) use a CGE method to analyze the impacts of the NZ ETS on the NZ macro economy in the year 2020 under 16 scenarios. Their study addresses three main areas: (1) the impact of continuing to exclude agriculture from the ETS past its scheduled introduction date of 2015; (2) differences between "one-for-two obligation" and domestic price caps; (3) impacts of either free allocation of carbon permits to industry at its 2012 level and free allocation to agriculture at its 2015 level, or the complete removal of the scheme. The model covers 131 industries and 210 goods. Results indicate that the impact on NZ's GDP ranges from -0.1% to -1% of its 2020 level, similar to the impact on welfare. A low carbon price has a slightly negative impact with the exception of agriculture. However, including agriculture helps to abate domestic emissions rather than losing agriculture competitiveness. In particular, at a low carbon price extending the "one-for-two" period has a small positive impact on welfare. By contrast, a high carbon price (world price \$100) negatively impacts welfare if agriculture is excluded from the scheme.

How to allocate carbon permits is a complicated and a politically-charged topic. Whether or not to include the agriculture sector into the ETS is also debatable. Kerr et al. (2009) address the issue of how to achieve equitable and acceptable cost sharing within the sector. Free allocation of carbon permits is intended to minimize any reduction in production, ease adjustment into the system, and to partially offset losses. The study analyzes two extreme allocation options, one is on the basis of farmer's loss of equity, and the other one is on the basis of output emissions. Both of these alternatives provide partial compensation. However, the first option can be more closely targeted to those most seriously affected. The original NZ legislation allocates 90% of the emissions at the 2005 level to the agricultural sectors, and then phases out linearly between the year 2018 and 2030. The free permits are supposed to compensate for the loss of equity and profit to NZ farmers. This suggests that free allocation would be issued to the most vulnerable commodities under the ETS.

2.3.3 Carbon trading study overseas

As an EU member, Portugal aims to reduce their GHG emissions to a target of at least 20% below their 1990 levels by 2020. Proenca and Aubyn (2012) used a hybrid bottom-up general equilibrium model (HyBGEM) to investigate the impact of a low-carbon policy on the Portuguese economy. The policy was simulated using three scenarios: (1) increase the non-ETS sectors emissions by 1% compared to 2005 level, while decreasing the ETS sector emissions to 21% below 2005 levels by 2020; (2) apply the cap-and-trade mechanism to energy-intensive sectors but the uniform domestic carbon tax to the non-ETS sectors; (3) transfer the tax revenues from carbon emissions to households. The HyBGEM model combines the bottom-up activity analysis of representation of the electricity sector with a top-down CGE framework. Portugal is treated as a small open economy with 19 sectors, which can be disaggregated into 5 energy intensive sectors and 14 non-energy sectors. Household, government, investment and export are agents that demand commodities.Three factors are used in production, labour, capital and natural resources. Natural resources are disaggregated into fossil fuel resources and renewable resources. Combustion of fossil fuels emits carbon dioxide which is modelled using Leontief functions. It is assumed that producers minimize costs of production by using constant elasticity of substitution (CES) function. The Armington assumption is used to model the substitution between domestic and imported goods, and describe a transformation technology between domestic production and export goods. Total electricity production generates homogeneous goods with 8 representative power generation technologies. The study showed that the emissions from the non-ETS sectors decrease by 7% whereas the emissions from the ETS sectors increased by about 11% between 2005 and 2020 in the business as usual (BAU) scenario. BAU refers to Portugal's economy growth in the absence of carbon emissions constraints. Welfare, real wage rates, real capital rental rates and trade all suffered losses in the low-carbon scenario. However, the findings demonstrate that Portugal can achieve its carbon emission targets without significant costs, but the challenge for policymakers is to develop a carbon emission reduction plan for Portugal's power sector.

The EU ETS officially started on 1 January 2005, and the first compliance period was between 2005 and 2007. Christiansen et al. (2005) provide an overview of emission allowance prices in the EU ETS, and highlight operations from other emission markets, including the US SO_2 allowance trading scheme and the UK ETS. Their study aimed to find the key parameters that players in the market should consider when estimating the potential carbon price. Under the UK ETS, which commenced on 2 April 2002, the clearing carbon permit price was £53.37 per tonne of CO_2e, the participant companies bid in emissions reductions around 4 million tonnes of carbon dioxide equivalent (CO_2e) by 2006. This is equivalent to £12.45 per tonne CO_2e after tax. The carbon price increased from £5 in May 2002 to over £12 in October 2002 (the rise of price was due to a lack of sellers and the participants hedging against the risk of high prices and non-compliance with relative targets), however, the price then dropped to £2-3 per tonne CO_2e and slightly increased to £3-3.5 per tonne CO_2e in 2004. This trend of carbon price change is similar to the EU ETS, with the estimation of an incremental increase from €5 per tonne CO_2 in March/April 2003 to €13 towards the end of 2003, after which the carbon price then hovered around €8-9 per tonne of CO_2. Three fundamental drivers that are likely to have an impact on the market price of carbon permits under the EU ETS are: (1) policy and regulatory issues; (2) market fundamentals; (3) market psychology.

Greaker and Hagem (2013) used a three-stage game between industrialized countries and a developing country, to examine the influence of investment strategies for both groups in abating costs. To differentiate from other studies, their research includes global trading in emission permits. They found that global permits trading changed the strategic effects of investment, and encouraged the industrialized countries to over-invest both at home and abroad. This "spillover" benefits the industrialized country because over-investment lowers the price of emission permits that the region will need in the future. However, this paper did not examine future region-specific abatement costs and the effects of R&D investments in order to analyze whether industrialized countries will gain from a common permit market with developing countries.

Diukanova (2014) used the Intertemporal Computable Equilibrium System (ICES) to evaluate the impact of post-2012 carbon policies on Annex I and non-Annex I parties to the United Nations Framework Convention on climate change. In particular, the paper focuses on the trading of emission permits in both international and domestic carbon markets for hot air-holding countries such as Russia and Ukraine. Results imply that only the international carbon permit trade motivates Russia and Ukraine to abate their emissions. Trading also benefits EU countries as the European carbon permit price is half of that of the domestic permit price. However, the study does not account for linkages between the EU ETS and other country's policies (e.g. NZ ETS). The impact of land use, land use change and forestry (LULUCF) is not considered in this study.

It has been proposed that the EU ETS be strengthened by linking it to other domestic or regional ETS such as in Canada, Japan and Australia. Alexeeva-Talebi and Anger (2007) apply a general equilibrium method to assess three aspects of integrating emissions trading schemes: (1) efficiency of integrating emissions trading schemes; (2) welfare impacts of linking the EU ETS; (3) impact of developing supra-European ETS. The research found that the international carbon permit price may decrease by linking the EU ETS internationally and the aggregate welfare impact is insignificant. Furthermore, linking various emissions trading schemes does not reduce the economy-wide EU competitiveness substantially. However, inefficient scheme design is shown to cause loss of competitiveness, in Canada and Japan. Carbon leakage, which occurs when there is an increase in carbon dioxide emissions in one country as a result of an emissions reduction by another country, may happen between the ETS covered sectors and non-covered sectors.

Adams et al. (2013) use a CGE model to analyze the impact of the Australian ETS on the Australian economy. In contrast to those studies which focus on the practical application of the models, their study provides more detail. Eight of the following issues are examined in their study, including: global emission leakage; regional effects on geographically distributed emission-intensive sectors; effects of recycling carbon tax or ETS income distribution; drivers of lumpiness of investment in electricity sector, etc are explained in the study. In particular, three models are applied: the Global Trade and Environment Model (GTEM), the G-Cubed model, and the Monash multi-Regional Forecasting model (MMRF). The GTEM and G-Cubed are multi-country models and MMRF is a single-country multi-regional model of Australia. The international permit price of A$24.3 per tonne is estimated at the starting year of 2012, and increases to A$49.3 in the year 2030. Their study finds that Australia may need to import permits due to a shortage of domestic abatement. Australia's GDP is shown to fall by a small margin in 2030. Real household consumption is also affected adversely. However, the forestry sector gains from the ETS because the carbon charge is a production subsidy. Non-hydro renewable and gas-fired generation within the electricity sector also benefit from the policy. The production of iron and steel, and aluminium also notably increased due to overcompensation during the transition period. However, the industries which are most closely related to energy consumption are adversely affected, such as automotive fuels for transport services, electricity for electrical equipment services, etc.

2.3.4 Debate on carbon tax and the ETS

It has been suggested that imposing a carbon tax can generate a "double dividend" effect: it may not only improve environment quality but also reduce certain costs of the tax system (Goulder, 1995). Parry (1995) supports the idea that the value of carbon tax revenues can reduce other tax distortions in the economy, but both GDP and welfare can decrease by having a carbon tax.

Metcalf and Weisbach (2009) found that a proper carbon tax can capture almost 80% of U.S. emissions with a modest additional cost. They designed a carbon tax for U.S with three central issues: tax rate, revenue spending, and tax base. Based on Pigou's model, the tax rate should be equal to either the marginal damages from producing an additional unit of emissions or the marginal benefit from abating a unit of emissions. Although a proper carbon tax can generate a "double dividend" effect, however, the adjustment to a carbon tax depends on the use of revenues and whether there are other distortions in the economy. Imposing a carbon tax may generate some distortions as it may reduce worker's incentive. A good carbon tax system should also adjust the income or payroll tax for any distributive effects.

If imposing either a carbon tax or a carbon permits trade policy, the method of allocating carbon permits or setting a carbon cap has to be considered. Fischer and Fox (2007) use a CGE model to compare different rules for allocating carbon permits with an output based allocation (OBA). They found that OBA can generate effective subsidies, perform like auctions, and clearly outperform lump-sum allocations. By setting a cap based on historical emission levels, OBA can counteract the carbon leakage issue for these polluting-intensive industries. This is because OBA based on emissions can limit a price rise in energy-intensive products. However, it is costly in terms of welfare. If the carbon cap is set by historical shares of value-added, OBA can effectively embed the proportional tax rebate into consumer prices and improve notably over lump-sum grandfathering (i.e. permits are distributed unconditionally among firms in all sectors).

Efforts at reducing GHG emissions by either carbon tax or cap-and-trade can lead to relocation of some energy-intensive industry in countries which implement a more lenient climate policy. Babiker (2005) used a multi-regional CGE model combined with increasing returns to scale production technologies among the firms producing energy-intensive products to examine the possible relocation issues under the Kyoto Protocol. The research found that a climate policy in industrialized countries will increase global GHG emissions. In particular, the homogeneity of traded products is a significant source of carbon leakage. Studies have found that the rate of carbon leakage is in range of 5% to 25% (Gerlagh & Kuik, 2007), yet the rate could increase to between 50% and 130%.

Freebairn (2010) compares the operation and economic effects of a carbon tax versus a tradable permit scheme for small open economy such as New Zealand and Australia. The author mentions that both carbon tax and tradable permits are essentially the same in a perfect knowledge world. New Zealand, as a small economy, implemented a market-based ETS since 2008 during the first commitment period under Kyoto Protocol. Australia proposed a tradable permit policy earlier than NZ. Without levying emission costs on final household consumption of petroleum products and gas, NZ and Australia's tradable permits policy actually generate extra costs for domestic production. Higher production cost leads to more imports and less exports, but the loss of export can be partially compensated by the depreciation of the currency. To reduce the carbon leakage problem, assistance on trade exposed and energy intensive goods is necessary. The author claims that a carbon tax can provide stability of cost increment but provides uncertainty of the amount of emission reduction. In contrast, tradable permits policy offers a greater stability of emissions volume by setting a cap. However, overall, a tax system has the advantage of providing stronger incentives for reducing emissions.

2.3.5 Issues with implementing climate policies

Implementing either a carbon tax or cap-and-trade system is challenging for any country. Measuring the effect of climate change policy on an economy requires specific data on each sector's production input. However, it is difficult to collect detailed data especially when measuring a global effect. Besides, each country has a different domestic policy, and carbon leakage often occurs between a country which has a climate policy and a country which does not.

Barker et al. (2007) found that the carbon leakage rate is not sustainable for EU members under the EU environmental tax reform (ETR). They used a dynamic econometric model to examine the carbon leakage effect on 6 EU member states in the long term. The study shows that the GDP would be reduced in ETR countries. In particular, due to the small scale of the ETR, the effect of carbon leakage is not strong. And it leads to a decrease in output but only in a highly competitive market, and particularly for energy intensive and trade-exposed commodities.

Three approaches are proposed by Parker and Blodgett (2008) for the U.S. government to avoid carbon leakage: (1) supporting domestic industries; (2) penalizing foreign competitors; (3) developing alternative sectoral approaches. Specifically, government can provide free allocation of carbon allowances to support domestic industries, in order to preserve their current competitive position. A border adjustment approach can be applied for penalizing foreign competitors. It includes imposing tariffs on importing carbon intensive goods and creating a fact tariff on importing goods accompanied by a prescribed "International reserve allowance" based on emissions generated in the production of those goods. Developing a sectoral approach is focused on carbon emission data collection in polluting-intensive sectors. However, it is difficult and complex to implement the above three methods for a single country.

Kuik and Gerlagh (2003) estimated carbon leakage by comparing two scenarios with and without free trade by means of import tariff reductions for Uruguay. They applied an energy-environmental version of the Global Trade Analysis Project (GTAP) model (GTAP-E) with aggregating the GTAP-4E database into 12 countries and 15 traded commodities. GTAP-E model has same structure as GTAP, which is a widely used multi-sector and multi-region general equilibrium model. Different from GTAP, GTAP-E has a detailed description of substitution among energy sources in production. Their study found that the rate of leakage increased by reducing the import tariff on energy intensive goods. In addition, they examined the effect of free trade based on the pollution haven hypothesis (PHH) and the factor endowment hypothesis (FEH). The PHH is the idea that polluting industries will relocate to areas with less stringent environment regulations. It predicts that under free trade, carbon leakage will rise and polluting firms will move to developing countries or regions, seeking lower environmental compliance costs. However, there is currently very little research on either PHH or FEH theory.

2.4 Computable general equilibrium approach

A computable general equilibrium (CGE) model consists of a set of equations which describe producer and consumer behavior, solved for a set of prices that balance supply and demand, and the quantity of goods that is produced and consumed is in equilibrium. CGE is a widely used approach for policy analysis nowadays (Wing, 2004). For instance, the most applied CGE model includes: Global Trade Analysis Project (GTAP) (Hertel, 1997), CGE model for Tanzania (Rutherford, 2003), ORANI model for Australia (Dixon & Jorgenson, 2013), and so on.

Some studies criticize the CGE model as not being easily accessible due to the complexity of data structuring and calibration. However, CGE has its advantage in capturing feedback and flow-through effects as all sectors are linked together (Gilbert & Tower, 2012). In addition, the CGE model is able to incorporate features of other economic models such as forest growth and imperfect competition. The model can help us evaluate values of macro economic variables within a complete economic system.

Figure 2.6 shows a domestic circular flow between all markets in a CGE model. In order to obtain an equilibrium, both the commodity market and factor market have to be clear.

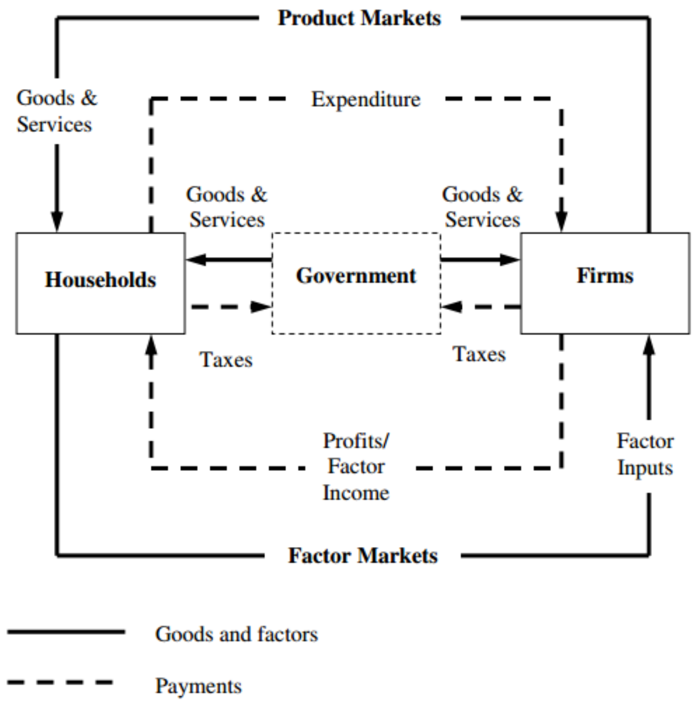

Figure 2.6: Circular flow of CGE model

Source:Wing (2004), p29

2.4.1 Comparison of CGE with partial equilibrium model

Unlike CGE, partial equilibrium examines the impact of economic shock on one or more specific markets, assuming the rest of the economy is fixed. It does not take the interaction of sectors into account. Therefore, it would be easier to calibrate a partial equilibrium model than a general equilibrium model.

Marshall (2011) measured land use impact on agriculture and forestry production and compared partial equilibrium with CGE framework for solving the problem. Again, although a partial equilibrium approach can provide a detailed production structure with land, it focuses on a specific sector rather than the entire economy.

2.4.2 Comparison of CGE with econometrics model

Econometric models aim to explain the reason for variable change through multivariate analysis based on time series or cross-sectional data. The advantage of such an approach is that it provides estimates of the relationship among variables in the short term, although it is weaker when estimating such relationships in the long term due to the limited data set (e.g. large across section data, time series data).

A typical econometric study estimating how land use responds to change in economic return in New Zealand is that of Kerr and Olssen (2012); Kerr et al. (2012). They analyzed land conversions among different dominated types of lands over years. The econometric model is able to estimate land shares and capture land use adjustments. However, econometric methods cannot capture the interaction of all sectors in the economy.

2.5 Conclusion

As a renewable resource, the forest sector contributes to the abatement of the effects of GHG emissions. Therefore, when implementing either carbon tax or the ETS, the forest sector should be considered. Some studies analyze how an optimal rotation age affects carbon sequestration and forester's profit, but they neglect the interaction of forestry mitigation with other sectors such as agriculture.

An applied CGE model aims to capture changes among all industries in an economy. This approach is particularly useful when estimating the impact of climate policy on forestry carbon sequestration and land use. To date, very few papers have used CGE to analyze the impact of NZ ETS on its economy including forestry mitigation.

The impact of the ETS can vary according to different policy designs. The NZ domestic carbon permit (NZU) price is indeed affected by the international carbon trading market. When examining other existing studies, I found that none of them optimized a domestic NZU price and the impact of the NZ ETS on the economy with a detailed forestry model. This thesis addresses these issues, and calculates an equilibrium NZU price in the domestic carbon market.

Although some New Zealand studies have looked at the impact of carbon policy on agriculture and forestry production and land use change (Kerr & Sweet, 2008; Kerr & Olssen, 2012; Hendy et al., 2007; Kerr et al., 2009; Greenhalgh et al., 2007), none of them apply a comprehensive model to analyze how carbon emissions change and land use changes in response to carbon policy. Some researchers have used a CGE model to analyze the ETS effect on NZ's macro economy (NZIER, 2008; NZIER & Infometrics, 2009b), however, they do not consider the effect of timber growth and carbon sequestration on land use change and the entire economy.

My study fills in this gap. I model an endogenous forestry model within a CGE model, estimating an optimal rotation age and analyzing how land use responses to carbon tax and ETS between forestry and agricultural sectors. New Zealand supply-use table released on March 2007 is used as a base for the social accounting matrix (SAM).

Chapter 3

Land use change between forestry and agriculture under a carbon tax

Introducing the forestry sector into a general equilibrium framework is challenging due to the complication of commercial forestry and associated intertemporal carbon management. In this chapter, I apply a CGE model to estimate the impact on land use between forestry and agriculture under a range of carbon taxes. Experiments involved four carbon tax rates \$0/t, \$25/t, \$50/t, and \$100/t. An innovative feature of my research involved linking the CGE model to a partial equilibrium forest model, to estimate the optimized harvested timber age.

Section 3.1 introduces NZ's ETS and shows an existing gap in the literature; section 3.2 establishes a CGE model and the partial equilibrium forest model; section 3.3 shows all the data applied in this chapter; section 3.4 assesses the effect of each of the four carbon tax rates on land use between forestry and agriculture, examines the change of forest variables and macro variables under different tax rates; section 3.5 conducts tests on the interest rate and elasticity of substitution in land use, in order to check the model's robustness; section 3.6 draws conclusions.

3.1 Introduction

In December 1997, United Nations Framework Convention for Climate Change (UNFCCC) parties signed the Kyoto Protocol, which committed Annex I countries to binding emission reduction obligations (NZIER, 2008). To meet Kyoto Protocol obligations, each participant was assigned an amount of emission rights based on their emission data. Participants could increase assigned amounts of carbon permit by either reducing domestic emissions or generating new amounts of absorption through a carbon sink such as forestry sequestration.

Forestry and land use are important considerations when analyzing policy responses to climate change (MFE, 2009). According to MFE's report in 2010, New Zealand has a total area of 26.9 million hectares, with almost 30% in native forest, 51% in grassland, 2% in new forest land (i.e. land with forest present in 2008 but not in 1990), 2% of cropping and horticultural use, 15% of other land use.

This chapter focuses on analyzing the change of land use between forestry and agriculture sectors under different carbon tax rates. Unlike other studies, I estimate an optimal timber rotation age using a timber yield function, and assess how it affects forest production, land use, and the macro economy by integrating the forest production into the CGE model.

3.2 Model

3.2.1 General Assumptions

This chapter uses a CGE model linked to a detailed forest model to examine land use change between forestry and four agricultural sectors under a carbon tax. New Zealand is treated as a small open economy with 12 industries described in Table 3.1. Land is allocated across five sectors: forestry; horticulture [1] and fruit growing; sheep, beef cattle and grain farming; dairy cattle farming; and other agriculture. Five types of land are categorized in the land cover database (LCDBV2). Industry use of the five types of land was supplied by AsureQuality Limited[2] and include: forest land; other land; grass land; scrub land; and crop land. Agents in the model are: household, government and rest of world (ROW). Equations of CGE model in this thesis are based on Chang (2010)[3].

[1] According to StatsNZ (2006), horticulture consists of floriculture, mushroom, vegetable growing, fruit, and tree nut growing under cover. "Under cover" is defined as greenhouses, cold frames, cloth houses and lath houses. This thesis applies this specification to the horticulture sector.

[2] The land use data is differentiated by industry in 2007, supplied by AsureQuality Limited NZ.

[3] Some variables use same character as shown in Chang (2010).

Table 3.1: Sectors

Ind 1	Forestry
Ind 2	Mining, oil and coal
Ind 3	Industrial processes
Ind 4	Horticulture and fruit growing
Ind 5	Sheep, beef cattle and grain farming
Ind 6	Dairy cattle farming
Ind 7	Other Agriculture
Ind 8	Forestry Manufacturing
Ind 9	Agricultural manufacturing
Ind 10	Manufacturing
Ind 11	Utilities
Ind 12	Services

Primary sectors

This chapter models the optimal rotation age and timber yield of post-1989 radiata pine under a "pruned, without production, thinning" regime across NZ. Although the focus is on forestry, other primary sectors such as horticulture, sheep-beef, dairy farming, and other agriculture are also included.

It is assumed that forestry is in a steady-state situation. Trees are harvested at the optimal rotation age which is determined by maximizing the NPV with respect to the rotation age. The harvesting and replanting costs which include land transition costs are endogenous in the model and the forest owner receives carbon permits for afforestation from government. The assumption of steady-state means that forestry profits are equalized each year from the planting to the optimal rotation age.

Natural forest and managed planting trees are participants in the NZ ETS. Managed plantations are categorized as: pre-1990 and post-1989 trees. Consistent with government policy, one-off carbon permits are given to pre-1990 forest land owners but post-1989 forest land owners are required to report annual emissions. Post-1989 forest land owners receive carbon permits for carbon stored but face liability when trees are harvested and carbon is released to the atmosphere.

Total harvested timber, along with produced goods from other industries are used as intermediate inputs in the forestry manufacturing sector. Forestry manufacturing utilizes capital, labour and intermediate goods. Horticulture and fruit growing; sheep, beef cattle and grain farming; dairy cattle farming and "other agriculture" are classified as agricultural sectors. These sectors use three factors of production: capital, labour and composite land. Industry pays a return to households, and pays indirect tax as a production tax to government. This assumption is in line with NZ's "supply-use" table which was released in March 2007.

Production can be consumed domestically or exported. Imported goods and domestic output make up domestic supply. Producers are assumed to maximize profit in order to reach the optimal output level.

Household

The representative household supplies factors of production (labour, capital, land) to industries and receives factor income. It also receives transfers from government and rest of world (ROW) savings for balancing its account. Household income is taxed. A portion of income is used as saving which is endogenous. Households consume final commodities, pay tax on consumption and are assumed to maximize utility to determine the optimal level of consumption for each commodity through the linear expenditure system (LES) function.

Government

Government consumes final commodities from industries and collects taxes. A Leontief function is used to model government consumption. Government gets a return from the capital use, saves a fraction of the income, transfers part of its savings to household and ROW aims to balance its account.

Land

As noted above, land is differentiated by type and allocated among five land-based sectors. Land supply is constrained by a CET function. In each sector, a CES function describes the substitution of land across sectors. Nesting of land allocation is shown in Figure 3.4 in section 3.2.4.

Carbon policy

All sectors producing GHG emissions face a carbon emission liability and pay the government accordingly. All sectors and gases are covered by this research. All GHGs are expressed as CO_2e. Forestry, on the other hand, receives a payment based on its contribution to sequestration and pays tax when trees are harvested.

Factor market

Factors used in production include capital, labour and composite land. The initial endowment of each factor is exogenous. Factors are mobile among sectors.

Investment-savings and closure

In terms of model closure, total investment is exogenous according to Johansen closure, which Gilbert and Tower (2012) note is also called an investment-driven closure because investment determines the quantity of savings. In this case, total savings must be endogenously determined in order to match investment.

Market Clearing

Commodity markets clear with factor markets. Zero profit conditions apply and tax revenue is allocated to expenditure, government and households.

Rest of world (ROW)

ROW receives income from imports, and transfers its savings to household and government. It also spends on exported commodities and transfers to households, tax and savings. The ROW is assumed to pay tariffs to NZ.

3.2.2 Forestry production

In general, total output involves a combination of aggregated intermediate and value-added input. The hierarchy tree used to represent the production process is shown in Figure 3.1. Industries are assumed to adopt the same production structure, but natural forest has a timber yield equation that describes the forester's growth rate over time. Optimal rotation age is determined by maximizing NPV for foresters. In the CGE literature, the elasticity of substitution is $\frac{1-\sigma_i}{\sigma_i}$ where i refers to substitutable factor in production.

Natural forest yield

Timber yields are used as an intermediate input into the forestry manufacturing sector. NZ producers are price takers in the international market, therefore, the price of timber is assumed to be constant over rotation. As a starting point, I apply an average domestic timber price in timber production. When the initial rotation age is estimated from the forest model, age is used in CGE model. Due to the assumption that all exported NZ timbers can be sold in the international market, the optimal rotation age is affected by the exchange rate. Forestry owners are assumed to make profits from log sales and carbon trading. Following Sands and Kim (2009), I selected a timber yield function which can be modified to include carbon sequestration incentives paid to forestry owners. The unit of production in the forest model is measured per hectare.

Biomass timber yield function is given by:

$$y_a = c_1 a^{c_2} e^{(-c_3 a)} \tag{3.1}$$

Where y_a represents biomass yield function per hectare; $\frac{y_a}{a}$ is the volume of harvested timber per year; $c_{1,2,3}$ are shape parameters that determine the timber growth curve, and a is the harvest age. The optimal rotation age is solved by maximizing the net present value of natural forest (Equation 3.10).

Given that the Equation 3.1 includes a single variable "a", I use a Leontief function to illustrate the natural forest production in the CGE model as shown in Equation 3.2. Timber production has three nested layers including intermediate, primary factors and composite land as shown in Figure 3.1. QA_t measures total timber yield, including all the land used in forestry sector. The harvested timber is used as an intermediate input for other industries including forestry manufacturing, forestry, other manufacturing, and the services sector.

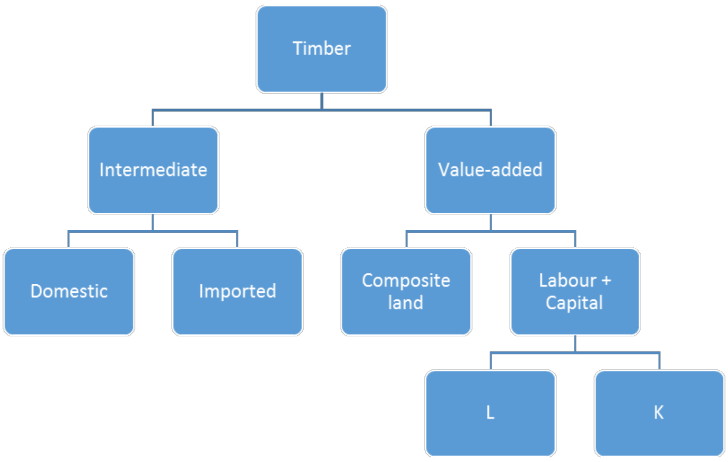

Figure 3.1: Timber production

In Figure 3.1, at each layer of the nesting, the producer minimizes cost in order to choose an optimal level of each input.

At the top level of the nesting, total costs include the aggregated intermediate input and the value-added input that involves primary factors (composite land, labour, and capital).

$$\min C_t = PINT_t * QINT_t + PVA_t * QVA_t + P_c * e_t * QA_t$$

s.t.

$$QA_t = \min[\min(\frac{QINTA_i}{\delta_1^i}), \frac{QVA_i}{\delta_2^i}] \tag{3.2}$$

Where C_t is the timber yield sector's total cost, and consists of aggregated intermediate input $QINTA_t$, aggregated value-added input QVA_t, and carbon emission cost $P_c * e_t * QA_t$. P_c is the carbon tax imposed on sectoral emission $e_t * QA_t$. $\delta^i_{1,2}$ is the share parameter of input use in timber production.

At the intermediate level, the Leontief function describes the proportion of domestic and imported goods used to produce the intermediate goods.

$$\min C^t_{int} = P^t_{dom} * Q^t_{dom} + P^t_{imp} * Q^t_{imp}$$

s.t.

$$QINTA_t = \min\{\frac{Q^t_{dom}}{\beta^i_1}, \frac{Q^t_{imp}}{\beta^i_2}\} \tag{3.3}$$

Where Q^t_{dom} and Q^t_{imp} are domestic and imported goods, $\beta^i_{1,2}$ is the coefficient of using domestic and imported goods to produce the intermediate goods.

At the value-added level, a CES function is used to illustrate the substitution between primary factors. Different from other sectors, the value-added nesting in agriculture and forestry includes composite land ($Land_{com}$). The composite land includes the five types of land used in sectoral production. The substitution between each land class is described in detail in section 3.2.4.

$$\min C^t_{va} = P^t_{land} * Land_{com} + P^t_{kl} * Q^t_{kl}$$

s.t.

$$QVA_t = [\delta^t_1 * Land_{com}{}^{\frac{1-\sigma^t_1}{\sigma^t_1}} + (1 - \delta^t_1) * Q^t_{kl}{}^{\frac{1-\sigma^t_1}{\sigma^t_1}}]^{\frac{\sigma^t_1}{1-\sigma^t_1}} \tag{3.4}$$

Where the upper script t represents timber production sector, δ^t_i is the share parameter between the composite land and the capital-labour bundle in the value-added nest. $\frac{1-\sigma^t_1}{\sigma^t_1}$ is the elasticity of substitution between each input.

At the bottom level of the nesting, the capital-labour bundle is nested by the elasticity of substitution $\frac{1-\sigma^t_2}{\sigma^t_2}$:

$$\min C^t_{kl} = P^t_l * L^t + P^t_k * K^t$$

s.t.

$$Q_{KL}^t = [\delta_2^t * L^{t\frac{1-\sigma_2^t}{\sigma_2^t}} + (1-\delta_2^t) * K^{t\frac{1-\sigma_2^t}{\sigma_2^t}}]^{\frac{\sigma_2^t}{1-\sigma_2^t}} \tag{3.5}$$

According to the forest growth model, forest owners are assumed to earn profits through three paths: selling timber, carbon sequestration, and pay liability when trees are harvested. Equations used to calculate the net present value (profits) for the forest owner are based on Sands and Kim (2009) and Van Kooten et al. (1995). $NPV_1(a)$ represents the net present value of forestry from logging trees in a single rotation per hectare at a steady state.

$$NPV_1(a) = [p_t y_a - c_h]e^{-ra} - c_g \tag{3.6}$$

Where p_t is the unit price of timber, c_h refers to the cost at harvest age, r is the discount rate, and c_g is the planting cost. It is assumed that harvest and planting costs are constant in the forest model. Cost varies with sectoral output when different carbon taxes are used.

Carbon is sequestered by growing trees, and released once the trees achieve their harvest age and are felled. Some studies set a pickling parameter β for carbon stored in wood permanently (e.g., Van Kooten et al., 1995; Sands & Kim, 2009; Gardiner, 2009). This paper follows these studies to calculate the benefit of carbon sequestration in a forest:

$$NPV_2(a) = \int_0^a P_c k y'(x)e^{-rx}dx = \underbrace{P_c * k * y(a)e^{-ra}}_{(A)} + \underbrace{P_c * k * r \int_0^a y(x)e^{-rx}dx}_{(B)} \tag{3.7}$$

Where NPV_2 represents the net present value of carbon sequestration benefit over a rotation length of a. The first part of Equation 3.7 (A) represents the carbon benefit at harvest age a, the second part (B) shows the continuous carbon benefit from the growing trees, k is a factor to convert cubic meters of timber to metric tons of carbon, and r is the discount rate.

Equation 3.8 shows that forest owners face a penalty for carbon emissions when logging timber at age a, and this cost is discounted to present value.

$$NPV_3(a) = -P_c k(1-\beta)y(a)e^{-ra} \tag{3.8}$$

The present value of net benefits for forest owners over all of the future timber rotations is calculated by integrating the above three NPVs as shown in Equation 3.9 (Sands &

Kim, 2009; Hertel et al., 2009). NPV_{for} is the total net present value of net benefits that forest owners obtain over their infinite time horizon (NPV_{for} is written as NPV_4 in later sections).

$$NPV_{for}(a) = \frac{NPV_1(a) + NPV_2(a) + NPV_3(a)}{1 - e^{-ra}} \tag{3.9}$$

Optimal rotation age a^* is obtained by differentiating $NPV_{for}(a)$ with respect to a. Equation 3.10 shows the process of calculating a^* (Sands & Kim, 2009).

$$\frac{(p_t + P_c k\beta)(y'(a)e^{-ra} - ry(a)e^{-ra}) + r * c_h * e^{-ra} + r * P_c * k * y(a) * e^{-ra}}{(p_t + P_c * k * \beta) * y(a) * e^{-ra} - c_h * e^{-ra} - c_g + r * P_c * k * \int_0^a y(x)e^{-rx}dx} = \frac{re^{-ra}}{1 - e^{-ra}} \tag{3.10}$$

The right hand side of Equation 3.10 shows that the interest rate r determines the value of land. The carbon payment from the government is part of a forester's income. Annual carbon sequestration value CFS is calculated by Equation 3.11.

$$CFS = \frac{NPV_2 * e^{ra}}{a} \tag{3.11}$$

CFS is the annual carbon payment that the forester receives from the government. NPV_2 is the discount cash flow for carbon sequestration, and $NPV_2 * e^{ra}$ refers to the net future value of the carbon sink.

The amount of carbon sequestration changes with tree growth and can be measured as shown in Equation 3.12.

$$C_{seq} = \Delta QA_t * C_{seq}^{base} \tag{3.12}$$

Where ΔQA_t is the change of timber production, and C_{seq}^{base} is the carbon sequestration amount at baseline scenario.

Carbon emissions (CE_{timber}) at harvest age are released from the harvested trees y_a, and the amount of emissions in steady state is shown in Equation 3.13.

$$CE_{timber} = k * (1 - \beta) * (\frac{y_a}{a}) \tag{3.13}$$

Forestry manufacturing

Harvested timber is used as an intermediate input in the forestry manufacturing sector as shown in Figure 3.2. Value-added and intermediate inputs are used in fixed proportions. Total nesting is illustrated in Figure 3.2.

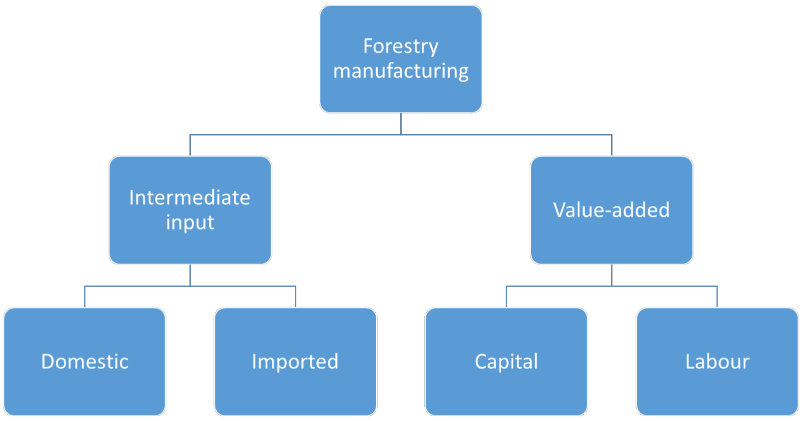

Figure 3.2: Forestry processing

Similar to natural timber production, the forestry manufacturer chooses the optimal level of each input through cost minimization as shown in Equation 3.14 to 3.19.

$$\min C_{for} = PINT_{for} * QINT_{for} + PVA_{for} * QVA_{for} + P_c * e_{for} * QA_{for}$$

s.t.

$$QA_{for} = \min[\min(\frac{QINTA_{for}}{\delta_1^{for}}), \frac{QVA_{for}}{\delta_2^{for}}] \tag{3.14}$$

Where QA_{for} is output from forestry manufacturing sector, $QINTA_{for}$ and QVA_{for} represent intermediate and value-added inputs, respectively, and $\delta_{1,2}^{for}$ are Leontief coefficients.

The price of forestry manufactured product is PA_{for} which is taxed at production tax rate t_{for} and the manufacturer pays a carbon tax P_c per tonne of CO_2e. Equation 3.14 can be written as Equation 3.15, which specifies the zero profit condition.

$$(1 - t_{for}) * PA_{for} * QA_{for} - P_c e_{for} QA_{for} = PVA_{for} * QVA_{for} + PINTA_{for} * QINTA_{for} \tag{3.15}$$

An optimal relation between output price and input price as shown by Equation 3.16, is given by substituting the Leontief function into the zero-profit condition, .

$$(1 - t_{for}) * PA_{for} - P_c * e_{for} = PINTA_{for} * \delta_{for1} + PVA_{for} * \delta_{for2} \tag{3.16}$$

At the intermediate input nesting shown in Figure 3.2, domestic goods are substituted with imported goods at an elasticity of substitution σ_{arm}^{for}.

$$\min C_{int}^{for} = P_{dom}^{t} * Q_{dom}^{t} + P_{imp}^{t} * Q_{imp}^{t}$$

s.t.

$$QINTA_{for} = \min\{\frac{Q_{dom}^{for}}{\beta_1^i}, \frac{Q_{imp}^{for}}{\beta_2^i}\} \tag{3.17}$$

Given a fixed output, producers allocate factors so as to minimize cost. Capital accumulation is not taken into account. The cost minimization problem for value-added input is depicted below:

$$\min C_{kl}^{for} = P_k^{for} * K_{for} + P_l^{for} * L_{for}$$

s.t.

$$QVA_{for} = [\theta_{for}^k K_{for}^{\frac{1-\sigma_{kl}^{for}}{\sigma_{kl}^{for}}} + (1 - \theta_{for}^k) L_{for}^{\frac{1-\sigma_{kl}^{for}}{\sigma_{kl}^{for}}}]^{\frac{\sigma_{kl}^{for}}{1-\sigma_{kl}^{for}}} \tag{3.18}$$

Where C_{kl} is the cost in the value-added nest; K_{for} is capital use in forestry; L_{for} is labour use in forestry; and QVA_{for} is the aggregated value-added input in forestry.

The first order condition is shown in Equation 3.19. It describes the equilibrium conditions where the factor price ratio equals the marginal rate of technical substitution.

$$\frac{P_k^{for}}{P_l^{for}} = \frac{\theta_{for}^k}{1 - \theta_{for}^k} * (\frac{labour_{for}}{K_{for}})^{\frac{1}{\sigma_{kl}^{for}}} \tag{3.19}$$

3.2.3 Agricultural production

In order to be consistent with the social accounting matrix, agricultural activity includes horticulture, sheep, beef cattle and grain farming; dairy cattle farming; and other agriculture. All sectors use the same production nesting. Total output of the agricultural sector is represented by QA_{ag}, a nested function with two sub nests: intermediate input and value-added. Similar to the forestry manufacturing sector, agriculture is represented by a Leontief function using intermediate inputs from domestic and imported goods.

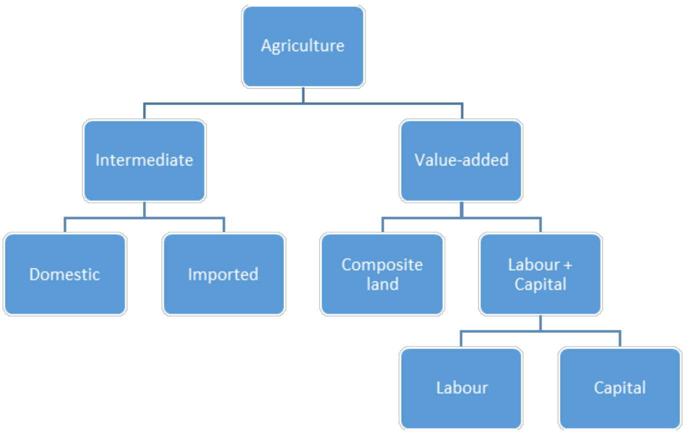

Figure 3.3: Agricultural production

The process of optimizing input use and output is the same as in the forestry and forestry manufacturing sectors. Equation 3.20 to 3.21 shows the zero profit condition at each nesting level as seen in Figure 3.3.

$$QA_{ag} = \min[\min(\frac{QINTA_{ag}}{\delta_1^{ag}}), \frac{QVA_{ag}}{\delta_2^{ag}}] \tag{3.20}$$

Where the Leontief coefficient $\delta_{1,2}^{ag}$ are the proportion of intermediate and value-added goods respectively used in total agricultural production. The zero-profit condition can be written as:

$$(1 - t_{ag}) * PA_{ag} - P_c e_{ag} = PINTA_{ag} * \delta_{ag1} + PVA_{ag} * \delta_{ag2} \tag{3.21}$$

At the intermediate input level, the zero profit condition is written as Equation 3.22.

$$\min C_{int}^{ag} = P_{dom}^{ag} * Q_{dom}^{ag} + P_{imp}^{ag} * Q_{imp}^{ag}$$

s.t.

$$QINTA_{ag} = \min\{\frac{Q_{dom}^{ag}}{\beta_1^i}, \frac{Q_{imp}^{ag}}{\beta_2^i}\} \tag{3.22}$$

At the value-added level:

$$\min C_{lkl}^{ag} = P_{land}^{ag} * Land_{com} + P_{kl}^{ag} * Q_{kl}^{ag}$$

s.t.

$$Q_{lkl}^{ag} = [\beta_{ag}^{lkl} * Land_{com}^{\frac{1-\sigma_{lkl}}{\sigma_{lkl}}} + (1 - \beta_{ag}^{lkl}) * Q_{kl}^{\frac{1-\sigma_{lkl}}{\sigma_{lkl}}}]^{\frac{\sigma_{lkl}}{1-\sigma_{lkl}}} \tag{3.23}$$

Where lkl stands for land, capital, and labour nesting. Equation 3.24 shows the optimal price ratio between the composite land and the labour-capital bundle.

$$\frac{P_{land}^{ag}}{P_{kl}^{ag}} = \frac{\beta_{ag}^{lkl}}{1 - \beta_{ag}^{lkl}} * (\frac{Q_{kl}^{ag}}{Land_{com}})^{\frac{1}{\sigma_{lkl}}} \tag{3.24}$$

3.2.4 Land allocation

Land is allocated to sectors on the basis of rents (land profitability) and used as composite land in each sector. Land supply to each sector is determined by a CET function. Within each sector, composite land includes five types of land which can be substituted for each other according to the nesting shown in Figure 3.4.

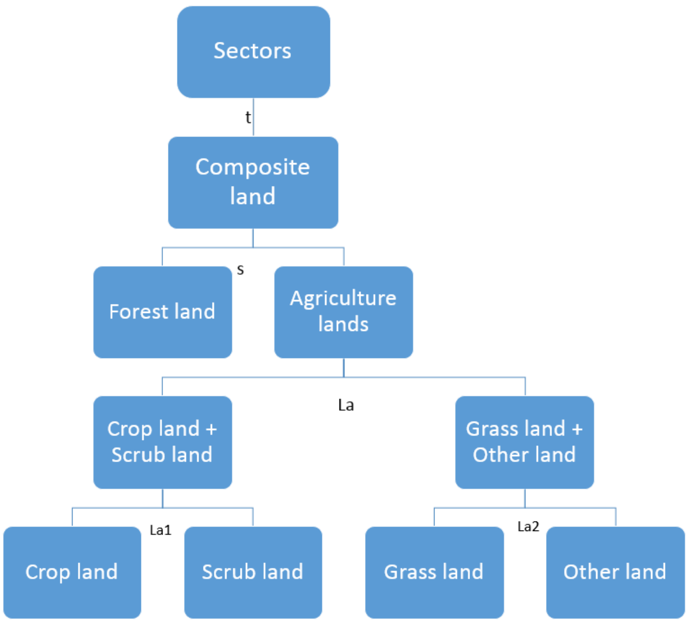

Figure 3.4: Land type nesting

Each sector uses composite land with substitution determined by a CES function between each land type. At the top level of the land allocation nesting in Figure 3.4, forest land competes with the aggregated other four types of land with the elasticity of substitution “s”. The other four types of land are divided into two bundles (crop land and scrub land, grass land and other land) with the elasticity of substitution La. The elasticity of substitution between each bundle is La1 and La2. The value of "s" is selected from literature (Strutt & Rae, 2011) which represents a low degree and the relative difficulty of substitution for forest land. I assume composite land is used by sectors at elasticity t, where the value of t is assumed to 1. It implies a relative high degree of elasticity and an easier transformation of composite land across sectors. Five types of land are listed in Table 3.2. Equations for land allocation and substitution are shown by Equations 3.25 to 3.28.

Table 3.2: Land type

type 1	forest land
type 2	other land
type 3	grass land
type 4	scrub land
type 5	crop land

Equations 3.25 to 3.28 show land type i allocating between sector i and j.

$$\min P_{comland} * Q_{comland} = P_{comland}^{sec_i} * Q_{comland}^{seci} + P_{comland}^{secj} * Q_{comland}^{secj} \tag{3.25}$$

s.t.

$$Q_{comland} = [\alpha_{land} Q_{comland}^{seci}{}^{\frac{\sigma_{sec}+1}{\sigma_{sec}}} + (1-\alpha_{land}) Q_{comland}^{secj}{}^{\frac{\sigma_{sec}+1}{\sigma_{sec}}}]^{\frac{\sigma_{sec}}{\sigma_{sec}+1}} \tag{3.26}$$

Where $Q_{comland}$ is composite land allocated between sector $seci$ and $secj$, in terms of elasticity of transformation σ_{sec} which is assumed as 1 (t=σ_{sec}); Q_{landi}^{seci} is land type i demanded by sector i; and $P_{comland}$ is composite land price allocated in the sector.

Within sector i, the cost minimization problem for each land use is shown in Equation 3.27 and 3.28.

$$P_{land}^{com} Q_{land}^{com} = P_{land}^{i} Land_i + P_{land}^{j} Land_j \tag{3.27}$$

s.t.

$$Q_{land}^{com} = [\beta_{land} Land_i^{\frac{1-\sigma_{land}}{\sigma_{land}}} + (1-\beta_{land}) Land_j^{\frac{1-\sigma_{land}}{\sigma_{land}}}]^{\frac{\sigma_{land}}{1-\sigma_{land}}} \tag{3.28}$$

The first order condition for land allocation is derived from the above combined equations as shown below:

$$\frac{Pland_i}{Pland_j} = \frac{\beta_{land}}{1 - \beta_{land}} * (\frac{Land_j}{Land_i})^{\frac{1}{\sigma_{land}}} \tag{3.29}$$

Where $Pland_i$ and $Pland_j$ are the rental prices of different land types that are demanded by different sectors; i and j refer to five land types in the land nesting graph; β_{land} is the share of each land in the land nesting bundles; and, σ_{land} is elasticity of substitution (in Figure 3.4 I use s, La, La1, La2 to represent elasticity of substitution between each land type instead of σ_{land}).

3.2.5 ROE production

The rest of economy (ROE) sectors include mining, oil and coal; manufacturing; utilities; industrial processes; and services, and the same production nesting structure is assumed. Labour and capital are used as primary factors of production. I assume an average emission factor for the rest of industries e_{ROE}. The nested production tree is shown as:

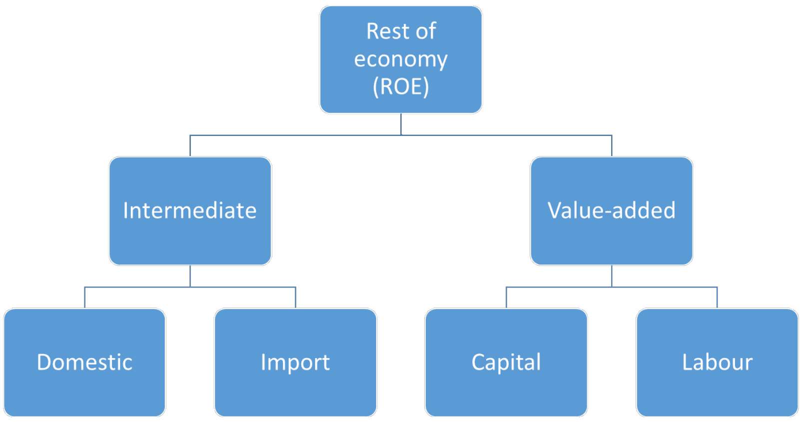

Figure 3.5: Rest of economy production

$$QA_{roe} = \min[\min(\frac{QINTA_{roe}}{\delta_1^{roe}}), \frac{QVA_{roe}}{\delta_2^{roe}}] \tag{3.30}$$

$$(1 - t_{roe}) * PA_{roe} * QA_{roe} - P_c * e_{roe} * QA_{roe}$$
$$= PINTA_{roe} * QINTA_{roe} + PVA_{roe} * QVA_{roe} \tag{3.31}$$

Similar to forestry manufacturing and agriculture sectors, the zero-profit condition is:

$$(1 - t_{roe}) * PA_{roe} - P_c e_{roe} = PINTA_{roe} * \delta_{roe1} + PVA_{roe} * \delta_{roe2} \tag{3.32}$$

Intermediate goods are a composite of domestic and imported commodities with elasticity of substitution σ_{arm}^{ROE}:

$$\min C_{int}^{roe} = P_{dom}^{roe} * Q_{dom}^{roe} + P_{imp}^{roe} * Q_{imp}^{roe}$$

s.t.

$$QINTA_{roe} = \min\{\frac{Q_{dom}^{roe}}{\beta_1^{roe}}, \frac{Q_{imp}^{roe}}{\beta_2^{roe}}\} \tag{3.33}$$

Capital and labour are used in the ROE production process as a value-added part, the equations are:

$$QKL_{roe} = [\psi^k * K_{roe}^{\frac{1-\sigma_{kl}^{roe}}{\sigma_{kl}^{roe}}} + (1 - \psi^k) L_{roe}^{\frac{1-\sigma_{kl}^{roe}}{\sigma_{kl}^{roe}}}]^{\frac{\sigma_{kl}^{roe}}{1-\sigma_{kl}^{roe}}} \tag{3.34}$$

The optimal factor price ratio is derived by the zero-profit condition:

$$\frac{P_k^{roe}}{P_l^{roe}} = \frac{\psi^k}{1 - \psi^k} * (\frac{L_{roe}}{K_{roe}})^{\frac{1}{\sigma_{kl}^{roe}}} \tag{3.35}$$

3.2.6 Linking forestry model to CGE

Linking the forest model to CGE is a significant contribution made by this thesis. From the forest model, the optimal rotation age a can be determined. As a starting point, timber price, harvest, and maintenance costs are exogenous in the forest model. The optimal rotation age is used again in the CGE model to determine the optimal level of timber price and timber yield. As a small economy the assumption is that NZ timber producers are price takers, domestic timber price is affected by the world price and exchange rate.

In the CGE model a large transformation elasticity (1000) is applied between exported timber and domestic timber because a higher elasticity of transformation implies an easier exportation to overseas markets. Equations 3.36 through 3.40 show the linkage between the two models.

$$y_a * land_{for} = QA_t \tag{3.36}$$

Equation 3.36 can be re-written as:

$$land_{for} = \frac{QA_t * e^{c_3 * a}}{c_1 * a^{c_2}} \tag{3.37}$$

Equation 3.37 specifies a correlation between rotation age and timber yield as well as land use for forestry. The unit of production in the forest model is per hectare, but the CGE model includes the total amount of timber at all forestry land hectares. Therefore, when linking the two models, forestry land use is multiplied by the timber yield. A positive change between timber yield QA_t and $land_{for}$ is shown in Equation 3.37.

Domestic timber price P_t is affected by the world market price PW_{timber}. Equation 3.38 describes the linkage between prices.

$$PW_{timber} * exr = P_t \tag{3.38}$$

Where PW_{timber} is the world price for NZ timber and exr is the exchange rate. Both maintenance and harvest costs are exogenous in the partial equilibrium forest model. However, the cost will change with timber yield and carbon price. Equation 3.39 and 3.40 reflects the change.

$$C_g = \frac{P_t * y_a * land_{for} * (1 + \frac{P_c}{CE_{for}}) * \bar{C_g}}{P_t * Q_t} \tag{3.39}$$

$$C_h = \frac{P_t * y_a * land_{for} * (1 + \frac{P_c}{CE_{for}}) * \bar{C_h}}{P_t * Q_t} \tag{3.40}$$

Where $\frac{P_c}{CE_{for}}$ shows a carbon tax rate that is added up to output price; $\bar{C_{g,h}}$ is the initial cost for the maintenance and harvest cost from the partial equilibrium model.

By linking the forest and CGE models, optimal rotation age, yield, and timber price are determined in equilibrium.

3.2.7 Carbon tax

This chapter investigates land use change under four carbon tax rate scenarios: NZ$0, $25, $50, and $100. Carbon tax at NZ$0 is assumed as baseline. The carbon tax collected is based on carbon dioxide equivalent (CO_2e) emissions from each industry. Individuals and consumers do not pay the carbon tax.

3.2.8 Demand

Consumers maximize their utility subject to disposable income. The final demand side contains four parts: household, investment, government and export.

Household

It is assumed there is a representative household demanding all final goods from the twelve industries. Household utility is based on the Linear Expenditure System (LES) function in which I set a committed quantity of consumption $\bar{x_i^h}$ [4] that contributes 10% of total household consumption. Committed consumption is considered as the basic need regardless of what the income. NZ is a developed country, thus, it is assumed a low proportion 10% of total income as a necessary expenditure for NZ household.

The household receives pre-tax returns from factors, the optimal demand is derived from maximizing utility subject to income constraint.

$$\max u(x_i^h) = \sum_{i=1}^{12} \beta_i^h ln(x_i^h - \bar{x}_i{}^h) \tag{3.41}$$

s.t.

$$\sum_{i=1}^{12} p_i x_i^h = (1 - t_h)Y_h \tag{3.42}$$

$$(1-t_h)Y_h = (\sum_{i=1}^{F} p_i F + transf_g^h + exr * transf_{ROW}^h) - (savings_h + transf_h^g + exr * transf_h^{ROW}) \tag{3.43}$$

[4] In the section 3.2.10, x_i^h is written as Q_h.

Where $(1-t_h)Y_h$ is the pre-tax income for household, t_h is income tax rate, Y_h is the income that comes from factor returns, transfers from government, and the rest of world (ROW). The portion of household income is used as saving, and the rest of income is transferred to government and the ROW with an exchange rate exr.

The quantity demanded of each commodity by household is shown in below.

$$x_i^h = \bar{x_i^h} + \frac{\beta_i^h[(1-t_h)Y_h - \sum_{i=1}^{12} p_i \bar{x_i^h}]}{p_i} \tag{3.44}$$

Government

Total government income includes a return on capital, income tax, carbon tax, import tax, and transfers from household and ROW. To keep the debt balanced, government transfers from its savings to the ROW at a currency exchange rate exr.

$$\max u^g(x_i^g) = \min(\frac{x_1^g}{a_1^g}, ...\frac{x_i^g}{a_i^g}) \tag{3.45}$$

s.t.

$$\begin{aligned} Y_g = {} & P_{k,i}K_i + \sum_{i=1}^{12} P_c * e_i * QA_i + t_h Y_h + \sum_m t_m PM * QM * exr + transf_h^g \\ & - exr * transf_g^{row} - transf_g^h - Saving_g \end{aligned} \tag{3.46}$$

Where a_i^g is share parameter of government consumption of commodity x_i, x_i^g is government consumption of commodity i, $p_{k,i}$ is price of capital supplied by government, K_i is government-owned capital, PM is imported good price, QM is amount of imported goods, exr is exchange rate, t_m is import tax rate, $t_i, i \in h$ is income tax rate, $transf_h^g$ is transfer from household to government, $transf_g^h$ is transfer from government to household, and $saving_g$ is government saving.

Government pays tax on its own consumption by t_g, it collects factor taxes from factor use; income tax from household; and carbon tax that comes from agriculture and timber processing but is subsidy on carbon sequestration to forest owners. Additionally, government receives import tax from the ROW.

Investment-Saving

As set by Johansen closure (Gilbert & Tower, 2012), in order to meet an equilibrium condition, total real investment is exogenous in the model, saving is endogenous to balance government income and expenditure. Investment does not require any final commodity. Expenditure E_{inv} equals investment value by using commodity price times fixed investment endowment $\bar{X_{inv}}$.

$$E_{inv} = \sum p_{inv} * \bar{X_{inv}} \tag{3.47}$$

Savings come from government and household with a saving rate p_s. Total savings in an open economy are described as:

$$saving = p_s(s_g + s_h + s_{ROW}) \tag{3.48}$$

3.2.9 Trade

In the commodity market, total output is allocated to exports and the domestic market in terms of constant elasticity of transformation (CET). Both imported goods and domestic production are sold in the domestic market. I assume that imported and domestic goods are heterogeneous, and are not perfect substitutes. The Armington function is used to depict substitution. To be consistent with Gilbert and Tower (2012), for an imported good, a positive value of t_m represents a tariff; whereas for exported goods, a negative t_x means export tax.

The allocation of outputs:

$$QA_i = [\delta_1 QD_i^{\frac{\sigma_1-1}{\sigma_1}} + \delta_2 QX_i^{\frac{\sigma_1-1}{\sigma_1}}]^{\frac{\sigma_1}{\sigma_1-1}}, i \in ag, for, ROE \tag{3.49}$$

Where QA_i is total output by sector i, QD_i is final goods that are sold in domestic markets while QX_i implies the goods that are exported to the rest of world. The allocation depends on share parameters $\delta_{1,2}$.

The zero-profit condition:

$$PA_i * QA_i = PD_i * QD_i + PX_i * QX_i \tag{3.50}$$

$$PX_i = (1 - t_x) * exr * PW_i^x \tag{3.51}$$

Export price is free on board (FOB) price, affected by exchange rate and world prices. Where PX_i is price of the exported good, t_x is export tax, exr is exchange rate for NZ to the export destination, PW_i^x is the world price of exports. The latter three are exogenous variables.

Therefore, the relationship between commodity price and domestic consumption and exports is shown in Equation 3.52.

$$\frac{PD_i}{PX_i} = \frac{\delta_1}{\delta_2} * (\frac{QX_i}{QD_i})^{\frac{1}{\sigma_1}} \tag{3.52}$$

Commodities supplied to the domestic market for final demand are composed of imported and domestic goods. The CES function is used to describe the allocation of imported and domestic commodities.

$$Q_i = [\delta_3 QD_i^{\frac{1-\sigma_2}{\sigma_2}} + \delta_4 QM_i^{\frac{1-\sigma_2}{\sigma_2}}]^{\frac{1}{\sigma_2}} \tag{3.53}$$

Where QM_i is imported goods, the allocation of domestic input and imported input is dependant on share parameters δ_3 and δ_4. Correspondingly, the ratio of domestic price to imported price is given by:

$$\frac{PD_i}{PM_i} = \frac{\delta_3}{\delta_4} * (\frac{QM_i}{QD_i})^{\frac{1}{\sigma_2}} \tag{3.54}$$

$$PM_i = (1 + t_m) * PW_i^m * exr \tag{3.55}$$

The import price is affected by exchange rate, world price of imported commodity PW_i^m and import tax t_m. These are also exogenous variables.

3.2.10 Market clearing

The model requires both factor and commodity markets to clear. Zero-profit is required for each producer. All domestic supply and production equals domestic final demand. Total commodity supply is composed of intermediate inputs including imported and domestic, household consumption, government purchase and investment demand. Furthermore, the Johanson macro-closure (Gilbert & Tower, 2012), is applied in this chapter .

Commodity market clearing:

$$QA_i = \sum QINT_i + \sum Q_h + Q_g + Q_{INV}^{-} \tag{3.56}$$

$$\sum_i^m PW_i^m QM_i = \sum_i^x PW_i^x QX_i + FSAV \tag{3.57}$$

$$FSAV = F\bar{S}AV \tag{3.58}$$

$$\bar{E_{inv}} = saving_h + saving_{gov} + F\bar{S}AV \tag{3.59}$$

$$\tag{3.60}$$

Where $\sum Q_h$ is total consumption by household; Q_g is government spending; $FSAV$ is savings from the rest of world. $FSAV$ is exogenous in the model. Exchange rate exr is endogenous in the model, and has to adjust in order to clear the trade balance.

Factor market clearing:

$$\sum labour_i = \overline{labour_i} \tag{3.61}$$

$$\sum k_i = \bar{k_h} + \bar{k_{gov}} \tag{3.62}$$

$$\sum land_i = \overline{land_i} \tag{3.63}$$

$$\tag{3.64}$$

Closure:

$$(1 - t_{inv})Y_{inv} = \sum Savings_i = \bar{E_{inv}} \tag{3.65}$$

3.3 Data

This section describes the data used in the forest-CGE model. Parameters in the CGE model are calibrated using the social accounting matrix (SAM) with 2007 as the base year. For instance, the Leontief coefficient α_i and η_i are determined by the ratio of inputs to outputs using the base data in 2007. Bench-mark data represents an equilibrium for the economy. The calibration follows the process suggested in Sánchez et al. (2004). After setting up the static model as shown previously, the social accounting matrix feeds the original values of production and factor use into the CGE equations to obtain the initial model solution at the baseline scenario. In order to calibrate land rent, I separated land value from capital use, and multiplied land sales price with an interest rate (8%).

Elasticities of substitution and transformation are taken from Rutherford (2003) and NZIER (2004). In particular, I set the elasticity of substitution among four land types (otherland, grassland, cropland, and scrubland) at 2 in production nestings except for forestland. To be in line with Strutt and Rae (2011) and Michetti and Parrado (2012), I set the elasticity of substitution between forestland and other four land types at 0.4. In this setting, it is difficult to convert other types of land to forestland but easy to switch among agricultural lands in New Zealand. Carbon dioxide equivalent CO_2e is modelled as the carbon emissions, and the initial GHG inventory data comes from the MFE (2009).

3.3.1 Natural forest yield

The National Exotic Forest Description (NEFD) report MPI (2011, 2013) provides a detailed description of timber yields in NZ. The yield table specifies two dominant trees in NZ: radiata pine and douglas fir for both pre-1990 and post-1989 planting across 12 regions. These regions are: Auckland (AKL), Canterbury, Central-north island (Central NI), East-coast, Hawkesbay, Marlborough (Mar), Nelson, Northland (NI), Otago, Southern-north island-east coast (SNI-E), Southern-north island-west coast (SNI-W), and Southland. The yield table contains the total standing volume (TSV) and total recovery volume (TRV) of trees with different silviculture regimes over 40 years. The TSV of radiata pine that is pruned without production thinning is chosen in order to estimate timber growth parameters $c_{1,2,3}$. I calculate the weighted ratio of each planting area to the national planting area to differentiate the planting volume of the post-1989 radiata pine. The weighted national timber yield table is seen as Table 3.3. The weighted ratios are shown in Table 3.4.

Table 3.3: Weighted National Timber Yield Table (m^3/ha)

Years	AKL	Canterbur	Central NI	Eastcoast	Hawkesba	Mar	Nelson	NI	Otago	SNI-E	SNI-W	Southlanc	National
	m3/ha	m3/ha	m3/ha	m3/ha	m3/ha	m3/ha	m3/ha	m3/ha	m3/ha	m3/ha	m3/ha	m3/ha	m3/ha
5	0.1	0.2	1.0	0.2	0.1	0.0	0.0	0.2	0.0	0.0	0.2	0.0	1.9
10	1.8	4.4	29.5	6.3	3.7	1.2	0.2	8.2	0.1	2.0	3.9	1.1	62.3
15	5.4	12.1	90.1	21.5	14.4	5.7	0.8	25.7	0.5	7.3	11.4	5.5	200.4
20	9.7	19.4	155.8	38.8	28.4	12.5	1.6	46.0	1.2	14.9	19.5	12.2	359.9
25	13.4	27.2	214.1	53.0	41.4	20.3	2.5	63.6	1.9	20.4	26.4	19.9	504.0
30	16.8	33.6	267.3	65.6	53.9	27.7	3.4	80.0	2.5	25.6	32.8	28.3	637.4
35	19.8	38.2	311.2	75.9	65.5	34.9	4.3	94.9	3.2	30.5	38.1	34.0	750.4
40	22.4	41.1	346.1	84.5	76.0	41.8	5.2	105.2	3.8	37.6	43.3	39.1	846.1

Table 3.4: weighted ratios for planting areas of post-1989 radiata pine

Region	**Hectares∗**	**Percentage of regional area to total area**
Auckland	40,039	2%
Canterbury	111,981	6%
Central North Island	553,956	32%
East Coast	156,136	9%
Hawke's Bay	131,735	8%
Marlborough	72,798	4%
Nelson	8,875	1%
Northland	201,196	12%
Otago	7,103	0%
Southern North Island-Eastcoast	66,226	4%
Southern North Island-Westcoast	93,774	5%
Southland	76,781	4%
Total NZ net stocked planted production forest area	1,728,500	

∗ Hectares are estimated total area by NEFD report MPI (2013)

source:MPI (2013)

Three shape parameters c_1, c_2 and c_3 from the timber growth function (Equation 3.1) are estimated using the weighted national post-1989 radiata pine volume data. Based on Sands and Kim (2009), I set c_2 as an integer for a closed-form integration function.

In this chapter, c_2 is set at 3, c_1 is 0.12385, and c_3 is 0.06276. In a closed functional form of NPV_2, I set $c_2 = 3.06947$ to better reflect the NZ timber growth. These parameters generate a more realistic timber yield curve for post-1989 radiata pine in NZ.

Figures 3.6 and 3.7 show the timber growth curve with estimated parameters and weighted data. The weighted curve is similar to the generated timber growth curve. In addition, the constant domestic timber price in the base year is set at NZ$88.44 per tonne delivered at mill (Tee et al., 2012). Manley (2012) introduces a fixed harvest cost to represent the costs of measurement, auditing and registration associated with carbon trading. I divide cost into two parts: unit harvest cost of NZ$20 and unit maintenance cost of NZ$10. The pickling factor β is set as 0 in the baseline (Gardiner, 2009) as currently used in the NZ ETS.

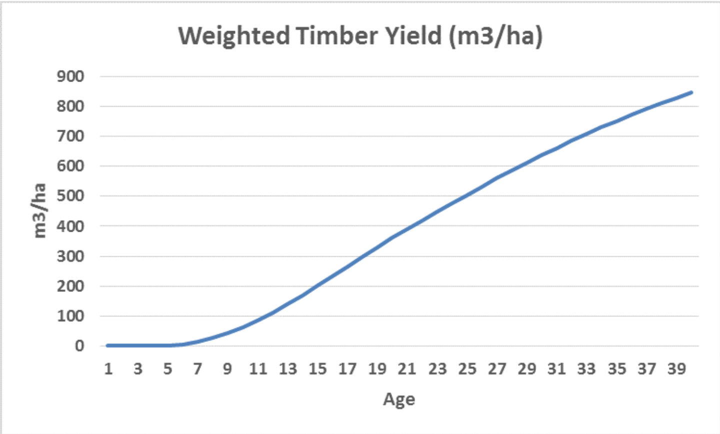

Figure 3.6: Weighted timber growth curve

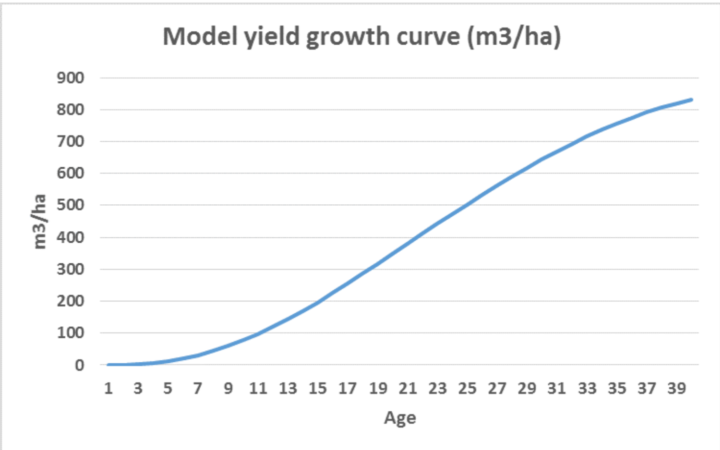

Figure 3.7: Model adjusted growth curve

Standard (2010) introduces a formula to calibrate the conversion factor from 1 cubic meter of timber to tons of CO_2e. I apply this method to calculate the parameter k in the forestry model as seen in Equation 3.66.

$$\begin{aligned}
&Stem\,volume\,*\,Biomass\,Expansion\,Factor\,*\,Wood\,density\,*\,Carbon\,fraction\\
&*\,(C\,-\,to\,-\,CO_2)\,*\,(1+root-to-shootratio)\\
&=1\,*\,1.1\,*\,0.3\,*\,0.5\,*\,3.666\,*\,(1+0.2)=0.7\,t\,CO_2
\end{aligned} \tag{3.66}$$

CO_2e is used to express the impact of different greenhouse gases in terms of the amount of CO_2 that would result in the same amount of warming. In this model, I assume 1 cubic meter of timber converts to 0.7 ton CO_2e in the forestry model (Paul et al., 2008).

Following Manley (2007, 2012), I use a constant interest rate of 8%. In section 3.5 sensitivity analysis illustrates how optimal rotation age changes with the interest rate.

3.3.2 CGE model

Share parameters calibration

The optimization problem is solved using "Mathematical programming system for general equilibrium" (MPSGE) language. Markusen and Rutherford (2004) point out that "MPSGE is an equation generator which automates the calibration function parameters to a benchmark equilibrium while simultaneously providing an automatic specification of the equations which define general equilibria". Thus, this section will briefly specify calibration of share parameters in production and minimum subsistence expenditure ratio in the LES function.

The share parameter from the CES/CET production function is calibrated as follows. At the first nesting level of production, output value equals input cost including intermediate $QINTA$ and value-added QVA. Therefore, the share parameter in each industry other than timber yield industry is calibrated as:

$$\delta_i = \frac{PVA_i * QVA_i^{\frac{1}{\sigma_i}}}{PVA_i * QVA_i^{\frac{1}{\sigma_i}} + PINTA_i * QINTA_i^{\frac{1}{\sigma_i}}}$$

Where i refers to industries in the social accounting matrix. The format of share parameters in the intermediate and value-added nests follow the same approach.

The LES function is used to calculate the optimal level of household consumption of each good. The share parameter β_i^h that represents the ratio of consumption of each commodity to total household expenditure is calibrated as:

$$\beta_i^h = \frac{(x_i^h - \bar{x_i^h})p_i}{(1-t_h)Y_h - \sum_i p_i \bar{x_i^h}}$$

Elasticity data

Elasticities used in the CGE model are derived from literature (e.g. Rutherford (2003); NZIER (2004)). Table 4.2 and Table 4.3 list details of elasticity used in this model.

Table 3.5: Elasticity interpretation

s	elasticity of substitution at the first nesting level
t	elasticity of transformation
t(for)	elasticity of transformation for timber
va	elasticity of substitution between value-added input
va(for)	elasticity of substitution between value-added input for natural timber sector
dm	elasticity of substitution in either domestic commodity or import commodity
d(dm)	elasticity of substitution between domestic and import commodities
id	elasticity of substitution between domestic and import goods used in sectoral intermediate production
la	elasticity of substitution between "crop land+scrub land" bundle and "other land+grass land" bundle
la1	elasticity of substitution between crop land and scrub land
la2	elasticity of substitution between grass land and other land

Table 3.6: Values of elasticities

Type	s	t	t(for)	va	va(for)	dm	d(dm)	id	la	la1	la2
Domestic production	0	0		0.7	0			0			
Allocation of output	0	2	1000								
Export		2									
Import goods		0				2	2				
Land allocation CET	1	1									
Land allocation CES	0.4								2	2	2
Investment	0										
Household consumption	1										
Government consumption	0										

Source: Rutherford (2003), NZIER (2004), Strutt and Rae (2011), Michetti and Parrado (2012)

3.4 Results

Results from four scenarios are described in this section. Four carbon tax rates are simulated as a policy shock. Again, these carbon tax rates are applied to all sectors and all gases. First, a baseline is established with carbon price P_c=\$0. Second, the carbon price is increased as P_c=\$25, which is the existing carbon price if units are purchased from the NZ government. The remaining two scenarios set P_c=\$50 and \$100. All monetary units are in New Zealand dollars.

Sensitivity analysis is conducted to assess how the optimal rotation age changes with the discount rate, and how land use changes under different elasticity of substitution among the five land types.

Subsections 3.4.1 and 3.4.2 drill down to research questions on land use conversion and change in forest variables with different tax rates. Analysis of the effect of four carbon tax rates on macro variables such as GDP, household and government consumption, factor prices, exchange rate, trade, sectoral output and net emissions are examined in subsection 3.4.3.

3.4.1 Land use conversion by sectors

Land is measured in hectares. In the baseline scenario, the sheep-beef sector uses the most land, 76% of the total. Horticulture and fruit growing uses the least land 1%. Dairy uses 11%, forestry uses 10%, and other agriculture uses 3%. Table 3.7 shows land use in hectares in the baseline scenario.

Table 3.7: Land use in baseline (hectare)

Carbon tax=0	Forest land	Other land	Grass land	Scrub land	Crop land	**Total**
Forestry	1105949	11330	64567	116454	904	1299204
Horticulture	8728	3063	38990	5304	66955	123040
Sheep-beef	989838	582505	7275154	1120353	285177	10253027
Dairy farming	133221	19572	1296734	52325	26121	1527973
Other agriculture	40552	14812	270028	38257	11048	374697
Total	2278288	631282	8945473	1332693	390205	13577941

According to Table 3.7, in the baseline, forestry uses the most forest land (85%), some scrub land (9%), grass land (5%), and other land (1%). Most crop land (54%) is used in the horticulture sector, and 32% of grass land is also used for horticulture. In fact, grass land dominates agricultural activities, especially the sheep-beef (71%), dairy farming sectors (85%) and other agriculture (72%).

At a higher carbon tax rate, agriculture producers have to pay more for emissions, but forest owners earn profits from carbon sequestration. The change in sectoral land use change is shown in Table 3.8. It is clear that forest land increases but all the other land gradually decreases at higher carbon tax rates. Specifically, horticulture reduces its land use by more than the rest of agriculture sectors. This change is associated with sectoral output and exports. At higher carbon tax levels, the horticulture sector decreases production significantly (13% at carbon tax 25/t, 23% at \$50/t, and 36% at \$100/t). As a result, horticultural exports decrease too (19% at carbon tax 25/t, 32% at \$50/t, and 50% at \$100/t). However, the percentage change in output and exports in sheep-beef and dairy farming sectors are smaller at each carbon tax level. In addition, the percentage of land use change reflects a change compared with the sector's baseline land use.

Table 3.8: Percentage change in sectoral land use (% on baseline)

Land hectare change by sector use			
	Carbon tax=25	Carbon tax=50	Carbon tax=100
Forestry	20%	37%	71%
Horticulture	-5%	-9%	-14%
Sheep-beef	-2%	-4%	-8%
Dairy farming	-1%	-2%	-4%
Other agriculture	-2%	-4%	-7%

Changes in each type of land use by sector are shown in Table 3.9[5]. In the agricultural sectors, horticulture reduces its use of each type of land at each increase in carbon tax rate. The sheep-beef sector reduces forest land significantly, however, it increases the use of crop land at higher carbon tax rate. The reason is that crop land is relative cheaper (given high elasticity of substitution at 2) for converting to forest land. The change is similar for dairy and other agriculture sectors.

[5]The first column in Table 3.9 represents sectors and the row shows five types of land. For instance, -18% can be illustrated as at a tax of 25/t, horticulture reduces 18% of forest land relative to baseline scenario.

Table 3.9: Change in land use by land type (% on baseline)∗

Carbon tax=25	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	17%	39%	40%	35%	41%
Horticulture	-18%	-5%	-4%	-7%	-4%
Sheep-beef	-16%	-1%	0%	-3%	1%
Dairy farming	-15%	0%	0%	-3%	1%
Other agriculture	-16%	-1%	0%	-3%	1%
Carbon tax=50	**Forest land**	**Other land**	**Grass land**	**Scrub land**	**Crop land**
Forestry	30%	83%	85%	73%	88%
Horticulture	-31%	-8%	-8%	-14%	-6%
Sheep-beef	-28%	-2%	-1%	-7%	1%
Dairy farming	-27%	0%	1%	-6%	2%
Other agriculture	-28%	-1%	0%	-7%	1%
Carbon tax=100	**Forest land**	**Other land**	**Grass land**	**Scrub land**	**Crop land**
Forestry	51%	204%	210%	166%	220%
Horticulture	-51%	-14%	-12%	-25%	-9%
Sheep-beef	-49%	-4%	-2%	-16%	1%
Dairy farming	-47%	-2%	0%	-14%	3%
Other agriculture	-47%	-2%	0%	-14%	3%

∗Note: 0% is grounded to 0 decimal, implying a negligible change in the land conversion.

The change of land in hectares leads to a change in land values. Figure 3.8 illustrates the change in composite land value under the four tax rates. Grass land is used the most by sheep-beef and dairy farming, and grass land takes 66% of total land hectares, thus, the reduction of land value in these two sectors is larger compared with other sectors. Due to an increasing demand for forest land, composite land value in forestry increases at higher carbon tax rates.

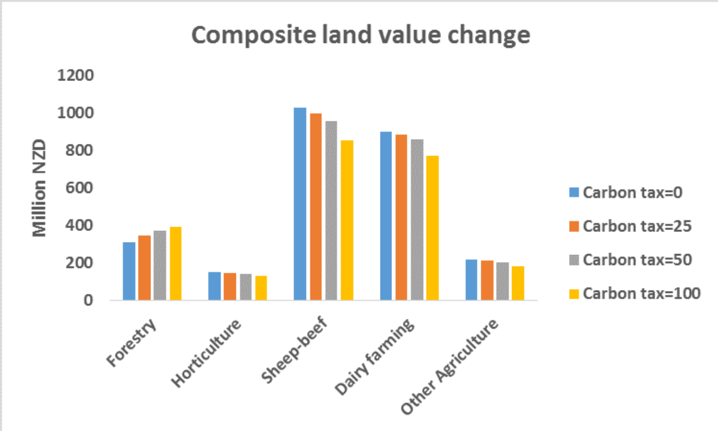

Figure 3.8: Composite land value change by sector

Figure 3.9 shows the change in demand price of forest land at different tax rates. Again, the percentage reflects the change in demand for forest land compared with the baseline scenario. Demand price of forest land increases the most among the five types of land. On one hand, it implies that higher carbon tax benefits the forester growing the trees, on the other hand, difficulty in accessing forest land at a low elasticity of substitution increases its price due to scarcity. At a carbon tax of NZ\$100, a sharply rising price change compared with the baseline, of over 1500% is achieved, due to a large increase (88%) in timber yield at this tax rate (NZ\$100) compared with the baseline.

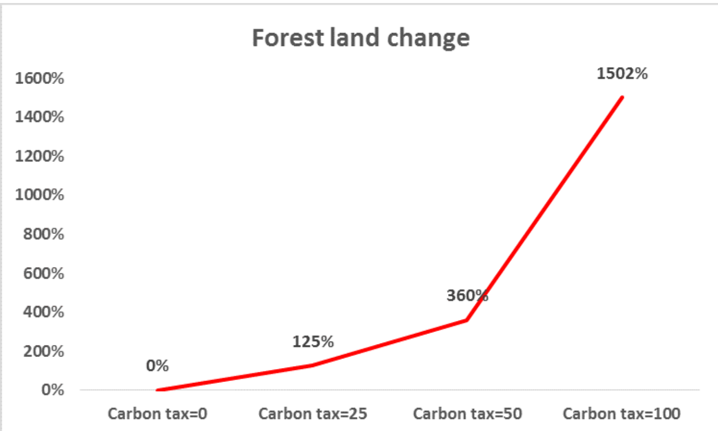

Figure 3.9: Forest land price

The other four types of land change by each type is shown in Figure 3.10. Except for scrub land, demand for other land types decreases with a higher carbon tax. In contrast, demand of scrub land increases. This is because using scrub land is cheaper with elasticity of substitution (2) across four land types.

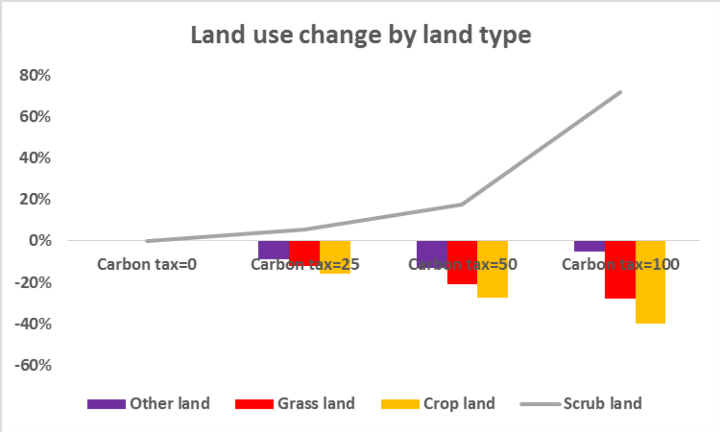

Figure 3.10: Other four types of land change

3.4.2 Forestry sector results

Since NZ is a small economy, the domestic timber price is determined by the world price. In the model, the government pays foresters for carbon sequestration and levies a penalty on carbon emissions from all sectors. Carbon emission and sequestration are measured per hectare. Therefore, as expected, at a higher carbon price, this is beneficial to forestry owners. A higher carbon price extends the optimal rotation age, increases timber yield and carbon sequestration as shown in Figures 3.11 to 3.13.

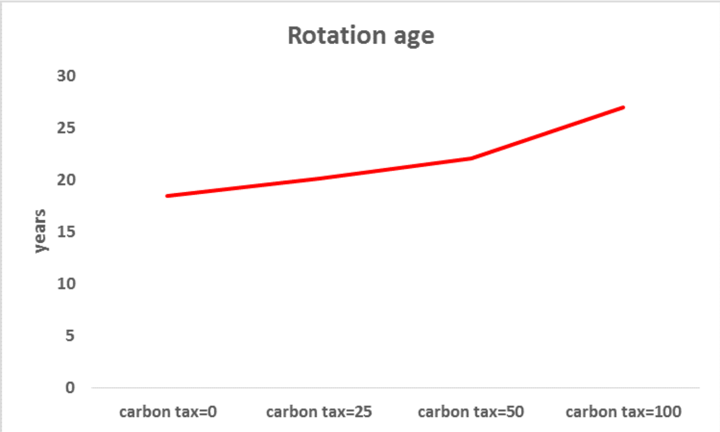

Figure 3.11: Rotation age

Figure 3.12 shows that timber yield increases by 88% from the baseline $P_c = 0$ to \$100. Given the small open economy assumption, all NZ exported timbers can be sold in overseas markets. Strong demand pushes up the timber price and increased yield leads to more emissions at harvested age.

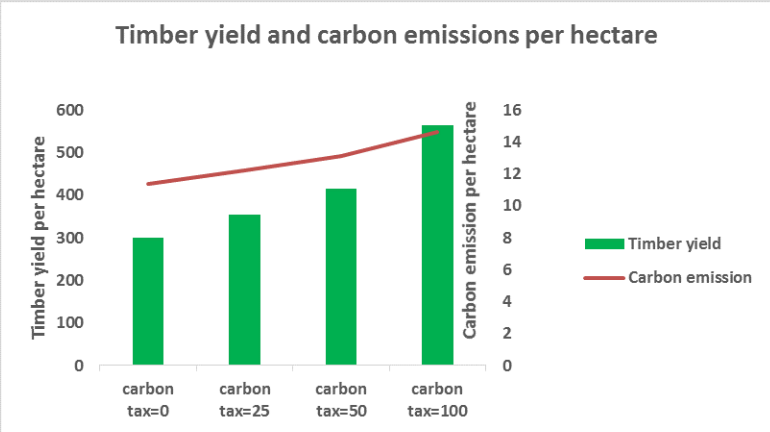

Figure 3.12: Timber yield and carbon emission from forestry

Due to the benefits to forest owners, carbon sequestration from growing trees increases at higher carbon tax rates as shown by Figure 3.13.

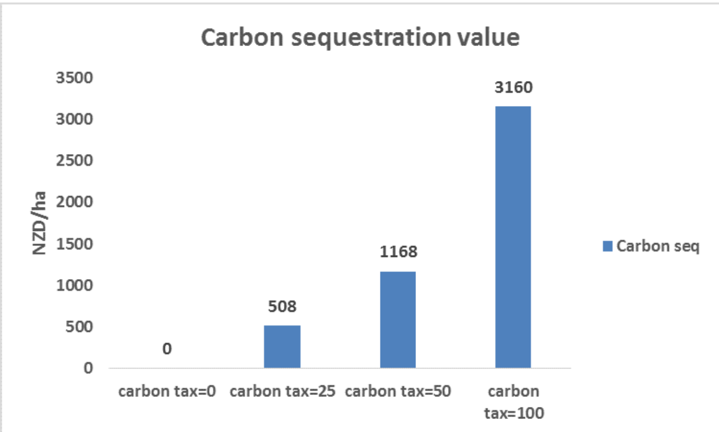

Figure 3.13: Change in carbon sequestration

Profit from planting trees, absorbing carbon, and payment to carbon emission is shown in Figure 3.14. The left vertical axis of Figure 3.14 shows the net present value of a stand of forest per hectare measured in NZD, and the right axis represents timber price per hectare.

This result is consistent with the findings of Manley (2012), but with a different level of optimal rotation age and amount of timber yield.

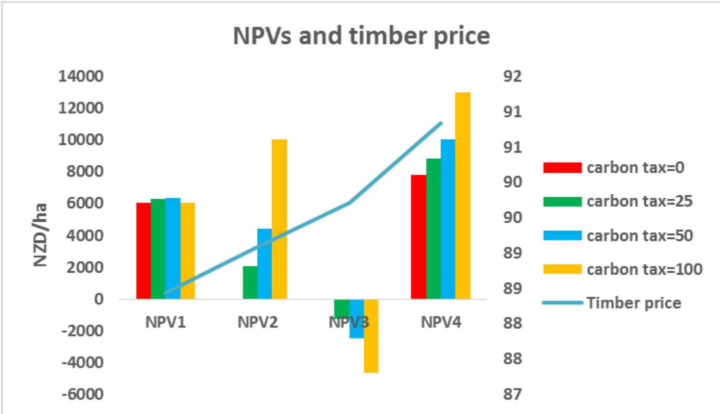

Figure 3.14: Change in NPV and timber price

In Figure 3.14, the profit from logging trees (NPV_1) increases with the increased timber price from carbon tax \$0 to \$50 but decreases at \$100. The decrease is caused by three reasons. Increased maintenance and harvest costs result in a decrease in timber selling profit at \$100 and rising terms of trade (by 3% at \$100) lowers export value and also decreases the profitability of selling timber. In addition, the longer optimal rotation age (27 years) and high discount rate (8%) decreases the net present value of selling timber in the future market.

As seen from model simulation results and Figures 3.11 through 3.14, the optimal rotation age extends from 18 years at baseline to 20 years at P_c equals \$25, to 22 years at carbon price is \$50, and to 27 years at P_c equals \$100. The reason the change of rotation year is small is the constant high discount rate. Compared to other sectors at higher carbon tax rates, the changed harvesting and maintenance costs include factors that move from other sectors, making factor use relative cheaper in forestry.

Table 3.10 outlines change in rotation age, timber yield, timber price and NPVs with different carbon tax rates. Forest owners face the liability of the release of carbon into atmosphere when trees are harvested or chopped down. Net present value of carbon sequestration (NPV_2) per hectare increases from carbon tax=\$0 to \$100, the liability for carbon emission (NPV_3) increases from 0 to \$4644. Overall, the annual profit for forestry increases from \$7820 to \$12991 per hectare from the baseline to the highest carbon tax among the four simulation scenarios.

Table 3.10: Forest variables change

	Rotation age	Timber yield	Timber price	NPV1	NPV2	NPV3	NPV4
Carbon tax=0	18	299	88	6034	0	0	7820
Carbon tax=25	20	352	89	6267	2048	-1234	8853
Carbon tax=50	22	414	90	6368	4433	-2490	10035
Carbon tax=100	27	563	91	6049	10055	-4644	13991

In a summary, higher carbon tax rates brings higher profit to forest owners. To earn more profits from carbon sequestration, forest owners postpone the time of harvesting or felling trees. This is why an optimal rotation age increases at higher tax rate from Table 3.10. It then results in higher timber yield. Due to the strong demand for wood from overseas markets, the timber price is pushed up. Although profits from selling wood NPV_1 increase from $\mathrm{P}_c = 0$ to \$50, they decrease at \$100. This is due to increased costs (from tax rate \$50 to \$100, total costs include maintenance and harvest increase by \$6488 per hectare, whereas the costs just increase \$2649 and \$3284 per hectare from baseline to $\mathrm{P}_c = 25$, and from $\mathrm{P}_c = 25$ to $\mathrm{P}_c = 50$, respectively.), high terms of trade and discount rate.

It is clear that forest owners can make higher profits from carbon sequestration at higher tax rates as shown by NPV_2. In contrast, if they chop down trees, they have to pay higher penalties as shown by NPV_3. The overall profits NPV_4 increase at a high carbon tax levels.

3.4.3 Change in macro variables

As expected, GDP decreases at a higher carbon tax rate as it is associated with reduced sectoral output. The household consumption price index is set as numeraire, hence, nominal GDP is equivalent to the real GDP in this study. The GDP remains unchanged at baseline scenario.

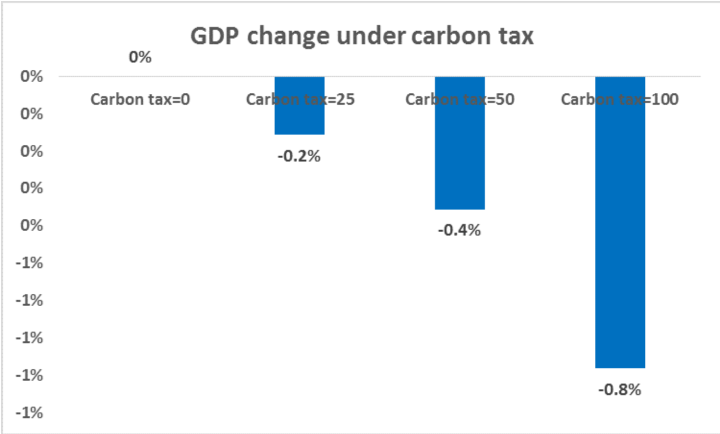

Figure 3.15: Change in GDP

The reduction of real GDP is smaller compared to NZIER's model in NZIER and Infometrics (2009a). This is caused by a different approach to model closure between this study and their research. In this study, a fully mobile of factors in the domestic market and a fixed endowment for each factor are applied as model closure, whereas the NZIER's model did not make such assumptions on factor market closure (NZIER & Infometrics, 2009a). The model closure has an impact on GDP change; Burfisher (2011) confirms that change in labour and capital affects the productive capacity of its economy, GDP declines less if national factor supply is exogenous at the initial level.

Change in government spending, and household consumption are shown in Figure 3.16.[6] There is a clear trade off between household and government consumption. Government expenditure increases at all tax rates as its income increases. In contrast, household decreases consumption because it receives less income from factor supply.

[6]The percentage shows a relative change of variable compared to the default value "1" at equilibrium.

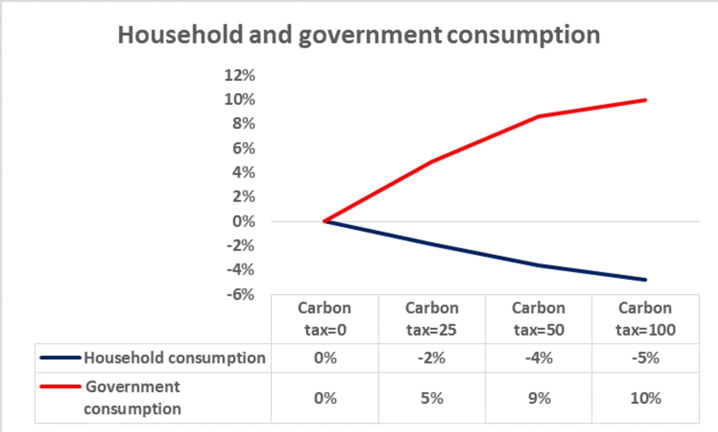

Figure 3.16: Household and government consumption change under carbon tax

Figure 3.17 shows a change in factor price. “L” and “K” stands for labour and capital, respectively. At higher carbon taxe levels, producers, especially agricultural producers pay more tax. Hence, sectoral output is reduced, and demand for factor use decreases. This is why household consumption declines.

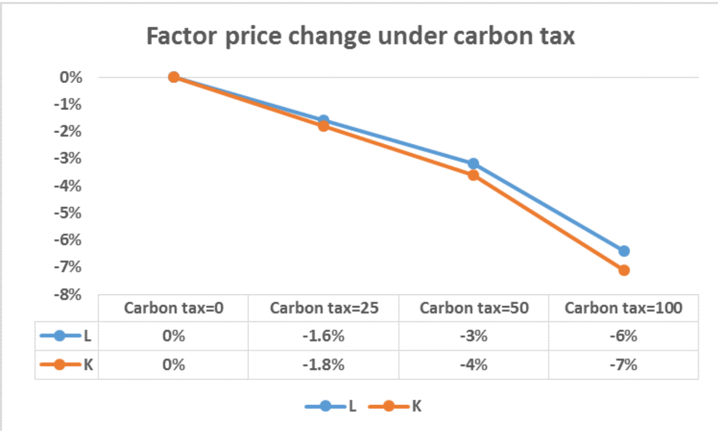

Figure 3.17: Factor price change under carbon tax

The terms of trade is endogenous in the model, increasing at higher carbon tax levels as shown in Figure 3.18. An increasing terms of trade implies an appreciated NZD which reduces exports. Unlike most of the commodities, timber output increases are driven by a rising demand for afforestation under a high carbon tax.

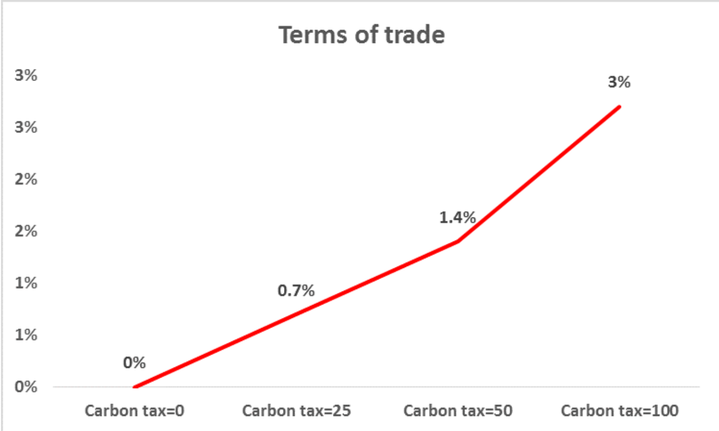

Figure 3.18: Change in terms of trade

Higher carbon tax increases the cost of domestic production. Imported goods are relatively cheaper due to the relatively easy substitution [7] assumed between domestic and imported goods. Agriculture, forestry, mining, and utility sectors increase their imports. In contrast, the increased output from the forestry sector, means that its downstream industry, the processed forestry sector decreases its imports. Factors are mobile domestically, therefore, labour and capital can move from sectors with high production costs (e.g. agriculture sectors) to those with lower costs such as service and manufacturing. Percentage change at each tax scenario for both imported and exported goods is shown in Table 3.11 and 3.12.

Table 3.11: Import change under carbon tax (compared with baseline)

Sector	**Carbon tax=$25**	**Carbon tax=$50**	**Carbon tax=$100**
Forestry	5%	9%	17%
Mining coal oil	1%	1%	3%
Industrial process	0.1%	0.3%	1%
Horticulture and fruit growing	5%	10%	18%
Sheep, beef cattle and grain farming	0.1%	1%	5%
Other agriculture	8%	15%	23%
Forestry manufacturing	-2%	-3%	-5%
Agriculture manufacturing	-1%	-1%	0%
Manufacturing	-2%	-3%	-7%
Utility	-0.1%	-0.1%	1%
Service	-2%	-4%	-8%
Total	-1%	-2%	-4%

[7] The elasticity is set as 2

Table 3.12: Export change under carbon tax (compared with baseline)

Sector	**Carbon tax=$25**	**Carbon tax=$50**	**Carbon tax=$100**
Forestry	40%	60%	65%
Mining coal oil	-9%	-17%	-29%
Industrial process	1%	2%	3%
Horticulture and fruit growing	-19%	-32%	-50%
Sheep, beef cattle and grain farming	-11%	-22%	-41%
Other agriculture	-20%	-34%	-52%
Forestry manufacturing	6%	13%	28%
Agriculture manufacturing	-7%	-14%	-28%
Manufacturing	3%	6%	12%
Utility	-2%	-4%	-7%
Service	3%	6%	11%
Total	-1%	-2%	-4%

Table 3.13 shows domestic commodity price changes under the four carbon taxes. Timber price is affected by the overseas market. With increasing terms of trade and strong demand, timber price increases across the four carbon tax scenarios. Output prices of horticulture, sheep-beef, dairy, other agriculture, utility and processed agricultural products increase due to reduced domestic production. Conversely, the price of processed forestry products decrease due to the increase of timber production. Labour and capital from the agricultural sectors move to services and manufacturing, which result in a minor decrease in the domestic output price of these sectors.

Table 3.13: Change in output price

Output price (Level change)	P_c=0	P_c=25	P_c=50	P_c=100
Forestry	1	1%	1%	3%
Mining coal oil	1	3%	5%	11%
Industrial processes	1	1%	1%	2%
Horticulture and fruit growing	1	4%	9%	17%
Sheep-beef cattle and grain farming	1	4%	8%	18%
Dairy cattle farming	1	3%	6%	13%
Other agriculture	1	8%	15%	27%
Forestry manufacturing	1	-0.4%	-1%	-2%
Agricultural manufacturing	1	1%	3%	6%
Manufacturing	1	-0.3%	-0.7%	-1%
Utility	1	1%	2%	5%
Services	1	-0.4%	-1%	-2%

The change in carbon emissions associated with a higher carbon tax is shown in Figure 3.19. The ratio is calculated by comparing with sector's emission in base year 2007. In the model, the carbon emission is assumed to change with sectoral output. Forestry sector sequestrates carbon, an upward column shown in Figure 3.19 illustrates the change of carbon sequestration under different carbon tax rate. All agricultural-related sectors reduce carbon emission at a higher level of carbon tax. Forestry manufacturing increases its emission due to an increased harvested timber output. Manufacturing, service, and industrial processes increase the emission as the outputs are increased.

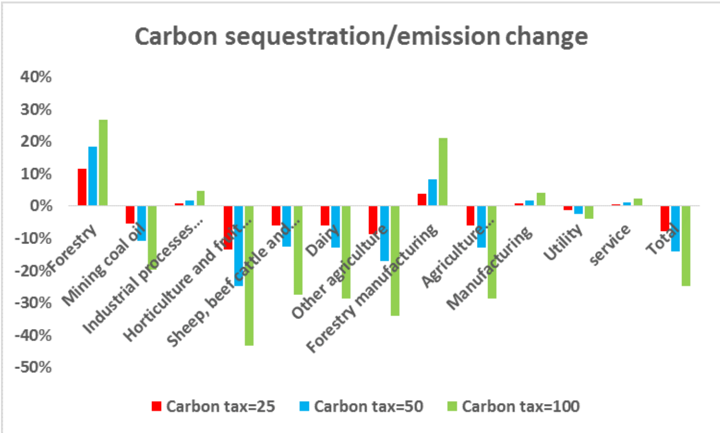

Figure 3.19: Change in sectoral carbon emission

3.5 Sensitivity tests

The discount rate used in this thesis is based on the forest valuer's survey in 2007 (Manley, 2007). The survey emphasizes that the average implied discount rate for post-tax cashflows is in the range of 5.1% to 8.8%, and 7.1% to 11.9% for pre-tax cashflows. As seen in Table 3.14, the optimal rotation age is about 24 years which is similar to the NZ study (Tee et al., 2012) which has a lower discount rate 4%. Some of the elasticity of substitution among land types is taken from existing literature. Considering the difference between this thesis and other studies on model specification and data collection, and in order to check the model's robustness, I conducted sensitivity tests by changing the discount rate in forest model and the elasticity of substitution among land types.

3.5.1 Optimal rotation age

At the baseline the discount rate is set to 8% (Manley, 2007) which is higher than the real interest rate in the model's base year of 2007. In this section I examine the rotation year change in the discount rate ranges from 0.01 to 0.1 under four carbon taxes. I find that the optimal rotation age is very sensitive to both discount rate and carbon tax. A higher discount rate implies a lower return for forest owners if they discount future cash flow to present value. Table 3.14 shows an optimal rotation age change with different discount rates and carbon tax figures.

Table 3.14: Sensitivity test on optimal rotation age

Discount rate	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
Carbon tax=0	30	28	26	24	22	21	20	18	17	16
Carbon tax=25	31	29	27	25	24	23	21	20	19	18
Carbon tax=50	31	30	28	27	26	24	23	22	21	20
Carbon tax=100	32	32	31	30	29	29	28	27	26	26

Table 3.14 shows that higher discount rate lowers optimal rotation age, but higher carbon tax rate increases the age. A higher carbon price results in increased revenue to the government for carbon emissions. Rotation age increases gradually with a higher discount rate between $P_c = \$50$ and $P_c = \$100$. For instance, the rotation age increases from 22 years to 27 years at discount rate of 8%, but slightly increases from 31 years to 32 years at a discount rate of 1%.

3.5.2 Land use change in hectares

Three scenarios are used to analyze what the land use change might be with different elasticity of substitution. Assuming that the land allocation between sectors in CET function stays the same, I put more focus on how land substitutes with each other with a higher elasticity. The elasticity of substitution is changed as seen in Table 3.15 and 3.16.

Table 3.15: Scenario 1

Elasticity of substitution	
s	0.4
la	20
la1	20
la2	20

Table 3.16: Scenario 2

Elasticity of substitution	
s	1
la	20
la1	20
la2	20

The elasticity between forest land and agricultural land remains 0.4. Among agricultural uses, I model the elasticity at each nesting level as equal to 20, i.e. among crop land, scrub land, grass land, and other land, all elasticity of substitution is 20.

The ratio change of land use in hectare by each sector is seen as Table 3.17. Then, I increased the elasticity of substitution between forest land and agricultural lands to 1, but kept 20 among agricultural lands as shown in Table 3.18. As expected, more agricultural lands move to forestry use since it is cheaper and easier to convert.

Table 3.17: Land use change ratio at elasticity 0.4; 20; 20; 20

s:0.4
la:20
la1(la):20
la2(la):20

Carbon tax=$25	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	17%	40%	40%	36%	42%
Horticulture	-18%	-5%	-5%	-8%	-4%
Sheep-beef	-16%	-1%	0%	-3%	1%
Dairy farming	-15%	0%	0%	-3%	1%
Other agriculture	-16%	-1%	0%	-3%	1%

Carbon tax=$50	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	30%	85%	86%	74%	90%
Horticulture	-31%	-9%	-9%	-15%	-7%
Sheep-beef	-28%	-2%	-1%	-7%	1%
Dairy farming	-27%	0%	1%	-6%	2%
Other agriculture	-28%	-1%	0%	-7%	2%

Carbon tax=$100	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	51%	208%	214%	168%	225%
Horticulture	-51%	-16%	-14%	-27%	-11%
Sheep-beef	-49%	-4%	-2%	-16%	1%
Dairy farming	-47%	-2%	0%	-15%	3%
Other agriculture	-48%	-2%	0%	-15%	3%

Table 3.18: Land use change ratio at elasticity 1; 20; 20; 20

s:1 la:20 la1(la):20 la2(la):20					
Carbon tax=$25	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	25%	65%	66%	58%	68%
Horticulture	-27%	-7%	-6%	-11%	-5%
Sheep-beef	-24%	-1%	0%	-5%	1%
Dairy farming	-23%	-1%	0%	-5%	1%
Other agriculture	-24%	-1%	-1%	-6%	1%

Carbon tax=$50	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	44%	149%	154%	126%	160%
Horticulture	-46%	-13%	-12%	-21%	-9%
Sheep-beef	-41%	-3%	-1%	-12%	1%
Dairy farming	-41%	-2%	-1%	-12%	2%
Other agriculture	-41%	-3%	-1%	-12%	1%

Carbon tax=$100	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	77%	260%	270%	204%	285%
Horticulture	-75%	-19%	-17%	-32%	-14%
Sheep-beef	-73%	-5%	-2%	-20%	2%
Dairy farming	-72%	-4%	-1%	-19%	3%
Other agriculture	-72%	-3%	0%	-18%	4%

3.6 Conclusion

This chapter studied the economic impact of NZ climate policy on land use change in two domestic primary sectors by linking a steady-state forest model to a CGE model. It is the first attempt at studying the impact of climate change policy in NZ with an endogenous forest model by using a CGE model. The SAM table reflects NZ's economy in the base year 2007. Results from this chapter are in accord with earlier studies (Kerr & Sweet, 2008; Kerr & Olssen, 2012), however, their work is based on econometric or partial equilibrium, different from the CGE model.

The current NZU is very low at around NZD $9 (Carbonnews, 2016). A low carbon permit price lowers the motivation of foresters to grow trees. In order to analyze the effect of carbon sequestration on land use change, this chapter sets a high carbon permit tax P_c per tonne CO_2e emission to analyze land use change between the forestry and agricultural sectors under four scenarios: $P_c = \$0$, $P_c = \$25$, $P_c = \$50$, and $P_c = \$100$. The partial equilibrium forest model is linked with the static CGE model to optimize New Zealand post-1989 radiata pine's rotation age and yield. Key findings are:

1. The optimal rotation age of the post-1989 radiata pine under the pruned without production thinning scheme is 18 years at a discount rate of 8%. As expected, the age increases with higher carbon prices and low discount rates. A lower discount rate results in longer growing period of timber and more timber yield. A strong demand for forestry products pushes up the domestic, imported, and export timber prices. Foresters benefit from a higher carbon tax.

2. Sheep-beef farming accounts for the largest land use in the baseline scenario (76% of total five types of land in hectares). However, after a carbon policy shock, as carbon price increases from $0 to $100, forestry sector land increases (from 10% at the baseline to 34% at $P_c = \$100$). High demand pushes up the forestland price, whereas the relative price of the other four types of land decreases due to the shrinking demand by agricultural sectors.

3. An appreciating of the NZ dollar leads to a decrease in export earnings. However, forestry, industrial processes, forestry manufacturing, manufacturing, and services increase the export value. This is because factors can move from high emission sectors to relative low emission sectors. All agriculture related sectors reduce their output under a higher carbon tax and total import values decrease. The small economy assumption implies that the timber price is affected by the exchange rate and there is an infinite demand from the rest of world. Thus, timber price and yield increase with a higher carbon tax. Higher carbon tax reduces agricultural sectors' domestic output but increases the domestic price from these sectors, because of the trade off between domestic production and import, so producers switch to use more imported goods;

4. Higher carbon cost reduces sectoral output, which decreases labour and capital demand. As a result, household income decreases with higher level of carbon tax;

5. Land use change is sensitive to the elasticity of substitution in sectoral production. It is clear that land use increases in the forestry sector with a higher elasticity. With higher elasticity among agricultural lands, some agricultural sectors such as sheep-beef, dairy, and other agriculture use more crop land.

Chapter 4

Application of the CGE model to determine carbon prices

This chapter is an extension of chapter 3, applying the forest-CGE model, with the price of carbon permits determined endogenously. Section 4.1 introduces the research question; section 4.2 extends the forest-CGE model to calculate an equilibrium carbon permit price for three different scenarios; section 4.3 describes all the data applied in this chapter; section 4.4 summarizes the effect of the equilibrium carbon permit price on the economy, sectoral emissions, forestry, and land use; section 4.5 conducts a sensitivity test and section 4.6 draws a conclusion.

4.1 Introduction

Chapter 3 analyzed land use conversion between forestry and agriculture under four carbon tax rates. A clear trade-off occurs between forestry and other agricultural sectors at a high tax rate. However, NZ has not implemented a carbon tax policy but instead introduced the ETS to reduce GHG emissions. This chapter computes an equilibrium carbon permit price under the ETS in a closed carbon market whereby carbon permits can only be traded within NZ. Three scenarios are examined: first, a pure ETS in which forestry supplies carbon permits only; second, an alternative "carbon pool" where government sells international permits purchased from the world market, along with forestry; and third, "free allocation" where the government allocates the international permits to all sectors freely. In each scenario, forestry supplies the permits from growing trees.

4.2 Model

Similar to the model used in chapter 3, this section outlines producer and consumer behaviour in an equilibrium context. The theoretical framework of this model is the same as in chapter 3. According to the general equilibrium theory, zero profits conditions are applied to all activities. “Agents” in this model include one representative household and the central government. Both of them are consumers and maximize utility subject to an income constraints. Sectors maximize profits to determine the optimal level of production, meanwhile, the production costs are minimized in order to choose an optimal level of factor use. Considering the main focus of this chapter is on calculating an equilibrium carbon price, equations that were included in chapter 3 are not repeated in this chapter [1].

Sixteen aggregated industries and 15 commodities spanning the economy are based on the ANZSIC (The Australian and New Zealand standard industrial classification) division. The industries are: 1. forestry; 2.stationary energy; 3. industrial processes; 4. synthetic gases; 5. waste; 6. horticulture and fruit growing; 7. sheep, beef cattle and grain farming; 8. dairy cattle farming; 9. other agriculture; 10. forestry manufacturing; 11. agriculture manufacturing; 12. retail and wholesale trade; 13. manufacturing; 14. non-renewable electricity ; 15. renewable electricity; 16. service. The rest of economy (ROE) is included in service sector. Electricity is produced from renewable and non-renewable sources. The renewable electricity sector comprises hydro, geothermal, and wind. Non-renewable sources of electricity include oil, gas, and coal. Primary factors used in production are: labour, capital, and land (between agricultural and forestry).

According to the ETS policy, polluters pay for their emissions. In this model, sectoral emissions are output-based, polluters purchase carbon permits from permit suppliers, that is from forestry and government. Forestry supplies the carbon permits in all the three scenarios, but is sole supplier only in the pure ETS scenario. Government sells the international surplus permits at NZ$25/t with total amount of 9.1 Mt in the carbon pool scenario, but allocates these permits freely to all sectors in the free allocation scenario at the same value.

[1] Repeated equations are shown from Equation 3.1 to 3.13 in chapter 3

Government is financed by an extra consumption tax from the household in the free allocation scenario, in order to keep its income neutral. Producers require carbon permits to cover their emissions. Demand for commodities other than carbon permits, comes from one representative household, central government, investment, and rest of world (ROW).

4.2.1 Production

All sectors are characterized by a nested production structure. Domestic production, is produced by the aggregated intermediate and value-added inputs based on the Leontief function. Domestic and imported goods are components of intermediate use. Primary factors, such as labour and capital, are value-added inputs. Composite land is an input factor in forestry and agricultural production. The electricity sector is disaggregated into non-renewable and renewable sources of energy. The non-renewable sector uses coal, oil, and gas as intermediate inputs, whereas renewable electricity sector uses three types of renewable resources: geothermal, wind, and hydro. In this study I assume renewable resources are only used in the renewable electricity sector; production is based on the Leontief function. Domestic goods are transformed to exported goods according to a CET function. Figure 4.1 and 4.2 illustrates the production structure for non-renewable and renewable electricity sectors.

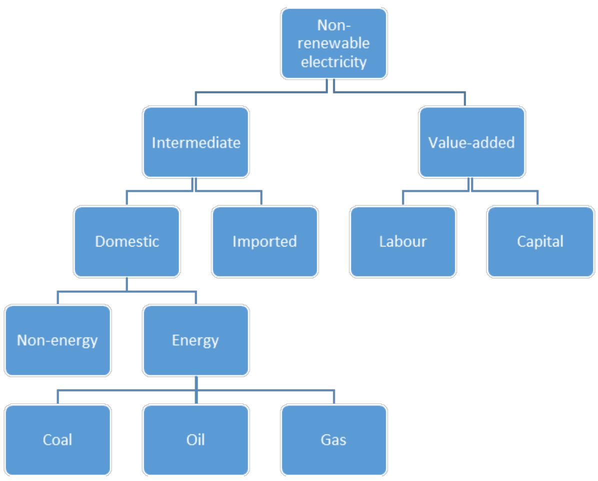

Figure 4.1: Non-renewable electricity production

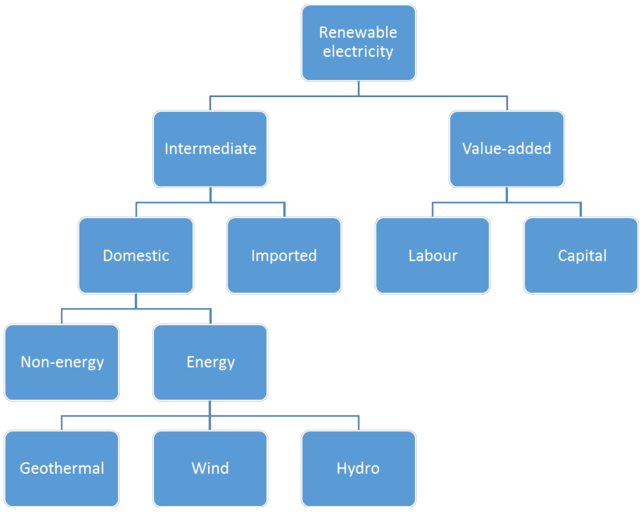

Figure 4.2: Renewable electricity production

Foresters supply carbon permits (NZU) that are available to all sectors in the ETS, and receive the equilibrium price for carbon as determined in the carbon market. The timber yield function is the same as in chapter 3, and is based on Sands and Kim (2009). Foresters pay a liability when deforestation occurs.

Stationary energy and industrial processes sectors are required to buy NZU to cover CO_2e emissions. Some literature assumes the permit allocation is proportional to value-added emissions, or based on the sector's historical emissions (Diukanova et al., 2008). In this chapter, I assume that the allocation of carbon permits is based on the sector's current emissions.

Synthetic gases, waste, and the ROE have the same nested production structure as I assume the emissions of these sectors are from their outputs rather than the value-added input. Nesting structure for agricultural sectors and forestry is the same as in chapter 3.

Sectoral production function and zero profit condition are shown in Equation 4.1 and 4.2.

$$QA_i = \min\{\frac{QINT_i}{\alpha_1}, \frac{QVA_i}{\alpha_2}, \frac{E_i}{\alpha_3}\} \tag{4.1}$$

$$PA_i * QA_i = PINT_i * QINT_i + PVA_i * VA_i + P_{carbon} * E_i \tag{4.2}$$

Where QA_i is the total output from the sector i, $QINT_i$ and QVA_i are the aggregated intermediate and value-added inputs, respectively; α_i shows a fixed percentage of aggregated intermediate, value-added inputs and emissions to the total output; PA_i, $PINT_i$ and PVA_i is the output price, intermediate input price and value-added price of sector i, respectively; P_{carbon} is an equilibrium carbon permit price, and E_i is the emission from sector i associated with its output.

Production functions for the intermediate and value-added inputs are shown in Equation 4.3 and 4.4.

$$QINT_i = \min\{\frac{Q^i_{dom}}{\sigma^1_{arm}}, \frac{Q^i_{imp}}{\sigma^2_{arm}}\} \tag{4.3}$$

$$QVA_i = [\sum_i \beta_i F_i^{\frac{1-\sigma_i}{\sigma_i}}]^{\frac{\sigma_i}{1-\sigma_i}} \tag{4.4}$$

Where domestic Q^i_{dom} and imported goods Q^i_{imp} are substitutes in terms of elasticity of substitution σ^i_{arm} used as intermediate input in sector i, β_i is the share parameter measuring the proportion of factor F_i used to sectoral production, F_i includes labour, capital, and land used in sector i, and σ_i is the elasticity of substitution between each factor.

A Leontief function is used for electricity production by renewable sources as shown in Equation 4.5.

$$Q^{renewable}_{energy} = \min\{\frac{Q_{geo}}{\gamma_1}, \frac{Q_{wind}}{\gamma_2}, \frac{Q_{hydro}}{\gamma_3}\} \tag{4.5}$$

Where $Q^{renewable}_{energy}$ is the bundle of renewable electricity produced, based on proportional (γ_i) use of renewable resources. The production function of timber is same as in chapter 3. Forestry production is shown in Equation 4.6.

$$QA_{for} = \min\{\frac{QINT_{for}}{\alpha_1}, \frac{QVA_{for}}{\alpha_2}, \frac{E_{for}}{\alpha_3}\} \tag{4.6}$$

$$E_{for} = \delta_{for} * y_a * Land_{for} = \alpha_3 * QA_{for} \tag{4.7}$$

Where E_{for} is total carbon sequestration, δ_{for} is the carbon sequestration rate of forestry y_a per hectare. The calculation of y_a is shown in chapter 3. $Land_{for}$ is the equilibrium forestry land use.

Factors can substitute for each other in either the intermediate or value-added bundles in a CES form. Producers minimize the input cost subject to sectoral production as seen in Equation 4.4. Land allocation has same nesting structure as seen in chapter 3. Demand by household, government, and ROW is same as in chapter 3.

4.2.2 Market clearing

Both factor and commodity markets clear in equilibrium. Factor endowments are fixed. Capital is immobile internationally which implies that capital can move freely only in NZ. Investment is fixed and savings are endogenous in the model. Foreign saving (FSAV) is determined by the model for balancing the international trade account.

$$\begin{aligned}
&QA_i = \sum_i QINT_i + Q_h + Q_g + \bar{Q}_{inv} \\
&\sum_i^m PW_i^m QM_i = \sum_i^x PW_i^x QX_i + FSAV \\
&FSAV = \bar{FSAV} \\
&\bar{E}_{inv} = saving_h + saving_{gov} + \bar{FSAV}
\end{aligned} \tag{4.8}$$

Factor market clearing:

$$\begin{aligned}
&\overline{labour_i} = \sum labour_i \\
&\bar{k} = \sum k_i \\
&\overline{land_i^i} = \sum land_i \\
&\overline{Geothermal} = Q_{geo} \\
&\overline{Wind} = Q_{wind} \\
&\overline{Hydro} = Q_{hydro} \\
&\sum E_i = E_{for}
\end{aligned} \tag{4.9}$$

(4.10)

Closure: The total investment is fixed.

$$(1 - t_{inv})Y_{inv} = \sum Savings_i = \bar{E_{inv}} \tag{4.11}$$

4.2.3 Carbon trading market

Carbon permits can be traded in the domestic carbon market. Three scenarios are examined: (1) pure ETS policy, all carbon permits are supplied by forestry; (2) carbon pool, refers to two suppliers in the market: government and forestry. Government sells 9.1 Mt of international permits at $25 to the market; (3) free allocation, government allocates 9.1 Mt to all sectors. To analyze the effect on the equilibrium carbon price of the various forms of permit supply, section 4.5 conducts a sensitivity test examining different prices and quantities of international carbon permits purchased by the government under the carbon pool and free allocation scenarios. In all three scenarios, forest owners supply permits to the market but face liability at deforestation.

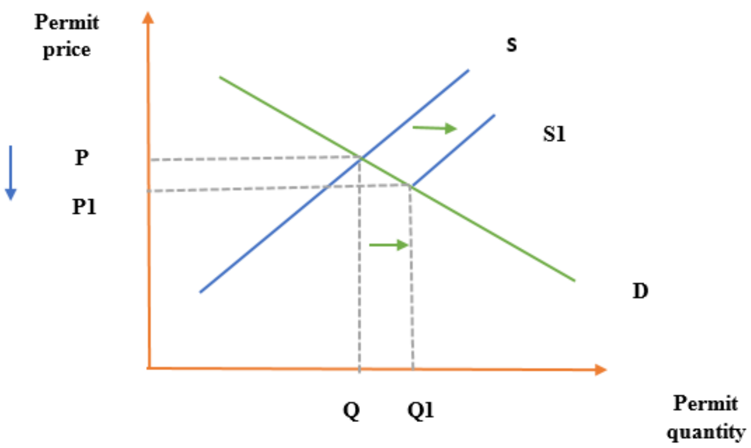

Figure 4.3: Supply and demand of carbon permit

Figure 4.3 illustrates how the carbon permit price is determined in the carbon market, where S represents forestry as the sole supplier of permits, and S1 includes both forestry and government as suppliers. Government acquisition of international permits shifts supply from S to S1 which, in principle, works to lower the equilibrium carbon permit price. A flow chart of supply and demand for carbon permits is shown in Figure 4.4 and 4.5.

Figure 4.4: NZU supply and demand in pure ETS

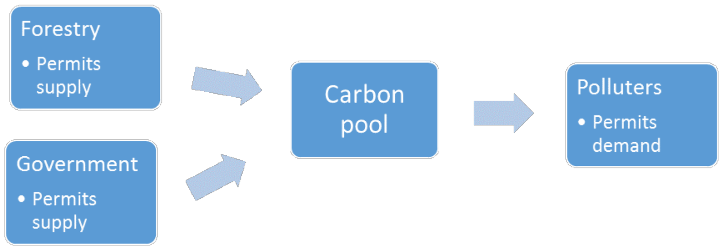

Figure 4.5: NZU supply and demand in carbon pool scenario

In Figure 4.4, only forestry supplies NZUs from carbon sequestration, and the NZUs are in demand by all emission sectors. Figure 4.5 includes government selling the international units of 9.1 Mt at NZ$25/t to emission producing sectors. The "carbon pool" comprises both forestry and government sourced permits. Government and foresters receive revenue from the supply of permits and emitters of CO_2e pay the market price. Emission sectors and owners of harvested trees face the emission charge.

Pure ETS scenario

In the model, each sector has own emission E_i based on its output; E_{for} represents carbon permit supply, from the carbon sequestration and is determined by the growing trees. All the sequestration and emission data can be seen in Table 4.1. One "permit unit" is equal to one tonne of CO_2e.

Followed by the market clear condition, the equilibrium carbon permit price P_{carbon} is determined by equalizing the supply and demand of permits. Each sector maximizes profit in order to determine the optimal factor use. The total carbon sequestration from forestry is assumed to be equal to the total carbon emissions. Equation 4.12 and Equation 4.13 outline the zero profit condition for sector i and forestry.

$$\pi_i = PA_i * QA_i - [PINT_i * QINT_i + w * L_i + r * K_i + P^i_{land} * Q^i_{land} + P^d_{carbon} * E_i] \quad (4.12)$$

$$\pi_{for} = PA_{for} * QA_{for} + P^s_{carbon} * E_{for} - [PINT_{for} * QINT_{for} + w * L_{for} + r * K_{for} + P^{for}_{land} * Q^{for}_{land}] \quad (4.13)$$

Where the left hand is profit for sector i, the right hand includes total revenue and intermediate cost, labour cost, capital cost, composite land cost, and emissions cost. w and r is price of labour and capital, respectively. By maximizing profit to sector i, the optimal level of input use can be determined as shown from Equation 4.14 to Equation 4.17. As a result, an optimal demand for carbon permits E_i, and supply for permits E_{for} can be calculated as a function of carbon permit price and other variables as shown in Equation 4.18 and Equation 4.19.

$$L^*_i = [\frac{Q_{lk}^{\frac{\sigma}{\sigma-1}} + \eta_1 - 1}{\eta_1}]^{\frac{\sigma-1}{\sigma}} \quad (4.14)$$

$$K^*_i = [\frac{Q_{lk}^{\frac{\sigma}{\sigma-1}} + \eta_1 - 1}{\eta_1 * (\frac{w}{r} * \frac{1-\eta_1}{\eta_1})^{\sigma}}]^{\frac{\sigma-1}{\sigma}} \quad (4.15)$$

$$Q^{com}_{land} = Q_{lk} * (\frac{P_{lk}}{P^{com}_{land}} * \frac{1-\beta_1}{\beta_1})^{\sigma} \quad (4.16)$$

Where η_1 is the share parameter of using L and K in the production, β_1 is the share parameter between composite land and Q_{lk} (nesting of L and K).

$$QVA_i = [\beta_1 * Q_{lk}^{\frac{\sigma-1}{\sigma}} + (1-\beta_1) * Q_{lk}^{\frac{\sigma-1}{\sigma}} * (\frac{P_{lk}}{P^{com}_{land}} * \frac{1-\beta_1}{\beta_1})^{\sigma-1}]^{\frac{\sigma}{\sigma-1}} \quad (4.17)$$

Given the optimal input use in sector i, the final product QA_i and emission E_i can be determined.

$$E_i = \frac{PA_i * QA_i - PINT_i * QINT_i - PVA_i * QVA_i}{P^d_{carbon}} \quad (4.18)$$

$$E_{for} = \frac{PA_{for} * QA_{for} - PINT_{for} * QINT_{for} - PVA_{for} * QVA_{for}}{-P^{s}_{carbon}} \tag{4.19}$$

$$\sum E_i = E_{for} \tag{4.20}$$

Where Q^i_{lk} is the demand of both labour and capital use in sector i. In order to meet the condition of market clear, all polluting sectors' carbon permit demand ($\sum E_i$) is equal to the supply E_{for} as shown in Equation 4.20. The equilibrium carbon permit price shows a negative change associated with emissions E_i, but a positive change with sequestration E_{for}. The equilibrium carbon permit price is derived as shown in Equation 4.21.

$$P_{carbon} = f(\overline{P^i_{lk}, P^i_{land}, PA_i, PINT_i, Q^i_{lk}, Q^i_{land}, \alpha_1, \alpha_3}, E_i, E_{for}) \tag{4.21}$$

The factor price (P^i_{lk}, P^i_{land}, $PINT_i$) and commodity price (PA_i) are determined when commodity market is clear, i.e. commodity supply from producers is equal to consumption from household, government, and the ROW. All sectors are price takers in an equilibrium condition. Equations are solved using MPSGE syntax in GAMS.

Government enters into the carbon market

Two scenarios where government enters the carbon market are applied to derive an equilibrium carbon price. Firstly, the carbon pool: government purchases international permits from overseas markets and sells the total amount 9.1 Mt at NZ$25/t. Secondly, free allocation: government allocates the 9.1 Mt of international permits at NZ$25/t to all sectors, and being financed by increasing the consumption tax at same value. The remaining permits are supplied by forestry sector. The reason for setting the permit price at NZ$25/t includes two points: 1. NZ polluters have to pay for their emissions at NZ$25/t from NZ government under the existing ETS; 2. the price is consistent with Infometrics (2007).

Infometrics (2007) presented a scenario that had a total value of government purchased emissions units from offshore as $228m per annum, which is equivalent to 9.1 Mt at $25/tonne. Hence, I assume the amount of purchased permits are 9.1 Mt in this chapter. In the free allocation scenario, the government allocates the permits to all sectors on the basis of their historical emissions. Historical emissions include forestry's net emissions. Foresters receive allocated permits for afforestation.

4.3 Data

4.3.1 Emission data

The basic income and expenditure data for all sectors is extracted from the 2007 NZ supply-use table. Sector classification is based on StatsNZ (2006). Apart from the basic data, new supply and use data for the renewable electricity sector are calibrated by using a fixed percentage of the each renewable resource to the total electricity production in 2007. Hydro electricity makes 55% of the whole electricity supply, geothermal contributes 8%, and wind makes 2% in 2007. Timber yield share parameters are the same as those used in chapter 3.

The Ministry for the Environment (MfE) reports the CO_2e emission data by sector and source (MFE, 2009). Total GHG emissions in 2007 were 75550.2 Gg CO_2e. A negative sign is attached to carbon sequestration shown in Table 4.1. The total agriculture sector contributed 36430 Gg CO_2e emissions, which was 48.2% of the total emissions. Because of the limited data reporting horticulture sector emissions, I assume that most emissions for horticulture and fruit growing come from the direct and indirect nitrogen loss from agricultural soils, and from the use of fertilizer. Under the agriculture soil category, direct N_2O soil emissions contribute 1680.7 Gg CO_2e, and indirect N_2O from nitrogen used emits 3270.7 Gg. Total emissions of horticulture and fruit growing sector are calculated by summing up the data.

From Table 4.1, emissions from the energy sector was the second largest in 2007 and represented 43.2% of the total emissions, or 32653.1 Gg CO_2e. Public electricity, heat production, and the road transportation contributed the largest share. I extracted non-renewable and renewable electricity emissions from the energy category in NZ's GHG inventory report (MFE, 2009). Under the renewable category, geothermal operations make 365.9 Gg CO_2e emission. Wind and hydro are assumed as clean energy emitting 0 Gg. Coal emissions are disaggregated from coal combustion, and contributed 261.8 Gg, oil and gas together contributed 1499.2 Gg in 2007.

Manufacturing industries include iron and steel, other non-ferrous metals, chemicals, pulp, paper and print, food processing, beverages and tobacco, and other uses. I tracked the manufacturing emissions by splitting the total emissions of manufacturing and construction. Total emissions for both sectors are 5380.9 Gg and the construction sector accounts for 860.4 Gg. Hence, I estimate 4520.5 Gg as manufacturing sector emissions.

Emission amount by sector is seen in Table 4.1. I treat these emissions amounts as the sector's output emissions in the model.

Table 4.1: Emissions by sector in 2007

Sector	**Emissions (Gg CO_2e)**
Forestry	$-23,836$
Stationary energy	$7,867$
Industrial processes	$4,602$
Synthetic gases	$1,499$
Waste	$1,822$
Horticulture and fruit growing	$4,951$
Sheep, beef cattle and grain farming	$8,789$
Dairy cattle farming	$8,531$
Other agriculture	$14,158$
Forestry manufacturing	0.8
Agricultural manufacturing	360
Retail and wholesale trade	$1,499$
Manufacturing	$4,521$
Non-renewable electricity	$1,761$
Renewable electricity	366
Service	$38,658$
Net emissions	$75,550$

Source: MFE (2009)

All emission data are measured as gigagrams (Gg), which are divided by 1000 to convert to metric tonnes (Mt).

4.3.2 Elasticity data

All elasticity data are taken from the studies of Strutt and Rae (2011) and Rutherford (2003). Table 4.2 and 4.3 show the definition and value of elasticity for the model.

Table 4.2: Elasticity interpretation

s	elasticity of substitution at the first nesting level
t	elasticity of transformation
va	elasticity of substitution between value-added inputs
va(for)	elasticity of substitution between value-added inputs for natural timber sector
dm	elasticity of substitution in either domestic commodity or import commodity
d(dm)	elasticity of substitution between domestic and import commodities
id	elasticity of substitution between domestic and import goods used in sectoral intermediate production
la	elasticity of substitution between forest land and agriculture land bundles
la1	elasticity of substitution between crop land and scrub land
la2	elasticity of substitution between grass land and other land

Table 4.3: Values of elasticities

Type	s	t	va	dm	d(dm)	id	la	la1	la2
Forestry production	0	0	0			0			
Other domestic production	0	0	0.7			0			
Allocation of output	0	2							
Export	0	0							
Armington goods		0		2	2				
Land allocation in CES	2						20	20	20
Land allocation in CET	1	1							
Investment	0								
Household consumption	1								
Government consumption	0								

4.4 Results

This section analyzed results under three scenarios: pure ETS, carbon pool, and free allocation. In the pure ETS scenario, only forestry supplies carbon permits from growing trees and the carbon market is only open to domestic users. In the latter two scenarios, government supplies the 9.1 Mt carbon permits at NZ$25/t purchased from the overseas market (Infometrics, 2007), along with forestry. Due to the same amount and price for permits supplied from government, the effect on equilibrium carbon permit price of both carbon pool and free allocation would be similar. In the free allocation the government is assumed to impose an extra consumption tax on households, in order to keep government income neutral.

Subsection 4.4.1 assesses the equilibrium carbon permit price and sectoral emissions across these three scenarios, subsection 4.4.2 examines forest variables such as optimal rotation age, timber yield, timber price, and forest owner's profits, subsection 4.4.3 analyzes land use change between forestry and agriculture, subsection 4.4.4 outlines an endogenous subsidy rate from free allocation scenario, and subsection 4.4.5 compares macro variables under the three scenarios.

4.4.1 Equilibrium carbon price and sectoral emissions

In the pure ETS scenario, only forest owners supply carbon permits. An equilibrium carbon price of NZ$23/t of CO_2e is determined by NZ's closed carbon market. In carbon pool and free allocation, the government supplies the permits that were purchased from the overseas market. As expected, the equilibrium price decreases if permit supply increases. Change in carbon permit price and net emissions is shown in Table 4.4.

Table 4.4: Change in equilibrium carbon permit price*

	Pure ETS	Carbon pool	Free allocation
Equilibrium carbon price	23	-0.3%	-3%
Total net emissions	-14%	-14%	-13%

*Note: -0.3% and -3% falls from $23. -14% and -13% is the change from baseline net emissions 76 Mt

As seen in Table 4.4, the equilibrium carbon permit price drops slightly in the carbon pool and free allocation scenario. Total supply of carbon permits provided by government in these two scenarios is the same, assuming other conditions are constant, an effect on carbon permit price and emissions would be similar under both scenarios. With a carbon pool, the magnitude of decrease in carbon price is lower (0.3%) than in free allocation (3%). This is largely due to decreasing sectoral outputs in carbon pool leading to less demand for carbon permits. In contrast, under the free allocation scheme - due to free allocation itself - sectors do not face a high carbon emission cost, hence, the sectoral output does not decrease as much as with the carbon pool. The total net emissions decline by around 14% across the three scenarios compared to the baseline. Specifically, net emissions decrease by 13.7% under the pure ETS, 13.5% under carbon pool, and 13% under free allocation. The percentage of change in results for three scenarios are similar, this is because the change in equilibrium carbon permit price is small. Given that the NZ carbon market is closed by assumption, the extra carbon permit surplus of 9.1 Mt does not increase the stock of carbon permits significantly, this can explain why the carbon permit price decreased by less under the carbon pool and free allocation scenarios. Change in sectoral outputs is shown in Table 4.5, all percentages are compared to the baseline.

Table 4.5: Change in sectoral output among three scenarios

Sector	Pure ETS	Carbon pool	Free allocation
Forestry	236%	236%	238%
Stationary energy	-8%	-8%	-7%
Industrial processes	-4%	-4%	-4%
Synthetic gases	-4%	-4%	-4%
Waste	-8%	-8%	-7%
Horticulture and fruit growing	-16%	-16%	-15%
Sheep-beef cattle and grain farming	-13%	-13%	-12%
Dairy cattle farming	-14%	-13%	-13%
Other agriculture	-14%	-13%	-12%
Forestry manufacturing	5%	5%	5%
Agriculture manufacturing	-14%	-13%	-13%
Retail and wholesale trade	0%	0%	0%
Manufacturing	-1%	-1%	-1%
Non-renewable electricity	-5%	-5%	-5%
Renewable electricity	0%	0%	0%
Service	1%	1%	1%

The equilibrium carbon price is different from that of Diukanova et al. (2008). They calculated an equilibrium carbon permit price at a range from NZ$13.2/t to NZ$17.7/t based on different model scenarios. The lowest carbon price at NZ$13.2 was associated with auctioning of emission permits, and the highest carbon price at NZ$17.7 occurred in a hybrid allocation with 90% emission based a grandfathering scenario. According to my model's calculation, the equilibrium carbon permit price is around NZ$23/t. The main reason for the price difference is due to Diukanova et al. (2008) not considering the impact of the optimal tree rotation age on carbon price. However, optimal rotation age needs to be considered as it determines forest profitability.

All sectors reduce production from baseline with a carbon emissions cost except for forestry, forestry manufacturing and services. Increased output in forestry is due to rising profit earned by forest owners at an equilibrium carbon price. Carbon sequestration changes from 23.8 Mt to approximate 27.8 Mt across three scenarios, each implies a high benefit to the forest owner. As a result, it leads to an increase in output from the forestry manufacturing sector. Factors can move to the services sector as they are freed up from high emissions sectors. Most sectors' output prices increase as these sectors supply less commodities. Percentage change in output price is shown in Figure 4.6.

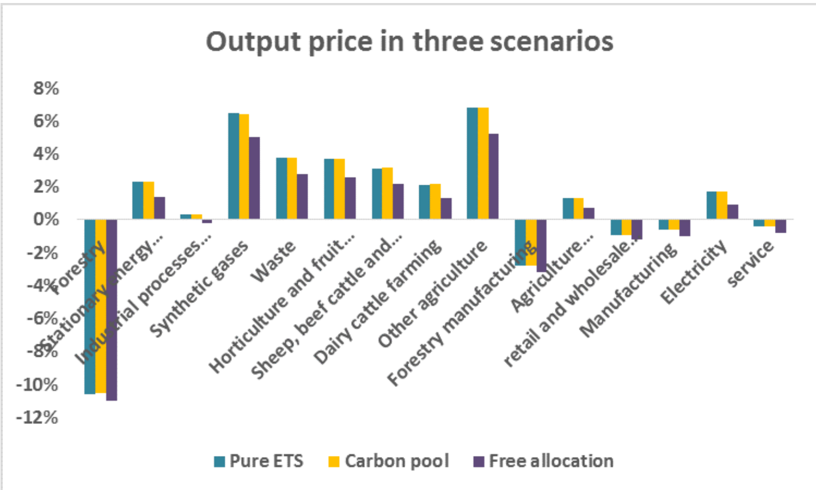

Figure 4.6: Output price change

Compared to baseline, total net emissions decrease across the three scenarios. Emissions from retail and renewable electricity sectors are not sensitive to the change in carbon price. This is due to the small emission amount from these sectors in the baseline shown in Table 4.1. Table 4.6 and Figure 4.7 reflect a change in demand for carbon permits, and change in emissions/sequestrations compared to sectoral baseline emissions.

Table 4.6: Demand for carbon permits (Mt*) in three scenarios

Sector	Baseline	Pure ETS	Carbon pool	Free allocation
Forestry	-24	-28	-28	-28
Stationary energy	8	7	7	7
Industrial processes	5	4	4	4
Synthetic gases	1	1	1	1
Waste	2	2	2	2
Horticulture and fruit growing	5	4	4	4
Sheep,beef cattle and grain farming	9	8	8	8
Dairy cattle farming	9	7	7	7
Other agriculture	14	12	12	12
Forestry manufacturing	0	0	0	0
Agriculture manufacturing	0	0	0	0
Retail and wholesale trade	1	2	1	1
Manufacturing	5	5	4	4
Non-renewable electricity	2	2	2	2
Renewable electricity	0	0	0	0
Service	39	39	39	39
Total carbon permit demand/supply	76	66	66	66

*Note: Negative figure implies carbon sequestration.

Change in carbon emission/sequestration across three scenarios is shown in Figure 4.7. This change is similar to the change in output, because the relationship between emissions and output is linear. In Figure 4.7, an upward bar illustrates increasing carbon sequestration, or rising sectoral output in forestry, forestry manufacturing, and services sectors; a downward bar in the rest of sectors indicates decreasing emissions, or declining sectoral outputs.

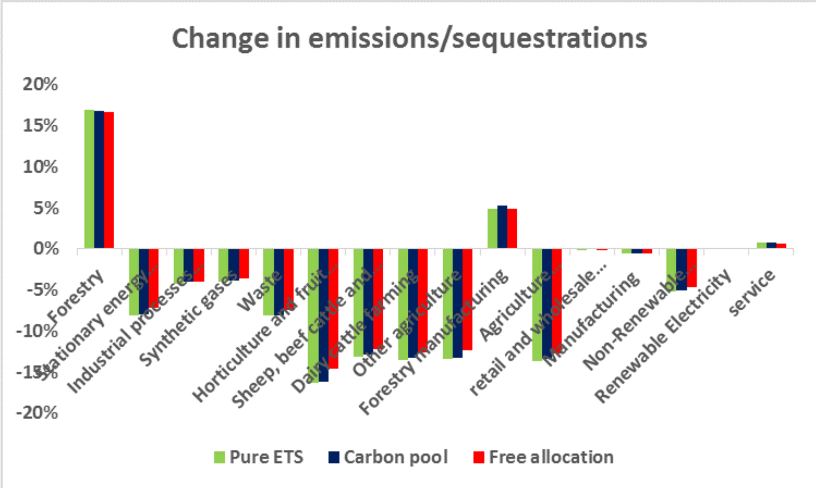

Figure 4.7: Change in carbon emissions by sector

4.4.2 Forestry

With an assumed interest rate of 8%, the equilibrium rotation age is 20 years across all scenarios which is equal to an optimal rotation age of trees at carbon tax level of $25. Timber price increases from baseline NZ$88 to NZ$90 in all scenarios. This is partly due to profits of selling carbon permits, and decreased terms of trade (-1.4%) increased export, leading to a rise in timber production.

NPV1 is the benefit from selling the trees. It decreases slightly in the carbon pool and free allocation scenarios, compared to pure ETS. This is associated with a decreased equilibrium carbon price. Cheaper carbon price reduces demand for planting trees and supplying carbon permits, leading to a fall in NPV_2. NPV_3 is the cost of cutting trees. It implies that less timber production results in a lower carbon emissions liability. NPV_4 measures total profits over the future periods. In free allocation, forest owners make the largest profit because forestry output increases the greatest amount (238%). Results for forest variables across the three scenarios are shown in Table 4.7.

Table 4.7: Forest variables results

Variables	Pure ETS	Carbon pool	Free allocation
Rotation age	20	20	20
Timber yield	350	350	349
Timber price	90	90	90
Carbon emission amount/ha	12	12	12
Carbon sequestration value/ha	468	466	453
NPV1 (timber sell)	6373	6364	6438
NPV2 (carbon sequestration profit)	1912	1904	1862
NPV3 (carbon emission liability)	-1159	-1155	-1132
NPV4 (overall profit)	8946	8932	9018

4.4.3 Land use change across three scenarios

Elasticity of substitution determines a level of land conversion between different land uses. In order to differentiate forest land and other types of land, I set a low elasticity at 2 for other lands converting to forest land, and a high elasticity of 20 which makes land conversion much easier with agricultural sectors than with forestry. This high elasticity of substitution is quoted from Strutt and Rae (2011). Low elasticity drives an increase in forest land for sector use.

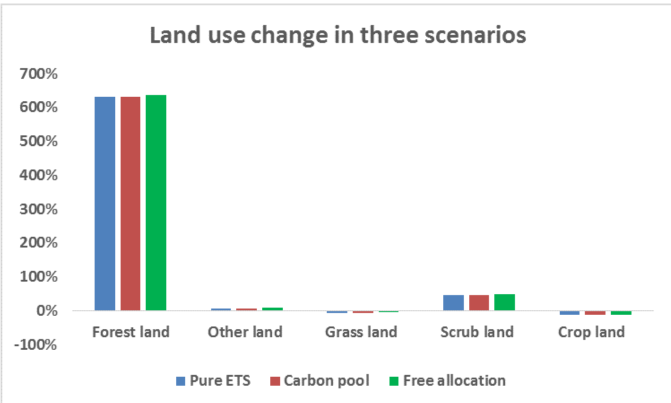

Figure 4.8: Change in land price by type

As seen in Figure 4.8, demand for forest land increases the most by all sectors across three scenarios. Change in land use is associated with sectoral outputs and elasticity of substitution at an equilibrium carbon price. On one hand, sectors demand more land for production if they increase production capacity. On the other hand, high elasticity of substitution implies an easier conversion between different land uses.

Sectoral output increases the most under free allocation as seen in Table 4.5. As expected, forest land and scrub land increase the most (636% and 48%, respectively) based on baseline use at carbon price NZ$23. Other land increases at 8% whereas it increases by 7% under pure ETS and carbon pool. Pricing on carbon permit reduces agricultural activities, leading to a decrease in dominant land use in agricultural sectors. In the baseline scenario grass land is mainly used in sheep-beef (71%), dairy (85%), and other agriculture (72%) sectors, at equilibrium carbon price NZ$22, grass land decreases by 6%, 6%, and 5% across scenarios. Crop land decreases at 13%, 12%, and 11%, respectively.

Specifically, Table 4.8 illustrates the change of land price in each sector among three scenarios. It is clear that the cost of all types of land decrease except for forest land. Similarly, only forestry land use increases across scenarios.

Compared with the baseline, where the carbon permit price is NZ$0, equilibrium carbon price at $23 would definitely provide motivation for obtaining and selling carbon permits. This is because forestry profit increases at a high carbon permit price. Two main factors affect land use among sectors: 1. sectoral output; 2. elasticity of substitution among land. Increasing output leads to rising demand for production factors such as land, labour, and capital. Besides, if elasticity of substitution is low between two types of lands, e.g. forest land and other land, it implies a difficulty in other land converts to forestry use. Again, in this chapter I set a low elasticity of substitution between forest land and other four types of land, which makes forest land relatively expensive because it is hard to access forest land. Besides, the demand of forest land increases at a high carbon price compared with the baseline.

As seen in Table 4.8, the level of change for each type of land use among the three scenarios is small. This is largely due to a very similar equilibrium carbon permit price grounded at NZ$23. Percentage of each type of land use in sector depicts a change in land price from demand side by sectors. All the prices measured in the model are a relative change from the numeraire (household consumption). For instance, 733% in Table 4.8 can be explained as the demand of forest land increases 733% relative to household consumption.

Table 4.8: Change in land use by land type (% on baseline)

Pure ETS	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	733%	130%	129%	134%	128%
Horticulture	68%	-16%	-17%	-15%	-17%
Sheep-beef	74%	-11%	-12%	-10%	-12%
Dairy farming	74%	-12%	-12%	-11%	-13%
Other agriculture	77%	-10%	-11%	-9%	-11%
Carbon pool	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	734%	130%	129%	134%	128%
Horticulture	68%	-16%	-16%	-15%	-17%
Sheep-beef	75%	-11%	-11%	-9%	-12%
Dairy farming	75%	-11%	-12%	-10%	-12%
Other agriculture	77%	-10%	-10%	-8%	-11%
Free allocation	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	738%	131%	129%	134%	129%
Horticulture	71%	-14%	-15%	-13%	-15%
Sheep-beef	77%	-10%	-10%	-8%	-10%
Dairy farming	76%	-10%	-11%	-9%	-11%
Other agriculture	79%	-9%	-9%	-7%	-9%

Table 4.9 examines the overall change in land use among three scenarios by sector and type. Percentage shows the hectare change of five types of land used in various sectors at different carbon permit prices. A clear trade-off between forestry and agricultural sectors shows that pricing carbon permit is beneficial to the forestry sector, but introduces a production cost to agriculture sectors. Among the three scenarios, the effect of equilibrium carbon price on sectoral land use is same under pure ETS and carbon pool. This is because all producers have to buy carbon permits from the market. Unlike the former two scenarios, in free allocation, GHG emitters receive free permits which compensate for the emissions cost. For the forestry sector, the potential profits from selling carbon permits decrease compared to the former scenarios. Therefore, overall land use in forestry slightly decreases;

horticulture increases 1% in land use. The rest of sectors show the same change of land use in all three scenarios.

Table 4.9: Percentage change in sectoral land use (% on baseline)

Hectare change of land use by sector	Pure ETS	Carbon pool	Free allocation
Forestry	79%	79%	78%
Horticulture	-11%	-11%	-10%
Sheep-beef	-8%	-8%	-8%
Dairy farming	-8%	-8%	-8%
Other agriculture	-8%	-8%	-8%

4.4.4 Rate of allocated permits to sectors

In the free allocation scenario, it is assumed that government allocates the international carbon permits purchased from overseas market at NZ$25 per 9.1 Mt to each sector based on its emissions. The allocated carbon permits received by each sector are shown in Table 4.10. At such high permit allocations, the endogenous allocation rate is also high as seen in Table 4.11. The high allocation rate of permits is similar to Diukanova et al. (2008). Forestry receives a subsidy for net emissions.

Table 4.10: Allocated carbon permit

Sector	**Allocated carbon permit (Mt)**
Forestry	-2.9
Stationary energy	0.9
Industrial processes	0.6
Synthetic gases	0.2
Waste	0.2
Horticulture and fruit growing	0.6
Sheep-beef cattle and grain farming	1.1
Dairy cattle farming	1
Other agriculture	1.7
Forestry manufacturing	0
Agriculture manufacturing	0
Retail and wholesale trade	0.2
Manufacturing	0.5
Non-renewable electricity	0.2
Renewable electricity	0
Service	4.7
Total	**9.1**

Table 4.11: Permit allocation rate by sector

Sector	Allocation rate
Forestry	3%
Stationary energy	13%
Industrial processes	13%
Synthetic gases	13%
Waste	13%
Horticulture and fruit growing	14%
Sheep, beef cattle and grain farming	14%
Dairy cattle farming	14%
Other agriculture	14%
Forestry manufacturing	12%
Agricultural manufacturing	14%
Retail and wholesale trade	12%
Manufacturing	12%
Non-renewable electricity	13%
Renewable electricity	12%
Service	12%

In this scenario, in order to keep government income neutral, an extra consumption tax is imposed on household consumption. The tax rate is also endogenous in the model, calculated at 0.4%. The small change of consumption tax rate does not result in a large decrease in household consumption. Household consumption decreases by 0.1%, but government consumption drops by 0.3%. Although the permit allocation rate is high, most of sectors decrease outputs. This is because the equilibrium carbon price is still high for sectoral production. However, compared to the pure ETS and carbon pool scenarios, the magnitude of output change is smaller under a free allocation scheme.

4.4.5 Change in macro variables

Table 4.12 measures the change in macro variables including GDP, terms of trade, export, import, factor price, household and government consumption across the three scenarios, compared to the baseline where carbon permit price is $0.

Table 4.12: Change in macro variables across three scenarios

Variables	Pure ETS	Carbon pool	Free allocation
GDP	-0.2%	-0.1%	-0.3%
Terms of trade	-1.4%	-1.3%	-2%
Export	2%	3%	3%
Import	2%	2%	2%
Labour price	-1.6%	-1.6%	-1.8%
Capital price	-1.5%	-1.5%	-1.7%
Household consumption	0%	0%	-0.1%
Government consumption	0.4%	-0.3%	-0.3%

As in chapter 3, the household consumption price index is set as numeraire. Therefore, the GDP is real GDP. As shown in Table 4.12, real GDP declines between 0.1% and 0.3% across all scenarios. This is in line with Diukanova et al. (2008) where the GDP falls by 0.3% in all scenarios. This effect can be explained by decreased sectoral output. The reduction in sectoral output leads to an increase in domestic commodity prices, which makes domestic supply relatively expensive to imported goods. Therefore, imports increase across three scenarios. The decreased terms of trade reflects a fall in the exported price, resulting in an increase in exports. Changes of import and export values in the three scenarios are shown in Table 4.13 and 4.14. The reduction in sectoral output decreases the demand for factor use in most of sectors except for forestry and its related sectors. Overall, the price of labour and capital decrease across all three scenarios. Household consumption does not change much in the pure ETS and carbon pool scenarios, because high income from supplying renewable resource compensates for the decrease in factor prices. However, in the free allocation scenario, household consumption declines because of the imposition of extra income tax on households in order to keep government income neutral. In the CGE model, all sectors meet the condition of zero profit. When government allocates the permits to the sectors freely, it has to be financed by the same value of tax collection. Government consumption falls by 0.3% in the carbon pool scenario, because the market based carbon price is lower than its purchase price ($25/t). The purchased price is measured in NZD adjusted by an exchange rate.

Table 4.13: Import value in million NZD

Import	Pure ETS	Carbon pool	Free allocation
Forestry	6	6	7
Stationary energy	6709	6706	6696
Industrial processes	4402	4402	4399
Synthetic gases	0	0	0
Waste	65	65	65
Horticulture and fruit growing	356	356	352
Sheep-beef cattle and grain farming	1	1	1
Dairy cattle farming	0	0	0
Other agriculture	338	338	334
Forestry manufacturing	2965	2963	2965
Agriculture manufacturing	2838	2832	2823
Retail and wholesale trade	149	138	149
Manufacturing	19823	19798	19830
Electricity	665	665	661
Service	13403	13361	13383
Total	**51720**	**51640**	**51664**

Table 4.14: Export value in million NZD

Export	Pure ETS	Carbon pool	Free allocation
Forestry	5657	5664	5704
Stationary energy	1265	1270	1288
Industrial processes	3253	3268	3271
Syntheticic gases	0	0	0
Waste	382	383	389
Horticulture and fruit growing	1033	1037	1068
Sheep-beef cattle and grain farming	172	173	176
Dairy cattle farming	0	0	0
Other agriculture	398	400	412
Forestry manufacturing	4317	4340	4315
Agriculture manufacturing	13127	13184	13321
Retail and wholesale trade	1695	1699	1690
Manufacturing	5409	5423	5407
Electricity	287	287	289
Service	11338	11350	11316
Total	**48333**	**48481**	**48648**

Both exports and imports increase the most under the free allocation scenario than in the other scenarios. This is due to the terms of trade decreasing the most (2%) in this scenario. As a result, under the free allocation scheme, land use and production in the forestry sector increases the most. And, the reduction in sectoral production, factor and land use from other sectors is less than in the carbon pool and pure ETS scenarios.

4.5 Sensitivity tests

In order to test the effect of ETS on equilibrium carbon price at different permit purchase prices and volumes from the government, a sensitivity test is conducted in this section. Two scenarios are examined: carbon pool and free allocation, the results are shown in subsection 4.5.1 and 4.5.2.

4.5.1 Test for carbon pool scenario

Two more initial carbon permit prices (NZ$10/t and NZ$50/t) at an amount of 9.1 and 20 Mt purchased by the government are used to examine the change in equilibrium carbon permit price. In the sensitivity test, the percentage is compared to the situation where the equilibrium carbon price is NZ$23.178/t when government purchases the international permits by $25 at 9.1 Mt.

Given that both government and forestry supply carbon permits, a trade-off of allocating the permits occurs between forestry and government. At the price of NZ$10 with 9.1 Mt, the equilibrium carbon permit price increases by 0.2% leading to an increase in government consumption by 0.4%. This results in a slightly decrease in forestry output (0.1%) compared to the situation where government purchases the permits at $25/t. In contrast, if the government purchases the international permits at the higher price of $50, government consumption falls by 1%. This then leads to a lower equilibrium carbon price by 0.3%. Figure 4.9 shows the change in equilibrium carbon price and government consumption at three government purchase prices.

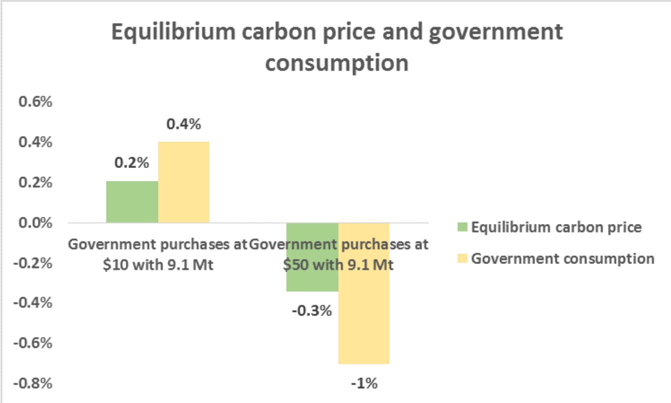

Figure 4.9: Sensitity test by changing purchase price

If government increases the supply of permits amount to 20 Mt at three international prices NZD$10, NZD$25, and NZD$50, compared with the situation where government purchases the permits by $25 at 9.1 Mt, the equilibrium carbon price increases by 0.04% by $10, but decreases by 0.4% by $25, and falls 1.2% by $50. Government consumption shows a similar change but with different magnitude as shown in Figure 4.10.

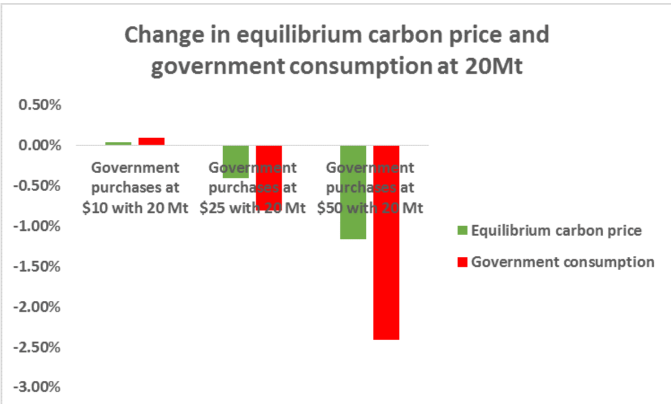

Figure 4.10: Sensitivity test by changing permits amount

As illustrated above, the small change in percentage from the sensitivity test implies that the equilibrium carbon price is not sensitive to government spending on carbon permits.

4.5.2 Test for the free allocation scenario

Two more allocation policies are examined here: 1. government allocates the carbon permit at price NZ$10, NZ$25, and NZ$50, and total allowance of the permits remains at 9.1 Mt;

2. with the same range of purchased prices, but the allocated amount changes to 3 Mt, 20 Mt, and 30 Mt.

In the first allocation method, in order to balance the government's account, it has to collect same value of consumption tax. As seen in Figure 4.11, the household consumption decreases due to the increased tax burden. Reduction in household consumption leads to a fall in commodity demand. Decreased production results in a fall in equilibrium carbon price.

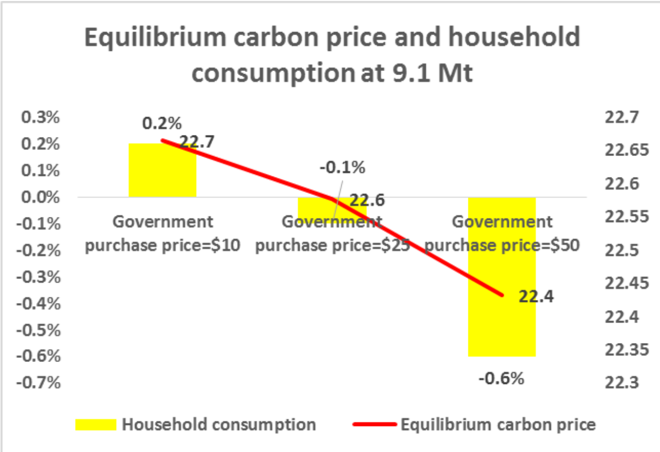

Figure 4.11: Equilibrium carbon price change

In Figure 4.11, the left axis shows the percentage change in household consumption, and the right axis presents the value of an equilibrium carbon permit price. Household consumption falls when the units price purchased by government increases from \$10/t, \$25/t, to \$50/t, because the extra consumption tax rate increases from 0.2%, 0.4% to 0.8%. Given an increased permit supply, the equilibrium carbon price decreases. In contrast, carbon sequestration increases; Figure 4.12 shows the percentage change of carbon sequestration in forestry, compared to the baseline scenario where total sequestration is 23 Mt.

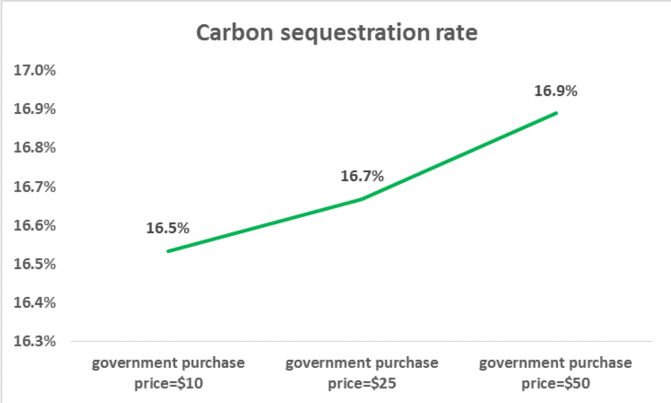

Figure 4.12: Carbon sequestration change

Carbon sequestration increases with higher government purchase price. When the purchase price goes up, government and household consumption tax increase in order to keep its income neutral. As a result, household consumption falls, leading to less demand for commodities. Further, most sectoral production decreases and the factor prices fall. However, compared to the baseline scenario, pricing on carbon increases forest profitability. Hence, more polluting activities switch to afforestation, leading to a rise in carbon sequestration.

Based on the second allocation method, the equilibrium carbon price is lower at the higher allocation amount. This is caused by an increased permit supply. At the lower allocation amount of 3 Mt, the equilibrium carbon price increases compared to the situation where government supplies 9.1 Mt of permits. However, the price gradually decreases at a higher allocation amount as shown from Table 4.15 to 4.17. The percentage compares with the free allocation scenario at 9.1 Mt of permits allocated by government at $25/t.

Table 4.15: Variable change at NZ$10

Government purchase price =$10			
Subsidy amount (Mt)	3	20	30
Equilibrium carbon price	2.1%	-2.6%	-5.1%
Household consumption	0.1%	0.3%	0.4%
Government consumption	0.1%	-1.2%	-1.9%

Table 4.16: Variable change at NZ$25

Government purchase price =$25			
Subsidy amount (Mt)	3	20	30
Equilibrium carbon price	2.0%	-3.4%	-6.3%
Household consumption	0.0%	-0.4%	-0.6%
Government consumption	0.2%	-1.1%	-1.7%

Table 4.17: Variable change at NZ$50

Government purchase price =$50			
Subsidy amount (Mt)	3	20	30
Equilibrium carbon price	1.8%	-4.8%	-8.3%
Household consumption	-0.2%	-1.4%	-2.2%
Government consumption	0.2%	-0.9%	-1.5%

At the low purchase price for international permits of $10, household consumption increases slightly. This is partly due to a decrease in the extra consumption tax rate (from 0.4% to 0.3%). In the other two scenarios, household consumption falls as government increases the extra tax to cover its cost. The change in household consumption is similar to the change in equilibrium carbon price, but opposite to the change in government consumption across the three tables. In summary, at a high purchase price for international permits, both household and government consumption decreases. But the magnitude of decrease in government consumption is less, because the extra consumption tax rate increases slightly. The equilibrium permit price falls as the supply of carbon permits increases.

4.6 Conclusion

This chapter calculated an equilibrium carbon permit price under three policies. One policy assumed the carbon market is closed, without government intervention. The second policy assumes government sells the surplus of international permits with forestry. The third scenario assumes that government allocates the surplus to all sectors.

Without government intervention, the equilibrium carbon permit price is NZD$23 per tonne. Compared with pure ETS, the price is lower by 0.3% in the carbon pool scenario, and 3% in free allocation scenario. This decreased carbon price is caused by an increase in the supply of carbon permits. Given that the total supply of permits from government is the same in the carbon pool and free allocation scenario, change in government consumption under the two policies is similar.

Most sectors reduce their emissions across all three scenarios. Retail, renewable electricity, and service are not sensitive to the change in carbon price. At the baseline, retail and renewable sectors do not generate much emission. With an increased carbon price, the mobility of factors among sectors leads to an increase in production and emissions in the low emissions sectors such as service. Demand for permits is smaller in the carbon pool compared with the free allocation scenario; the positive relationship between production and emissions leads to fewer emissions in the carbon pool scenario than under a free allocation scheme.

Land use change is similar in all three scenarios. Forest land use increases the most with free allocation of permits because forestry output increases the most under this scenario. In addition, as the forestry land use increases, land use in horticulture, sheep-beef, dairy, and other agriculture decreases, leading to a reduction in the agricultural sector's production and emissions.

The main contribution of this study is the calculation of an endogenous carbon permit price under NZ ETS policy. Most of the studies use a fixed carbon price (i.e. carbon tax) because it is relatively easier for model calibration. The equilibrium carbon permit price calculated by this study is for all ETS sectors, with an endogenous forest sector linked to a CGE model.

Next, I will compare the ETS and carbon tax, and highlight which policy performs better in terms of macro economic variables such as GDP, international trade, and carbon emissions abatement.

Chapter 5

Analysis of the impact of carbon tax and ETS on the New Zealand economy

Ian et al. (2015) state that "the incidence of a carbon tax and that of its main market-based alternative, an emissions trading system (ETS) or cap-and-trade, are potentially quite similar". The government could auction some ETS permits to generate the same revenue as under a carbon tax, and the incidence depends on how the revenue is used. The main difference is that the tax rate is determined by government, whereas the equilibrium carbon price is market based. However, which policy is more effective? This chapter analyzes the effect of these two policy instruments based on the results from chapter 3 and 4, and compares the impact of both policies at the same carbon price on the NZ economy.

Section 5.1 introduces the effect of imposing either a carbon tax or an ETS on land use change and the macro-economy; section 5.2 analyzes and compares these two carbon policies based on results from chapter 3 and 4; section 5.3 draws some conclusions.

5.1 Introduction

This chapter compares a carbon tax and the pure ETS scenario at the same carbon permit price of NZ$23/t, especially on the land use change between forestry and agriculture, and the variables from the forest growth model such as an optimal rotation age.

Land is a primary factor of production, imposing a carbon tax or pricing on carbon emissions causes an effect on the change of land use between rural sectors. Many studies set up a specific model for assessing the effect on land use change under different economic conditions. For instance, applications in NZ study include: "NZ-FARM", which is an optimization model at catchment level (Daigneault et al., 2011); "LURNZ" is a statistical model at national level (Hendy et al., 2007); a dynamic general equilibrium model "CliMAT-DGE" integrating the climate policy adaptation (Fernandez & Daigneault, 2015). At the global level it includes a regional CGE model such as Monge et al. (2013) and global land use model "GTAP-AEZ" (Burniaux, 2002). Pricing carbon emissions causes a higher production cost for polluting sectors but provides a benefit through GHG emissions reduction. Monge et al. (2013) find that about 76 million acres of agricultural land were afforested in the central plains in the US at a carbon price of \$10/mt CO_2. Daigneault et al. (2011) had similar findings by using the NZ-FARM model, demonstrated a fall in net revenue from 7% to 15% when carbon price increases from \$20/t to \$40/t; in contrast, the GHGs emissions decrease from 3% to 21%. The decreased net revenue in the polluting sectors results in less demand for use of land and other factors. As a result, factors from the polluting sectors shift to the forestry sector, and afforestation activities are encouraged.

Regarding the macro variables, the change of real GDP is associated with total sectoral production. When introducing a carbon price on emissions, reduced sectoral output leads to a decline in GDP (Diukanova et al., 2008; NZIER & Infometrics, 2011). The demand of labour, capital, and other factors also declines in sectors which face high emissions costs. At the same carbon price, the change of macro variables under both carbon tax and the ETS is similar. Macro variables such as household consumption, export and import show a substantial decrease at a higher carbon emission cost, especially under the ETS. In this study, household consumption decreases at higher carbon tax rates, but reduced household income can be offset under the ETS. The difference is caused by assumptions under these two carbon policies. In the carbon tax scenario, the household supplies labour, capital and land to sectors. However, as a further extension on the first model, under the ETS three renewable sources are involved and they are supplied by the household. This is why household expenditure can be offset under the ETS compared to carbon tax. Exports and imports by polluting sectors decrease under the carbon tax, but increase under the ETS because of the change in the foreign exchange rate (exchange rate increases under carbon tax but decreases under the ETS). However, the level of export and import increase in the sectors which expand production such as forestry and services. Tree rotation age shows a positive change along with higher carbon price, because carbon price increases a forest owner's profitability.

The main contribution of this PhD thesis is linking a partial equilibrium model of forest growth to a static CGE model. Endogenous forest growth is an important variable affecting an equilibrium carbon permit market. Three scenarios were assessed in the chapter 4 simulating the effect of NZ ETS: pure ETS, carbon pool, and free allocation. In this chapter, the pure ETS has been selected for a comparison with the carbon tax scenario - at the same carbon price - because forestry is the sole supplier of carbon permits in both scenarios. Across the existing NZ studies, this is the first examination of the effect of NZ ETS by a CGE model with endogenous forest growth. It provides important insights into NZ's climate policy.

5.2 Comparison of the two policies

This section evaluates the effects of the NZ ETS on land use, forest growth, and macro variables by comparing a carbon tax to the pure ETS scenario at carbon permit price of NZ$23/t. Carbon price NZ$0/t is treated as the baseline. Subsection 5.2.1 compares land use change and the variables from the forest growth model under both policies; subsection 5.2.2 outlines changes to macro variables such as household and government consumption, factor use, exchange rate, and GDP under both policies. The effect of two other scenarios, a "carbon pool" and a "free allocation" scheme, on land use between forestry and agriculture is also examined and compared to the tax at NZ$23/t of emissions in subsection 5.2.3.

5.2.1 Land use and forest growth

In order to compare the effect of both carbon tax and the ETS on the land use change, I adjust the elasticity of substitution between each land type in sectors to the same level in both policies [1]. In this chapter, the substitution between forest land and the other four types of land is 2. Among the other four types of land, the elasticity of substitution is 20. This is consistent with the elasticity setting in chapter 4.

In both policies, a clear trade-off of land use occurs between forestry and agricultural sectors as shown in Table 5.1, Table 5.2 and Table 5.3. Table 5.1 shows the land_i [2] used by each sector in the baseline scenario. The percentage is calculated by the use of land_i^j [3] divided by total sectoral land use ($\sum land_i^j$). The forest land is dominant for use in the forestry sector, crop land is widely used in the horticulture sector, and grass land is used the most by the other sectors.

Table 5.1: Percentage of land use by sectors in baseline

Equilibrium carbon price =$0					
	Forest land	Other land	Grass land	Scrub land	Crop land
Forestry	85%	1%	5%	9%	0%
Horticulture	7%	2%	32%	4%	54%
Sheep-beef	10%	6%	71%	11%	3%
Dairy farming	9%	1%	85%	3%	2%
Other agriculture	11%	4%	72%	10%	3%

Under the ETS, the total land use in forestry sector increases by 79% compared to the baseline. This is because forest owners can sell the carbon permit under the ETS, which results to increased forestry. Therefore, more land from other sectors convert to forestry use. As shown in Table 5.2, the percentage written in brackets shows the difference of land_i use compared to the baseline. Equation 5.1 illustrates the calculation of this difference.

[1] The elasticity of substitution between each land type in sectors is lower under the carbon tax than the ETS.

[2] "i" includes forest land, other land, grass land, scrub land, and crop land.

[3] "j" includes sectors. For instance, 85% in the first row of Table 5.1 means 85% of forest land is used by forestry sector.

At the equilibrium carbon price, all of the agricultural sectors reduce land use. Within each sector, the demand for grass land, scrub land and crop land increases instead of the forest land. This is because accessing these three types of land is easier than forest land because of the high elasticity of substitution. Although forest land is still a dominant use in the forestry sector, it decreases slightly across the five sectors given the substitution of other types of land. In addition, the terms of trade decreases under the ETS, leading to an increase of timber exports. Stronger demand for timber from both domestic and overseas markets result in a large gain in forestry output, and the demand of land use.

Table 5.2: Percentage change of land use under the ETS

Equilibrium carbon price =$23						
	Forest land	Other land	Grass land	Scrub land	Crop land	Total
Forestry	81% (-5%)	1% (0%)	7% (2%)	11% (2%)	0% (0%)	79%
Horticulture	5% (-4%)	3% (0%)	32% (1%)	4% (0%)	56% (3%)	-11%
Sheep-beef	7% (-6%)	6% (0%)	73% (6%)	11% (0%)	3% (0%)	-8%
Dairy farming	7% (-5%)	1% (0%)	87% (5%)	3% (0%)	2% (0%)	-8%
Other agriculture	8% (-7%)	4% (0%)	75% (6%)	10% (0%)	3% (0%)	-8%

$$percentage = \frac{Land_i^j(scenario)}{\sum land_i^j(scenario)} - \frac{Land_i^j(baseline)}{\sum land_i^j(baseline)} \tag{5.1}$$

Where land_i^j is land type i used in sector j. Table 5.3 depicts the land use change under a carbon tax regime. The change of land_i^j is similar, but the change of total land use by sectors is different. Forestry increases total land use by 34%. This is because forestry is not allowed to sell the permits which would lessen the demand for conducting forestry activities. Additionally, the terms of trade increase under the carbon tax scheme, leading to a decline in the export of timber production, resulting in a shrinking of forestry output compared to that under an ETS. However, the high carbon price still benefits forest owner, as other sectors reduce their output at a high emissions cost.

Table 5.3: Percentage change of land use under the carbon tax

Carbon tax =$23						
	Forest land	Other land	Grass land	Scrub land	Crop land	Total
Forestry	80%(-4%)	1% (0%)	7% (2%)	11% (2%)	0% (0%)	34%
Horticulture	3% (-2%)	3% (0%)	33% (0%)	4% (0%)	58% (1%)	-8%
Sheep-beef	4% (-2%)	6% (0%)	77% (2%)	10% (0%)	3% (0%)	-4%
Dairy farming	3% (-2%)	1% (0%)	90% (2%)	3% (0%)	2% (0%)	-3%
Other agriculture	4% (-3%)	4% (0%)	78% (3%)	10% (0%)	3% (0%)	-4%

Due to the strong demand for forest land under both policies, the price of forest land increases compared with the baseline as seen in Figure 5.1. The magnitude of forest land demand is much higher under ETS. This can be explained by the following: 1. more factors move to forestry and forestry manufacturing sectors from the polluting sectors the carbon permit price is high; 2. forestry and relevant sectors increase production; 3. the export of timber production increases under the ETS because of a stronger demand from overseas; 4. the difficulty in acquiring the forest land at a low elasticity of substitution under both policies. In this chapter, all the percentages shown in figures are compared to the baseline.

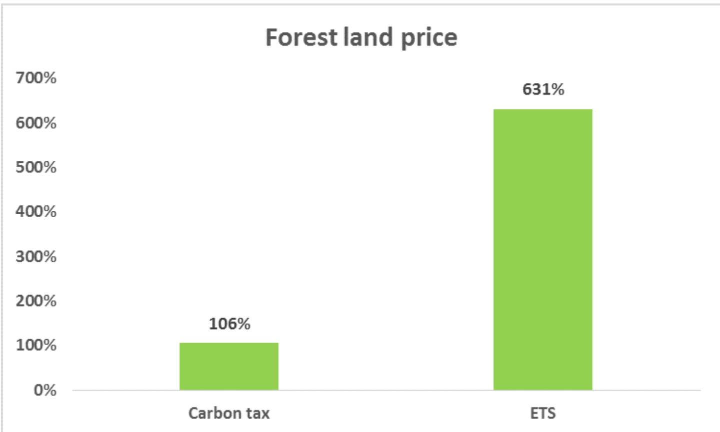

Figure 5.1: Comparison of forest land prices

The demand of the other four types of land is shown in Figure 5.2. The price of grass land and crop land decreases, whereas the price of other land and scrub land increases. This can be explained by the preference for converting scrub and other land to forestry could reduce the demand for grass land. The change of scrub land is negligible under both policies.

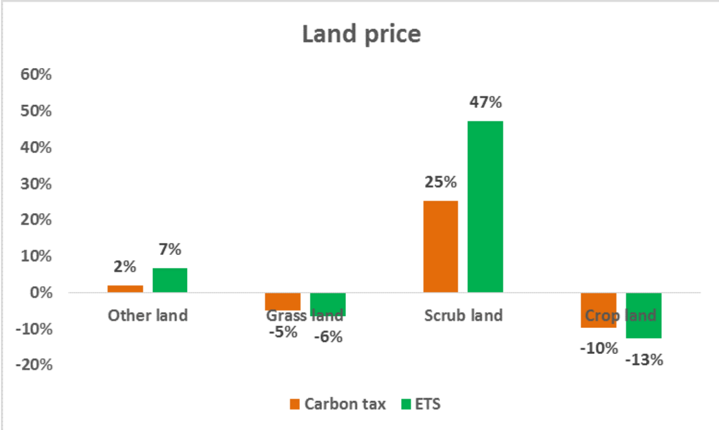

Figure 5.2: Comparison of other types of land price

More land used in forestry contributes to emission abatement. With a carbon price of \$23/t CO_2e, sectoral sequestration and the emission change ratio is shown in Table 5.4 and 5.5. At a carbon tax rate of \$23/t, total net emissions decrease by 11%; whereas the reduction becomes 14% under the ETS. This strongly suggests that the ETS has more potential to abate emissions than a carbon tax.

Table 5.4: Sequestration/Emission change at carbon tax \$23

Sector	Sequestration/Emission
Forestry	21%
Mining, oil and coal	-5%
Industrial processes	1%
Horticulture and fruit growing	-13%
Sheep-beef cattle and grain farming	-7%
Dairy cattle farming	-7%
Other agriculture	-9%
Forestry manufacturing	3%
Agricultural manufacturing	-7%
Manufacturing	1%
Utility	-1%
Services	1%
Total	-11%

Table 5.5: Sequestration/Emission change under ETS

Sector	**Sequestration/Emission**
Forestry	17%
Stationary energy	-8%
Industrial processes	-4%
Synthetic gases	-4%
Waste	-8%
Horticulture and fruit growing	-16%
Sheep-beef cattle and grain farming	-13%
Dairy cattle farming	-14%
Other agriculture	-13%
Forestry manufacturing	5%
Agricultural manufacturing	-14%
Retail and wholesale trade	-0.1%
Manufacturing	-1%
Non-renewable electricity	-5%
Renewable electricity	0%
Services	1%
Total	-14%

Table 5.6 compares timber price, rotation age, and forester's profits under the two policies. It is clear that the ETS brings more profit to foresters as timber price and NPV_4 increase. Under a small economy assumption, all NZ's exported timber products can fully enter the international market. At a high carbon price, timber price is affected by an increasing demand to plant trees. The difference of forest variables is similar under both policies.

Table 5.6: Forest variable change comparison

Variable	**Carbon tax=$23**	**Equilibrium carbon price =$23**
Timber price	89	90
Rotation age	20	20
Timber yield	349	350
Emission	12	12
Sequestration value	468	468
NPV1	6258	6373
NPV2	1896	1912
NPV3	-1147	-1159
NPV4	8782	8946

The increase in forestry output benefits not only carbon sequestration, but also forestry manufacturing. At an equilibrium carbon price, forestry manufacturing increases its output, therefore, more processed timber can be sold to overseas markets, and, available labour and capital from other sectors can move to forestry and its manufacturing sectors.

5.2.2 Comparison of macro variables under the two policies

Figure 5.3 shows the change of household and government consumption in both policies. Government spending increases, especially under the carbon tax, because carbon tax collected is part of the government's revenue, but government does not earn this revenue in the ETS. Due to the difference in industry specification between the carbon tax model and the ETS, households do not supply renewable resources under the carbon tax scenario [4], hence household consumption decreases under the tax scenario.

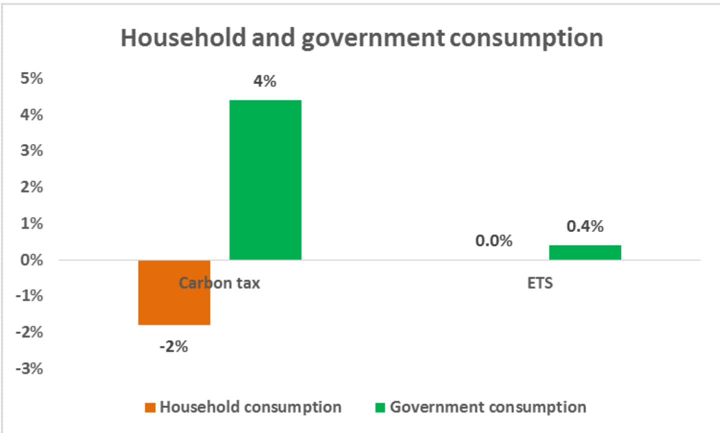

Figure 5.3: Comparison of household and government consumption

Factor prices decrease under both policies as seen in Figure 5.4. This implies that under both policies, factor demand is reduced due to lowered demand in production. Specifically, compared to the carbon tax, the level of labour price decreases under the ETS as reduced household income leads to reduced tax payments to the government. Hence, government consumption decreases compared to the levels in the carbon tax scenario (see Figure 5.3).

[4] In a carbon tax model, the electricity generation sector only includes the traditional resources.

In contrast, the cost of capital decreases with a carbon tax as the taxation lowers sectoral output, which leads to less demand for capital. Government supplies capital together with the household sector and an increased supply of capital results in the price of capital lower than labour. However, the change in factor prices is very similar.

Increase in forestry manufacturing and services sectors results in a rising demand for factors used in these sectors. Labour and capital can, and do, move to these sectors from other sectors. Figure 5.4 compares the factor price change under both policies with baseline when P_c=0.

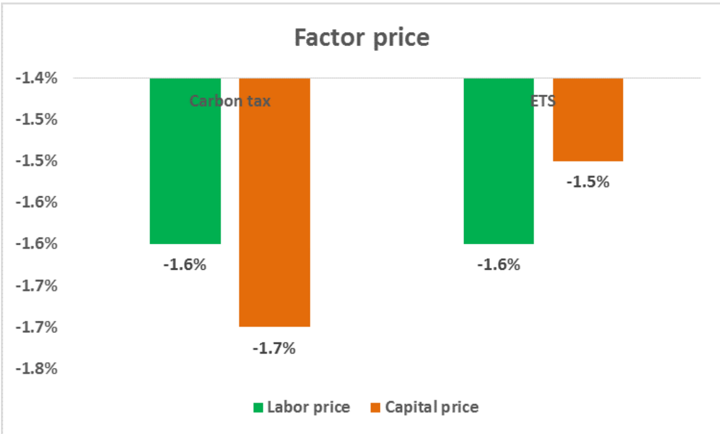

Figure 5.4: Comparison of factor price

The terms of trade is lower under the ETS. A depreciated NZD leads to an increase in the value of exports. Either a carbon tax or a cap-and-trade scheme imposes an emission cost to GHG producing sectors, therefore, the use of domestic factors or intermediate goods is relatively more expensive compared with imported goods. In response, imported goods increase. Figure 5.5 and Figure 5.6 show the change of exchange rate and international trade at a carbon price of NZ$23.

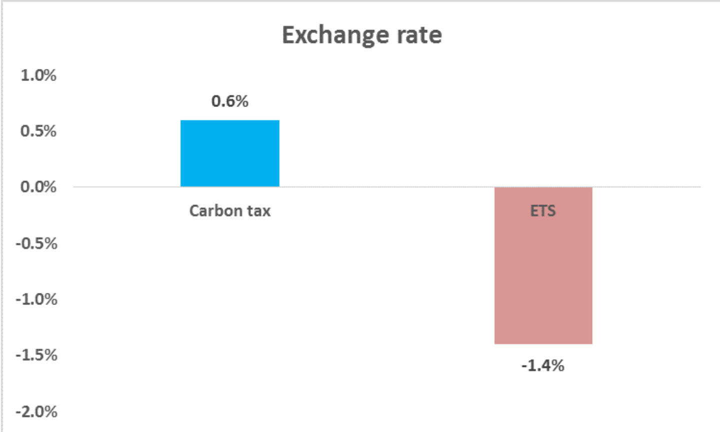

Figure 5.5: Comparison of exchange rate

Figure 5.6: Comparison of international trade

At a carbon permit price of NZ$23/t, the pure ETS shows a greater effect on GDP, factor price, household and government consumption, and international trade. As shown in Figure 5.7, real GDP decreases by 0.2% under both policies. This effect can be explained by the reduction of sectoral production at emissions cost. The change in real GDP is very small, due to a trade off between emission-related sectors and forestry. Although most sectors reduce production with rising emission costs, increased output in forestry and its relevant sectors (e.g. forestry manufacturing and service) can compensate for the loss. In addition, exports increase under the ETS but decrease under a carbon tax regime, which is why GDP decreases by less under the ETS. Changes of sectoral output are illustrated in Table 5.7, a negative sign represents a fall in the output. All percentages are compared with baseline results.

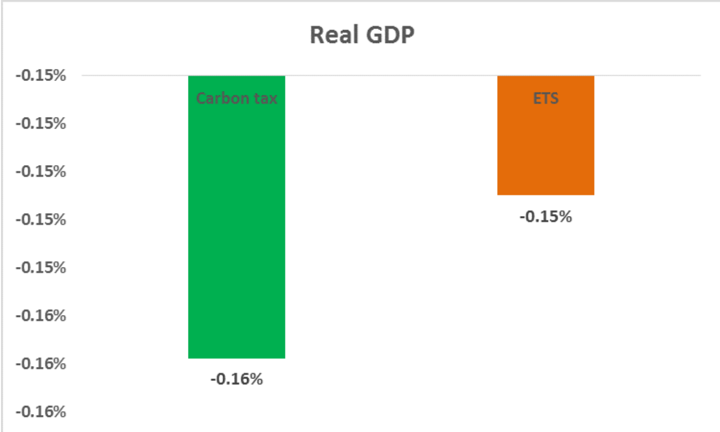

Figure 5.7: Comparison of GDP

Table 5.7: Comparison of sectoral output at carbon price $23

Sectors in carbon tax	Percentage change	Sectors in the ETS	Percentage change
Forestry	24%	Forestry	236%
Mining	-5%	Stationary energy	-8%
Industrial process	1%	Industrial process	-4%
Horticulture	-13%	Synthetic gases	-4%
Sheep-beef	-7%	Waste	-8%
Dairy farming	-7%	Horticulture	-16%
Other agriculture	-9%	Sheep-beef	-13%
Forestry manufacturing	3%	Dairy farming	-14%
Agricultural manufacturing	-7%	Other agriculture	-14%
Manufacturing	1%	Forestry manufacturing	5%
Utility	-1%	Agricultural manufacturing	-14%
Service	1%	Retail and wholesale trade	0%
		Manufacturing	-1%
		Non-renewable electricity	-5%
		Renewable electricity	0%
		Service	1%

As shown in Table 5.7, a reduction in sectoral production leads to a fall in GDP. Production in most sectors contracts in the ETS relative to the carbon tax, hence, GDP declines further under the ETS. In contrast, forestry benefits through trading carbon permits, therefore, a large increase in output is shown in the forestry sector with the ETS.

5.2.3 Comparison of land use change under carbon pool, free allocation to carbon tax

The pure ETS scenario is the main policy used to compare with the carbon tax model, because the role of forestry is emphasized under this scenario when deriving the carbon price. Another two scenarios (carbon pool and free allocation) include the role of government in providing carbon permits. This section assesses the difference in land use under these two carbon policies, respectively.

Table 5.8 through Table 5.11 illustrate the change in each type of land use by sectors under the three carbon policies. Since the equilibrium of the carbon permit price is very close across the pure ETS, carbon pool and free allocation scenarios, the effect on the land use is similar. Under the carbon pool scenario, where the government and forestry sell the permits to the NZ carbon market the change in land use is identical to that of the pure ETS. In contrast, due to the different assumptions made in the free allocation scenario, total land use decreases slightly in the forestry and horticulture sectors under this scheme. This is caused by a decrease in other sectors' output when compared to the carbon pool and pure ETS. Given that forestry also receives the free allocated permits from government, the real increase of forestry output under a free allocation scenario decreases. As a result, less land is used in the forestry sector.

Table 5.8: Percentage change of land use under the carbon pool scenario

Equilibrium carbon price =$23.178						
	Forest land	Other land	Grass land	Scrub land	Crop land	Total
Forestry	80% (-5%)	1% (0%)	7% (2%)	11% (2%)	0% (0%)	79%
Horticulture	3% (-4%)	3% (0%)	33% (1%)	4% (0%)	58% (3%)	-11%
Sheep-beef	4% (-6%)	6% (0%)	77% (6%)	10% (0%)	3% (0%)	-8%
Dairy farming	3% (-5%)	1% (0%)	90% (5%)	3% (0%)	2% (0%)	-8%
Other agriculture	4% (-7%)	4% (0%)	78% (6%)	10% (0%)	3% (0%)	-8%

Table 5.9: Percentage change of land use under the carbon tax

Carbon tax =$23.178						
	Forest land	Other land	Grass land	Scrub land	Crop land	Total
Forestry	81% (-4%)	1% (0%)	7% (2%)	11% (2%)	0% (0%)	34%
Horticulture	5% (-2%)	3% (0%)	32% (0%)	4% (0%)	56%(1%)	-8%
Sheep-beef	7% (-2%)	6% (0%)	73% (2%)	11% (0%)	3% (0%)	-4%
Dairy farming	7% (-2%)	1% (0%)	87% (2%)	3% (0%)	2% (0%)	-3%
Other agriculture	8% (-3%)	4% (0%)	75% (3%)	10% (0%)	3% (0%)	-4%

Table 5.10: Percentage change of land use under the free allocation

Equilibrium carbon price =$22.577						
	Forest land	Other land	Grass land	Scrub land	Crop land	Total
Forestry	80% (-5%)	1% (0%)	7% (2%)	11% (2%)	0% (0%)	78%
Horticulture	3% (-4%)	3% (0%)	33% (1%)	4% (0%)	58% (3%)	-10%
Sheep-beef	4% (-6%)	6% (0%)	77% (6%)	11% (0%)	3% (0%)	-8%
Dairy farming	3% (-5%)	1% (0%)	90% (5%)	3% (0%)	2% (0%)	-8%
Other agriculture	4% (-7%)	4% (0%)	78% (6%)	10% (0%)	3% (0%)	-8%

Table 5.11: Percentage change of land use under the carbon tax

Carbon tax =$22.577						
	Forest land	Other land	Grass land	Scrub land	Crop land	Total
Forestry	81% (-4%)	1% (0%)	6% (1%)	11% (2%)	0% (0%)	33%
Horticulture	5% (-2%)	3% (0%)	32% (0%)	4% (0%)	56% (1%)	-7%
Sheep-beef	7% (-2%)	6% (0%)	73% (2%)	11% (0%)	3% (0%)	-4%
Dairy farming	7% (-2%)	1% (0%)	87% (2%)	3% (0%)	2% (0%)	-3%
Other agriculture	8% (-2%)	4% (0%)	75% (2%)	10% (0%)	3% (0%)	-4%

When the carbon tax is set at NZ$22.58, total land use in the forestry sector is lower compared to the change under other carbon permit prices because of a decline in motivation for conducting forestry activities and decreased exports at the lower carbon permit price. However, forest owners still benefit from planting trees under the carbon policies.

5.3 Conclusion

This chapter compares the impact of carbon tax and the ETS on NZ's macro economy based on results from chapter 3 and 4. I examine and compare the effect of both policies - at the same carbon permit price - on land use change between domestic primary sectors. Identifying which of the two climate change policies most benefits NZ's macro economy becomes critical because climate change may cause severe environmental and economic problems in the long term. The latest global effort at abating GHG emissions commenced on December 2015 in Paris where the first global, legally binding international climate deal was agreed by 195 countries. NZ is a participant in COP21 and has made further commitments towards reducing GHG emissions.

The main findings from the results are summarized as follows:

1. The ETS contributes the most to the abatement of GHG emissions. Total emissions are reduced by 14% under the ETS, whereas emissions decrease by only 7% with a carbon tax. Carbon emission is associated with the sectoral output change, implying more reduction in sectoral production under the ETS than carbon tax.

2. GDP decreases under both policies. This is due to a decrease in most sectoral production (except forestry) at a high carbon price. The magnitude of change in GDP is similar under both policies.

3. A depreciated NZ dollar leads to an increase in exports under the ETS, whereas, in contrast, exports decrease under a carbon tax. Both imports and exports increase under the ETS because domestic production is relatively more expensive due to a reduction in output, and imported goods substitute for domestic goods.

4. Factor (labour, capital) prices fall under both policies. The reduced demand for factors is caused by reductions in sectoral production. However, due to the mobility of factors across sectors, factors can move to forestry and other relevant sectors where output is increased.

5. Both policies increase the land use in forestry but reduce land use in agricultural sectors. Specifically, under the ETS, more land can convert to forestry use. Given that forest owners

are allowed to sell the permits under the ETS, the motivation for afforestation increases at high carbon prices under the ETS. In addition, the increased overseas demand for timber leads to a large increase in forestry output.

6. Due to the strong increase in forestry output under the ETS, there is a sharp rise in forest land demand relative to the situation with a carbon tax. The land use change under carbon pool and free allocation schemes is similar to the pure ETS, but total land use decreases slightly under the free allocation scenario as the equilibrium carbon price is lower.

In comparison with a carbon tax set at the same rate, and assuming a closed NZ carbon market, the ETS shows a greater impact on NZ's macro economy and contributes to a greater reduction in GHG emissions.

Chapter 6

Conclusion

6.1 Research objective

COP21 held a forum on global climate change in Paris at the end of 2015, with the aim of achieving a legally binding universal agreement, and keep global warming below 2°C. New Zealand was a participant at the forum and will contribute to the abatement of GHG emissions. Different from most countries in EU and Asia, the main emission source in NZ comes from agriculture (MFE, 2009; MFE, 2015b). In contrast, NZ has a large areas of forestry which sequestrates carbon from its growing trees. Forest owners can sell carbon permits to earn profit under the NZ ETS.

The thesis examined land use change between forestry and agriculture under a carbon tax scheme and the ETS, and analyzed the impact of both policies on NZ's macro economy, for instance, GDP, household consumption, and international trade. I investigated three research questions as follows:

1. land use change between forestry and agriculture under a carbon tax.

2. assess the impact of NZ ETS with an endogenous carbon permit price.

3. compare the effects of a carbon tax and the ETS on NZ's macro economy.

This thesis is the first attempt at linking a partial equilibrium forest model to a CGE model (forest-CGE) with the aim of analyzing NZ ETS in NZ. An optimal rotation age of NZ's post-1989 radiata pine is estimated from the forest model of Sands and Kim (2009) and Van Kooten et al. (1995); rotation age affects a forest owner's decision when to harvest trees. Due to the interaction of each agent in the CGE model, the equilibrium carbon permit price, macro variables, and land use change are effected by this rotation age. In order to ensure the robustness of the forest-CGE model, sensitivity tests were conducted in both chapter 3 and 4.

Estimating an equilibrium carbon permit price within a closed carbon market by the forest-CGE model is another contribution. Three scenarios are examined: 1. pure ETS where only forestry supplies carbon permits; 2. a carbon pool where both forestry and government can sell carbon permits to the NZ market; 3. a free allocation scheme where government subsidizes the surplus of international permits to all sectors. These scenarios provide insights into an evaluation of the ETS, especially the equilibrium NZU price that is determined when the NZ carbon market is closed. According to the government's latest review of the ETS, the value of forested land has decreased due to unrestricted cheaper international carbon permits, such as Hot air from Ukraine and Russia, imported into the NZ market. A low NZU price generates loss of economic welfare and lowers forest owners profits. Therefore, it is important to understand what an equilibrium carbon permit price should be, with and without government intervention.

Similar research had been undertaken to assess the impact of an endogenous carbon permit price on the macro economy (e.g. Diukanova et al. (2008)). However, their study did not take into account the impact of growing trees on the carbon permit supply. Studies that use an econometrics approach (e.g. Kerr and Sweet (2008); Kerr and Olssen (2012); Kerr et al. (2009)) to analyze the effects of different permit allocation methods on land use have limitations in their model, as the econometrics approach does not assess the interaction of all variables within the economy.

6.2 Results summary

6.2.1 The impact of carbon tax

The optimal rotation age of timber is extended with high carbon tax on the sector's emission. Since forest owners can make profit from carbon sequestration, higher carbon tax benefits foresters who own growing trees. Rotation age is lower at higher interest rates.

At higher carbon tax rates, more land is converted to forestry use. Forestry increases its land use in hectares by 71% at tax rate=$100. All agriculture sectors reduce their land use at a high tax rate, in particular, sheep-beef and dairy decrease their land hectares by -8% and -4%, respectively. Across land types, sheep-beef increases grass land use to 72% at tax rate=$25, 73% at tax rate=$50, and 76% at tax rate=$100. Similarly, the dairy sector increases grass land use with a ratio of 86%, 87%, and 89% in line with the carbon tax rate change. In the baseline scenario grass land is the dominant use in agriculture sectors, for instance, sheep-beef uses 71% and dairy uses 85%.

Terms of trade increases with a higher carbon tax, which implies the appreciation of the NZ dollar (NZD), leading to a fall in exports. GDP decreases at a high carbon tax rate, illustrating that the carbon tax affects domestic production. Apart from forestry and forestry manufacturing, all sectors reduce their output at a high carbon tax. As a result, factor prices and household consumption decrease.

6.2.2 The impact of ETS with endogenous carbon permit price

Three policy scenarios are examined in Chapter 4: "pure ETS" in which forestry is the only carbon permit supplier; "carbon pool" where government sells the surplus of international permits to the market along with forestry; "free allocation" which allows government to allocate the surplus to all sectors based on historical emissions. Under a pure ETS, an equilibrium carbon permit price is calculated as NZ$23/t. In the other two scenarios, the augmented supply of carbon permits lowers the equilibrium carbon price by 0.3% (in carbon pool) and 3% (in free allocation).

Sectoral production decreases which implies a reduction in total emissions. Forestry sequestration increases across the three scenarios, resulting in an increase in forestry and production in related sectors. Land use change between forestry and agriculture is similar under both a carbon tax regime and the ETS. More land is converted to forestry use under each of the three scenarios. Agriculture sector land use decreases along with the decrease in production. This results in a decrease in factor prices in most sectors under the ETS.

6.2.3 Comparison of both policies

Chapter 5 compared the effect of carbon tax and "pure ETS" on the NZ macro economy. The ETS contributes more to the abatement of GHG emissions (-14%) than did carbon tax (-11%) at an equilibrium carbon price of $23/t. This is due to a greater reduction in production under the ETS than with a carbon tax, except in forestry, forestry manufacturing, and services. The factors move from the high GHG emission sectors to the low emission sectors with a rising emission costs, resulting in an increase in low emission sectors' productions.

Unlike the carbon tax, the ETS results in a decrease in the terms of trade, leading to a depreciated NZD and as a result, the volume of exported goods increases. Less sectoral output supply, such as in agriculture, pushes up commodity prices, making domestic intermediate goods more expensive, leading to an increase in imports in both scenarios.

GDP is reduced by -0.2% under the pure ETS and -0.3% under a government allocation system. This is caused by a reduction in sectoral output. In particular, in the government allocation scenario, GDP decreases due to an extra consumption tax.

Land use change between forestry and agriculture are similar with both a carbon tax and the ETS. However, land use change in forestry under the ETS is higher than with a carbon tax. Because of the profit that forest owners can obtain from supplying carbon permits under the ETS, more trees are planted.

6.3 Suggestions for further research

This thesis has limitations. Firstly, because the latest NZ supply-use table is for the 2007 year, the data used in this research cannot reflect the changes in today's economy.

Some data need to be further examined, including the coefficient used for the elasticity of substitution and transformation. Although sensitivity tests were conducted to check the robustness of the model, more precise elasticity is required in further study.

The forest model is in steady state, but does not include a dynamic change of timber growth and carbon sequestration. The CGE model used in this research is also static and limited to show the effect of capital flows on forest owners' decisions, and future investment.

The NZ carbon market is assumed to be closed, whereas an open carbon market is needed when evaluating the ETS policy.

Lastly, more detailed land classification across the regions may result in more fine-grained data for further research.

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