Land use change between forestry and agriculture under the NZ ETS

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Abstract

Global warming is attributed to the anthropogenic emissions greenhouse gases such as those associated with transport, industry and agriculture. Increased frequency of extreme conditions such as flooding, droughts, and cyclones are predicted. The Emissions Trading Scheme (ETS) is a key pillar in New Zealand (NZ)'s approach to climate change. The ETS, as currently designed, is quite unique because it involves most sectors and all greenhouse gases (GHG). To date, most greenhouse gas emitting sources and sinks have been incorporated into the ETS; agriculture is due to be included in 2015. However, the latest indications are that the entry date for agriculture may be after 2015.

Emitters are required to cover their emissions with New Zealand units (NZUs) and other tradable international units, or face liability at a rate of $25 per unit. This thesis analyzes land use conversion between forestry and agriculture under the ETS. A static computable general equilibrium (CGE) model with steady-state forestry is applied, with runs on GAMS using the MPSGE.

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1 Introduction

In December 1997, United Nations Framework Convention for Climate Change (UNFCCC) parties signed Kyoto Protocol, which committed Annex 1 countries to binding emission reduction obligations (NZIER, 2008). To meet Kyoto Protocol obligations, each participant obtained an assigned amount of emission rights based on their emission data. Participants could gain assigned amounts by either reducing domestic emissions or generating new amounts through a carbon sink such as forestry sequestration.

The agreement also supplied two other market-based instruments: clean development mechanisms (CDM) and joint implementation (JI) projects. As part of the Annex 1 countries classified by the OECD in 1992, New Zealand is party to the obligations. The New Zealand Emissions Trading Scheme (NZ ETS) was created as an amendment to the Climate Change Response Act 2002, after the 2008 general election. The legislation was reviewed as the Climate Change Response Amendment Act 2009 after the election. The scheme was implemented in 2008. The ETS specifies eligible participants. Based on self-assessment of emissions, each participant has to report the calendar year's emissions to government, and to surrender the NZUs to New Zealand Emission Unit Register (NZEUR) by the following year.

Introducing the forestry sector into a general equilibrium framework is a difficult task due to the complicated forestry and intertemporal carbon management. In this study, we estimate the NZ land use change between forestry and agriculture within a static CGE framework. The forestry sector is treated as being in a steady-state situation in the long run. Agriculture and the rest of the economy (roe) are included in a static situation.

Forestry is a significant sector in climate change mitigation due to its great potential of carbon sequestration. Land use change under the ETS is also a key topic in NZ. Although NZ researchers have applied the CGE model to estimate how the climate policy impacts the macro economy (e.g. NZIER & INFOMETRICS, 2009), research has yet to take the land use constraint into account.

Land use consists of economic activity that make use of the land, which is different from land cover. In 2008, New Zealand has a total area of 26,821,600 hectares, with almost 50% of pastoral land area, 37% of natural forest, new forest land and pre-1990 forest land altogether, 4% of scrubland, 2% of cropping and horticulture, 2% of lakes and rivers and 3% of which is undesignated.

In the NZ context, some studies use a partial equilibrium or dynamic econometric approach (see Kerr & Sweet, 2008; Kerr & Olssen, 2012; Hendy, Kerr, & Baisden, 2007; Kerr et al., 2012) to focus on land use change between forestry and agriculture only, which does not reflect the potential drivers for land owners to make land conversion decisions. Also, the partial equilibrium method ignores the impacts of climate change policy in forestry on other economic activities. Most studies do not take the wood processing sector into account. In this paper, we apply the natural forestry yield as the intermediate input for wood processing sector, to better capture the impact of the ETS on forest owners.

The total land endowment for both sectors is fixed. Forestry land is used for growing timber which in turn is used as an intermediate input for the wood processing sector. Agricultural land is used as one of the factors for production. The land use is determined endogenously. An integrated assessment modeling (IAM) links the economic model with biology or physical models to capture the implications of climate change policies on the economy. In particular, the IAM is more suitable for global land use competition and dynamic CGE modeling. However, we do not adopt the IAM because NZ is treated as a small economy and the land is not classified across the nation.

2 Literature review

2.1 Introduction

Introducing forestry into a CGE model is difficult due to the time lag for timber growth and intertemporal management of forest carbon(Sohngen, Golub, & Hertel, 2008). The few studies that incorporate land use (e.g. Darwin, Tsigas, Lewandrowski, & Raneses, 1995; Hertel, Lee, Rose, & Sohngen, 2009; Lubowski, Plantinga, & Stavins, 2006), uses a variety of methods. Dynamic studies (see Hertel et al., 2009; Golub, Hertel, & Sohngen, 2008;

Sedjo & Lyon, 1989; Sohngen, Mendelsohn, & Sedjo, 1999) are mostly based on a partial equilibrium model. Few studies are based on steady-state study forestry within a CGE context (see Dee, 1991a; Stenberg & Siriwardana, 2006; Dee, 1991b). Steady-state modeling focuses on how timber growth and carbon sequestration achieve equilibrium in a long run. However, Dee (1991a) and Dee (1991b) only focus on timber yield without considering wood processing sector. Non-land inputs are treated as a fixed bundle. The following steps will summarise different methods estimating the impact of rotation length, carbon sequestration and land value on forest owners and land use change.

2.2 Optimal rotation length

Classical models used to estimate the optimal rotation age of a forest are based on Faustmann (1849) and Hartman (1976). Faustmann's formula indicates that the optimal rotation time equals the rate of return on the next best investment (Gardiner, 2009). The maximum sustainable yield (MSY) method is also used to find the optimal rotation age. Gardiner (2009) summarizes that the rotation length is shorter by using the MSY method because it does not take opportunity cost into account. In addition, Samuelson (1976) states that the MSY method is only correct when the interest rate is zero. Faustmann's formula only concerns the net present value of timber to the forest owner. Van Kooten, Binkley, and Delcourt (1995) point out that decisions based on the Faustmann rotation do not necessarily yield the greatest net benefit to society.

Hartman (1976) incorporated carbon sequestration with the timber growth into his work. The functional form for present value of timber plus carbon is shown: (see Van Kooten et al., 1995)

$$\frac{[pv(T)-C]e^{-rT}+\int_0^T \gamma(t)e^{-rt}dt}{1-e^{-rT}}$$

The first order condition for the above function is written as:

$$pv\prime(T) + \gamma(T) = rpv(T) + r\frac{[pv(T)-C]e^{-rT}+\int_0^T \gamma(t)e^{-rt}dt}{1-e^{-rT}}$$

Where $\gamma(t)$ represents the benefit of carbon sequestration of a forest. The first order condition shows that the benefit of the forest owner is made up of timber value plus carbon value at a harvest age T. Carbon sequestration is taken into account by some (see Hertel et al., 2009; Lubowski et al., 2006; Gardiner, 2009; Sohngen, Tennity, Hnytka, & Meeusen, 2009). Van Kooten et al. (1995) show that carbon benefits are a function of the change in biomass growth. This article points out that the growing rate of timber is more important than the tree's age. An important factor is introduced to describe carbon sequestration in timber products called "pickle", which indicates the ratio of carbon that is permanently stocked in timber products.

2.3 The steady-state of forestry

Dee (1991a) used a multisectoral CGE model in which the forestry sector was 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 climate policies such as the ETS. Therefore, the standard factor demand and zero profit equations are replaced by a set of steady-state production relationships. The following equations are taken from Dee (1991b).

$$F(T) = \frac{K}{1-[1-\frac{K}{F(0)}]e^{-gT}}$$

Where $F(T)$ is volume of timber growth per hectare, T is timber growth time length, K is the maximum possible volume of timber per hectare and g is the maximum intrinsic growth rate of trees.

$$R(F; P_f; P_x; X) = [P_f(F - F^*) - P_x X](1 - t_n)$$

Where R refers to net revenue in per hectare per rotation, P_f is output price, P_x is price of non-land input, X is an exogenous fixed bundle of non-land input per hectare per harvest. In addition, F^* states the volume of timber per hectare left standing immediately after each harvest, and t_n is tax on returns to land in forestry.

The present value of net revenue :

$$V(T) = Re^{-r(T-T^*)}[1 - e^{-r(T-T^*)}]^{-1}$$

Where r is discount rate, T^* is the minimum age for trees, so $T - T^*$ is the rotation period.

Optimal harvest is based on max $V(T)$ and then translated into annual output for the whole forest.

$$Y = \frac{(F-F^*)N}{T-T^*}$$

Annual non-land input bundle is calculated as:

$$Z = \frac{XN}{T-T^*}$$

Where Y is annual timber output, N is total land hectares. In a general equilibrium framework, all revenues equal input expenses generate a zero-profit for foresters:

$$P_f Y = P_n N + P_x Z$$

2.4 Impact of carbon sequestration on forestry and land use

Sands and Kim (2009) estimated endogenous land use change in response to climate policy in the US using a model called the Agriculture and Land Use version 2 (AgLU). Previous AgLU models were not able to simulate land use over time in a stable manner without considering the intertemporal nature of forest decisions. The authors assume that the land is allocated among crops, pasture and forests to maximize economic returns to land owners. Land productivity varies across regions. Population growth, income growth and autonomous increases in future crop yields are three main drivers of land use change. However, the authors do not capture all dynamics of forestry. Instead, they simulate forests in their steady state. Under the general equilibrium context, the model finds a set of prices that equate supply and demand for each commodity. Production processes that do not use land directly are described by the CES function, and the demand by consumer is modeled by the Linear Expenditure System (LES). The timber growth function is based on Van Kooten et al. (1995):

$$y(a) = c_1 a^{c_2} e^{-c_3 a}$$

Where a is rotation age, $c_{1,2,3}$ are shape parameters for timber growth curve. This function is used to explore the optimal rotation age by the first order condition. The optimal rotation age a is determined by maximizing the net present value of forest owners at harvest, known as the Faustmann equation:

$$NPV_1(a) = [p_t y(a) - c_h] e^{-ra} - c_g$$

This is a NPV for a single forest's rotation per hectare. Costs here are harvesting and maintenance cost. Maintenance cost refers to the money that is spent on support service to forestry and logging. r is interest rate, p_t is timber price.

$$p_t y\prime(a*) = \frac{r}{1-e^{-ra*}}(p_t y(a*) - c_h - c_g)$$

The left hand side represents the increment to revenue from increasing tree rotation by one year, while the right hand side shows profit at harvest annualized over years. In fact, the benefits of forestry include both timber harvested as well as carbon gains or penalties once carbon is released into the atmosphere. Following Van Kooten et al. (1995), the NPV of carbon sequestration is expressed as below:

$$NPV_A(a) = p_c k[y(a)e^{-ra} + r\int_0^a y(x)e^{-rx}dx]$$

Equation (2.4) shows the net present value of forest land use by positive carbon sequestration from a growing tree, p_c is carbon price, k is a factor to convert cubic meters of timber to metric tons of carbon, and r is interest rate.

Aside from this, carbon emission is taken as a cost for forest owner. The article assumes a parameter β that accounts for carbon "locked" in wood; commonly referred to as "pickling". Therefore, calculation of carbon emission is:

$$NPV_B(a) = -p_c k(1-\beta)y(a)e^{-ra}$$

The NPV for a whole forest stand is described by summing up the above three parts as shown below:

$$NPV(a) = \frac{NPV_1(a) + NPV_A(a) + NPV_B(a)}{1-e^{-ra}}$$

Sands and Kim (2009) shows that the optimal rotation age becomes longer with a higher carbon price. However, this article does not address problems such as carbon emissions from unmanaged forests, or the effect of increasing carbon price on forestry.

Lennox, Turner, Daigneault, and Jhunjhnuwala (2011) review forest carbon accounting protocols and simulate the impact of a hypothetical US ETS on forestsry by using a multiregional, intertemporal general equilibrium model called "climat-dge" (climate mitigation, adaption and trade in dynamic general equilibrium). The aim of the study is to seek an optimal management of even-aged planted or naturally regenerating forest production, finding out the optimal rotation length. The input proportions and rotation period are determined endogenously from the model. Carbon credit outputs are also modelled. However, the model is restricted as the land input is the same in all periods. Also, the computational considerations limit the number of regions in the model.

2.5 Land Expectation Value method

Other than CGE modeling, some studies make an effort to analyze climate policy and carbon sequestration impact on forest and land use (e.g. Straka & Bullard, 1996; Manley, 2012; Manley & Maclaren, 2010). Manley (2012) assumes that the NZ ETS creates two streams of cashflow for forestry profitability: one relates to traditional forestry and another one associates with carbon trading. The study examines the impact of the ETS on forest valuation which involves carbon trading value. The constant discount rate is set at 8%, with \$25/t carbon price and \$30/ha fixed cost, which is similar to Manley and Maclaren (2010) who use the same discount rate, but a different carbon price of \$30/t and fixed cost of \$60/ha. Land expectation value

(LEV) rises with the increment of carbon price (e.g. the LEV is \$3392 at carbon price \$15/t and \$6647 at \$30/t) and calculation of crop value for LEV has challenges such as non-permanence of carbon stock and ongoing liability of residues. Since carbon credits are required to be surrendered at the harvest age and for the decay of residues, this means that the carbon component of crop value is negative from about mid-rotation and that the negative will last to harvest when there is no forestry crop value to offset it. In particular, the reason why there is little afforestation recently is that the LEV of traditional forestry is lower than the land cost (e.g. the LEV of traditional forestry for the clearwood regime is \$1223/ha whereas land costs are at least \$3000/ha). However, this study applies a static model of short rotation length and ignores how other sectors and stand impacts on forest value. Also, it does not consider the impact of the forestry profitability on the local labor market.

Manley and Maclaren (2010) investigate whether to establish new forest, choice of species and silviculture as well as rotation length for NZ radiata pine, douglas fir and eucalyptus nitens under the NZ ETS. This work uses financial return as LEV and NPV to analyze the impact of the carbon trading scheme on forestry. It shows that the rotation length increases with expected carbon price. The weakness of this paper is that the log price is fixed by assumption.

Loza-Balbuena (2009) studies the role of forestry in mitigating NZ climate policy. It also analyzes the impact of different mechanisms on potential areas across NZ in terms of comparing the difference between LEV and LMV (land market value) for forest owners. The LEV is calculated as:

$$LEV = NPV * \frac{(1+i)^n}{(1+i)^n - 1}$$

Where the NPV is profit gained by forest owners that is discounted to present value:

$$NPV = \sum_{y=0}^{n} \frac{R_y}{(1+i)^y} - \sum_{y=0}^{n} \frac{C_y}{(1+i)^y}$$

The LEV refers to the willingness to pay for the land. If the LMV is greater than LEV, then new planting areas may be considered. This method is used to evaluate potential land use for sectors. However, the approach to seek the difference between the LEV and LMV is based on rational economic decisions, while in fact not all land use decisions are economically rational. The results are compared to the carbon balance at the national level. This paper does not examine the carbon value as carbon sink.

2.6 Conclusion

In summary, the methods used to evaluate forestry land use and carbon sequestration vary. Studies of the optimal rotation show that this length is shorter by using the MSY method than by Faustmann evaluation. Samuelson (1976) shows the MSY method does not take into account of land value of forest, therefore, the MSY is only correct if the land value equals zero and the optimal rotation length will be same as the Faustmann rotation. Timber volume depends on rotation age. However, in most studies the price of stumpage trees are assumed to be fixed. A steady-state forest runs in the long-term with equal size of forest in each period. The CGE method captures changes among all industries in an economy. Therefore, CGE method is particularly useful when estimating the impact of climate policy on forestry carbon sequestration and land use.

3 Model

3.1 General Assumptions

This article studies the land use change between forestry and four agricultural sectors in a general equilibrium context. New Zealand is treated as a small open economy. The model involves 12 industries as seen in table 1. Land is allowed to convert in five of them: horticulture and fruit growing; sheep, beef cattle and grain farming; dairy cattle farming; other agriculture; and forestry. This paper includes five types of land based on land cover database (LCDBV2) classes. Industry use of the five types of land is supplied by Agribase company. Different lands are used in agricultural and forestry activities as: forest land; other land; grass land; scrub land; and crop land. Agents in the model are: households, government, enterprise and rest of world (row).

Primary	Primary	Agriculture	Horticulture and fruit growing
Primary	Primary	Agriculture	Sheep, beef cattle and grain farming
Primary	Primary	Agriculture	Dairy cattle farming
Primary	Primary	Agriculture	Other Agriculture
Primary	Primary	Forestry	Forestry
Primary	Primary	Mining, oil and coal	Mining, oil and coal
Secondary	Manufacturing	Agricultural Manufacturing	Agricultural manufacturing
Secondary	Manufacturing	Forestry Manufacturing	Forestry Manufacturing
Secondary	Manufacturing	Other Manufacturing	Other Manufacturing
Utility	Utility	Utility	Utility
Construction	Construction	Construction	Construction
Tertiary	Service Industries	Services	Services

Table 1: Industries

3.1.1 Industry

It is assumed that forestry is in a steady-state situation. Trees are not chopped down until at the optimal rotation age. We consider a constant harvesting and replanting cost which includes land transition cost. Profits of forester are equalize each year from the beginning to optimal rotation age.

Natural forest and managed planting trees are participants to the NZ ETS. Managed planting trees involve two parts: pre-1990 and post-1989 trees. Government distributes one-off carbon credits to pre-1990 forest land owners but mandates post-1989 forest land owners. As post-1989 forest land owners, they will receive carbon credit as carbon stored but face liability when carbon is released to atmosphere. This paper selects pruned trees without production thinning pine as sample.

Total harvested timbers, along with final goods from the other industries are used as intermediate inputs for forestry processing sector. Forestry manufactures utilize capital, labor and intermediate use. We assume agricultural activity includes horticulture and fruit growing; sheep, beef cattle and grain farming; dairy cattle farming and other agriculture. These sectors apply three factors for value-added: capital, labor, composite land. Industries pay return to household, and pay indirect tax as production tax to government. Domestic production is allocated as domestic sale and export. Imported goods and domestic output makes up whole domestic supply. Producers are assumed minimize factor costs seeking the optimal level of factor use. Besides, they maximize profits to reach the optimal output level. The model is a static version but forestry plays in a steady-state situation.

3.1.2 Households

The representative household in the model supplies and receives a return, on all factors and transfers from enterprise and government as well as the row, to industries. Household income is taxed by government. Portion of the income is used as saving. Household consumes on final commodities and pay tax on the consumptions. Household maximizes utility to find out the optimal level of each commodity consumption by the Linear Expenditure System (LES) function. We assume 10% as least consumption level for household.

3.1.3 Government

Government consumes final commodities from industries and pay tax. This paper assumes a Leontief function for government consumption. Government saves a fraction of income, transfers to household and row.

3.1.4 Land

Land is assumed heterogeneously in the model, allocated among five sectors. Each of the sector uses composite land into production. Composite land is allocated by five types in terms of CET elasticity. Each type of land has fixed endowment.

3.1.5 Carbon policy

We model carbon tax in this paper with a fixed carbon price NZD$25. All industries face carbon emission liability and pay to government. Subsidies go to forester who owns growing tree.

3.1.6 Factor market

Factors that are used in the production include capital, labor and land. The initial endowment of each factor is exogenous. Capital and labor are mobile among sectors.

3.1.7 Enterprise

Enterprise receives income from capital supply, transfers part of savings and pays direct tax to government.

3.1.8 Investment-savings

In terms of model closure, we assume the investment is exogenous in the model. Investment is driven by enterprise and government. Savings and investment pay indirect tax to government.

3.1.9 Closure

We are going to apply neoclassical closure to factor market which fixes initial factor endowment. Labor is fully employed and factors are mobile across sectors. The Johanson macroeconomic closure (Gilbert & Tower, 2012) is used to fix the investment in terms of government consumption, we set savings as endogenous in this model.

3.1.10 Market Clearing

Commodity markets need to clear at the same with factor market. All agents have zero profit and tax revenue will be allocated to expenditure, investment and households.

3.1.11 ROW

The row sector receives incomes from imports, enterprise transfer, household transfer and government transfer. It also spends on exported commodities and transfers to enterprise, household, tax and savings. ROW needs to pay tarrif to government.

3.2 Forestry production

In general, total output is made by combination of aggregated intermediate and value-added input. The hierarchy tree is used to represent the industry production process as shown in figures below. Each industry follow same production function other than natural forest yield since it is treated in a steady-state situation. We use elasticity of substitution $\frac{\sigma_i - 1}{\sigma_i}$ to replace ρ_i in the production function.

3.2.1 Natural forest yield

We assume a steady-state forestry modeling within a CGE framework. Biomass timber yields are used as an intermediate input demanded by forestry processing. Due to the NZ log prices being effected by export in fact, therefore, the price of timber is assumed constant over rotation. Forestry owners are assumed to make profits from log sales and carbon trading. Following Sands and Kim (2009), we select a timber yield function which can be modified to include carbon sequestration incentives paid to forestry owners.

Biomass timber yield function is given by:

$$y_a = c_1 a^{c_2} e^{(-c_3 a)} \tag{1}$$

Where y_a represents biomass yield function per hectare. $\frac{y_a}{a}$ is harvested timber. $c_{1,2,3}$ are shape parameters to determine the growth timber curve, a is harvested timber age. The optimal rotation age can be solved by maximizing the net present value of natural forest yield over rotation. Timber production activity applies intermediate goods, composite timber land and labor which are nested in production trees:

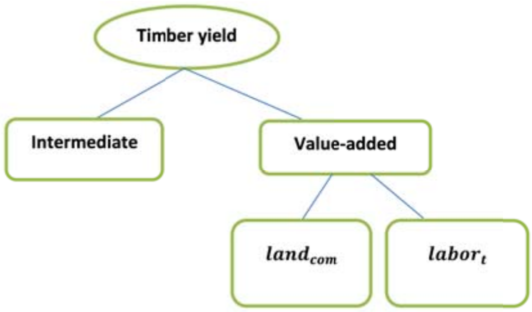

Figure 1: Timber production

Timber yield Q_t uses intermediate inputs, land and labor. Suppose forester receives same profit each year by benefits from logging trees and carbon credit from growing trees. Q_t is total timber production a year. Harvested timber yield is used as intermediate input for other industries as forestry processing, forestry, other manufacturing, and services sector QA_i. Due to the growth function includes single variable a, thus we apply Leontief function to describe the production nesting as shown in figure 1.

$$Q_t = \alpha_{i2} * QA_i$$

$$Q_t = \alpha_{i3} * QVA_t \tag{2}$$

$$QVA_t = \eta_{t1} * labor_t = \eta_{t2} * land_{com} \tag{3}$$

Where α_{i2} and α_{i3} is Leontief coefficient, demonstrates proportion of how much goods from industry i are purchased by timber industry. QA_i is final output from other industries. η_{t1} and η_{t2} imply proportion of land and labor in timber production, while $labor_t$ is amount of labor use in timber yield sector.

Benefits for foresters from logging trees are calculated each year, discounted to present value are:

$$NPV_1(a) = [p_t y_a - c_h]e^{-ra} - c_g \tag{4}$$

Where p_t is unit price of timber, c_h refers to the cost at harvest age. r is the discount rate and c_g is planting cost. It is assumed that harvest and planting cost as constant.

Carbon is sequestered in a growing timber, however, it is released once the trees achieve to their harvest age. 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:

$$NPV_2(a) = \int_0^a p_c k y'(x) e^{-rx} dx = p_c k[y(a)e^{-ra} + r\int_0^a y(x)e^{-rx} dx] \tag{5}$$

Where k is a factor to convert cubic meters of timber to metric tons of carbon, r is interest rate. The integral part represents carbon sequestration with growing timber from planting to harvest age.

On the other side, forest owners will face penalty for carbon emission when logging timber at age a, so the loss of carbon discounted to present value is based on Sands and Kim (2009):

$$NPV_3(a) = -p_c k(1-\beta)y(a)e^{-ra} \tag{6}$$

The present value of net benefits for the forest owners over all of the future timber rotations is calculated by integrating the above three NPVs (Sands & Kim, 2009; Hertel et al., 2009).

$$NPV_{for}(a) = \frac{NPV_1(a) + NPV_2(a) + NPV_3(a)}{1-e^{-ra}} \tag{7}$$

NPV_{for} shows a net benefit that forest owners obtain from year 0 to optimal rotation age. The optimal rotation age a is obtained by differentiating $NPV_{for}(a)$ with respect to a. Based on Sands and Kim (2009) the modified Faustmann condition is derived to find the optimal a:

$$\frac{(p_t+p_c k\beta)(y'(a)e^{-ra}-ry(a)e^{-ra})+r*c_h*e^{-ra}+r*p_c*k*y(a)*e^{-ra}}{(p_t+p_c*k*\beta)*y(a)*e^{-ra}-c_h*e^{-ra}-c_g+r*p_c*k*\int_0^a y(x)e^{-rx}dx} = \frac{re^{-ra}}{1-e^{-ra}} \tag{8}$$

The above equation is derived from setting the numerator of differentiating $NPV_{for}(a)$ equals zero. The result implies the natural forest yield land use value.

Equation (7) determine the optimal rotation age for timbers with assumption of never chopping down trees until the year a. In steady state situation, forester cuts trees and replant with the same amount each year. Therefore, $\frac{y_a}{a}$ trees are chopped down per year. The new benefit of selling timber annually is given as:

$$NPV_1^t = \frac{(p_t^t * \frac{y_a}{a} - \frac{\bar{c_h}}{a}) * e^{-ra} - \frac{\bar{c_g}}{a}}{1 - e^{-ra}} \tag{9}$$

Following the NZ ETS policy, post-1989 forest land owner receives carbon credit as subsidy when carbon is stored but faces penalty as carbon is released. We assume a "pickling factor" β (see Sands and Kim (2009); Van Kooten et al. (1995); Gardiner (2009)) for permanent carbon storage in wood. If β equals zero, all carbon is released into atmosphere.

Annual carbon subsidy is taken as part of forester's income. In a steady state situation, carbon subsidy is equally each year. NPV of carbon subsidy that forester received from growing trees each year is given:

$$NPV_2^t = \frac{r * NPV_2}{1 - e^{-ra}} \tag{10}$$

We assume a payment for forest land every year gives the same increase in NPV_2^t. Therefore, a steady state payment per hectare is $r * NPV_2$ of carbon sequestration. r is interest rate.

We simulate carbon emission as chopped trees and harvested trees each year, repeating to optimal rotation age. Each year the amount of chopped trees are $\frac{y_a}{a}$, therefore, amount of carbon emission is given:

$$CE_{timber} = k * (1 - \beta) * (\frac{y_a}{a}) \tag{11}$$

Annual carbon cost that is paid by forester is calculated as $CE * P_c$.

3.2.2 Forestry processing

The total harvested timber is used as one of intermediate inputs for wood processing. Production nesting is seen as figure 2. We apply the Leontief function to describe substitution between value-added and intermediate inputs, and among intermediate inputs. Productivity is assumed as 1 because of perfect competitive market. Total output for wood processing sector:

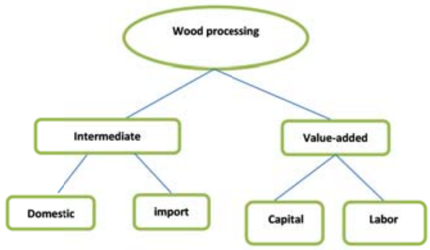

Figure 2: Forestry processing

$$QA_{for} = [\delta_{for1} * QINTA_{for}^{\frac{\sigma_{for}-1}{\sigma_{for}}} + \delta_{for2} * QVA_{for}{}^{\frac{\sigma_{for}-1}{\sigma_{for}}}]^{\frac{\sigma_{for}}{\sigma_{for}-1}} \tag{12}$$

Because of the Leontief elasticity, so σ_{for} equals 0. It implies no matter how the yearly timber price changes, harvested timbers are purchased by the wood procession sector. Producer price is written as PA_{for} which will be taxed for production and carbon emission.

$$(1 + t_{for} + \frac{p_c}{PA_{for}} e_{for}) PA_{for} * QA_{for} = PVA_{for} * QVA_{for} + PINTA_{for} * QINTA_{for} \tag{13}$$

$$\frac{PVA_{for}}{PINTA_{for}} = \frac{\delta_{for2}}{\delta_{for1}} * (\frac{QINTA_{for}}{QVA_{for}})^{\frac{1}{\sigma_{for}}} \tag{14}$$

We allow for possibility that intermediates might transform between domestic and imported goods with elasticity of transformation σ^{for}. However, the σ^{for} equals zero. It implies production has leontief use of intermediate consumption. Domestic timber is harvested trees generated from natural timber industry. The value-added part includes capital and labor, which can substitute for each other.

$$QINTA_{for} = [\delta_1 QINT_{for,d}^{\frac{\sigma^{for}-1}{\sigma^{for}}} + \delta_2 QIM_{for}^{\frac{\sigma^{for}-1}{\sigma^{for}}}]^{\frac{\sigma^{for}}{\sigma^{for}-1}} \tag{15}$$

Where QA_{for} -aggregate output for forestry

t_{for} –tax rate on wood processing output

δ_{for1} -share parameter for intermediate input in forestry production

δ_{for2} -share parameter for value-added input in forestry production

δ_1 -share parameter for intermediate inputs between domestic and imported

δ_2 -share parameter for intermediate inputs between domestic and imported

QVA_{for} -quantity of value-added input in forestry production

σ_{for} -substitution elasticity

$QINT_{for,d}$ -domestic intermediate goods

QIM_{for} -imported intermediate goods

$QINTA_{for}$ -quantity of aggregate intermediate input in forestry processing

PA_{for} -wood commodity price

PVA_{for} -aggregate forestry value-added input price

$PINTA_{for}$ -aggregate intermediate input price

The value-added bundle composes two primary factors: capital (k) and labor (l). Producers pay tax t_k and t_l for factor use. Given a fixed output, the producers allocate factor use subject to cost minimization. The capital accumulation is not taken into account, therefore, the cost minimization problem for value-added input is depicted as below:

$$QVA_{for} = [\theta^k_{for} k_{for}^{\frac{\sigma^{for}_{kl}-1}{\sigma^{for}_{kl}}} + (1-\theta^k_{for}) labor_{for}^{\frac{\sigma^{for}_{kl}-1}{\sigma^{for}_{kl}}}]^{\frac{\sigma^{for}_{kl}}{\sigma^{for}_{kl}-1}} \tag{16}$$

$$\min c_{kl} = p^{for}_k * k_{for} + p^{for}_{labor} * labor_{for}$$

$$s.t. QVA_{for} = [\theta^k_{for} k_{for}^{\frac{\sigma^{for}_{kl}-1}{\sigma^{for}_{kl}}} + (1-\theta^k_{for}) labor_{for}^{\frac{\sigma^{for}_{kl}-1}{\sigma^{for}_{kl}}}]^{\frac{\sigma^{for}_{kl}}{\sigma^{for}_{kl}-1}}$$

$$\frac{p^{for}_k}{p^{for}_{labor}} = \frac{\theta^k_{for}}{1-\theta^k_{for}} * (\frac{labor_{for}}{k_{for}})^{\frac{1}{\sigma^{for}_{kl}}} \tag{17}$$

Where c_{kl} -cost in value-added nest

k_{for} -capital use in forestry

$labor_{for}$ -labor use in forestry

QVA_{for} -aggregate k-l output in forestry

3.3 Agricultural production

Being consistent with social accouting matrix, agricultural activity includes horticulture and fruit growing; sheep, beef cattle and grain farming; dairy cattle farming; and other agriculture. It is assumed all of them use same production nesting. This paper uses QA_{ag} to represent agricultural sector. The nested function includes two sub nests: intermediate input and value-added. Similar to wood processing sector, agriculture applies leontief use of intermediate input from domestic and imported goods.

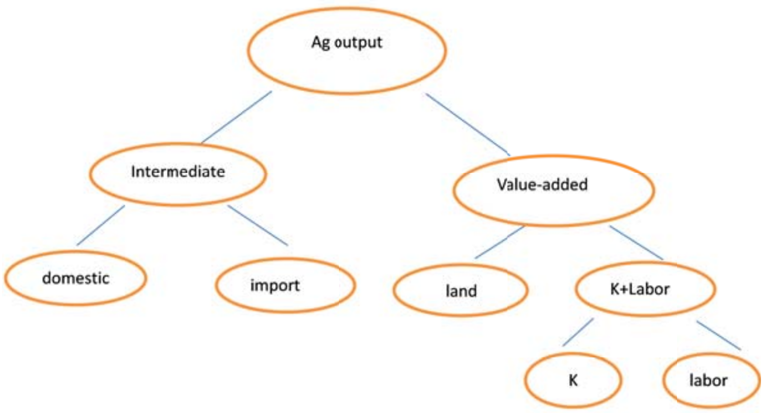

Figure 3: Agricultural production

Total output of agriculture products are:

$$QA_{ag} = [\delta_{ag} QINTA_{ag}^{\frac{\sigma_{ag}-1}{\sigma_{ag}}} + (1-\delta_{ag}) QVA_{ag}^{\frac{\sigma_{ag}-1}{\sigma_{ag}}}]^{\frac{\sigma_{ag}}{\sigma_{ag}-1}} \tag{18}$$

$$(1 + t_{ag} + \frac{p_c}{PA_{ag}} e_{ag}) * PA_{ag} QA_{ag} = PINTA_{ag} QINTA_{ag} + PVA_{ag} QVA_{ag} \tag{19}$$

$$\frac{PVA_{ag}}{PINTA_{ag}} = \frac{1-\delta_{ag}}{\delta_{ag}} (\frac{QINTA_{ag}}{QVA_{ag}})^{\frac{1}{\sigma_{ag}}} \tag{20}$$

Intermediate goods between domestic and imported commodities with elasticity of transformation σ^{ag} which is zero:

$$QINTA_{ag} = [\delta_3 QINT_{ag,d}^{\frac{\sigma^{ag}-1}{\sigma^{ag}}} + \delta_4 QIM_{ag}^{\frac{\sigma^{ag}-1}{\sigma^{ag}}}]^{\frac{\sigma^{ag}}{\sigma^{ag}-1}} \tag{21}$$

3.3.1 Agriculture value-added nest

Agriculture plays a significant role in carbon-equivalent gas emissions in NZ. Land and fertilizer are set as a bundle to substitute with capital, labor and energy bundle. Land is a composite land use in agriculture production. Similar to forestry processing, to achieve a target quantity, at each level producer minimizes input cost.

At the bottom level of value-added nest for capital-labor bundle:

$$\min c_{kl} = p_k * k + p_{labor} * labor$$

s.t.

$$Q_{kl} = [\beta_{ag}^{kl} * k^{\frac{\sigma_{kl}-1}{\sigma_{kl}}} + (1-\beta_{ag}^{kl}) * labor^{\frac{\sigma_{kl}-1}{\sigma_{kl}}}]^{\frac{\sigma_{kl}}{\sigma_{kl}-1}} \tag{22}$$

$$\frac{p_k}{p_{labor}} = \frac{\beta_{ag}^{kl}}{1-\beta_{ag}^{kl}} * (\frac{labor}{k})^{\frac{1}{\sigma_{kl}}} \tag{23}$$

At the first level of value-added nest for land-kl bundle:

$$\min c_{lkl} = p_{land} land_{com} + p_{kl} * Q_{kl}$$

s.t.

$$Q_{lkl} = [\beta_{ag}^{lkl} * land_{com}^{\frac{\sigma_{lkl}-1}{\sigma_{lkl}}} + (1-\beta_{ag}^{lkl}) * Q_{kl}^{\frac{\sigma_{lkl}-1}{\sigma_{lkl}}}]^{\frac{\sigma_{lkl}}{\sigma_{lkl}-1}} \tag{24}$$

$$\frac{p_{land}}{p_{kl}} = \frac{\beta_{ag}^{lkl}}{1-\beta_{ag}^{lkl}} * (\frac{Q_{kl}}{land_{com}})^{\frac{1}{\sigma_{lkl}}} \tag{25}$$

Each equation has different value for composite land, labor and capital use in different sectors. Sectors include horticulture and fruit growing; sheep, beef cattle and grain farming; dairy cattle farming and other agriculture.

3.4 Land allocation

Land is heterogeneous in the model with different price by industry. We use CET function to disaggregate composite land as two uses by industry, model six types of land in each sector use. In the land production nesting, we first aggregate three agricultural activities into agriculture nest, leave forest to forestry nest. We label land type with six numbers as seen in table 2.

type 1	forest land
type 2	other land
type 3	grassland
type 4	scrub land
type 5	cropland

Table 2: land type

Each of the land applied in five sectors follow same land use nesting as seen in fig 4.

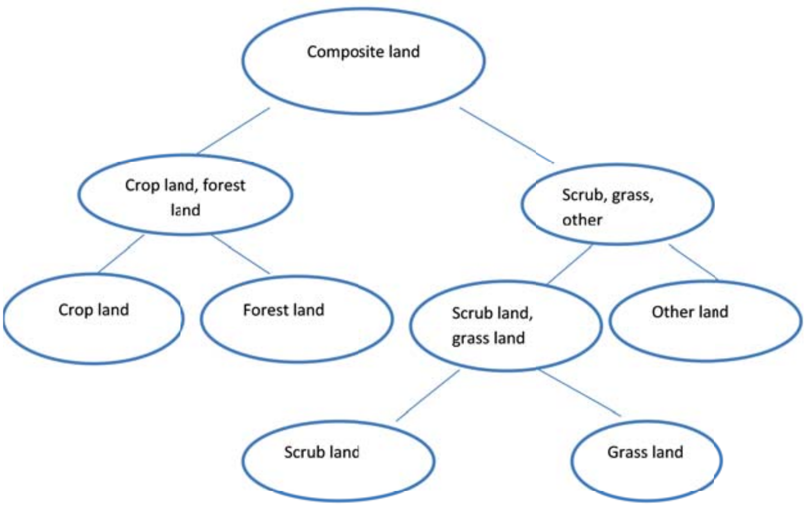

Figure 4: land type nesting

Following market clearing condition, land supply function is given in CET format:

$$Q_{land}^{com} = [\beta_{land} Land_i^{\frac{\sigma_{land}-1}{\sigma_{land}}} + (1-\beta_{land}) Land_j^{\frac{\sigma_{land}-1}{\sigma_{land}}}]^{\frac{\sigma_{land}}{\sigma_{land}-1}} \tag{26}$$

Land supply equation is given by:

$$\frac{Pland_i}{Pland_j} = \frac{\beta_{land}}{1-\beta_{land}} * (\frac{Land_j}{Land_i})^{\frac{1}{\sigma_{land}}} \tag{27}$$

Where $Pland_i$ and $Pland_j$ are price of different land types that are demanded by different sector. i and j refer to five land types in the land nesting graph. β_{land} is share of each land in the land nesting bundles, and σ_{land} is elasticity of transformation.

3.5 ROE production

Sectors in ROE are Mining, oil and coal; Other manufacturing; Utility; Construction; Services. All of the sectors apply similar production nesting with other industries. We assume an average emission factor in the rest of industries e_{roe}. The nested production tree is shown as:

$$QA_{roe} = [\delta_{roe} QINTA_{roe}^{\frac{\sigma_{roe}-1}{\sigma_{roe}}} + (1-\delta_{roe}) QVA_{roe}^{\frac{\sigma_{roe}-1}{\sigma_{roe}}}]^{\frac{\sigma_{roe}}{\sigma_{roe}-1}} \tag{28}$$

$$(1 + t_{roe} + \frac{p_c}{PA_{roe}} e_{roe}) PA_{roe} * QA_{roe} = PINTA_{roe} * QINTA_{roe} + PVA_{roe} * QVA_{roe} \tag{29}$$

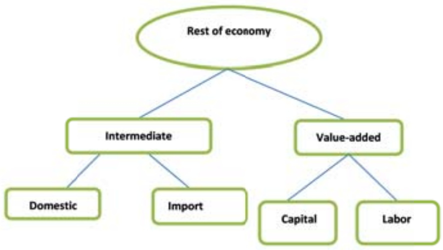

Figure 5: Rest of economy production

$$\frac{PVA_{roe}}{PINTA_{roe}} = \frac{1-\delta roe}{\delta_{roe}}\left(\frac{QINTA_{roe}}{QVA_{roe}}\right)^{\frac{1}{\sigma_{roe}}} \tag{30}$$

Intermediate goods between domestic and imported commodities with elasticity of transformation σ^{roe}:

$$QINTA_{roe} = [\delta_5 QINT_{roe,d}^{\frac{\sigma^{roe}-1}{\sigma^{roe}}} + \delta_6 QIM_{roe}^{\frac{\sigma^{roe}-1}{\sigma^{roe}}}]^{\frac{\sigma^{roe}}{\sigma^{roe}-1}} \tag{31}$$

Capital and labor are used into the roe production process as value-added part, producers need to pay tax for factor use:

$$QKL_{roe} = [\psi^k * k_{roe}^{\frac{\sigma_{kl}^{roe}-1}{\sigma_{kl}^{roe}}} + (1-\psi^k) labor_{roe}^{\frac{\sigma_{kl}^{roe}-1}{\sigma_{kl}^{roe}}}]^{\frac{\sigma_{kl}^{roe}}{\sigma_{kl}^{ag}-1}} \tag{32}$$

$$\frac{p_k^{roe}}{p_{labor}^{roe}} = \frac{\psi^k}{1-\psi^k} * (\frac{labor_{roe}}{k_{roe}})^{\frac{1}{\sigma_{kl}^{roe}}} \tag{33}$$

3.6 Joint production

Based on 2007 New Zealand supply-use table and social accounting matrix, the aggregated four industries have joint production but not much. Joint production implies one industry produces more than one goods at the same time. Since the amount for each industry producing other industries' goods is not much, here we assume the relative good which is produced from one industry is by-product. For instance, agriculture produces dairy, which is similar to dairy product produced by the roe. This paper applies the Leontief function to describe the output production.

$$QA_i = [\delta_i QINTA_i^{\frac{\sigma_i-1}{\sigma_i}} + (1-\delta_i)QVA_i^{\frac{\sigma_i-1}{\sigma_i}}]^{\frac{\sigma_i}{\sigma_i-1}} \tag{34}$$

We use input-output coefficient α_{ij} to describe the joint output:

$$QA_j = \alpha_{ij} * QA_i \tag{35}$$

Where i and j refer to different industries.

3.7 Carbon tax

This paper investigates land use change under the carbon tax scenario, with a fixed carbon price NZD$25. Carbon tax is collected base on carbon emissions in each industry. Carbon emission amount for agriculture and rest of economy in base year 2007 is given by social accounting matrix. Therefore, carbon tax rate for all industries are given:

$$t_{c,ag} = \frac{p_c * CE_{ag}}{PA_{ag} * QA_{ag}} \tag{36}$$

$$t_{c,timber} = \frac{p_c * CE_{timber} * land_{com} - CFS * land_{com} * e^{ra}}{p_t * y_a * land_{com}} \tag{37}$$

$$t_{c,for} = \frac{p_c * CE_{roe} * QA_{for}}{PA_{for} * QA_{for} + PA_{roe} * QA_{roe}} \tag{38}$$

$$t_{c,roe} = \frac{p_c * CE_{roe} * QA_{roe}}{PA_{roe} * QA_{roe} + PA_{for} * QA_{for}} \tag{39}$$

3.8 Demand

Consumers maximize their utility subject to disposable income. Final demand side contains four parts: household, investment, government and export. The commodity has twelve categories ($i = 12$) which come from twelve industries.

3.8.1 Household

It is assumed there is a representative household in the model demanding all final goods from the three industries. To better reflect the fact, we choose the Linear Expenditure System (LES) function in which we set a minimum quantity of consumption $\bar{x_i}$. The household receives pre-tax returns from factors, the optimal demanded quantity is explored by maximizing utility subject to income constraint:

$$\max u(x_i^h) = \sum_{i=1}^{12} \beta_i^h ln(x_i^h - \bar{x_i}^h)$$
$$s.t. \sum_{i=1}^{12} p_i x_i^h = (1 - t_h)Y_h \tag{40}$$

$$(1-t_h)Y_h = (\sum_{i=1}^{F} p_i F + transf_g^h + transf_{ent}^h + exr * transf_{row}^h) - (savings_h + transf_h^g + transf_h^{ent} + exr * transf_h^{row}) \tag{41}$$

Where t_h is an income tax that household needs to pay, Y_h is the disposable income that comes from factor returns and transfers from government, enterprise and the row. Portion of household income is used as saving, the rest of the income are transferred to government, enterprise and the row with an exchange rate exr.

Therefore, the demanded quantity of each commodity by household is:

$$x_j^h = \bar{x_j^h} + \frac{\beta_j^h[(1-t_h)Y_h - \sum_{i=1}^{12} p_i \bar{x_i^h}]}{p_j} \tag{42}$$

3.8.2 Government

Total income for government includes factor tax, income tax, imported tax, transfers from household and enterprise. To keep the debt balance, government transfers to the row with a currency exchange rate exr.

$$(1-t_g)Y_g = \sum_i t_i P_i F_i + P_c * k * QA_{ag} + P_c * k * QA_{for} + NPV_3 - NPV_2 + t_h Y_h + t_{ent} Y_{ent} + \sum_m t_m PM * QM * r + transf_{ent}^{g} + transf_{h}^{g} - exr * transf_{g}^{row} - transf_{g}^{h} - Saving_g \tag{43}$$

Government pays tax for its own consumption by t_g, it collects factor taxation from factor uses; income tax from household and enterprise; and carbon tax that comes from agriculture and wood processing but is as subsidy to natural forest owners. Additionally, government receives imported tax from the row.

The paper assumes a fixed ratio a_i^g of consumption on each commodity in terms of Leontief function given by:

$$\max u^g(x_i^g) = \min(\frac{x_1^g}{a_1^g}, \ldots \frac{x_i^g}{a_i^g}) \tag{44}$$

Where p_{fi}–price of factors that are used in industry productions, $i \in industries$

x_i^g-government consumption of commodity i, $i \in industries$

a_i^g-share parameter of government consumption of commodity x_i

$t_i, i \in h, f, ent$
–tax rate of income and factor

$transf_h^g$
–transfer from household to government

$transf_g^h$
–transfer from government to household

$transf_{ent}^{g}$
–transfer from enterprise to government

$transf_{g}^{ent}$
–transfer from government to enterprise

$saving_{g}$
–government saving

3.8.3 Investment-Saving

As set by Johanson closure (Gilbert & Tower, 2012), the total investment is exogenous in the model, saving is endogenized aiming to balance government income and expenditure. Investment does not require any final commodity. The expenditure E_{inv} equals investment value by using commodity price times fixed investment endowment.

$$E_{inv} = \sum p_{inv} * \bar{X_{inv}} \tag{45}$$

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

$$saving = p_s(s_{ent} + s_g + s_h + s_{row}) \tag{46}$$

3.8.4 Enterprise

Enterprise receives returns from capital, transfers from household and the row. The disposable income for enterprise is depicted as:

$(1-t_{ent})Y_{ent} = p_k K + transf_h^{ent} + transf_{row}^{ent} - (transf_{ent}^h + transf_{ent}^g + transf_{ent}^{row} + savings_{ent})$
(47)

3.9 Rest of World

Now we consider an open economy for NZ market. Total output are allocated to export and domestic market in terms of the constant elasticity of transformation (CET) functional form. Imported goods and domestic production are sold in the domestic market. We assume that the imported and domestic goods are heterogeneous, therefore, they are not perfectly substitute. Armington function is used to depict the substitution. Equations are given by:

$$QA_i = A[\delta_1 QD_i^{\frac{\sigma_1 - 1}{\sigma_1}} + \delta_2 QX_i^{\frac{\sigma_1 - 1}{\sigma_1}}]^{\frac{\sigma_1}{\sigma_1 - 1}}, i \in ag, for, roe \tag{48}$$

Where 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 $\delta_{1,2}$.

$$PA_i * QA_i = PD_i * QD_i + PX_i * QX_i \tag{49}$$

$$PX_i = (1 + t_x) * exr * PW_i \tag{50}$$

Export price is free on board (FOB) price, effected by exchange rate and world price of commodity. Where t_x is export tax, exr is exchange rate for NZ to the export destination, PW is the world price. These are exogenous variables to the model.

Therefore, we can obtain the relationship between commodity price and amount for both domestic and export:

$$\frac{PD_i}{PX_i} = \frac{\delta_1}{\delta_2} * (\frac{QX_i}{QD_i})^{\frac{1}{\sigma_1}} \tag{51}$$

Commodities supply on domestic market are composed by imported and domestic goods. This is also the aggregate goods categories by final demand. It is described by Armington assumption with the CET functional form.

$$Q_i = B[\delta_3 QD_i^{\frac{\sigma_2 - 1}{\sigma_2}} + \delta_4 QM_i^{\frac{\sigma_2 - 1}{\sigma_2}}]^{\frac{1}{\sigma_2}} \tag{52}$$

QM_i is the value of imported goods, the allocation of domestic input and imported input is depending on share parameter $\delta_{3,4}$. Correspondingly, the ratio of domestic price to imported price is given by:

$$\frac{PD_i}{PM_i} = \frac{\delta_3}{\delta_4} * (\frac{QM_i}{QD_i})^{\frac{1}{\sigma_2}} \tag{53}$$

$$PM_i = (1 + t_m) * PW_i * exr \tag{54}$$

The import price is effected by exchange rate, world price of commodity i and impot tax t_m. These are also exogenous variables.

4 Market clearing

The model requires both factor and commodity markets clearing at the same time. Zero-profit is required for each producer. All domestic supply and production need to equal domestic final demand. Total commodity supply is composed of intermediate inputs including imported and domestic, household consumption, government purchase and investment demand. Furthurmore, the Johanson macro-closure is applied in this paper.

Commodity market clearing:

$$Q_i = \sum QINT_i + \sum Q_h + \bar{Q_g} + Q\bar{_{INV}} \tag{55}$$

$$QA^s_{ind} = \sum x^d_i, i \in household, government, investment, export \tag{56}$$

Factor market clearing:

$$labor^d_i = lab\bar{o}r^s_h \tag{57}$$

$$k^d_i = \bar{k^s_h} + k^{\bar{s}}_{ent} \tag{58}$$

$$lan\bar{d}^{com}_{for} = land^{hor}_{for} + land^{other}_{for} + land^{sheep}_{for} + land^{dairy}_{for} + land^{for}_{for} \tag{59}$$

Where $\bar{land}^{com}_{for}$ is endowment of composite forestry land. $land^{hor}_{for}$ is forestry land used in horticulture sector, $land^{for}_{for}$ is forestry land used in its own sector, $land^{other}_{for}$ is forestry land used in other agricultural sector, $land^{sheep}_{for}$ is forestryland used in sheep-beef industry, lastly, $land^{dairy}_{for}$ is forestry land used in dairy cattle sector.

$$\bar{land}^{com}_{crop} = land^{hor}_{crop} + land^{other}_{crop} + land^{sheep}_{crop} + land^{dairy}_{crop} + land^{for}_{crop} \tag{60}$$

$$\bar{land}^{com}_{scrub} = land^{hor}_{scrub} + land^{other}_{scrub} + land^{sheep}_{scrub} + land^{dairy}_{scrub} + land^{for}_{scrub} \tag{61}$$

$$\bar{land}^{com}_{other} = land^{hor}_{other} + land^{other}_{other} + land^{sheep}_{other} + land^{dairy}_{other} + land^{for}_{other} \tag{62}$$

$$\bar{land}^{com}_{grass} = land^{hor}_{grass} + land^{other}_{grass} + land^{sheep}_{grass} + land^{dairy}_{grass} + land^{for}_{grass} \tag{63}$$

Closure:

$$p^{i}_{factor} = \bar{p^{i}}_{factor}, i \in agriculture, forestry, roe$$

$$(1 - t_{inv})Y_{inv} = \sum Savings_i = \bar{E_{inv}} \tag{64}$$

5 Data

This section describes data collection in the forest-CGE model. Parameters in the CGE model are calibrated by the social accounting matrix in the base year. Bench-mark data represents an equilibrium for the economy. This part follows the calibration process as suggested in Sánchez et al. (2004). After setting up a static model as shown in previous part, all equations are fed with data from social accounting matrix. Elasticities of substitution and transformation are used from other literature (Rutherford (2003) and NZIER (2004)).

5.1 Natural forest yield

The National Exotic Forest Description (NEFD) report (MPI, 2011) supplies a yield table used to estimate three shape parameters c_1, c_2 and c_3 in timber growth function.

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, Canterbury, Central-north island, Eastcoast, Hawkesbay, Marlborough, Nelson, Northland, Otago, Southern-north island-east coast, Southern-north island-west coast, and Southland. The yield table observes the total standing volume (TSV) and total recovery volume (TRV) of trees with different silviculture over 40 years. For convenience, this paper selects the TSV of radiata pine which is pruned without production thinning as a sample. Based on Sands and Kim (2009), we set parameter c_2 as integer for a closed-form integration function. For calibration by Excel solver, we set c_1 as 0.003, c_2 as 4, and c_3 as 0.09.

To confirm with Manley (2012), we use a constant interest rate as 0.08. As the New Zealand timber market is impacted by overseas, this paper uses the average export price of log per JAS m3 f.o.b.$187 in March 2007 (NZIER, 2004).

5.2 CGE model

5.2.1 Share parameters calibration

The paper sets the unity price of variables from the social accounting matrix and seek the share parameter from the CES/CET production function.

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 social accounting matrix. Format of share parameters in intermediate and value-added nests are the same as the above formula.

The forestry sector assumes a leontief coefficient between all timber production and input. Therefore, share parameters in timber production function are:

$$\alpha_{i3} = \frac{Q_t}{QVA_t}$$

$$\eta_{t1} = \frac{QVA_t}{labor_t}$$

$$\eta_{t2} = \frac{QVA_t}{land_{com}}$$

The Stone-Geary utility and the linear expenditure system (LES) is used to calculate the optimal level of household consumption on each good. The share parameter β_i^h that represents the ratio of consumption of each commodity to total household expenditure is calibrated as:

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

5.2.2 Elasticity data

The social accounting matrix used is based on the New Zealand supply-use table released on 2012. The social accounting matrix is a balanced table and it is also used as database for a general equilibrium model. The dataset supplied by Agribase provides the data for industrial use at March 2007. Agribase supplies survey data from farm owners by AsureQuality. The dataset contains farm areas and farm types as reported by farmers. By merging the Agribase dataset with the land cover database (LCDB2), we obtain land use by industry in hectares.

Elasticities that are used in the CGE model are applied from other literature (Rutherford (2003); NZIER (2004)). Being consistent with MPSGE code, we have five types of elasticities in total.

s	elasticity of substitution between domestic and import
t	elasticity of transformation between domestic and export
elas	elasticity of substitution between value-added input
elas(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

Table 3: Elasticity interpretation

Type	s	t	va	va(for)	dm	d(dm)
Domestic production	0	0	0.7	0		
Allocation of output	0	2				
Export	0	0				
Armington goods		0			2	0
Armington lands	2	2				
Investment	0					
Household consumption	1					
Government consumption	0					

Table 4: Values of elasticities
source:Rutherford (2003), NZIER (2004)

6 Simulation results

This section analyzes the results under four scenarios. There are four carbon taxes set as policy shock. Firstly, we have a baseline at carbon price p_c equals \$0. After this, carbon price is increased as p_c equals \$25, which is the same as the carbon price set by the New Zealand "cap and trade" policy before 2012. The remaining scenarios are p_c is \$50 and \$100. Note that all monetary units are New Zealand dollars.

6.1 Land use conversion by industries

Figure 6 presents land use by five industries at baseline, where carbon tax equals zero. Out of the five sectors, sheep-beef industries take up the most land; 76% in total. Grassland takes up the largest proportion of the total land used by the sheep-beef sector at 71%. Most common after this is scrub land with 11%, forest land with 10%, other land types with 6% and cropland with 3%.

The dairy-cattle sector occupies 11% of the total land. Similarly, the sheep-beef sector, grassland is heavily demanded by dairy-cattle and with a baseline as high as 85%. Forest land takes up 9%, scrub land takes 3% and crop and other land use takes up nearly the same proportion at 2%.

Other agricultural sectors only apply to 3% of total land. Forest land comprises 2% of this. However, grassland still takes a large proportion at

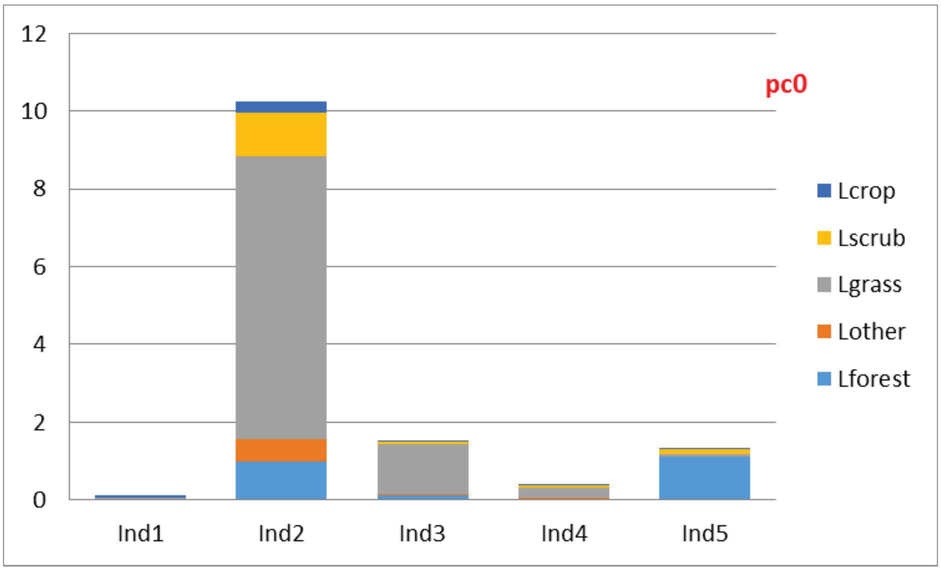

Figure 6: Baseline land use

72%. Other land, scrub land and crop land are used sparingly by this sector, with proportions of 4%, 10%, and 3%, respectively.

Horticulture and fruit growing sector uses only 1% of total land. This sector represents the least land use.

The forestry sector manages 10% of the total land use out of the five sectors. Specifically, 85% of it is forest land, 9% is scrub land and 5% is grass land. Crop land is the type that is used least by forestry at 0%. Lastly, 1% is taken by the other land.

Figure 7, 8, and 9 shows land use change that occur after a policy shock. In brief, more land is converted for forestry use but then the agricultural sector uses less land. Land use in the forestry sector has increased from 10% - 11%, and 13% - 22% under different carbon prices. Forestry has the largest proportion of forest land. The percentage of forest land used in forestry sector to total forest land under the four scenarios are: 49%, 56%, 64%, and 87%. Comparatively, sheep-beef land use decreases with ratios of 76%, 75%, 73%, and 64% under the four scenarios. This is due to increased carbon tax rises, which in turn raise production costs for agricultural sec-

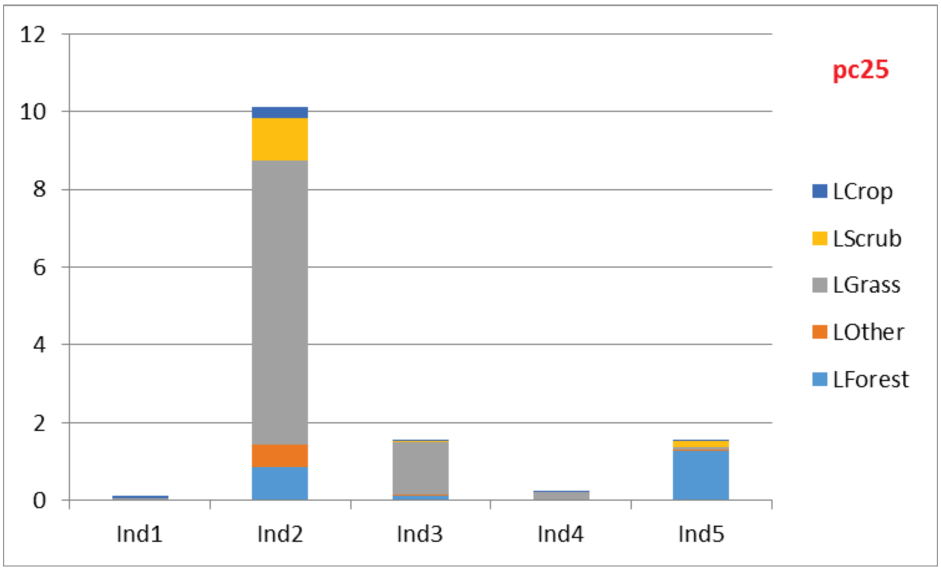

Figure 7: Land use at carbon price of $25

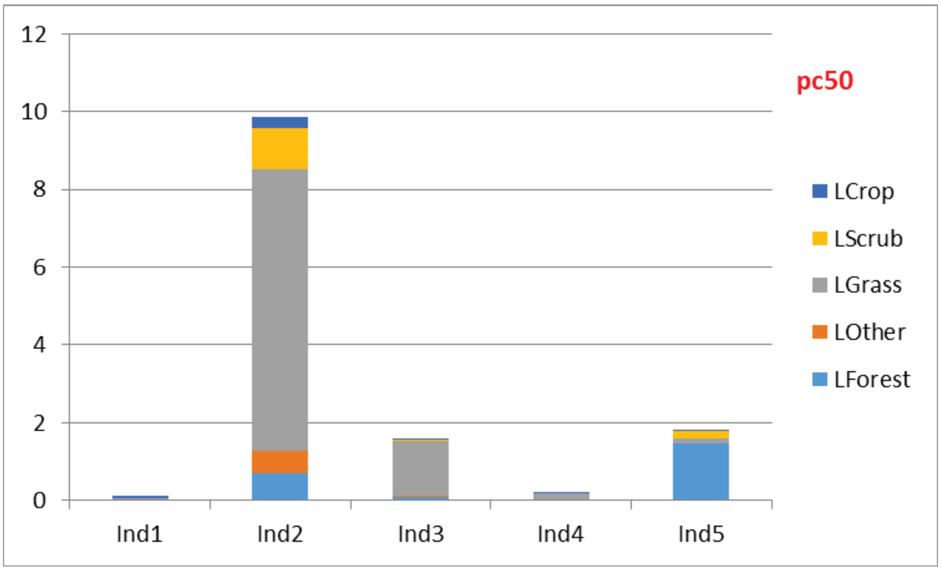

Figure 8: Land use at carbon price of $50

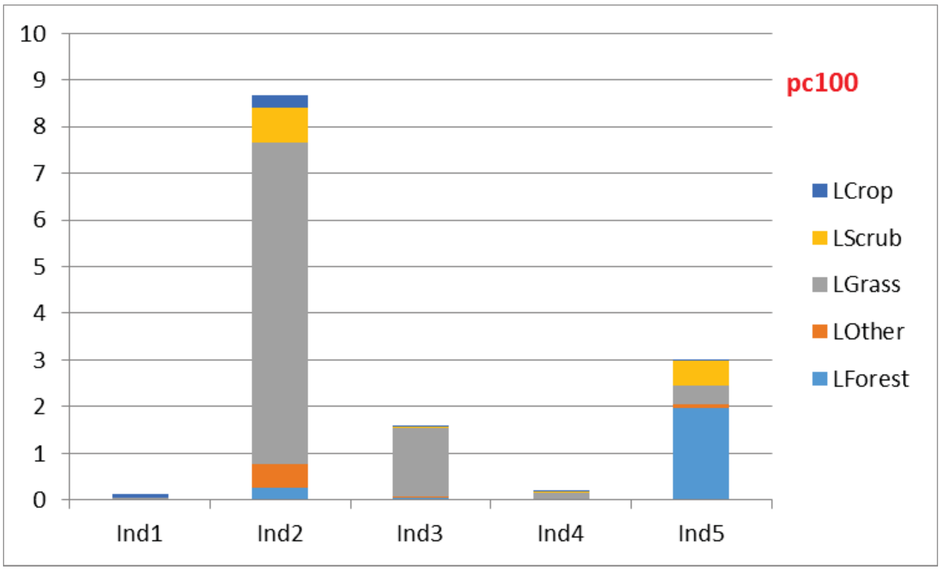

Figure 9: Land use at carbon price of $100

tors. Conversely, government issues a subsidy for carbon sequestration to the forestry sector, therefore more land is used by the forestry sector.

The proportion of land use in horticulture and fruit growing sector to total land remains the same at 1%. However, the land use has been changed in the sector. Forest land use has decreased to 7%, 6%, 5%, and 2% under the four carbon taxes. Other land uses maintain static at 3%. Grassland use increases a little from 32% - 34%. On the other hand, scrub land decreases from 4% to 3% at higher carbon price. This sector uses more crop land as the baseline figure of 54% goes up to 55%, 56% and 58%. Biologically, horticultural sector uses cropland a lot. However, the ratio does not change much, and the industrial land use does not change under different carbon shock.

The change of land use ratios in each industry is given by Table 10. Land use change by land allocation ratio is seen in Table 11.

Land price changes with the amount of land demanded by industries. The CGE model reports relative price at the baseline where each land price is around "1". With higher carbon price, every type of land price is decreased

pc0	LForest	LOther	LGrass	LScrub	LCrop
ind1	7%	3%	32%	4%	54%
ind2	10%	6%	71%	11%	3%
ind3	9%	2%	85%	3%	2%
ind4	11%	4%	72%	10%	3%
ind5	85%	1%	5%	9%	0%
pc25					
Ind1	6%	3%	32%	4%	55%
Ind2	8%	6%	72%	11%	3%
Ind3	7%	2%	86%	3%	2%
Ind4	9%	4%	74%	10%	3%
Ind5	84%	1%	6%	10%	0%
pc50					
Ind1	5%	3%	32%	4%	56%
Ind2	7%	6%	74%	11%	3%
Ind3	6%	2%	87%	3%	2%
Ind4	8%	4%	75%	10%	3%
Ind5	81%	1%	7%	11%	0%
pc100					
Ind1	2%	3%	34%	3%	58%
Ind2	3%	6%	79%	9%	3%
Ind3	2%	2%	91%	3%	2%
Ind4	3%	4%	81%	8%	3%
Ind5	66%	2%	14%	18%	0%

Figure 10: Ratio of land use to total industrial land use

pc0	LForest	LOther	LGrass	LScrub	LCrop
Ind1	0%	1%	0%	0%	17%
Ind2	43%	91%	81%	84%	73%
Ind3	6%	4%	14%	4%	7%
Ind4	2%	3%	3%	3%	3%
Ind5	49%	2%	1%	9%	0%
pc25					
Ind1	0%	1%	0%	0%	17%
Ind2	37%	91%	82%	83%	74%
Ind3	5%	4%	15%	4%	7%
Ind4	1%	2%	2%	2%	2%
Ind5	56%	2%	1%	11%	0%
pc50					
Ind1	0%	1%	0%	0%	17%
Ind2	31%	90%	81%	79%	73%
Ind3	4%	4%	16%	4%	7%
Ind4	1%	1%	2%	2%	2%
Ind5	64%	3%	1%	15%	1%
pc100					
Ind1	0%	1%	1%	0%	20%
Ind2	11%	83%	77%	56%	69%
Ind3	2%	4%	16%	3%	8%
Ind4	0%	1%	2%	1%	2%
Ind5	87%	11%	5%	39%	2%

Figure 11: Ratio of land allocation change

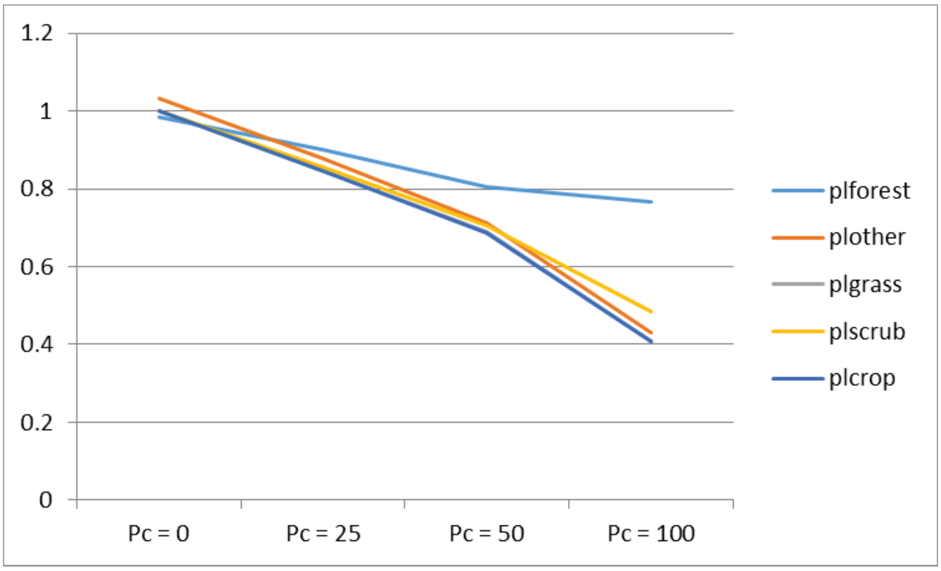

Figure 12: Land price change

as seen in Figure 12. Although the relative price is decreasing, forest land price is still higher when compared to the other four types of land at higher carbon price shock. Crop land price suffers a greater loss.

6.2 Forestry sector results

The government gives a subsidy to the carbon sequestration sector but levies a penalty on the carbon emission industry. Therefore, at a higher carbon price, this is beneficial to forestry activity owners. A higher carbon price extends optimal rotation age and enlarges timber yield. This conclusion is consistent with the findings of Manley (2012).

As seen from model simulation results, the optimal rotation age extends from 21.324 years at baseline to 21.721 years at p_c equals \$25, then to 22.158 years at carbon price is \$50 and to 23.187 years at p_c equals \$100. One possible reason why the change is comparatively smaller is because we assume a constant interest rate, fixed harvesting and replanting costs. Timber yield amount also increases by 4% from baseline to \$100 carbon tax. At baseline, optimal timber yield which is 91.018 units per hectare, which becomes

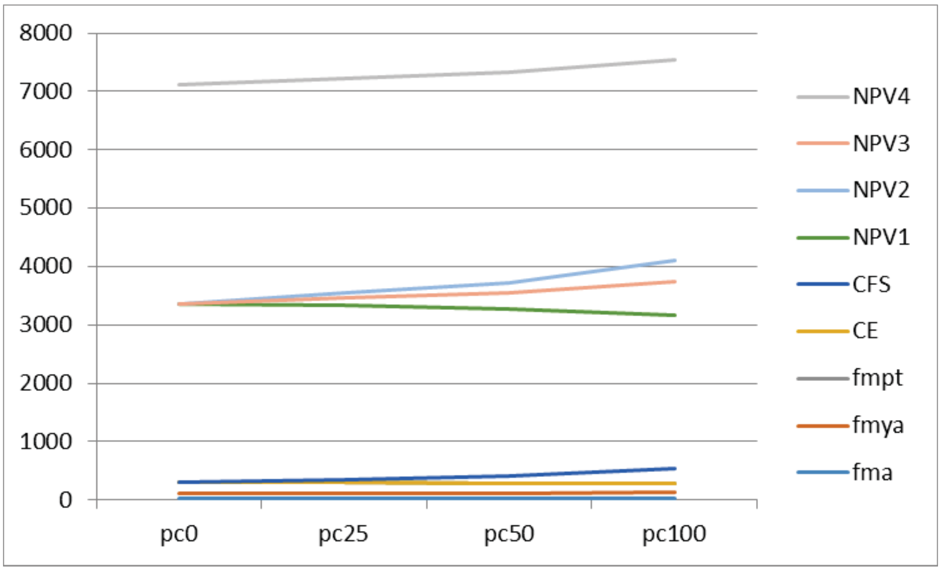

Figure 13: Forestry change

107.594 units per hectare at a carbon price of \$100. Due to increased timber supply, timber price per unit reduces from \$186.832 - \$156.55 (\$180.025, \$172.517, and \$156.55). Forest owners face the liability of the release of carbon into atmosphere when trees are harvested or chopped down. Results show that the amount of carbon emission per hectare is slightly increased from 0.896 - 0.974, while carbon subsidy has increased from \$57.437 - \$259.916 per hectare at p_c is \$25 and \$100. The net present value of carbon sequestration has increased to 77%.

6.3 Commodity change

This model assumes 12 industries have joint production. The exchange rate is endogenous as determined by the model. Figure 14 shows an increasing export price due to the depreciation of the New Zealand dollar in international markets.

We assume processed dairy products can be exported, but that farmers are not allowed to export dairy cattle directly. Therefore, the results do not contain "commodity 3" export. Figure 15 presents the value of exported

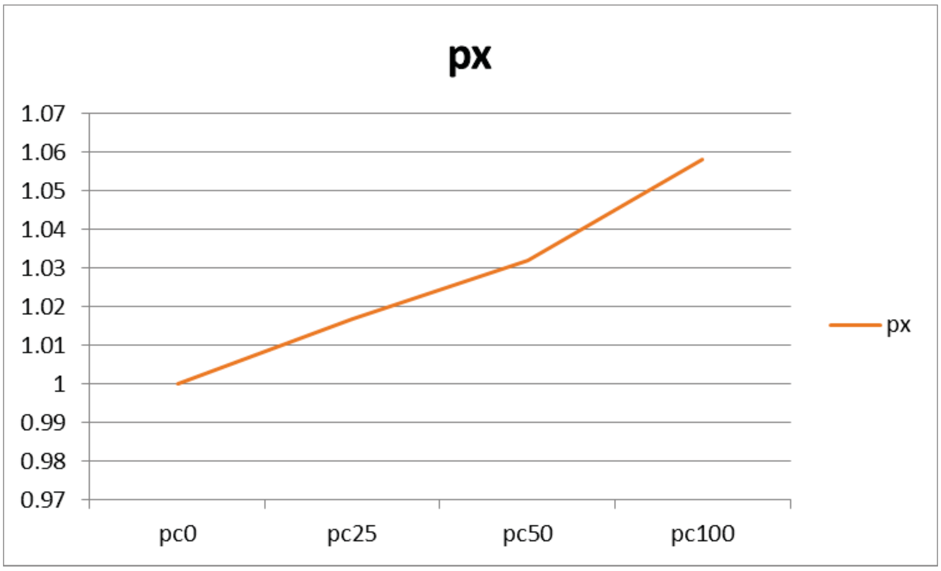

Figure 14: Export price

commodities under each scenario.

The export values of agricultural commodities are decreased in each scenario because of diminished production. Since higher carbon price extends optimal rotation age, the timber yields more at higher carbon price. The export of timber and processed forest commodities increase. In addition, higher carbon tax brings more exports of mineral products, utility, construction, services and other manufacturing products due to an increased export price.

Figures 16 and 17 show domestic commodity price changes under the four scenarios. Figure 17 presents a large percentage increase of 75% for "other agricultural commodities". Some of the agricultural output price is pushed up due to a reduced supply of fruit, dairy and processed agricultural products. The price of sheep-beef products decrease slightly. This is because the production levels in the sheep-beef industry do not change much in the short term. Similarly, due to a large conversion to forest land, forestry and processed forestry supply more products which lowers commodity price.

Demand for energy use and Manufacturing goods is still strong in New

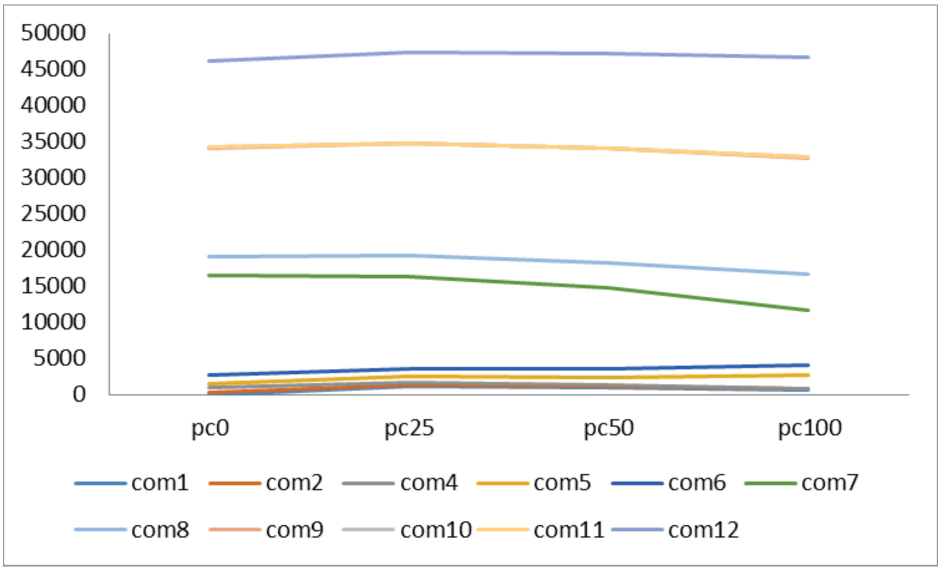

Figure 15: Export commodity value

Zealand. Great demand is one of drivers that push up utility and manufacturing output price. Although carbon price is assumed to go up to NZD$100, it might not increase the costs for these industries.

7 Conclusion

This paper analyzes land use change between the forestry and agricultural sectors under different carbon tax scenarios. The steady-state forest model is linked with the static CGE model to optimize timber rotation age and yield. We assume five types of land switch among five sectors in terms of the Armington assumption. This model highlights that more land would be transferred to forest use at a higher carbon price. Sheep-beef farming takes up the largest land use when carbon price equals zero. After a carbon policy shock, such as the increase of carbon price from 0 to 100, forestry sector manages the largest proportion of land.

There are still some questions which need to be further studied. Firstly, as New Zealand regulates the Emissions Trading Scheme (ETS), we need

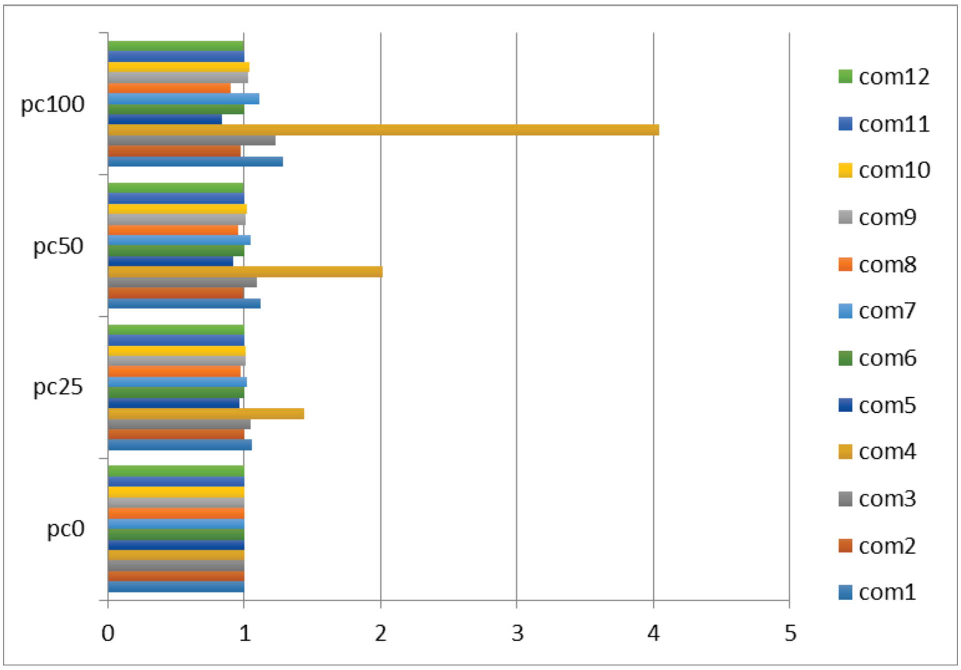

Figure 16: Commodity price change

Output price		pc0	pc25	pc50	pc100
	com1	1	1.057	1.121	1.28
	com2	1	1	0.993	0.97
	com3	1	1.045	1.096	1.228
	com4	1	1.439	2.018	4.041
	com5	0.999	0.963	0.923	0.837
	com6	1	0.999	0.999	1.004
	com7	1	1.023	1.047	1.115
	com8	1	0.978	0.955	0.901
	com9	1	1.006	1.012	1.029
	com10	1	1.007	1.016	1.037
	com11	1	0.999	0.999	1
	com12	1	0.997	0.994	0.995

Figure 17: Output price change

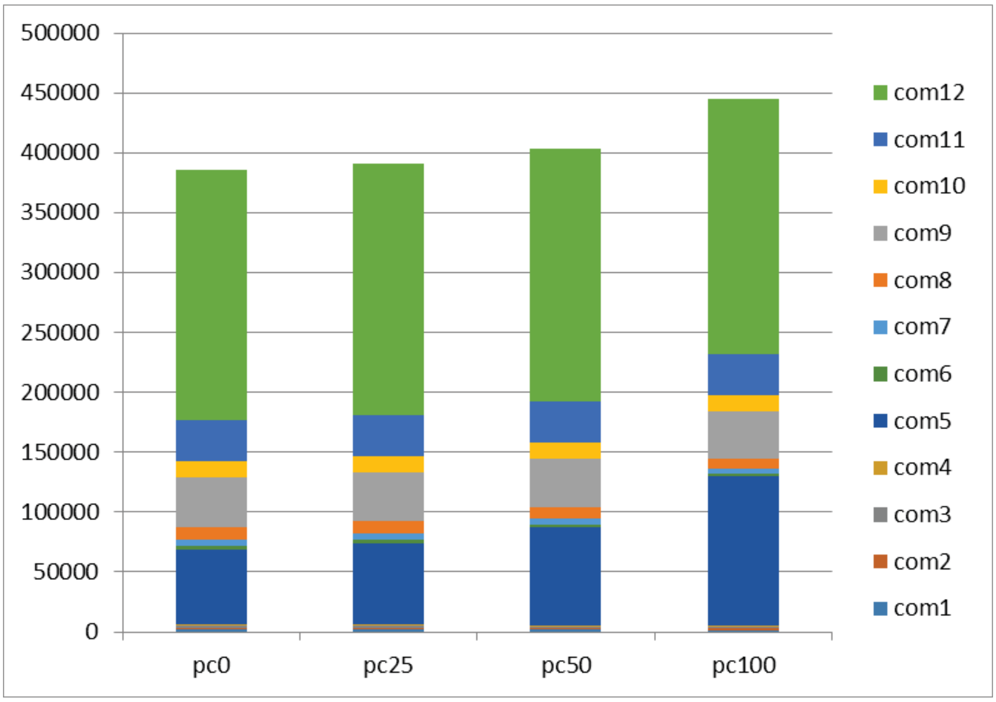

Figure 18: Commodity amount change

to consider a carbon market which links overseas as the Europe market. Energy production occupies a secondary position in terms of New Zealand's total emissions. However, we do not take energy into account in this work.

Secondly, in this paper land only switches among a few selected sectors, when in fact land is also largely used by construction and other areas. Studies which also deal with the inclusion of national land use and regional land use is needed in future.

References

Darwin, R., Tsigas, M. E., Lewandrowski, J., & Raneses, A. (1995). *World agriculture and climate change: economic adaptations* (Tech. Rep.). United States Department of Agriculture, Economic Research Service.

Dee, P. S. (1991a). *The economic consequences of saving indonesia's forests* (No. 91-97). National Centre for Development Studies, Research School of Pacific Studies, Australian National University.

Dee, P. S. (1991b). *Modelling steady state forestry in a computable general equilibrium context* (No. nos. 91-98). National Centre for Development Studies, Research School of Pacific Studies, Australian National University. Retrieved from `http://books.google.co.nz/books?id=kY26AAAAIAAJ`

Faustmann, M. (1849). Calculation of the value which forest land and immature stands possess for forestry. *Journal of Forest Economics*, *1*.

Gardiner, K. (2009). *Responsiveness of the optimal rotation of pinus radiata forests to new zealand unit prices.* University of Auckland.

Gilbert, J., & Tower, E. (2012). *Introduction to numerical simulation for trade theory and policy.* World Scientific.

Golub, A., Hertel, T., & Sohngen, B. (2008). *Land use modeling in recursively-dynamic gtap framework* (Tech. Rep.). Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University.

Hartman, R. (1976). The harvesting decision whena standing forest has valuea. *Economic Inquiry*, *14*(1), 52–58.

Hendy, J., Kerr, S., & Baisden, T. (2007). The land use in rural new zealand model version 1 (lurnzv1): Model description. *Available at SSRN 994697*.

Hertel, T. W., Lee, H.-L., Rose, S., & Sohngen, B. (2009). Modeling land-use related greenhouse gas sources and sinks and their mitigation potential. *Economic analysis of land use in global climate change policy*, 123–154.

Kerr, S., Anastasiadis, S., Olssen, A., Power, W., Timar, L., & Zhang, W. (2012). Spatial and temporal responses to an emissions trading scheme covering agriculture and forestry: Simulation results from new zealand. *Forests*, *3*(4), 1133–1156.

Kerr, S., & Olssen, A. (2012). *Gradual land-use change in new zealand: results from a dynamic econometric model* (Tech. Rep.). Motu Economic and Public Policy Research.

Kerr, S., & Sweet, A. (2008). *Inclusion of agriculture and forestry in a domestic emissions trading scheme: New zealand's experience to date* (Tech. Rep.). Motu Economic and Public Policy Research.

Lennox, J. A., Turner, J. A., Daigneault, A. J., & Jhunjhnuwala, K. (2011). Modelling forestry in dynamic general equilibrium. In *2011 conference, august 25-26, 2011, nelson, new zealand.*

Loza-Balbuena, I. (2009). Potential of the new zealand forest sector to mitigate climate change.

Lubowski, R. N., Plantinga, A. J., & Stavins, R. N. (2006). Land-use change and carbon sinks: Econometric estimation of the carbon sequestration supply function. *Journal of Environmental Economics and Management*, *51*(2), 135–152.

Manley, B. (2012). Impact of the new zealand emissions trading scheme on forest valuation. *Forest Policy and Economics*, *14*(1), 83–89.

Manley, B., & Maclaren, P. (2010). Potential impact of carbon trading on forest management in new zealand. *Forest Policy and Economics*.

MPI. (2011). *National exotic forest regional yield tables.* Retrieved from http://www.mpi.govt.nz/news-resources/statistics-forecasting/statistical-publica

NZIER. (2004). *Nzier cge model specification.* Retrieved from http://www.mfe.govt.nz/publications/climate/waikato-weather-mar04/html/page20.htm

NZIER. (2008). The impact of the proposed emissions trading scheme on new zealand's economy.

NZIER, & INFOMETRICS. (2009). *Macroeconomic impacts of climate change policy* (Tech. Rep.).

Rutherford, T. F. (2003). *A gams/mpsge model based on social accounting data for tanzania* (Tech. Rep.). Retrieved from http://www.mpsge.org/tza/tzamdl.htm

Samuelson, P. A. (1976). Economics of forestry in an evolving society. *Journal of Natural Resources Policy Research*, *4*(3), 173–195.

Sánchez, C., et al. (2004). *Rising inequality and falling poverty in costa rica's agriculture during trade reform: a macro-micro general equilibrium analysis.* Shaker.

Sands, R. D., & Kim, M.-K. (2009). Modeling the competition for land: Methods and application to climate policy. *Economic Analysis of Land Use in Global Climate Change Policy. Routledge, London, UK*, 154–181.

Sedjo, R. A., & Lyon, K. S. (1989). The long-term adequacy of world timber supply.

Sohngen, B., Golub, A., & Hertel, T. (2008). The role of forestry in carbon sequestration in general equlibrium models.

Sohngen, B., Mendelsohn, R., & Sedjo, R. (1999). Forest management, conservation, and global timber markets. *American Journal of Agricultural Economics*, *81*(1), 1–13.

Sohngen, B., Tennity, C., Hnytka, M., & Meeusen, K. (2009). Global forestry data for the economic modeling of land use. *Economic Analysis of Land Use in Global Climate Change Policy*, 49–71.

Stenberg, L. C., & Siriwardana, M. (2006). The steady-state treatment of forestry in cge models. *International journal of agricultural resources, governance and ecology*, *5*(1), 1–17.

Straka, T. J., & Bullard, S. H. (1996). Land expectation value calculation in timberland valuation. *Appraisal Journal*, *64*, 399–405.

Van Kooten, G. C., Binkley, C. S., & Delcourt, G. (1995). Effect of carbon taxes and subsidies on optimal forest rotation age and supply of carbon services. *American Journal of Agricultural Economics*, *77*(2), 365–374.