Towards a functional Ecol-Econ CGE model with a forest as biomass capital

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Abstract

This paper presents a theoretical Dynamic Computable General Equilibrium model which combine economic and ecological aspects of forest biomass that provide for policy analysis. The paper introduce a age-structured framework for modeling the growth of a bio-mass stock which interact with the economic sectors. Harvest and demand for forest products and forest amenities are determined endogenously in an inter-temporally consistent way. The general idea in this framework of modeling dynamic growth and harvest of a renewable bio-mass stock hinges on the concept of Markov growth. The paper will demonstrate how to measure the valuation of the forests non market values such as carbon sequestration and recreation/bio-diversity. The result from this simulation illustrate how harvest behavior when the economy is subject to shocks. The results also demonstrate the conflict of interest between recreation/bio-diversity and carbon sequestration.

Key words: Ecosystem modeling; Inter-temporal optimization; Infinite-horizon equilibria; Dynamic CGE; Markovian growth
JEL classification: C68; D58; Q26

1 Introduction

The use of Computable General equilibrium Models (CGE) models in the analysis of the forest sector has been motivated by the importance of links between the forest sector and the rest of the economy (Haynes et al. 1995). In regions where the forest sector is an important contributor to employment and gross domestic product, the effect of changes in the forest sector on the economy may be of interest. In for example, (Binkley et al. 1994) a CGE model was used to analyze the economic impact of reductions in the annual allowable cut in the Canadian province of British Columbia where the forest industry is a major economic activity. The Global Trade Assessment Project (GTAP) model was used as part of an Asia-Pacific Economic Cooperation (APEC) study to assess the effects of the removal of specific non tariff barriers to forest product trade on country gross domestic product, welfare, and trade (New Zealand Forest Research Institute 1999).

On the other hand, the effect of changes in non-forestry sectors on the forest sector may be the most important issue, in which case partial equilibrium (PE) analysis may be used. One example is the CINTRAFOR Global Trade Model (CGTM) which describes many aspects of forest products production: forest growth, wood supply, processing capacity, and final demand. The CGTM solves market equilibria on a year by year basis by an optimization program. Dynamic elements in the CGTM are inter-period changes in forest inventory. The CGTM has been applied to many forest sector issues, (Perez-Garcia 1994), (Perez-Garcia 1995), (Eastin et al. 2002). Detailed descriptions of the CGTM are presented in (Kallio et al. 1987) and (Cardellichio 1989). An other example of a PE model is the Global Forest Product Model (GFPM), (Buongiorno 2003). The GFPM integrates timber supply, processing industries, product demand and trade and for each year an equilibrium is computed, while year-by-year changes are simulated by recursive programming. Both CGTM and GFPM are designed as policy analysis tools, but they do not attempt to predict the feedback of changes in the forest sector on the rest of the economy. Nor do they attempt to optimize the forest sector over the planning horizon. Yet another example of a partial equilibrium model is the Timber Assessment Market Model (TAMM), (Adams and Haynes 1980). The TAMM focuses mostly on North America, but has also been used to analyze international issues (Adams and Haynes 1996). The two main components of the TAMM are a market model and an inventory projection module. The market model covers supply and demand for wood divided by regions and sectors. Exogenous inputs to the model are pulp fiber requirements and projections of forest inventory and forest growth. In TAMM the spatial equilibrium is found by "reactive programming" which make it difficult to represent policy scenarios involving constraints on endogenous variables, (Adams and Haynes 1996) recognize.

The CGE and PE models just discussed consider in about the same detail the supply and the demand sides of the forestry sector. An other feature of these models are that they are static, or have dynamic elements that link each period's solution, such as CGTM, GFPM and TAMM, but are not optimal in an inter-temporal sense. The Timber Supply Model (TSM) (Sedjo and Lyon 1998), on the other hand, was developed to study the transition of the world's forests from old growth to second growth and to plantation-grown wood and focus on the issue of the global timber supply. The modeling approach uses control theory to determine the inter-temporal economically optimal transition. The TSM is a dynamic model focusing on accurately describing the wood supply sector. But as such, it is not really suitable to use as a means for policy analysis.

This study presents a elementary Dynamic CGE model which combine economic and ecological aspects of the forest biomass and provide for policy analysis. The paper introduce a detailed modeling of growth and harvest of a bio-mass stock interlinked with the rest of the economy. Harvest and demand for forest products and forest amenities are determined endogenously in an inter-temporally consistent way. The general idea in this framework of modeling dynamic growth and harvest of a renewable bio-mass stock hinges on the concept of Markov growth[1]. Although this is a theoretical model focusing on bio-mass growth, it can be extended and fed with available data from national accounting and national forest inventories and provide real policy scenario analysis, either as a CGE model or a PE model focusing on the forest dependent sectors. The range of possible different policy decisions include the usual CGE questions regarding taxes, subsidies and tariffs, but questions such valuation of carbon sequestration and cost of setting aside special parts of forest land for recreation can also be addressed. Further, it is possible to impose restrictions on how the forest is harvested in accordance with prevailing regulations.

[1]The Markov growth is a well known mathematical model for the random evolution of a memoryless system, that is, one for which the likelihood of a given future state, at any given moment, depends only on its present state, and not on any past states.

Following this introduction the paper will continue as follows. Section 2 briefly explains the ecological model of the forest. In section 3 the construction of the CGE model is demonstrated. Results are presented in section 4 and in section **??** some concluding remarks are offered.

2 The Ecological model

The Ecological part of the model is based on the forest growth model presented (Sallnäs 1990). Based on this model a software called EFISCEN, see (Schelhaas et al. 2007), is developed by the European Forest Institute and is used for projections of forest resources. Input to EFISCEN is based on national forest inventories. Input data are available for 31 European countries. The EFISCEN software generates an initial Area distribution vector (ADV), describing the state of the forest, and a Transition Probability Matrix (TPM), which describes the growth process of the forest. The indices of the ADV can be viewed as a two-dimensional space, with age and volume classes on the axes. The value in the vector represent an area measure. In short, the ADV divides the total area forest into age and volume classes. In each time increment the area compartments in the ADV moves to a higher age class and with some probability, p, the compartment moves to a higher volume class. The probability for staying in the same volume class is $1 - p$. This process is governed by the TPM. These two outputs, ADV and TPM, can be used in a combined economic-ecological model and thus provides for economic projections into the future. The EFISCEN model can be disaggregated to several different levels, with a ADV for each aggregate. The aggregation information provided by the EFISCEN software is:

Country

Region

Owner type (small, big)

Site productivity class

Tree type (Spruce, Pine)

The EFISCEN model further supply information, apart from area measure, for each item in the ADV. The different kinds of information provided is:

Mean biomass volume per ha

Carbon content per ha

Share of Stem/Tops/Branches/Bark per ha

All this information enables a large spectra of analysis opportunities, but in this study we will focus on recreational values and carbon sequestration.

3 Formulation of the Econ-Eco-model

In this very simple dynamic equilibrium model we have a single infinitely-lived representative agent. The closed economy consists of a household which own the stock bio-mass. The stock of bio-mass is the only source of consumption, i.e. there is no production of goods in this economy. The consumption bundle consists of harvest of the bio-mass stock and the standing bio-mass stock. Consumption of the standing bio-mass stock is regarded as recreation. Individuals are assumed to have an infinite horizon, and expectations by private agents are forward-looking and rational. Hence, all agents have perfect foresight because there is no uncertainty. These assumptions imply that the optimal allocation of resources by a central planner who maximizes the utility of the representative agent is identical to the optimal allocation of resources in an undistorted decentralized economy. However, as (Scarf and Hansen 1973) states "The determination of prices that simultaneously clear all markets cannot, in general be formulated as a maximization problem in a useful way. Rather than being a single maximization problem, the competitive model involves the interaction and mutual consistency of a number of maximization problems separately pursued by a variety of economic agents." This well known fact in the literature of computable general equilibrium modeling leads to an approach different from that of the optimization. Following (Mathiesen 1985), the market equilibrium in the model is defined by non-negative price-activity pairs that satisfy the following conditions:

(i) The zero profit condition

Every activity in the economy earns non-positive profits, and activities operated at positive levels earns zero profits.

(ii) The market clearance condition

Excess supply for each commodity is non-negative, and a positive price implies zero excess supply for that commodity.

(ii) The income balance condition

Expenditure does not exceed income, and a positive income implies that expenditure equals income.

These conditions exhibits complementarity with the price-activity pairs. Thus we will formulate a general equilibrium model as a square system of weak inequalities, each with an associated non-negative variable. This is referred to as a complementarity problem in mathematics, and the associated variables are referred to as complementary variables.

In this formulation of a general equilibrium individual optimizing behavior and decisions of agents are embedded in functions describing the agents' choices in response to the values of variables facing them. Typically, demand and supply functions are derived from these individual optimization problems. These functions describe how agents will react to prices, taxes, and other variables.

This formulation is commonly known as the mixed complementary format (MCP) and there exist effective algorithms capable of solving this type of problem.

The MCP has several tractable features and is commonly used in applied general equilibrium models. Some of these features and how a non-linear program (NLP) can be transformed into the MCP format is presented (Böhringer 1998).

This section will proceed by presenting the model first as a NLP and then transforming this NLP to the MCP format.

3.1 NLP Formulation

The primal NLP formulation is based on an explicit representation of the utility function for the single representative household. The social planner maximizes the present value of lifetime utility for the representative household. The representative household receives instantaneous utility from the harvest and the standing stock. The utility received from the standing stock could be regarded as representing some non-market value of the standing stock, for example recreational value, bio-diversity value, or carbon sequestration value. These non-marketed components of the utility is modeled as functions of the standing stock but while the instant utility function is assumed homothetic and separable in its arguments, the functional notation is omitted in favor of a more general representation. The representative agent maximizes utility subject to the constraint on the growth and harvest of the forest stock. This constraint essentially captures the results from (Sallnäs 1990). The stock in each period equals the growth of the stock in the previous period less harvest in the previous period. The Non-linear Programming (NLP) problem is stated as:

$$
\begin{aligned}
max \ & \sum_{t=0}^{\infty}(\frac{1}{1+\rho})^t U(\boldsymbol{c}_t, \boldsymbol{n}_t) \\
s.t. \ & Q\boldsymbol{s}_t - (I - B)\boldsymbol{h}_t - \boldsymbol{s}_{t+1} \geq \mathbf{0}, \ \forall t, \\
& \overline{\boldsymbol{s}}_0 - \boldsymbol{s}_0 \geq \mathbf{0}, \\
& \boldsymbol{h}_t - \boldsymbol{c}_t \geq \mathbf{0}, \ \forall t, \\
& \boldsymbol{f}(\boldsymbol{s}_t) - \boldsymbol{n}_t \geq \mathbf{0}, \ \forall t, \\
& \boldsymbol{c}_t, \boldsymbol{n}_t, \boldsymbol{s}_t, \boldsymbol{h}_t \geq \mathbf{0}, \ \forall t
\end{aligned}
$$

where ρ is the time preference rate, $\boldsymbol{c}_t$ is the consumption vector of area harvest in period t, $\boldsymbol{n}_t$ is the "non market quantity" yielding non market value of the standing stock in period t, $\boldsymbol{f}(\cdot)$ is an increasing general purpose function quantifying non market goods from the forest stock (specified later in the document), and $U(\cdot)$ is the instantaneous utility of consumption assumed homothetic. $\boldsymbol{s}_t$ is the area distribution vector, the state, of the forest stock in period t, I is the identity matrix, B is a matrix that project the harvested area compartments into the bare land compartment, $\boldsymbol{h}_t$ is the vector of harvest in period t, and Q is the Markov probability transition matrix governing the growth of the stock. The initial forest stock in period $t = 0$ is specified exogenously.

The Lagrangian of the NLP is:

$$
\begin{aligned}
\mathcal{L} = & \sum_{t=0}^{\infty}(\frac{1}{1+\rho})^t [U(\boldsymbol{c}_t, \boldsymbol{n}_t) + \\
& \boldsymbol{p}_{t+1}^{s\prime}(Q\boldsymbol{s}_t - (I - B)\boldsymbol{h}_t - \boldsymbol{s}_{t+1}) + \\
& \boldsymbol{p}_t^{c\prime}(\boldsymbol{h}_t - \boldsymbol{c}_t) + \\
& \boldsymbol{p}_t^{n\prime}(\boldsymbol{f}(\boldsymbol{s}_t) - \boldsymbol{n}_t)] + \\
& \boldsymbol{p}_0^{s\prime}(\overline{\boldsymbol{s}}_0 - \boldsymbol{s}_0)
\end{aligned}
$$

where $\boldsymbol{p}_t^s$, $\boldsymbol{p}_t^c$, and $\boldsymbol{p}_t^h$ are the associated lagrangian multipliers, or shadow prices, for the area distribution vector, harvest consumption vector, and "non market quantity" respectively. From here on, transpose of a vector is indicated by a prime. The system yields the following Karush-Kuhn-Tucker (KKT) conditions:

$$\boldsymbol{p}_t^c \geq U_{\boldsymbol{c}_t} \;\perp\; \boldsymbol{c}_t \geq \mathbf{0} \tag{1}$$
$$\boldsymbol{p}_t^n \geq U_{\boldsymbol{n}_t} \;\perp\; \boldsymbol{n}_t \geq \mathbf{0} \tag{2}$$
$$\boldsymbol{p}_t^s \geq \frac{1}{1+\rho}\boldsymbol{p}_{t+1}^{s\prime} Q + \boldsymbol{p}_t^n \frac{\partial f}{\partial \boldsymbol{s}_t} \;\perp\; \boldsymbol{s}_t \geq \mathbf{0} \tag{3}$$
$$\frac{1}{1+\rho}\boldsymbol{p}_{t+1}^{s\prime}(I-B) \geq \boldsymbol{p}_t^c \;\perp\; \boldsymbol{h}_t \geq \mathbf{0} \tag{4}$$
$$\boldsymbol{h}_t \geq \boldsymbol{c}_t \;\perp\; \boldsymbol{p}_t^c \geq \mathbf{0} \tag{5}$$
$$\boldsymbol{f}(\boldsymbol{s}_t) \geq \boldsymbol{n}_t \;\perp\; \boldsymbol{p}_t^n \geq \mathbf{0} \tag{6}$$
$$Q\boldsymbol{s}_t + (I-B)\boldsymbol{h}_t \geq \boldsymbol{s}_{t+1} \;\perp\; \boldsymbol{p}_{t+1}^s \geq \mathbf{0} \tag{7}$$
$$\overline{\boldsymbol{s}}_0 \geq \boldsymbol{s}_0 \;\perp\; \boldsymbol{p}_0^s \geq \mathbf{0} \tag{8}$$

3.2 MCP Formulation

The formulation of the equilibrium, by (Mathiesen 1985) relies on the existence of closed-form demand functions which express consumption demands as a function of market prices and income, $\boldsymbol{M}$. The demand functions for harvest, and non market value consumption are determined through utility maximization and are defined by:

$$D_t^{\boldsymbol{h}}(\boldsymbol{p},\boldsymbol{M}) \in \underset{\boldsymbol{c}_t}{argmax}\Big(\sum_{t=0}^{\infty}\big(\frac{1}{1+\rho}\big)^t u(\boldsymbol{c}_t,\boldsymbol{n}_t)\Big|\sum_{t=0}^{\infty}\boldsymbol{p}_t^{c\prime}\boldsymbol{c}_t + \boldsymbol{p}_t^{n\prime}\boldsymbol{n}_t = \boldsymbol{M}\Big)$$
$$D_t^{\boldsymbol{n}}(\boldsymbol{p},\boldsymbol{M}) \in \underset{\boldsymbol{n}_t}{argmax}\Big(\sum_{t=0}^{\infty}\big(\frac{1}{1+\rho}\big)^t u(\boldsymbol{c}_t,\boldsymbol{n}_t)\Big|\sum_{t=0}^{\infty}\boldsymbol{p}_t^{c\prime}\boldsymbol{c}_t + \boldsymbol{p}_t^{n\prime}\boldsymbol{n}_t = \boldsymbol{M}\Big)$$

Having defined uncompensated demand functions, we can characterize the equilibrium KKT conditions in terms of the above ((i)-(iii)) three classes of equations.

The zero profit conditions with associated variables are:

$$\boldsymbol{p}_t^s \geq \frac{1}{1+\rho}\boldsymbol{p}_{t+1}^{s\prime}Q + \boldsymbol{p}_t^n \frac{\partial f}{\partial \boldsymbol{s}_t} \;\perp\; \boldsymbol{s}_t \geq \mathbf{0}$$

$$\frac{1}{1+\rho}\boldsymbol{p}_{t+1}^{s\prime}(I-B) \geq \boldsymbol{p}_t^c \;\perp\; \boldsymbol{h}_t \geq \mathbf{0}$$

The market clearance conditions in each period are:

$$\begin{aligned} \boldsymbol{f}(\boldsymbol{s}_t) &\geq D_t^{\boldsymbol{n}}(\boldsymbol{p}, \boldsymbol{M}) \;\perp\; \boldsymbol{p}_t^n \geq \mathbf{0} \\ \boldsymbol{h}_t &\geq D_t^{\boldsymbol{h}}(\boldsymbol{p}, \boldsymbol{M}) \;\perp\; \boldsymbol{p}_t^c \geq \mathbf{0} \\ Q\boldsymbol{s}_t + (I-B)\boldsymbol{h}_t &\geq \boldsymbol{s}_{t+1} \;\perp\; \boldsymbol{p}_{t+1}^s \geq \mathbf{0} \\ \overline{\boldsymbol{s}}_0 &\geq \boldsymbol{s}_0 \;\perp\; \boldsymbol{p}_0^s \geq \mathbf{0} \end{aligned}$$

An income-balance constraint relates the value of expenditure to factor earnings:

$$\boldsymbol{M} = \boldsymbol{p}_0^s \overline{\boldsymbol{s}}_0 \;\perp\; \boldsymbol{M} \geq \mathbf{0}$$

Note that we, by assumption of non-satiation, also get

$$\boldsymbol{p}_0^s \overline{\boldsymbol{s}}_0 = \sum_{t=0}^{\infty} \boldsymbol{p}_t^{n\prime}\boldsymbol{n}_t + \boldsymbol{p}_t^{c\prime}\boldsymbol{c}_t$$

3.3 Terminal conditions

In the equilibrium of the classical forest rotation model by (Faustmann 1849) forest growth, timber volume, annual harvesting, are constant over time. This outcome is usually referred to as the Normal forest and is a commonly used assumption in forest management. However, present economic research indicate that under positive discounting, optimal forest vintage structure may evolve into stationary cycles without convergence toward the normal forest (see for example (Mitra and Wan Jr 1985) and (Wan Jr 1994)). Yet, in an extension, (Salo and Tahvonen 2003) shows that with alternative land use, the stationary cycles are replaced by a saddle point path with damped oscillations and convergence toward the normal forest. The reason for this is stated by "[c]yclical timber harvesting would imply that the value of the bare forest land would either exceed or be below the marginal land value in the alternative use. Such a situation cannot be optimal, implying that in equilibrium the cycles vanish."

In light of these studies, it is not unreasonable to use the concept of normal forest as a means for terminal condition. The intuition of this assumption is that after the analysis horizon there will be at least stock left for future generations as in the last period included in the analysis horizon. Stationary rotation or steady state in this model of forest growth means that the intensity of harvest is at a constant level that keeps the stock (state) of forest constant in each period. We can state this more intuitively as, the harvest equals the growth of the forest. In order to achieve this end, variables for prices of post terminal stock is introduced in the equilibrium conditions, and an extra set of equations are necessary to control the levels of these variables. Let T indicate last period of the horizon then the extra market clearance condition will be:

$$Q\boldsymbol{s}_T + (I - B)\boldsymbol{h}_T \geq \boldsymbol{s}_T \;\perp\; \boldsymbol{p}^s_{T+1} \geq \mathbf{0}$$

and the correction of the income balance constraint:

$$\boldsymbol{M} = \boldsymbol{p}^s_0\overline{\boldsymbol{s}}_0 - \boldsymbol{p}^s_{T+1}\overline{\boldsymbol{s}}_T \;\perp\; \boldsymbol{M} \geq \mathbf{0}$$

where by non-satiation we have

$$\boldsymbol{p}^s_0\overline{\boldsymbol{s}}_0 - \boldsymbol{p}^s_{T+1}\overline{\boldsymbol{s}}_T = \sum_{t=0}^{T} \boldsymbol{p}^c_t\boldsymbol{c}_t + \boldsymbol{p}^n_t\boldsymbol{n}_t$$

3.4 Scenarios

In demonstrating the usefulness of this model two scenarios will be provided. In the first scenario the representative agent get an increased sense of wellbeing from recreational values of the forest. In the second the wellbeing is increased from an increased carbon sequestration in the forest. In the implementation of the model all goods and services provided by the forest is present in the utility function. That is, harvest, recreation, and carbon sequestration. In the model it is assumed that the recreational service is provided by oldest and most voluminous parts of the forest, ie., the highest age and volume class. The carbon sequestration takes place in all compartments of the forest, but at different rates (explained below). As stated before the non marketed quantities is represented by the function $f(\boldsymbol{s}_t)$. We can now specify it further by separating it into parts

$$\boldsymbol{f}(\boldsymbol{s}_t) = [k(\boldsymbol{s}_t)\ l(\boldsymbol{s}_t)]'$$

where $k(\boldsymbol{s}_t)$ represents the quantity of recreation and $l(\boldsymbol{s}_t)$ represents the quantity of carbon sequestrated in each period. As a measure of quantity of recreation the size of area in the highest age and volume class is used. The carbon sequestrated is computed by taking the difference of carbon content per hectare between periods and multiply by the area distribution vector.

$$k(\boldsymbol{s}_t) = \boldsymbol{e}'\boldsymbol{s}_t$$
$$l(\boldsymbol{s}_t) = \Delta\boldsymbol{c}\boldsymbol{s}_t$$
$$\Delta\boldsymbol{c} = \boldsymbol{c}'(Q' - I)$$

where $\boldsymbol{e}$ is a unit vector $[0\ 0\ ...\ 0\ 1]'$ with one in the position for the highest age and volume class, $\boldsymbol{c}$ is the vector of carbon content per hectare forest in respective age and volume class, and $\Delta\boldsymbol{c}$ is a measure of carbon sequestration per hectare and period in respective age and volume class.

4 Results

The data provided for this simulation is totally constructed but the characteristics of the forest growth is based on a reduced form of data supplied by the EFISCEN software. The state of the forest is divided into four age classes and four volume classes with bare land being one compartment. This sums up to seven different compartments. The harvest is restricted to three compartments residing in the highest age class.

Numerically, the model is implemented in MPSGE (Rutherford 1999) as a subsystem of GAMS (Brooke et al. 1996) using PATH (Dirkse and Ferris 1995) for solving the MCP problem.

Bearing in mind that this is primarily a theoretical model the simplest assumption for replicating a business as usual bench mark is to assume stationary rotation of the forest stock as a starting point for analysis. Stationary rotation or steady state in this model of forest growth means that the intensity of harvest is at a constant level that keeps the stock (state) of forest constant in each period.

The different scenarios are very uncomplicated and implemented as an increase in the shares in the utility representation of first recreational value and then sequestration, i.e. by changing the shape of the instant utility functions (the shares). The results are presented in four figures which shows benchmark and scenarios of different variables with focus on the development of the forest. The variables showed are aggregated harvest, aggregated stock, average age, and carbon sequestrated over the horizon of interest. Aggregated variables are chosen in order not to get overwhelmed by details, but bear in mind that the changes are different in different compartments of the forest.

In figure 1 we see that the harvest goes down, at an declining rate, when the valuation of recreation shifts up. The declining rate is due to the fact that recreational value is defined for only one, the oldest forest, compartment and it takes time for the system to accommodate the shock. In short, it takes time for the forest to grow old and produce recreational value. The effect on harvest due to an increased valuation of carbon sequestration is more distinct. The harvest shifts up with a tiny over-swing and rapidly find a constant value. Here the opposite arguments holds, the carbon sequestrating ability of the forest lies in the younger parts of the forest. There is no waiting in cutting down old forest to get a higher rate of carbon sequestration. From this figure, as well as figures 2, 3, 4, it becomes obvious that there is an conflict of interest between recreational values and carbon sequestration. The two different scenarios displays opposite effects on harvest behavior.

Figure 2 displays the changes in the total volume of bio-mass that occur with respect to the scenario shifts. The stock of bio-mass is of course a function of harvest and when harvest go down in response to the higher valuation of recreation, the stock will gradually increase until it reaches steady state. The reverse happens when harvest shift upwards as a reaction of greater appraisal of carbon sequestration, a progressive increase in aggregate stock volume. Note that aggregate stock reaches steady state earlier in the case of higher valuation of carbon sequestration. This is agree with the findings of harvest behavior presented in figure 1.

The changes in the average age of the forest is illustrated in figure 3. The average age is computed as a weighted average of the mean age times the bio-mass volume of the different compartments. It can be seen that average age goes up when recreational values are higher regarded, and down when carbon sequestration is of greater concern. This figure merely mirrors what can be seen in figure 2, but it distinguish the demarcation of age with respect to the amenities recreation and carbon sequestration. Old forest is associated with

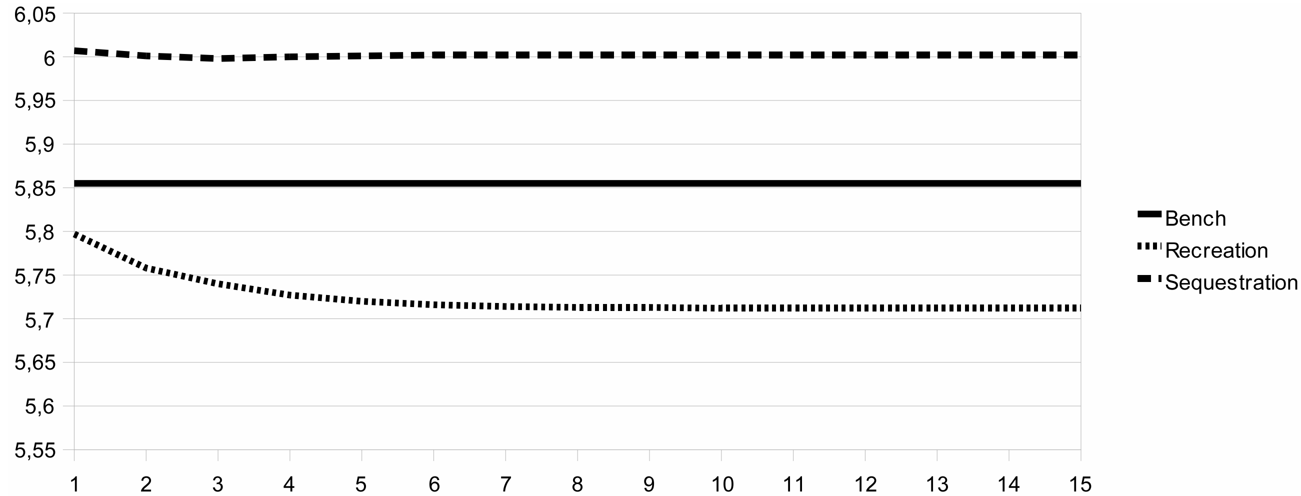

Figure 1: Aggregate harvest

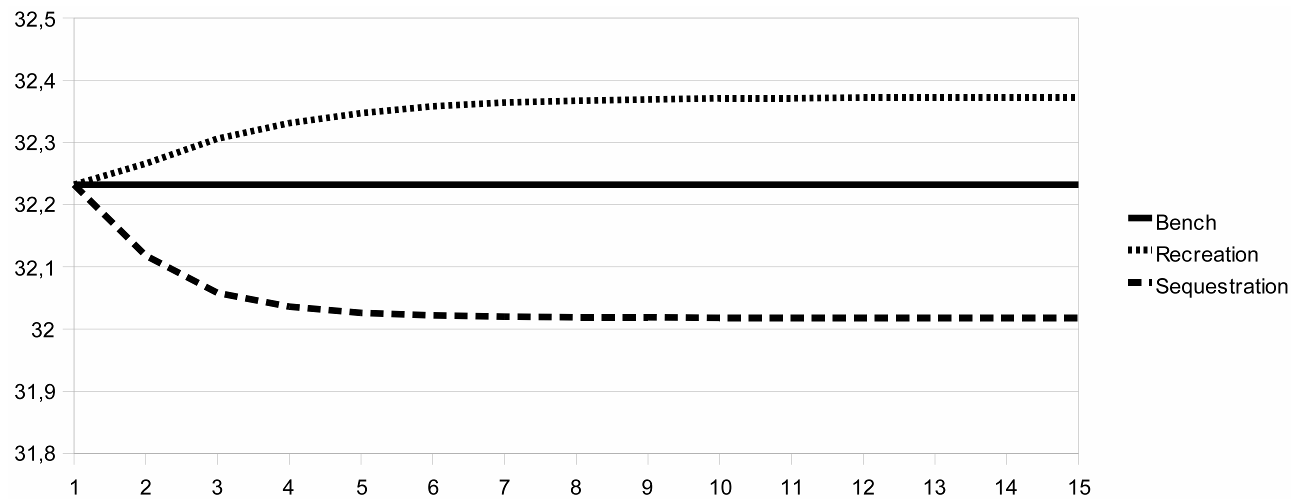

Figure 2: Aggregate stock

high values of recreation and the carbon sequestration capacity is greater in younger forest.

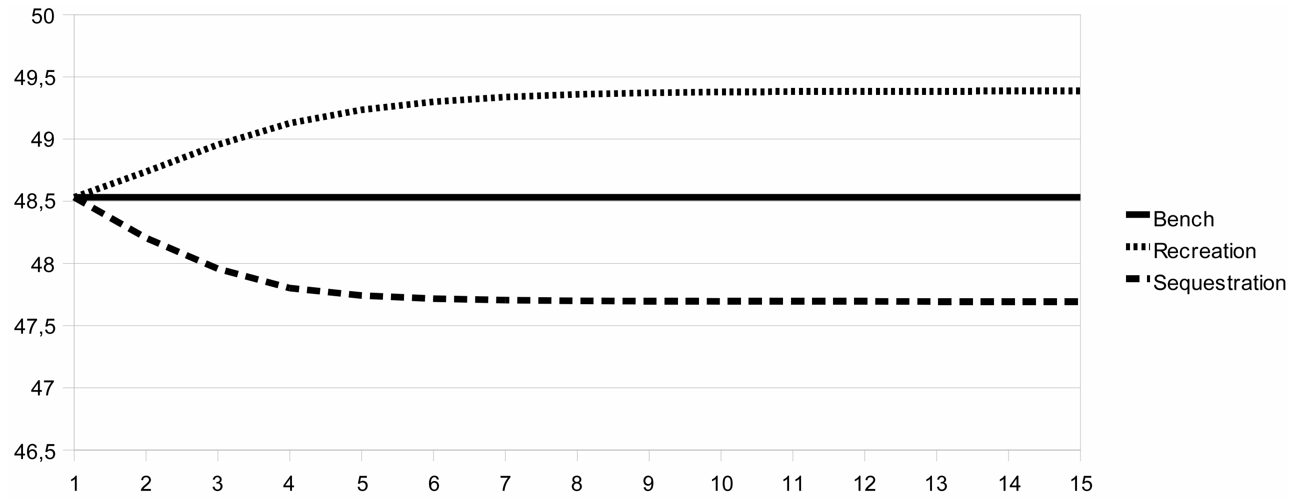

Figure 3: Average age

Carbon sequestration adoption in response to the scenario shifts are presented in figure 4. The carbon sequestration lessens when the age of the forest increase as a consequence of stronger valuation of recreational values. And obviously the carbon sequestration is elevated when the valuation of the same is intensified.

To sum up, changes in the valuation of non marketed amenities provided by the forest bio-mass stock alters the harvest behavior of the representative agent. When recreational values are hold in higher regard the rate of harvest will decline. When, on the other hand, carbon sequestration efficiency is in greater esteem, the harvest effort increase. These reversal behaviors are reflections of the age-specificity of the different amenities.

5 Conclusion

This study propose a skeleton for modeling a renewable bio-mass stock, in which the growth and harvest have implications on economic activities. The model presented pay special attention to age-specific properties of the bio-mass stock studied. The specific bio-mass stock investigated is the forest.

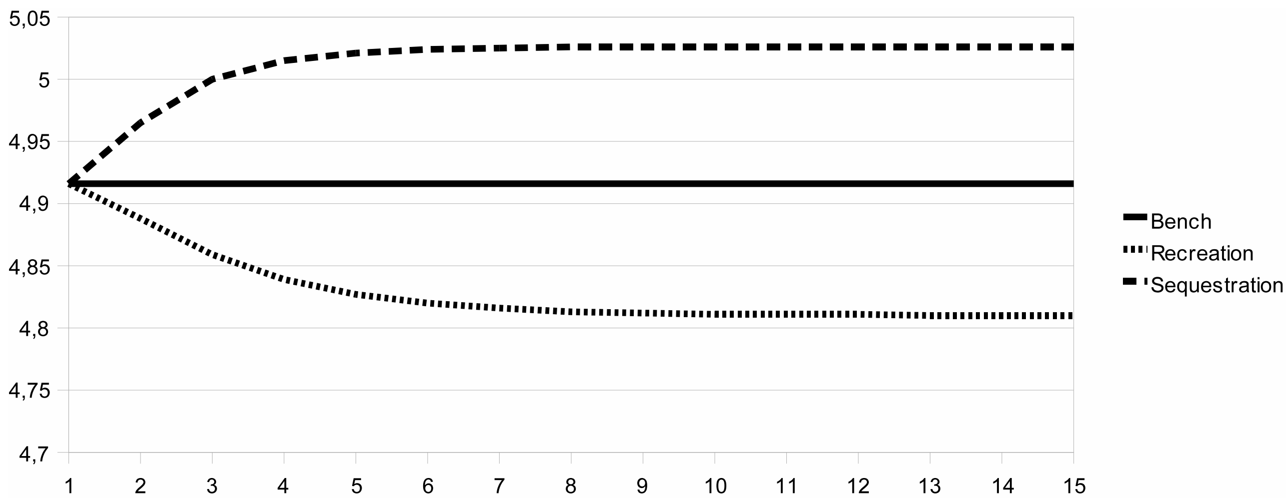

Figure 4: Carbon Sequestration

Harvest and demand for the renewable bio-mass stock are determined endogenously in an inter-temporally consistent way. The growth process of the stock is governed by a transition probability matrix, commonly known as a Markov matrix.

The paper explain how changes in the valuation of non marketed amenities provided by the forest bio-mass stock alters the harvest behavior of the owner of the stock. When recreational values are hold in higher regard the rate of harvest will decline. When, on the other hand, carbon sequestration efficiency is in greater esteem, the harvest effort increase. These reversal behaviors are reflections of the age-specificity of the different amenities. The results of the study it also reveals the conflict of interest between recreational values and carbon sequestration.

As a case for future research the framework can be extended with more economic sectors and fed with available data from national accounting and national forest inventories to provide for real scenario analysis, either as a CGE model or a PE model focusing on the forest dependent sectors. For real scenario analysis the assumption of forest being in steady state at the start of the time horizon might not be a feasible construct. Data for a base period may be inconsistent with a steady-state growth path. Data supplied from Swedish forest inventory, for example, show that growth of forest exceeds the harvest. Therefore some assumption has to be made on how the forest and harvest will evolve. One possible solution for model calibration in the case of the of-steady-state data is to assume that growth initially exceed harvest, but converges to a steady state growth and harvest over time. Calibrating dynamic models to a benchmark data which are not on a steady-state means finding a path on which prices, demand and production coincide and end up in steady state.

The MCP format provide for discriminating different groups of preference systems. This seems to be an interesting area of future investigation of this forest model while a number of econometric studies have revealed that harvesting decisions depend on owner-specific characteristics such as non-forest income, wealth and owner's age (e.g. (Binkley 1981); (Romm et al. 1987); (Dennis 1988); (Dennis 1990); (Jamnick and Beckett 1988); (Kuuluvainen and Salo 1991).

While this paper focus on the forest as a renewable bio-mass stock, the model presented could be translated to other bio-mass stocks possessing similar age-structured properties and needs economic examination. The growth and harvest of fish, for example, have been modeled by transition probability matrices in several studies, see (Getz and Swartzman 1981), (Rothschild and Mullen 1985), and (Evans and Rice 1988).

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