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Whole-tree harvesting with stump removal versus stem-only harvesting in peatlands when water quality, biodiversity conservation and climate change mitigation matter ☆

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ABSTRACT

This article examines alternative forest harvesting regimes when ecosystem services in terms of water quality, biodiversity conservation and climate change mitigation are included in the analysis. The harvesting regimes are whole-tree harvesting with stump removal and conventional stem-only harvesting. The harvesting regimes are evaluated under two alternative climate policy contexts. The first alternative is a carbon neutral bioenergy policy, which assumes the carbon dioxide (CO_2) neutrality of bioenergy and produces substitution benefits, as bioenergy replaces fossil fuels. The second alternative climate policy, a carbon non-neutral bioenergy policy, takes into account the fact that bioenergy causes carbon dioxide emissions, producing substitution costs, and that harvested woody biomass affects the ability of a forest to act as a carbon sink. We extend the traditional Faustmann (1849) rotation model to include nutrient load damage, biodiversity benefits, and climate impacts. The empirical analysis is based on Finnish data from a catchment experiment carried out on drained peatland forests. The empirical results show that under a carbon neutral bioenergy policy, whole-tree harvesting with stump removal produces the highest net social benefits. However, if a carbon non-neutral bioenergy policy is assumed, the net social benefits are greater under stem-only harvesting.

1. Introduction

Increasing the use of renewable energy is an important tool of climate mitigation policy in both the EU and US. Bioenergy, such as forest residues, is regarded as a potential means for substituting conventional fossil fuels, since the use of biomass for energy production reduces fossil fuel emissions and replaces non-renewable energy sources. Due to the increasing economic potential of forest residues, there is a need to reconsider alternative harvesting methods and policy regimes. In conventional stem-only harvesting, only the stems are harvested and the logging residues are left on the site. In contrast, whole-tree harvesting also removes forest residues (tree tops, branches and foliage) from the site. Furthermore, in addition to the above-ground tree biomass, the tree stumps can also be removed from the site and used as an energy source.

The two possible harvesting regimes impact differently on the ecosystem services provided by forests. In addition to climate change mitigation, forests provide timber, biodiversity conservation, amenities, and water quality (Fisher et al., 2009). Forest ecosystems cover provisioning services, regulating services, cultural services, and supporting services (Millennium Ecosystem Assessment, 2005, page v). The sustainability of whole-tree harvesting, in particular, has been challenged due to its potential negative impacts on several forest ecosystem services.

A primary concern of whole-tree harvesting and stump removal is the depletion of soil nutrients and its effect on future forest productivity (e.g. Mann et al., 1988; Bengtsson and Wikström, 1993; Olsson et al., 1996; Jacobson et al., 2000; Egnell and Valinger, 2003; Merino et al., 2005; Walmsley et al., 2009). Furthermore, the extraction of both harvest residues and stumps causes habitat loss for saproxylic species, thereby affecting biodiversity (Jonsell, 2007; Lattimore et al., 2009; Walmsley and Godbold, 2010; Jonsell and Hansson, 2011; Bouget et al., 2012). Whole-tree harvesting also weakens the ability of a forest to act as a carbon sink (Repo et al., 2011).

Several studies have discerned high total mercury (TotHg) and methylmercury (MeHg) concentrations in water leaching from tree harvesting areas (Munthe and Hultberg, 2004; Porvari et al., 2003; Sørensen et al., 2009). Moreover, logging residues left in a clear-cut

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area are a potential source of heavy metals when the dry deposited substances that have accumulated on the surface of the logging residues are leaching away. All forest management measures, including harvesting, are considered to increase sediment and nutrient export to watercourses (e.g. Grip, 1982; Ahtiainen and Huttunen, 1999; Laurén et al., 2005; Miettinen et al., 2012).

The aim of this article is to consider the optimal forest management practice when various ecosystem services are included in the analysis. We extend the traditional Faustmann (1849) rotation model to include nutrient load damage, climate impacts, and biodiversity benefits. We address the selection of the optimal rotation age so as to balance different environmental externalities caused by harvesting under the two alternative harvesting regimes: stem-only harvesting and whole-tree harvesting with stump removal. We assess these harvesting regimes from two alternative climate policy perspectives. First, in the spirit of Kyoto Protocol, we postulate a carbon neutral bioenergy policy, which assumes the CO_2 neutrality of bioenergy such as forest fuels and produces substitution benefits as bioenergy substitutes for fossil fuels. Our second perspective is a carbon non-neutral bioenergy policy, which takes into account that using forest biomass in bioenergy production releases CO_2, producing substitution costs, and that harvested woody biomass affects the ability of a forest to act as a carbon sink.

Our choice of carbon neutral and non-neutral perspectives reflects current discussion. Forest bioenergy has traditionally been regarded as a carbon neutral (or low-carbon) energy source, because the carbon dioxide emissions released into the atmosphere when harvested vegetation is converted to energy are taken up again by the growth of the new tree generation (e.g. Wihersaari, 2005; Stupak et al., 2007). Recently, however, the carbon neutrality of forest bioenergy has been questioned (Repo et al., 2011, 2012; Searchinger et al., 2009) by the argument that neutrality crucially depends on the time horizon and on indirect carbon dioxide emissions.

More specifically, to estimate the efficiency of forest bioenergy in reducing carbon dioxide emissions and mitigating climate change, in addition to direct emissions from the bioenergy production chain (Palosuo et al., 2001; Mälkki and Virtanen, 2003; Wihersaari, 2005; Lattimore et al., 2009), the temporal dimension and indirect carbon dioxide emissions into the atmosphere must be considered (e.g. Schlamadinger et al., 1995; Palosuo et al., 2001; Lattimore et al., 2009; Melin et al., 2010; Repo et al., 2011, 2012). In a carbon non-neutral bioenergy policy, we assume that carbon dioxide emissions resulting from bioenergy combustion are in the short-term greater than emissions from fossil fuels (the default emission factor is 94.6 tCO_2/TJ for coal and 109.6 tCO_2/TJ for forest fuelwood (Statistics Finland, 2011)).

Our model combines two different lines of literature. We incorporate water protection issues in forestry using the approach provided in Miettinen et al. (2012), who included a nutrient load damage function in the Faustmann model.[1] Modeling of carbon sequestration is based on van Kooten et al. (1995), who included the carbon sequestered by the growth of timber and carbon released due to harvesting in the Hartman (1976) model.[2] We include biodiversity benefits following modeling in the conventional Hartman model. In an empirical analysis, we use data including nitrogen, phosphorus and mercury loads from a catchment experiment carried out in eastern Finland. Under the two alternative climate policies we examine for a given rotation length which harvesting regime produces higher net social benefits for drained peatland forests. We are unaware of previous empirical analyses similar to this. The closest studies to ours have included, for instance, Kaltschmitt et al. (1997), Miranda and Hale (2001), Gan and Smith (2006, 2007), Olschewski and Benítez (2010), Valente et al. (2011), and Alavalapati and Lal (in press).

The rest of the paper is organized as follows. In the next section we present the theoretical frame of the study. In Section 3, the study area and methods used in the ecological study are described. The economic data and estimation of social costs and benefits used in the empirical analysis are provided in Section 4. In Section 5 the empirical analysis and the results of alternative harvesting regimes are presented Section 6 contains the sensitivity analysis. Finally, in Section 7 we provide our conclusions.

2. Socially optimal harvesting under environmental costs and benefits

Here, we examine social welfare from a representative forest stand under carbon neutral and non-neutral bioenergy policies. Under both climate policies, the economic problem of the social planner is to choose the harvesting regime and the optimal rotation age so as to maximize social welfare from forestry subject to relevant ecosystem services (water quality, biodiversity conservation and climate change mitigation). In the following, we start with the carbon neutral policy.

2.1. The socially optimal rotation age under a carbon neutral bioenergy policy

In the steady state, the social planner starts with bare land. We denote rotation age under two management alternatives by T^i, $i = 1,2$ (stem-only harvesting is denoted by superscript 1 and whole-tree harvesting with stump removal by superscript 2). The growth function as a function of rotation age is denoted by $Q(T^i)$ with $Q'(T^i) > 0$ and $Q''(T^i) < 0$ over the relevant range of forest age. The wood price, $P(T^i)$, is the average sum of the wood prices for sawlogs, pulpwood, and logging residues and stumps, p_l, p_p and p_h respectively, weighted by the proportions of sawlogs, $\alpha_l(T^i)$, pulpwood, $\alpha_p(T^i)$, and logging residues and stumps, $\alpha_h(T^i)$ from the total amount of wood harvested, $Q(T^i)$. Hence, the wood price is defined as follows:

$$P\left(T^i\right) = \alpha_l\left(T^i\right)p_l + \alpha_p\left(T^i\right)p_p + \alpha_h\left(T^i\right)p_h. \tag{1}$$

In stem-only harvesting, the proportion of logging residues and stumps is zero, $\alpha_h(T^i) = 0$. Let c denote regeneration costs and r the real interest rate. The Faustmann net present value of harvest revenue, V^i, from the harvested sawlogs, pulpwood, and logging residues and stumps in the absence of environmental aspects is defined as: $V^i = \left[P\left(T^i\right)Q\left(T^i\right)e^{-rT^i} - c\right]\left(1 - e^{-rT^i}\right)^{-1}$. It is straightforward to demonstrate that in the Faustmann model with Eq. (1), the optimal rotation age is implicitly determined by the optimality condition,

$$V^i_{T^i} = P'\left(T^i\right)Q\left(T^i\right) + P\left(T^i\right)Q'\left(T^i\right) - rP\left(T^i\right)Q\left(T^i\right) - rV^i = 0. \tag{2}$$

We next introduce ecosystem services in the model and start with negative externalities. Without the loss of generality, we focus on nutrient loads (the empirical analysis also includes mercury loads). Nutrient loading starts one period after the stand is harvested. The load first increases, and then with the growth of the stand it decreases to the background level.[3] Following Miettinen et al. (2012), let k^i be the number of years that nutrient loads occur under each harvesting regime i. The nutrient load after harvesting, $g(s)$, is expressed as a function of time, s. The nutrient load damage $D(z^i)$ as a function of the present value of the periodic loads, z^i, can then be written as:

$$D\left(z^i\right) = d\int_0^{k^i} g(s)e^{-rs}ds, \tag{3}$$

where d denotes the constant marginal damage.

[1] Articles focusing on water protection applications in forestry: Miller and Everett (1975), Clinnick (1985), Matero (1996, 2002, 2004), Matero and Saastamoinen (1998), Creedy and Wurzbacher (2001), Sun (2006), Laurén et al. (2007), Matta et al. (2009), and Eriksson et al. (2011). For more economic studies on water protection in forestry see Miettinen et al. (2012).

[2] For reviews of economic carbon sequestration studies in forestry, see Sedjo et al. (1995), van Kooten et al. (2004), Richards and Stokes (2004), and Boyland (2006).

[3] According to Sillanpää et al. (2006), final harvesting and site preparation increases the runoff for 7 to 11 years at the most.