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The Costs and Benefits of Intensive Forest Management

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Abstract

This paper presents an approach for studying the socio-economic benefits and costs (CBA) of the introduction of intensified management measures in forestry. Besides from valuation of changes in timber production, assessments of different types of externalities are included in the assessment. The model is exemplified with the use of data from a Swedish governmental study undertaken in 2009 which present impacts on the Swedish forest sector if intensified management measures are applied on environmentally low-valued land and abandoned agricultural lands. The CBA shows that intensified management measures typically are private financially profitable. If these measures also become profitable from the society's point of view depend on the size of the external effects including carbon balance.

KEYWORDS: cost-benefit analysis, external effect, timber production, carbon sequestration, fuel substitution

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1. Introduction

Forests have increasingly taken on a more multifaceted role in today's society. In addition to providing industry with raw materials, forests play a key role in bioenergy and climate policy. Forests and forestlands are also increasingly important as a pool for biodiversity, recreation, and other ecosystem services. However, the increasing demands on forestlands lead to an increased number of restrictions. In other words, as society's use of forests has increased, so too has its value. In this context, intensive forest management (IFM)[1] policies have become increasingly relevant. Such policies focus on increasing forest productivity on existing forestlands and/or on reforesting previously abandoned agricultural lands.

From a sustainable development perspective, forests should not only be seen as a source of raw materials but also for their production of other important goods and services that contribute to society's welfare. This is particularly important with respect to the forest's capacity for producing biofuels and absorbing carbon dioxide. The contribution forests make to sustainability explains their increasingly important role in the debate on how to combat global warming. In fact, the primary motivation for IFM is the positive contribution a forest makes in storing atmospheric carbon.

The objective of this paper is twofold: (1) to provide a framework for a cost-benefit analysis (CBA) of silvicultural activities in general and IFM in particular taking also non-market values into account; and (2) to give an empirical illustration of a particular IFM project. In particular, we will focus in both these parts on the effects of internalizing non-market values, particularly carbon sequestration.

Studies on the economics of carbon sequestration (see, for example, Sedjo et al., 1997) and effects of climate change (for example, van Kooten, 2004) have been the focus for many researchers. An early study by Hoen and Solberg (1994) is an example of how silvicultural management can affect the economic efficiency of carbon sequestration in forest biomass. In a recent study, Simonsen et al. (2010) examined the (private) profitability of IFM measures to increase forest growth. However, empirical CBAs of IFM measures, which also account for different types of external effects, are to our knowledge not present in the literature. Such a study is therefore highly encouraged.

To fill this gap in the literature, we exploit the welfare-theoretic model presented by Lundgren et al. (2008) and provide a case study that illustrates a practical application of this model. The case study is based on the Swedish Government's report on IFM completed in 2009 (see Larsson et al., 2009). In addition to highlighting CBA as a relevant tool for this type of analysis, the report

[1] Intensive forest management is sometimes referred to as intensive forest cultivation. We use the two terms interchangeably in this article.

emphasizes the importance of accounting for external effects and public goods when measuring the social profitability of IFM.

It should be pointed out that there are many uncertainties involved in a study like this, both concerning physical effects on the natural environment due to IFM and due to which values to attach on the physical effects. Furthermore, it is highly probable that the intensive cultivation practices considered in our analysis may lead to future effects that we are unaware of today. In light of this, our CBA of intensive cultivation on a national level should be interpreted with some caution. However, we believe that our study underscores the importance of considering public goods and externalities in evaluating a project of this kind.

This article is organized as follows. Section 2 provides a background and explanation of IFM. Section 3 provides a simple theoretical framework for CBA, where we emphasize the importance of public goods and external effects related to silvicultural activities. We address the monetary valuation of public goods and external effects in Section 4. Finally, in Section 5 we present the CBA results of a particular IFM as an illustration and summarize conclusions in Section 6.

2. Background

In the present Swedish Forestry Act,[2] preservation of natural and environmental values is just as important as the forest's production value. Nature conservation has thus gained a stronger position and the appropriate nature conservation in forestry has been written into law. The current law includes less detailed management regulations and more freedom is given to forest owners regarding alternative methods for regeneration of forests. The obligation to pre-commercial thinning and thinning has been removed, and the minimum age for final felling has been reduced. By contrast, reforestation is still a duty, but the options on how to do it, for example, by planting, seeding or natural regeneration using seed trees are extended, and in most cases decided by the forest owner. There are also regulations aiming at prevention of forest damages, for example, in cases of storm felling. Also, the rules of maximum bare and young forest area remain on properties over a certain size.

The current forestry legislation can largely be summed up as freedom with responsibility. The individual forest owners have relatively great freedom to choose methods to manage their forests, but must ensure that regeneration will be successful and that the forest is not affected by insects, etc.

Traditionally, the primary goal of forest policy in Sweden has been to provide the forest industry with raw material. This was manifested in legal standards concerning, for example, regeneration, both in terms of magnitude of

[2] The Swedish Forestry Act SFS 1979:429. See also the Swedish Forest Agency website.

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regeneration and what type of trees that should be planted. Forest policy has changed, however, due in part to increased environmental awareness and new political goals related to sustainable development. The conventional view of forest management has, as a result of this, reached a point where forest policy is strongly connected to various environmental and energy policy goals. The increased environmental awareness and interest in forests has led to increasing demands on forest goods and services. These increased environmental demands may, for example, argue for *in situ* forest preservation in order to protect biodiversity. These increased demands may also affect the various cultural, ethical, and social values associated with forests (Government Bill, 1992–1993:226). Explicitly, conflicts surrounding negative externalities from forestry arise primarily in connection with clear cutting and concern, for example, impacts on biodiversity in the area, flora, fauna, and recreation. To mitigate these impacts it is written into Swedish law that, for example, left behind must be a certain amount of dead wood, high stumps, buffer-zones around watercourses and nature trails, trees with grouse nests, etc.

The demand for bioenergy from forests is directly related to the Swedish target concerning reduction of greenhouse gas emissions as well as the EU Climate and Energy package, which among other things have ambitious goals concerning renewable energy. This together with an increasing worldwide demand for biofuels ultimately integrates climate, energy, and forest policy. In addition, the role of the forests in national and global climate policy is further strengthened by the fact that forests also store carbon. Thus, there is an increasing demand for using the forests as a source for biofuels as well as a carbon sink. At the same time, there is an increasing demand for traditional forest products as well as forest conservation for recreational use and biodiversity.[3] To meet all these needs, one possible solution that has been suggested is to increase biomass production, both in terms of productivity and taking more land into account, through IFM.

A proposed definition of the concept of "intensive forest cultivation" is provided in the Swedish Government Bill 2007–2008:108 (our translation):

> *Intensive forest cultivation includes forestry practices aimed at increasing the value or volume of forest products and which may push the limits of regulations or legislation designed to protect forest resources. These may include shortened rotations, more intensive land clearing, land drainage and/or fertilizer use. Intensive management may put less consideration on natural, cultural or social values associated with a forest.*

[3] An empirical analysis of this type of goal conflicts can be found in Geijer et al. (2011).

Intensive cultivation essentially refers to productivity-enhancing measures within forestry. Productivity can be enhanced in two ways: either by increasing the area of forest production by cultivating agricultural land that were previously abandoned and/or by improving production on existing forestlands. The following have been identified as key measures for intensive forest management in Sweden (SOU 2006:81):

- Reforest agricultural lands that are no longer cultivated but are, by definition, forestlands.
- Use the best available forest cultivation material and robust methods for rejuvenation.
- Increase the use of fertilizer relative to current practices.
- Clean out old ditches that no longer serve their function.
- Proactive measures to prevent damage to seedlings from moose and other wild game.
- Make better use of the cultivation of non-conventional types of trees that are allowed under existing forest protection laws.

IFM is in principle cultivation, or a silvicultural activity, that goes beyond current common practices (Larsson et al., 2009). In Sweden, the concept is only expected to be applied on a relatively small percentage of the country's extensive forestlands and therefore is seen as a complement to – not a substitute for – conventional forestry (Government Bill, 2007–2008:108, p. 110). In particular, it is designed primarily for existing and abandoned agricultural land that are classified as supporting low levels of environmentally valuable services (e.g., biodiversity and recreational values).

A concrete example of how IFM may be applied in practice can be found in Larsson et al. (2009).[4] The study considers several different intensive cultivation scenarios covering 3.5 million hectares (8.6 million acres) of forestlands with relatively low environmental values (approximately 15% of Sweden's existing forestlands). The scenarios also proposed intensive cultivation on an additional 0.4 million hectares of currently abandoned agricultural land. The specific cultivation methods used across the different Swedish regions are described in more detail in Lundström and Glimskär (2009) (in Swedish – Faktaunderlag till Larsson et al., 2009). Another recent study about these measures is Nilsson et al. (2011).

One of these scenarios is chosen for the CBA in this paper. This scenario includes the implementation of IFM on 3.5 million hectares during a 50-year

[4] See also Fahlvik et al. (2009) (in Swedish – Faktaunderlag till Larsson et al., 2009) for a description of the different intensive cultivation methods that are considered in Larsson et al. (2009).

"investment period" and on 0.4 million hectares of abandoned agricultural land, which should be afforested during a 40-year investment period. Figures 1 and 2 illustrate the expected outcome of this scenario with respect to timber harvest and biomass inventory over the first 90-year planning period (up to year 2100).

Figure 1 shows that the harvests increase fairly modestly until year 2050. From that point in time benefits of using IFM (dashed curve) results in a large increase in annual harvests, and at the end of the planning period the harvest level is more than doubled. Figure 2 shows that the inventory of biomass increases fairly quickly and reaches maximum around year 2080. Interestingly, both IFM and normal forestry reach basically the same state of inventory at the end of the planning period.[5] The figures indicate that the private economic effect from increased timber production could be substantial; however, a social CBA is needed to shed light on the profitability of IFM from a society's point of view.

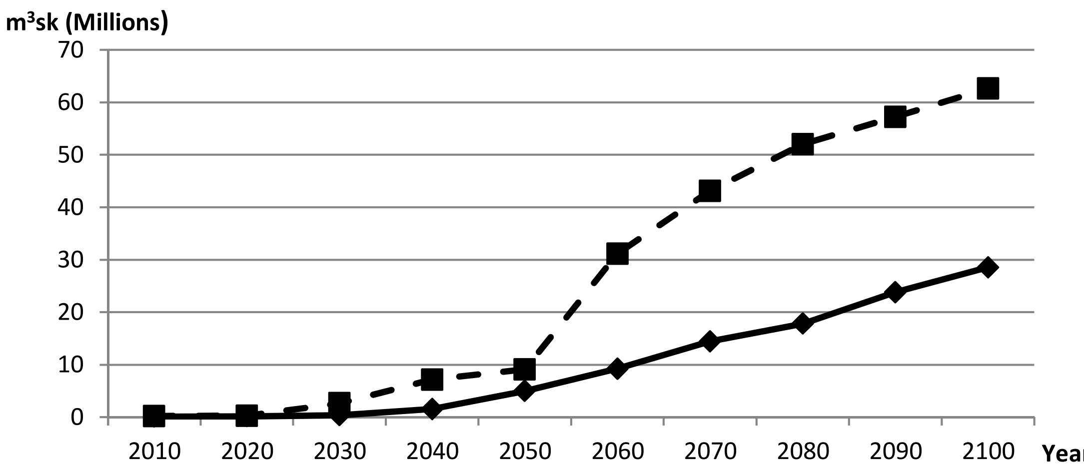

Figure 1. Timber Harvest using IFM (dashed curve) versus Normal Forestry Measures (solid curve).

[5] The IFM forest inventory growth slows down after the 50-year investment period.

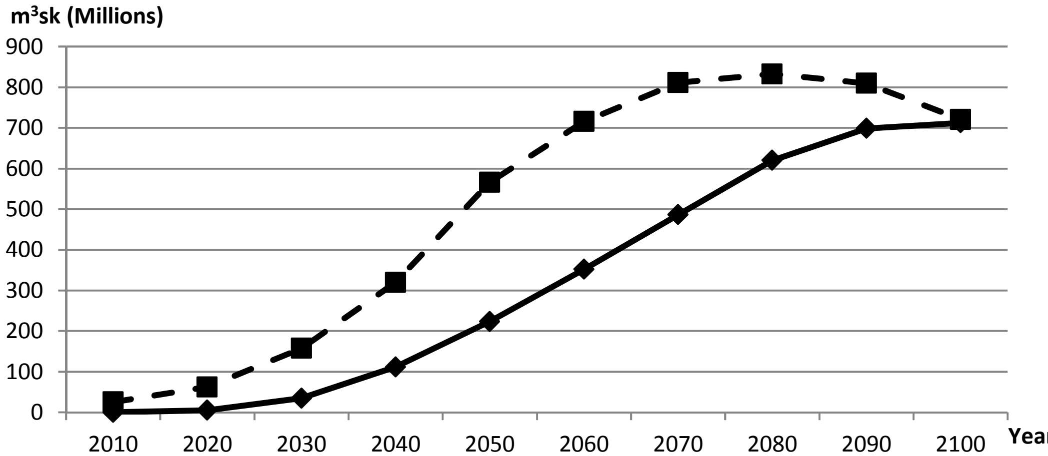

Figure 2. Inventory of Biomass using IFM (dotted curve) versus Normal Forestry Measures (solid curve).

3. Cost-Benefit Analysis (CBA)

The fact that society considers intensive cultivation as an alternative to conventional methods indicates some kind of market failure. In other words, there appear to be social values attributable to forests that do not enter into the decision-making process of individual private forest owners. As a result, forest resources are allocated inefficiently, leading to a welfare loss, motivating policy interventions.

In principle, all relevant effects that an intensive cultivation project has on social welfare should be considered when assessing the social profitability of such a policy. This includes, for example, a forest's role in storing carbon. One way to accomplish this is through a formal CBA framework.[6]

In this section, we describe the cost-benefit framework relevant to the scenario above (described in Larsson et al., 2009). Lundgren et al. (2008) provide a formal welfare-economic model in which biomass use is connected to the climate, the environment, and the rest of the economy. From their model it is possible to derive the following welfare effects[7] from a project that increases biomass growth, promotes bioenergy, and substitutes away from fossil fuels:

- Market effects
- Value changes in resource stocks (stock effects)
- Environmental effects
- Climate effects

[6] For a general discussion of CBA from an environmental perspective, see, for example, Johansson (1993) and Hanley and Barbier (2009).

[7] See Lundgren and Marklund (2012) for a formal derivation of these effects.

Market effects are any effects that stem from changes in the production of consumption and investment goods in the economy. In our case, this entails changes in harvested volumes, and bioenergy and fossil energy utilization. The stock effects are twofold: (1) substitution away from fossil fuels will create an increased *in situ* value of non-renewable resources, whereas (2) the net effect of increased growth and harvest of biomass will determine the value effect of the renewable resource. The stock effects are not assumed to be significant for a small project, and therefore they are not considered in our CBA analysis. By environmental effects we refer to all types of impacts on the environment, positive as well as negative, related to increased productivity and harvest of biomass and decreased extraction of fossil fuels. These effects could be related to changes in landscape, recreation, acidification, biodiversity, etc. Climate effects are atmospheric changes in carbon balance generated by the proposed project. The change in carbon release is determined by the project-induced increase in biomass growth, how we use the increased harvest, and the degree of fossil fuel substitution. The harvest can be either incinerated (bioenergy), which means immediate release of carbon, or made into more or less "carbon emitting" products (some sort of solid wood product). A piece of wood used in building a house will store carbon for a relatively long time, whereas a product such as toilet paper will release its carbon content rather fast. We try to account for this in our CBA below. It is shown in the CBA that the valuation of the climate effects will be important for the valuation of the project.

4. Monetizing Climate and Environmental Effects

Quantifying and monetizing the marginal effects of an intensive cultivation project is, in practice, indeed a challenging task. For example, one must assess the value associated with changes in a forest's capacity to store carbon. It is likely that such a project will give rise to several different types of marginal external effects, and some of these may be tricky to quantify and monetize. In light of this, our CBA of intensive cultivation on a national level should be interpreted with some caution. We believe that the main contribution of our study is to underscore the importance of considering public goods and externalities in evaluating a project of this kind.

4.1. Climate Effect

The actual net effect of IFM on carbon emissions to the atmosphere depends on the how the IFM-induced forest growth is ultimately used. Intensive cultivation has an impact on the carbon cycle by having effects on a forest's capacity to "sink" carbon, but also by having substitution effects (bioenergy can substitute fossil energy). The carbon sink effect is related to increased biomass. For example, if intensive cultivation leads to an increased stock of biomass, that is, wood growth is larger than the wood harvest, then the calculation would result in a net uptake of carbon. The substitution effect is related to how intensively cultivated forest is subsequently used, for example, it could be used to substitute fossil fuel for forest fuel, or building wooden houses or other solid wood products.

Formally, the present value climate effect of IFM, *CE*, may be expressed as follows:

$$CE = \sum_{t=1}^{T} \left\{ P \left[0.9N_t - \left(0.9 \times 0.5 \left((H_t + 0.1H_t) + \sum_{t-i=2}^{T-1} 0.1H_{t-i} \right) \right) + 0.5H_t \, 2.744/11.5 \right] \Big/ 1.34^t \right\} \quad (1)$$

Increased carbon sequestration — Carbon emissions — Avoided carbon dioxide release due to substitution

for $t = 1,2,...,T$, and $i = 0,1,...,T-1$, where increments are decades (10 years). N_t denotes the decade growth induced by IFM, and H_t is harvest. The first term within brackets, $0.9 \times N_t$, is the resulting positive effect from carbon sequestration (the CO_2 content of 1 m^3 wood is 0.9 ton CO_2). The carbon dioxide emissions from the "use" of intensively cultivated forest are modeled as a negative effect: $-0.9 \times 0.5((H_t + 0.1H_t) + \sum_{t-i} 0.1H_{t-i})$. As we actually do not know how the intensively cultivated forest would be used, we assume here that 50% of the harvested forest is used for fuel and 50% is used for timber, paper, etc.[8] Explicitly, the carbon dioxide release from using wood as fuel is $0.9 \times 0.5 H_t$, and the release or dissipation from using wood for producing marketed products, such as building houses is $-0.9 \times 0.5(0.1H_t + \sum_{t-i} 0.1H_{t-i})$. In the latter case, we assume that produced products "depreciates" and release carbon at a rate of 10% every 10 years (i.e., these products release their carbon dioxide over their 100 year life).[9] The third term within brackets, $0.5H_t \times 2.744/11.5$, describes avoided carbon dioxide release from oil use when replacing oil with wood-based fuel. That is, we assume that all bioenergy generated from the IFM program can replace fossil energy in the same amount (in energy units). Here, the substitution effect from replacing oil is given by the factor 2.744/11.5 (the content of CO_2 of 1 m^3 oil is 2.744 ton, and the energy content of 1 m^3 oil is 11.5 times higher than of 1 m^3

[8] This is not an unreasonable assumption as one of the main motives behind the very idea of IFM is to address the climate problem and promote bioenergy.

[9] For instance, it is not unreasonable to think of, for example, a wooden house serving its purpose for 100 years.

wood). Finally, the decade discount rate is set to 34%, which corresponds to 3% per year and is the level normally used in Swedish forestry.[10]

Also, in the CBA we evaluate the use of forest fuel under two different preconditions: (1) forest fuel being carbon neutral, and (2) not being carbon neutral. There is a vital and growing discussion about the appropriateness of regarding bioenergy as carbon neutral, see, for example, Searchinger et al. (2009), Cherubini et al. (2011), or Lundgren and Marklund (2012). Eq. (1) builds upon forest fuel not being carbon neutral and is therefore to be seen as an expression for what we label the short run (SR) case. However, for the purpose of also modeling forest fuels as being carbon neutral in the long run (LR), the negative effect from using intensively cultivated forest as bioenergy (emissions) is excluded.[11] Then the climate effect expression in Eq. (1) collapses to:

$$CE = \sum_t \left\{ P\left[0.9N_t + 0.5H_t \times 2.744/11.5\right] / 1.34^t \right\}.$$

Finally, to be able to calculate the climate effect, we need values on the carbon sink and substitution effects, and hence we need a monetary value on carbon dioxide, *P*, that is, the social cost of carbon.

The normal basis for establishing the value, or price, of a negative environmental impact in project evaluation is the *damage costs* associated with an additional unit of environmental impact. For carbon dioxide this amounts to estimating the social cost of carbon, which is based on the damage associated with a marginal emission of carbon to the atmosphere (see, for example, Pearce 2003). Several studies have tried to value the marginal damage costs associated with carbon emissions.[12] These cost estimations are particularly challenging and the results are influenced by various assumptions and uncertainty associated with various parameters.

Based on Tol (2008), we use the estimated value of the marginal social cost of carbon, 170 SEK per ton, as one alternative of pricing carbon in the calculations.[13,14] The carbon price is expected to increase over time due to increased damage. Therefore, when calculating the present value of reduced emissions to the atmosphere, the price of carbon changes according to the optimal policy tax ramp suggested by Nordhaus (2008, p. 92). In the calculations we also

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[10] $1000/1.03^{10} \approx 744$ and $1000/744 \approx 1.34$.

[11] For a more detailed discussion and formal analysis, see Lundgren and Marklund (2012).

[12] Clarkson and Deyes (2002) and Tol (2005, 2008) provide overviews.

[13] In Tol (2008), the average value of 1 ton carbon (C), based on 125 estimates published in peer-reviewed scientific articles, is US$75.4 in 1995 prices. Converting to ton CO_2, the price is US$20.5 (=75/3.67). Using an exchange rate of SEK 7 per US$, the price of 1 ton CO_2 is 143.8 SEK. Finally, expressed in 2008 prices the price is 169, 7 (=143.8 × (300.6/254.8)) SEK per ton CO_2.

[14] In 2008 1 € was approximately 9.60 SEK.

use an alternative price of carbon based on a political valuation; the Swedish carbon dioxide tax, which is currently 1000 SEK per ton.[15] We use these two alternative valuations to illustrate the sensitivity of our CBA results to our assumptions about the price of carbon dioxide.

Below, we discuss the quantification and valuation of some of the additional effects, which act as key inputs into our CBA. We focus on the quantification and monetization of two types of effects: (1) other externalities and (2) timber production.[16]

4.2. Other Environmental Effects

Our CBA also considers other relevant external effects including: (1) acidification and nutrient loading; (2) landscape changes and recreation (including hunting); and (3) biological diversity. We focus on the first two effects. The third effect, biological diversity, is excluded from our CBA.

Biological diversity is also affected by intensive cultivation. One obvious effect is that increased nitrogen will disproportionally benefit certain vegetation (Swedish Board of Forestry, 2007). However, it is not clear how such changes may affect human activities or biological diversity itself. It is likely that some species will benefit while others will suffer, but the net effect is uncertain. The key question is how to quantify impact and value the net impact of IFM on biological diversity to determine net changes in welfare. This is, in practice, an extremely challenging task. As far as we know, there is no study that even comes close to covering and quantifying a significant number of effects of IFM on biological diversity. Additionally, the effects must be valued, which *per se* is very difficult and values are uncertain. For this reason, we do not include the effect of intensive cultivation on biological diversity due to a lack of information required to include the relevant effects in our analysis. For a general discussion regarding quantifying effects on biodiversity, see, for example, Hooper et al. (2005). Regarding the valuation issue, see, for example, Hanley and Barbier (2009), where valuing ecosystems and habitat protection are discussed.

Acidification is mostly due to deposition of sulfur and nitrogen, combined with an increase of the removal of wood residues from forest land. Intensive forestry, through the use of more nitrogen fertilizer, also leads to an increase in

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[15] Because this price of carbon is already relatively high, we do not apply the tax ramp procedure.

[16] Surely there are other relevant externalities, negative as well as positive, to account for in a welfare analysis. However, in our case, lack of data, not the least due to the complexity associated with quantifying and monetizing externalities, causes us to exclude them. An example of a positive external effect would perhaps be water shed improvement. In the case of Sweden and the particular IFM project in study, though, we believe that the effect is marginal. The reason is that the Forestry Act already has a paragraph which sets limits concerning forestry activities in relation to water sheds. This constraint will also be binding in the analyzed IFM project.

acidification. The reason is that the uptake of nitrogen by organic material and trees is not complete (Swedish Board of Forestry, 2007); hence, there may be a "nitrogen leakage" which can adversely affect groundwater, lakes, waterways, and marine environments (Swedish Board of Forestry, 2007). Furthermore, harvesting heavily fertilized forestlands can lead to increased nitrogen leakage relative to non-fertilized lands.

We value the impact of acidification and nutrient loading based on the prices found in Bickel and Friedrich (2005, pp. 229–237), which relies on the "Standard Price Approach." This approach estimates a price based on the costs associated with an environmental policy measure, thus representing society's willingness to pay (WTP) for reduced acidification and nutrient on ecosystems. The marginal WTP per hectare to protect ecosystems in Europe is estimated to a rounded number of 100 €/year, which amounts to 961 SEK/year in 2008 prices, and assumes that the WTP is constant across all Member States. We assume that measures taken to prevent acidification and nutrient loading are necessary to undertake on at least 5–20% of the area where intensive fertilization programs will take place (on a final area of approximately 1.03 million hectares achieved in a 50-year period). The cost per hectare is then somewhere between 48 and 192 SEK/year. The total costs associated with increased acidification and nutrient loading is then:

$$C^{nuitrent} = \sum_{t=0}^{t=49} \frac{area_t \times \sum_{t=0}^{99-t} \frac{48(192)}{1.03^t}}{1.03^t} = 861 \;\; (3445) \text{ million SEK,} \qquad (2)$$

where $area_t$ captures the areal spreading of IFM activities during the 50 years of implementation. The total cost will be ranging from 861 to 3445 million SEK [number within parentheses in Eq. (2) equals the upper limit].

Intensive cultivation on previously abandoned agricultural lands or low-valued forestlands can lead to aesthetic impacts on the landscape, which may adversely affect social values. Landscape impacts can be significant at the local level. Open agricultural landscape is lost when previously abandoned fields are used for IFM. We estimate this loss based on Drake (1992, 1999), presenting a WTP per hectare for preservation of the Swedish agricultural landscape amounting to 1838 SEK/year in 2008 prices.[17] Our scenario includes 0.4 million hectares of previously abandoned fields, which will be afforested over a 40-year period (which is a 10-year shorter implementation period than for the other

[17] Drake (1999) concludes that in Sweden the most important motives for preservation of agricultural landscape are that plants and animals are dependent of it, and that it is beautiful.

measures included in the program). The total effects are summed over the first 100 years of the program. This implies that the total costs associated with landscape changes are approximately:[18]

$$C^{landscape} = \sum_{t=0}^{t=39} \frac{area_t \times \sum_{t=0}^{99-t} \frac{1838}{1.03^t}}{1.03^t} = 13{,}711 \text{ million SEK.} \qquad (3)$$

Intensive cultivation also leads to other landscape effects. For example, some conventionally managed forests will transition to intensively cultivated areas, leading to potential recreational impacts, such as changed prerequisites for taking walks, picking mushrooms, etc. In Holgén and Mattsson (2000), it is shown that the choice of silviculture activities is very important for the recreational value. Their results show that to increase the recreation value of a forest is to 'mix' the rotation periods, that is, to operate via some overlapping mechanism in which the natural regeneration is established beneath a shelter of old trees. A similar conclusion is drawn in Gundersen and Frivold (2008), who in a review of 53 valuation studies in Finland, Norway, and Sweden found that the public tend to give high scores to irregular forest stands with a mixture of trees of different sizes. Thus, one can expect that at least some of the measures considered in an intensive forest management program will have adverse effects on recreational values. Our CBA assumes that adverse impacts on recreation will occur across a total of 3.5 million hectares of Swedish forests exhibiting low environmental value.

We value the impacts associated with aesthetic and recreational impacts on the landscape based on Mattsson and Li (1993), who found that a forest's total non-timber value per individual is 7748 SEK/year in 2008 prices. Non-timber value concerns in this particular case: on-site consumption (such as hiking, taking walks, camping, and picking berries and mushrooms), and off-site experience (i.e., enrichment of landscape scenery). The non-timber value per hectare is then, based on the assumption that approximately 6.7 million Swedish citizens (aged 18–74 years in December 31, 2010) would be affected by intensive cultivation across Sweden's 23 million hectares of forestland, 2257 (7748 × 6.7 million/23 million) SEK/year. However, this is unrealistic because it assumes that the value of every acre of forestland is completely lost. Instead, we assume that only 5–20% of this non-timber value per hectare is impacted (i.e., 113–451 SEK/year) and that the total impacted area is 3.5 million acres (excluding previously abandoned fields). The total cost of aesthetic and recreational loss is then:

[18] Note that here we assume that 100% of the open landscape aesthetic value is lost when forested.

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$$C^{rec} = \sum_{t=0}^{t=49} \frac{area_t \times \sum_{t=0}^{99-t} \frac{113\ (451)}{1.03^t}}{1.03^t} = 8040\ (32{,}159) \text{ million SEK,} \tag{4}$$

thus, ranging from 8040 up to 32,159 million SEK. The value associated with hunting on forestlands in Sweden is based on studies by Mattsson et al. (2008, 2009), who estimate a gross value of 11,872 SEK for the typical hunter in Sweden during the hunting season 2005–2006 in 2008 prices, which includes both meat value and recreation value.[19] A total of 280,000 hunting licenses were sold that year, giving a total hunting value of 3.32 (11,872 × 280,000) billion SEK. Because hunting is equally likely to occur on all forestlands in Sweden (23 million hectares) the annual per hectare value is approximately 144 SEK/year, which corresponds to 7–29 SEK/year when at least 5% or 20% of the hunting is made impossible on 3.9 million hectares under intensive forestry. The total cost is then calculated by summing over the whole planning period, i.e.:

$$C^{hunt} = \sum_{t=0}^{t=49} \frac{area_t \times \sum_{t=0}^{99-t} \frac{7\ (29)}{1.03^t}}{1.03^t} = 513\ (2052) \text{ million SEK} \tag{5}$$

thus, ranging from 513 to 2052 million SEK.

Other environmental effects can then be summarized to:

$$EE = C^{nutrient} + C^{landscape} + C^{rec} + C^{hunt} = 23{,}125\,(51{,}367)$$

The next section provides additional inputs for our CBA by examining the private costs and revenues associated with intensively cultivated timber production, the market effects (*ME*).

4.3. Effects on Timber Production

The Faustmann model is used to calculate the Land Economic Value (*LEV*) of timber production.[20] Maximization of Eq. (6) with respect to *t* is used to assess *LEV*:

[19] Most hunting time is devoted to moose, followed by roe dear, and hare.

[20] Using the Faustmann model is a widely accepted and a commonly used approach to value changes in timber production. For a formal presentation of the Faustmann model see, for example, Pearse (1990).

$$LEV_t = \left(\frac{pV(t)}{1.03^t} - c \right) \times \frac{1}{1 - 1.03^{-t}} \qquad (6)$$

where p is the net value (price minus cutting cost) per m^3 of timber, $V(t)$ is the volume of standing timber at time t, c is regeneration cost, and the discount rate is equal to 3%. IFM measures are assumed to only affect $V(t)$ so that more timber is produced during shorter rotation periods, which implies that *LEV* increases (*ceteris paribus*). A change in *LEV*, which here is equal to the difference in *LEV* between IFM forestry and conventional forestry ($LEV^{IFM} – LEV^{\boldsymbol{CF}}$). This is our measure of the value of timber production which is included in the CBA.

To illustrate the private effects of IFM we consider three scenarios with alternative assumptions about the net value (p) of Swedish timber production:

- Scenario A – Low net value of timber production.
- Scenario B – Net value corresponding to 2008 year prices (main scenario).
- Scenario C – High net value of timber production.

Scenario B can be considered as a type of business as a usual scenario in which the unit timber value is unchanged. Scenario A is assumed to illustrate the effect of lower timber prices due to lower quality of the roundwood, or changes in assortment resulting from intensive cultivation.[21] Scenario C is assumed to illustrate the effect of higher timber prices due to an increased demand for biofuel motivated by climate and energy policy. Timber prices for scenarios A and C is assumed representing approximately 80% and 120%, respectively, of 2008 year prices.

Given the different timber price scenarios we estimate the *LEV* of timber production based on an added value calculation. The change in *LEV* used in our CBA is based on the difference in "per hectare market value" between an IFM cultivated area and a conventionally cultivated area. Five different measures, i = 1,…,5, of intensively cultivated measures are implemented in the program. The total value ($Value^{tp}$) of these measures is sum of all changes over the 50-year implementation period.

$$\underset{i=1,\ldots,5}{\mathrm{Value}_t^{\mathrm{tp}^i}} = \sum_{t=0}^{49} \frac{area_t^1 \times \left(LEV_t^{IFM^i} - LEV_t^{CF^i} \right)}{1.03^t} \qquad (7)$$

[21] It is not unreasonable to assume that roundwood resulting from IFM may be of a quality that is less suitable as sawnwood and hence be of less value on the market. For example, trees that grow faster will have less density and thus likely lower market price. In addition, there may be a supply effect, that is, an increase in supply puts pressure on the market price.

We estimate the value of timber production on abandoned agricultural land by assuming planting of spruce. In our scenario, 0.4 million hectares of abandoned land will be afforested. As these agricultural lands are indeed abandoned, that is, no agricultural production is going on or is expected to begin, the opportunity cost is equal to 0.

$$\Delta LEV^{A} = \sum_{t=0}^{t=39} \frac{LEV_t^{F} - 0}{1,03^{t}} = 5952 \text{ million SEK.} \quad (8)$$

yielding a total sum equal to 5952 million SEK.

To sum up, all scenarios assume that IFM management applies to approximately 3.5 million hectares of forestlands and 0.4 million hectares of abandoned agricultural land. The CBA takes account for a 50-year implementation period (2010–2060) and sum the effects of the first 100 years. The assessments of the economic impacts are, as previously mentioned, calculated to present values using a 3% discount rate.

5. Results

We argue that a CBA based on economic welfare theory (Lundgren et al., 2008; Lundgren and Marklund, 2012) can be used to determine whether the application of IFM is socially profitable. We considered two types of forestlands – both those that support low or marginal environmental services and those that have abandoned agricultural land. The results of this analysis can be used to compare and rank IFM with alternative social projects. We should point out, however, that there are many uncertainties involved in the calculations due to the assumptions that have to be made. This holds especially true for the quantification and monetization of external effects, which may not accurately capture the true values associated with the projected changes.

The results from the different scenarios are summarized in Table 1.

Table 1. Social Profitability of Intensive Forest Cultivation Relative to Conventional Forestry ("Business as Usual"), million SEK in 2008 prices.

	Scenario A (low timber price)	*Scenario B (main scenario)*	*Scenario C (high timber price)*
Monetized impacts	*Social cost of carbon CO_2 = 1 SEK/kg (political valuation), SR*[a]		
Timber production from IFM on abandoned agricultural lands	4762	5952	7142
Increased timber production from IFM	–1070	15,581	23,647
Carbon	1974	1974	1974
Other external effects	–51,367 to –23,125	–51,367 to –23,125	–51,367 to –23,125
Total	**–45,701 to –17,459**	**–27,860 to 382**	**–18,604 to 9638**
	Social cost of carbon CO_2 = 0.17 SEK/kg (literature review), SR[a]		
Timber production from IFM on abandoned agricultural lands	4762	5952	7142
Increased timber production from IFM	–1070	15,581	23,647
Carbon	550	550	550
Other external effects	–51,367 to –23,125	–51,367 to –23,125	–51,367 to –23,125
Total	**–47,125 to –18,883**	**–29,284 to –1042**	**–20,028 to 8214**
	Social cost of carbon CO_2 = 1 SEK/kg (political valuation), LR[b]		
Timber production from IFM on abandoned agricultural lands	4762	5952	7142
Increased timber production from IFM	–1070	15,581	23,647
Carbon	12,582	12,582	12,582
Other external effects	–51,367 to –23,125	–51,367 to –23,125	–51,367 to –23,125
Total	**–35,093 to –6851**	**–17,252 to 10,990**	**–7996 to 20,246**

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Table 1 (continued)

	Social cost of carbon CO_2 = 0.17 SEK/kg (literature review), LR[a]		
Timber production from IFM on abandoned agricultural lands	4762	5952	7142
Increased timber production from IFM	–1070	15,581	23,647
Carbon	2707	2707	2707
Other external effects	–51,367 to –23,125	–51,367 to –23,125	–51,367 to –23,125
Total	**–44,968 to –16,726**	**–27,127 to 1115**	**–17,871 to 10,371**

Source: Larsson et al. (2009) and Brännlund et al. (2009).
[a] IFM will lead to increased carbon emissions in the short run (SR), that is, increased timber production increases emissions due to increased use of bioenergy.
[b] In the long run (LR) scenario, consumption of bioenergy is assumed to be carbon neutral, that is, neutralized by biomass growth.

As evident from Section 4, the CBA results presented in Table 1 include sensitive analyses that depend upon: (1) three timber price scenarios, that is, whether the price is low (80% of the observed 2008 price, whether it is the 2008 price), or whether it is high (120% of the observed 2008 price); (2) the price put on carbon emissions (political or scientific price); and (3) whether wood fuels are carbon neutral or not (i.e., the short run versus the long run perspective).

In all scenarios our impact analysis shows that IFM as described above reduces carbon dioxide emissions to the atmosphere. This result is independent of the price of carbon and whether wood fuels are regarded as carbon neutral. Assuming that (1) timber production is priced as in 2008 (Scenario B); (2) intensive cultivation increases carbon emissions in the short run; and (3) carbon is priced according to a "political valuation," we found that the net present value of the reduced emissions to the atmosphere during the 100-year period of analysis is 1974 million SEK (2008 prices).

Other externalities monetized in this analysis that arise from IFM – that is, acidification and nutrient loading, landscape changes, and recreation (including hunting) – are assumed to be unaffected by the price of timber and carbon. The implementation of the intensive cultivation project leads to a social cost of 23,125 to 51,367 million SEK. We observe from the results that the values of these externalities are considerable, which implies that overall analysis will be sensitive to changes in the valuation of these externalities.

The impact of intensive cultivation on the value of timber production is strongly affected by the assumptions about future timber prices. When we assume prices that reflect 2008 levels (Scenario B), intensive cultivation leads to an increase in timber production valued at 21,533 million SEK, with production from abandoned agricultural lands and existing forestlands representing 5952 million SEK (28%) and 15,581 million SEK (72%), respectively. The assumption of low prices (Scenario A) leads to a net outcome equal to 3692 million SEK, whereas an assumption of high prices (Scenario C) leads to an increase in timber production valued at 30,789 million SEK.

Under Scenario A, intensive cultivation leads to an unambiguous final result implying a net loss in social welfare in all four cases. For scenario B, we observe that IFM is profitable in three out of four cases *if* "other external effects" are valued at their minimum figures. Thus, this result is dependent on the magnitude of other external effects (acidification, landscape changes, recreation). For scenario C, IFM is profitable irrespective of short or long run perspective, and irrespective of the price assigned (political or scientific) to carbon emissions. But, again, crucial for this outcome is the extent of other external effects.

6. Conclusions

Our results indicate that it can be socially profitable to intensively manage forests in areas of low environmental value and on currently abandoned agricultural lands. Although the results in Table 1 reflect uncertainty in several dimensions, the numbers underscore the importance of carbon valuation – the price we assign to carbon storage – in CBA. The results also highlight the importance of quantifying and valuing the impacts associated with non-priced activities such as recreation and hunting.

Some of the main conclusions of this CBA include the following:

- Intensive cultivation is privately profitable given today's prices and costs;
- Intensive cultivation gives rise to several "external effects" that are not considered in the decision-making process by private landowners;
- The impacts associated with these external effects provide ample motivation for policy intervention;
- The net value of the external effects varies significantly due to the complexity associated with quantifying and monetizing them, that is, they are characterized by high levels of uncertainty;
- The fact that intensive cultivation contributes to a reduction in carbon dioxide emissions is not, in itself, a sufficiently compelling motivation for implementing this forest management approach.

Given that intensive cultivation is profitable for private companies and that many of the intensive cultivation measures are already allowed in Sweden today (to some limited extent), one might ask why forest owners are not already managing their forests intensively? There are several possible explanations: [22] deeply rooted traditions about how a forest should be managed, a general skepticism towards the possible environmental benefits of this new method, or a denial by forest owners that positive economic outcomes are indeed possible (e.g., those indicated by Scenarios B or C in Table 1). Given a positive net welfare effect of IFM, the first two explanations may justify governmental intervention aimed at encouraging forest owners to intensively cultivate (e.g., guidance and information campaigns, regulatory reform, etc.). However, if the slow adoption of intensive forest management is instead explained by general pessimism, efforts to alter landowner behavior are unlikely to succeed. In that case, a given forest owner's economic calculations regarding future profitability are presumably no better or no worse than another's.

In addition to increased timber value for private landowners, intensive forest management also produces several external effects that are likely to be ignored in a forest owner's private decision making. Intensive cultivation contributes to a reduction in carbon dioxide emissions, which leads to increased acidification and negatively impacts, among other things, hunting and recreation. The existence of external effects may justify regulatory intervention to influence the behavior of forest owners. However, it is important to note that if forest owners receive financial compensation for the carbon storage their forests capture, but are also asked to pay for the concurrent negative effects from intensive cultivation, then the incentives for these landowners to management forests intensively may be very different than they are today.

A key input into the CBA calculations and the resulting outcomes is the quantification and monetization of external effects, which is a challenging task in itself. For example, valuing the effects on biological diversity is extremely complicated and impacted by high levels of uncertainty. There are no studies available today that specifically quantify the effects of intensive cultivation in terms of changes in biological diversity. Even if such studies exist and quantify such impacts, establishing a reasonable price based on welfare economics is challenging. Furthermore, to determine climate impacts associated with intensive cultivation, a CBA must make assumptions about whether forest-based products are considered climate neutral both in the short and long run, or only in the long

[22] Note that we are not assuming profit maximization necessarily, as many forest owners, especially small private owners, take into account much more than just profits (recreational values, owner's "warm glow", social/cultural pressure, etc.). You may look at it as the forest owner is maximizing utility, and this utility function can be very different depending on owner type, such as private small owners and forest industry companies.

run. From a welfare economics perspective, these forest products should not be considered climate neutral over the short run.

The fact that intensive management gives rise to external effects (e.g., reduced carbon emissions to the atmosphere) provides a reasonable justification for political intervention in the forest market. It is important to note that even though intensive cultivation reduces carbon dioxide emissions this is not, in itself, a sufficient justification for governmental support of intensive cultivation. Instead, discussions about forests and forest management should be an integral part of the climate policy debate. Just as policymakers address fossil fuel *emissions* through a carbon dioxide tax (or tradable permits), it is equally reasonable that policies also address carbon *uptake* from forest management activities through a landowner compensation scheme (see Lundgren et al., 2008 for a detailed analysis).

In conclusion, we stress that the welfare-related implications of the CBA presented here should be interpreted with some caution, namely: (1) the analysis is based on sensitive assumptions regarding, among other things, forest production possibilities and hence the economic outcome for private forest owners; (2) the impact of intensive cultivation on carbon sequestration is heavily dependent on these assumptions; and (3) the forest economic model used to estimate the effect of intensive cultivation on timber production is not an optimization model, which means that the present value of the forest's future production is not necessarily maximized – neither in the reference scenario ("business as usual") nor in the intensive cultivation scenario. The inability to optimize has certain implications for model interpretation, namely that we cannot exclude the possibility that the choice of optimal rotation time – and therefore timber supply and effects on carbon uptake – may change considerably under an intensive cultivation scenario. Furthermore, an increase in demand for bioenergy has similar dynamic effects in the sense that forestry investments may become more profitable. This in turn will increase carbon sequestration and can offset the carbon losses due to increased harvesting of forests for energy. Indeed, the increase in demand could result in an expansion of forests and with it associated forest carbon.

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