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Boreal zone of the globe has the highest percentage of forest land and in many respects determines the importance of forests in functioning biosphere. At the same time these forests have been studied not enough in order to assess their environmental role, their resource potential and social importance. Presentations devoted to interaction of boreal forests with environment contribute to the proceedings of the conference. A special attention is paid to productivity of forests, their multipurpose use and resistance to disturbances. An urgent problem of forest importance in the carbon balance of the atmosphere and their high susceptibility to wild fires is touched upon as well. Socio-economic problems of human activity control in boreal forests are considered.
Holding the conference coincides with twenty year anniversary of IBFRA foundation.

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Conference proceedings are intended for researchers of scientific institutions, post-graduates and students as well as for specialists of state, public and private organizations dealing with protection and natural utilization of boreal forests.

Key words: boreal forests, productivity, resources, environment, natural and anthropogenic disturbances, stability, carbon, socio-economical problems, forestry, forest use, management of boreal forests.

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BOREAL FORESTS AS A CARBON SINK: A REAL OPTIONS PERSPECTIVE

S. FUSS[1], M. GUSTI[1,2], F. KRAXNER[1], K. AOKI[1], J. SZOLGAYOVA[1,3]

[1]International Institute for Applied Systems Analysis, Ecosystems Services and Management Program, Laxenburg, Austria
[2]Lviv Polytechnic National University, Lviv, Ukraine
[3]Comenius University, Bratislava, Slovakia

Boreal forests mainly serve two functions. On the one hand, they are the source of income of coniferous industrial wood suppliers; on the other hand, they play an integral role in the regulation of the Earth's climatic system [1]. People have actively (through the extraction of wood for commercial purposes) and indirectly (through an aggravation of climatic change) intervened in this system. At the same time, policymakers have repeatedly expressed their interest in using the forest as a sink for climate change mitigation. In principle, more carbon could be stored in the boreal forests if larger areas were accessible to enable improvements in forest management. However, in the face of uncertainty about the realization of policy, the returns on investment in expanded infrastructure and enhanced management are uncertain as well. We employ a simple real options framework to broaden the policymaker's perspective in this respect.

Boreal forests have long been established to hold a major fraction of the Earth's terrestrial carbon [2]. As a result, the policy debate has put boreal forest sinks as part of a wider mitigation portfolio forward. However, it is not possible to look at this benefit of boreal forests without understanding their part in the larger system. [1] give an extensive account of boreal forests. Figure 1 tries to simplify the main ideas emphasized by the authors.

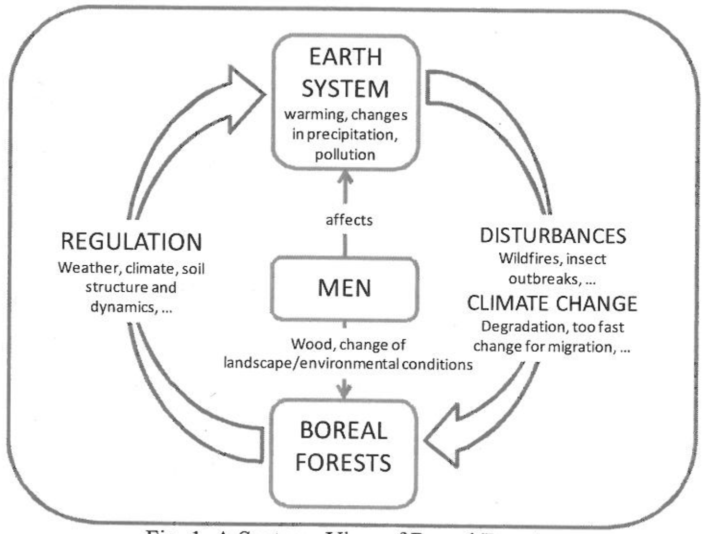

Fig. 1. A Systems View of Boreal Forests.

From Figure 1, it becomes clear that boreal forests are not only an integral part of the Earth system regulating climate and environmental conditions, but they are also a major source of income for the extraction of wood for commercial purposes. In addition, the extraction of other natural resources such as natural gas and minerals also occurs at the expense of boreal forests' environment and living conditions.

Many previous studies have provided estimates of the extent of the carbon sink potential of Canadian and Russian boreal forests. For example, Canadian forests were found to be a net sink before 2000, but due to steep increases in frequency and intensity of wildfires and insect outbreaks, they are a net source nowadays, which is supposed to continue for at least two more decades [3]. [4] estimated Russian boreal forests to be a net sink of 160 Mt C in 1993 and claimed that this number might even increase, while more recent studies find huge variations in these numbers (e.g. [5]).

Even though the need to provide incentives for storing more carbon in forests has been part of the international discussion on climate change mitigation, no decisive action has been taken – except for some isolated CDM[1] projects related to avoiding deforestation and afforestation activities. On the other hand, it is also possible to use forests as a carbon sink as a result of improved management [6]. This is particularly relevant in the Russian boreal forest, where expansion to unused areas opens up the possibility to improve forest

[1] Clean Development Mechanism

management, such as thinning or the increase of rotations on the more productive areas to store higher amounts of carbon. However, such an expansion requires the building of new infrastructure to make a larger area accessible and this represents a major investment to decision-makers. Furthermore, there is no commitment to a clear carbon policy as of yet, so decision-makers face high uncertainty about the returns to their investment: if they cannot be sure when or how much they will be rewarded for storing carbon, this might represent a major obstacle to investments into infrastructure and enhanced management.

In this paper, we demonstrate that a systems perspective as drawn by [1] and others is important, but that the uncertainty created by the policy dimension adds a substantial option value to committing resources to new infrastructure and better management, even if the results would be a desirable increase in the carbon sink. We use a real options model to illustrate the tradeoffs at work in the face of uncertain policy dynamics.

Real Options Theory rests on the idea that a real decision has features similar to a financial option and that keeping such an option open consequently has an economic value. For example, if an investment involving large costs to be sunk in the face of uncertainty about the future profit streams can be postponed, it may pay off to do so and make a better decision based on more complete information later on. This example illustrates the three characteristics of a decision problem that make real options a suitable approach: (a) the decision can be timed flexibly, (b) exercising the option (e.g. investing) is irreversible (e.g. since it involves large sunk costs), and (c) there is uncertainty about future costs and/or benefits associated with the decision [7].

Obviously, considering boreal forests as a carbon sink warrants similar considerations, as the decision to invest into sink-increasing options has uncertain returns if policymakers do not credibly commit to a carbon payment for each ton of stored carbon.

As we intend to offer a perspective to policymakers rather than offering numerically precise predictions on investment dynamics, we abstract from many things such as the potential valuation of ancillary benefits and also the impacts of climate change, which will have further implications for the development of the carbon sink (cf. Figure 1). Instead, our thought experiment assumes that the decision maker's profits π_t are composed of the proceeds of selling the harvested wood $P_W \cdot Q$ less the cost of extracting the wood from the forest $VC(x) \cdot Q$. In addition, he receives a carbon payment P_t per ton of stored carbon $C(x)$ per year[2]. Note that the amount of carbon stored is dependent on state x: if $x = 2$ upon investment into new infrastructure costing I enabling improvements in forest management and hence increasing the carbon stored, i.e. $C(2) > C(1)$. It will be possible, furthermore, to extract the same amount of wood in state 2, as the wood extracted through thinning can also be sold, but the cost of extraction will be higher, i.e. $VC(2) > VC(1)$. As the price for wood and the quantity extracted are constant across both states, we can drop them from the calculations and only focus on VC and C.

The source of uncertainty in this thought experiment emanates from carbon policy, which is mimicked by P_t, the carbon credit paid out for the amount of carbon stored in the forest. We assume that the development follows a Geometric Brownian Motion similar to experiences with current carbon markets to begin with.

$$dP = \mu \cdot P_t \cdot dt + \sigma \cdot P_t \cdot dz_t \qquad (1)$$

where μ is the trend, σ the volatility parameter and dz_t the increment of a standard Wiener process. Let us further define the gain from investing and improving management as G, which is composed of the additional carbon stored, ΔC multiplied by the price received per ton of carbon. The value of the investment if investing at time t is thus

$$V(G_t) = E\left(\int_0^T e^{-r \cdot t} \cdot (G_t - Q \cdot \Delta VC)\, dt \right) \qquad (2)$$

where T is the end of the planning horizon, r the discount rate and the income from selling wood is assumed to be constant for both states. Assuming $T = \infty$ for the moment, integration gives us equation (3).

$$V(G_t) = \frac{G_t}{r - \mu} - \frac{Q \cdot \Delta VC}{r} \qquad (3)$$

[2] This might be paid out of a dedicated REDD (Reduced Emissions from Deforestation and Degradation) fund, as part of a project in a type of CDM setting or through linkage with an existing carbon market. The details of the implementation of such funding are beyond the scope of this exercise.

The decision-maker will only invest into infrastructure and better forest management if this value exceeds the value of the option to invest, $F(G_t)$. In other words, there is an economic value to waiting for better information on the development of the carbon policy and reacting optimally on this at a later point in time. The critical value G^*, which will trigger investment, can be found by equation the marginal value of waiting with the value of exercising the option evolving according to the changes in $F(G_t)$ over time, as described in detail by [7]. Following this procedure, we find differential equation (4), which holds for $G \in [0, G^*]$:

$$rF(G) = \mu GF'(G) + \frac{\sigma^2}{2} G^2 F''(G) \tag{4}$$

where time subscripts are omitted for clarity of exposition.

The boundary conditions are given by equations (5) to (7):[3]

$$\lim_{G \to \infty} F(G) = 0 \tag{5}$$

$$F(G^*) = V(G^*) - I \tag{6}$$

$$F'(G^*) = \frac{1}{r - \mu} \tag{7}$$

The problem being completely analogous to the one described in [7], we follow the same procedures arriving at the following solution form for $F(B)$.

$$F(G) = A_1 G^{\beta_1} + A_2 G^{\beta_2} \tag{8}$$

where we are only interested in β_1 as $\beta_2 < 0 : \beta_{1,2} = \frac{\sigma^2}{2} - \mu \pm \sqrt{(\mu - (\sigma^2/2))^2 + 2r\sigma^2} / \sigma^2$ and $A_1 = (G^*)^{1-\beta_1} / \beta_1 (r - \mu)$, so we can solve for the threshold of the gain, at which investment occurs:

$$G^* = \frac{\beta_1}{\beta_1 - 1}(r - \mu) \cdot \left(\frac{Q \cdot \Delta VC}{r} - I\right) \tag{9}$$

which implies that the threshold level of the necessary carbon credit needs to be higher the lower the amount of additionally stored carbon ΔC is.

Employing some rough estimates for the parameters, we can plot the value less the investment cost, *(V-I)* and the option value, *F*, in Figure 2. Where the two lines cross, we have the threshold value of the carbon gain, G^*.[4]

Note that the data are rough estimates abstracting for the time being from some important dynamics, so more research is needed to account for the full cost of expansion and the dynamics underlying the carbon budget. However, we can already on the basis of this simple exercise say that a rising CO_2 price would at least need to reach €8/ton with an expectation of further rises to trigger investment into the required infrastructure for improved forest management and thus additional carbon storage. The following table demonstrates that relaxing the assumption of an infinite lifetime further raises this threshold and higher than anticipated investment costs do the same.

So, while the absolute numbers should not be taken at face value before a more complete dataset can be tested, the sensitivity analysis gives us important information about the impact of different parameters and how they change the underlying tradeoffs. In particular, a lower than expected carbon price will raise the carbon price

[3] See [7], pages 108 and 109 for an economic explanation and derivation of the boundary conditions.

[4] We assume for Q that the 2010-2050 average projected harvest of 173.99 mill m^3 applies per year for the Russian boreal forest and that the area necessary expansion is 29.575 mill. ha, where 10m à 10€ are needed to make 1 additional ha accessible for forestry. Operational costs will be higher by 0.44€ per m^3, as under improved forest management some wood is extracted through thinning, which is more expensive to do than extracting it through simple clear-cut. 92 Tg CO_2 are additionally stored due to improved forest management each year, where the G4M WEO scenario data have been rescaled according to the 2003-2008 average net ecosystem balance by [8] adjusted furthermore by the accumulation in living biomass, which is about 35% (personal communication A. Shvidenko). The discount rate is about 20% according to [9].

needed to entice investment, which is also true for higher than anticipated operational (and maintenance costs). Most importantly for policymakers, is the message conveyed by the sensitivity of the trigger price with respect to carbon price volatility: even if policymakers can make a credible commitment to raising carbon payments for additionally stored carbon in the forest, fluctuations in the same represent a disincentive for committing resources to the building of the necessary infrastructure.

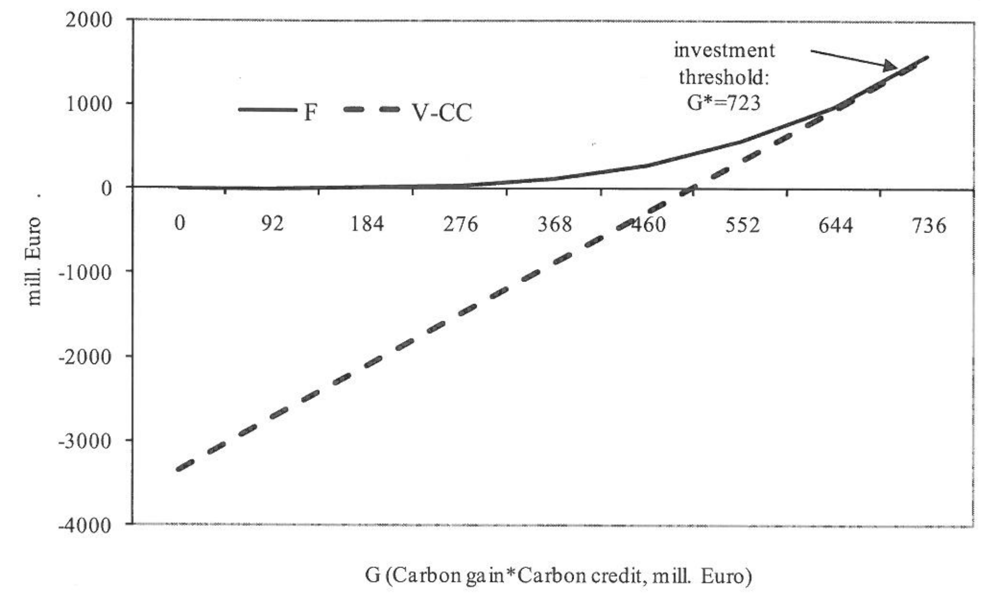

Fig. 2. Option value (solid line) versus net present value (dashed line).

Table 1: Sensitivity analysis

	G* (mill EUR)	P* (EUR/ton)
baseline	723	7.86
carbon gain halved, ΔC	723	15.72
Increased carbon price volatility, σ	836	9.08
double investment cost, I	1,363	14.81
double operational cost	806	8.76
Shorter planning horizon, T=50	1,196	13.00

Future research should therefore not only concentrate on the composition of a more complete dataset, but also tackle different forms of uncertainty. The current analysis assumes that there will be carbon payment scheme evolving in a similar way as current carbon markets, but this is not guaranteed. On the contrary, there is also substantial uncertainty about the timing when such carbon payments could be introduced and there is also the question whether it will be introduced at all and if so whether it will be kept, which could be mimicked by introducing a Markov process.

In this paper, a simplistic yet important thought experiment has been carried out to provide a new perspective to the maintenance and sustainable use of boreal forests in Russia. In particular, we have employed a small real options application to model decision-making in the face of uncertain carbon policy, thereby illustrating the importance of clear commitments and unambiguous signals on the part of policymakers in order to achieve improved forest management and enable the storage of larger amounts of carbon in the forest as part of a larger mitigation portfolio.

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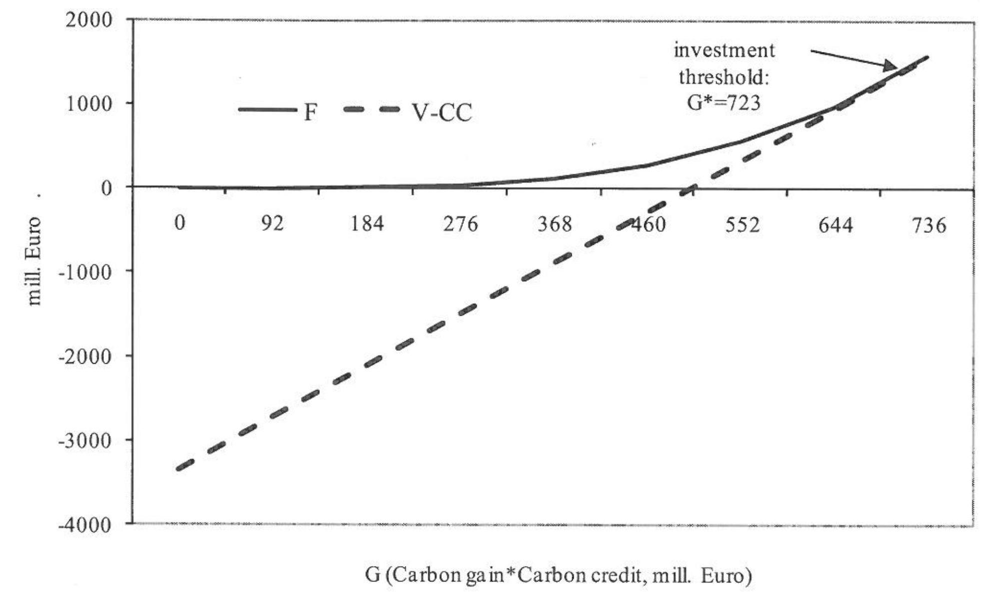

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SOCIO-ECONOMIC LOSS FROM IRRATIONAL FOREST USE IN KRASNOYARSK REGION

A.A. LALETIN[1,2], V.A. SOKOLOV[1], A.P. LALETIN[2]

[1]Sukachev Institute of Forest SB RAS, Krasnoyarsk, Russia
[2]NGO "Friends of the Siberian Forests", Krasnoyarsk, Russia

This article shortly characterizes the forest reserves of one of the largest forest regions of Russia – Krasnoyarsk region. It can be seen in dynamics that for the last 50 years the quality of the forest reserves has degenerated significantly. This degeneration is caused by the irrational and unsustainable forest management. Authors propose some basic principles for sustainable forest management and provide some socio-economic mechanisms of solving the problem of illegal logging.

Forest resources of Krasnoyarsk region. Timber resources of the forests

In connection with the union of three subjects of the Russian Federation on 1 January 2007 - Krasnoyarsk Territory, Taimyr (Dolgan-Nenets) and Evenki autonomous districts into one entity - Krasnoyarsk Region, the Krasnoyarsk Region land balance has changed. The total land area of the united region as if 01.01.2008 amounts to 236,679.7 ha. Area of the region increased by 164,312.6 hectares. Area of forest land of Krasnoyarsk region amounts to 155,565.0 hectares. Area of lands under forest have increased by 97,578.5 ha in the united region. In the structure of land of Krasnoyarsk region forest fund lands constitute 65.7%. [4]

More than half of the forests in the region are represented by larch, about 17% by spruce and fir, 12% by pine and more than 9% by cedar. 88% of forests in the region are coniferous.

More than 10% of Russian timber reserves are concentrated in Krasnoyarsk region.

Forest dynamics of Krasnoyarsk region

The analysis of forest dynamics is based on the forest resource assessments, since 1961, – the year of the first simultaneous assessment of Siberian forests, when they were assessed with the inventory methods of varying accuracy: the method of III–IV categories of forest management regulation and the method of remote sensing by airplane (more than half of the area). [3]

During the 45-year period (1961 – 2007) in Krasnoyarsk Territory (Krasnoyarsk region, Republic of Khakassia), the area covered by forests decreased by 5108.2 thousand ha (5 %), and the area of mature and over-mature coniferous and larch stands declined by 17210.4 thousand ha (25 %) and 1670.5 thousand ha (17 %), respectively. The total reserves of timber decreased by 3174.99 million m^3 (12 %); the accessible reserves of timber in coniferous stands decreased by 3725.06 million m^3 (35 %), but accessible reserves in deciduous stands increased by 10.14 million m^3 (1 %).

Consequently, the quality forest reserves of Krasnoyarsk region have already been degenerating for almost 50 years. The process of degradation has slowed down during the last years due to the sharp decline in logging volumes.

Development of the bases for forest management

According to the Russian Federation Forest Code (FC) the forest estate lands should be federally owned (article 8). Before the FC was released, however, parcels of forest land and forestry enterprises were transferred to the Subjects of the Russian Federation's management under federal law #199 dated 31.12.2005. Forest enterprises have been converted into forest districts – local forest and field services management authorities