RUSSIAN FORESTS FOR CLIMATE CHANGE MITIGATION

AN ECONOMIC ANALYSIS

Alexander Golub

Harvard Forest

Harvard University

Cambridge, Mass.

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Executive Summary

The industrialized countries, including the United States and Russia, are assessing options to reduce their greenhouse gas (GHG) emissions. Right now, many OECD countries are interested in investing in carbon reductions in Russia and Eastern Europe where the cost might be considerably lower.

The form in which such transactions might emerge is still unclear. There is the possibility of buying and selling carbon credits between countries, which can lead to more cost-effective GHG reductions. These credits could only be exchanged when the selling country is below its reduction target. In a trading scheme, carbon reductions or sinks will have value that will be manifest in the price of carbon credits. Countries could limit their current emissions of greenhouse gases to a level below their obligated limit, or they could increase their allowable GHG emission limits by implementing projects that can capture and sequester carbon by means of forest projects, such as reforestation, afforestation, assistance to natural regeneration, and sustainable forest management. Because the types of sequestration projects that might be eligible for carbon credits are uncertain, this study will only focus on forestlands planted after 1990. Assuming this conservative constraint, this report analyzes how much carbon could be sequestered by biomass sequestration projects in Russia, given different prices for carbon reduction credits.

In this study, we developed a bottom-up model of Russia's potential forestland. Our results show that sequestration is quite price sensitive, with a range from no carbon sequestration at prices under $20 per ton of carbon to over 500 million tons of carbon stored if the price for a ton of carbon is $50.

Russia's potential carbon credit supply (million tons of carbon) given different prices for carbon, by regions, and total for Russia (during first budget period, 2008–2012)

	Less than $20	20	25	30	35	40	45	50	55	60	65	70	75	80
European part of Russia	0	25	75	100	120	135	150	160	170	180	190	200	205	210
Asian part of Russia	0	0	0	140	225	270	315	350	380	400	420	430	450	470
Total Russia	**0**	**25**	**75**	**240**	**345**	**405**	**465**	**510**	**550**	**580**	**610**	**630**	**655**	**680**

It is also critical to note that positive revenue streams do not appear until 10-15 years into the project--a potential problem because almost all costs will occur in the first year, and the discount rate is relatively high (10%), so the economic value of the revenue stream is still close to zero after 20 years.

Conclusions

Timing issues are extremely important in making sequestration projects feasible. Almost all the costs are at the beginning, while the revenue stream for carbon permits is maximized 10-15 years in the future, and is only significantly positive if the price is above $25 per ton of carbon. Our conclusions from the study are as follows:

- **Forward Sales Enhance Revenue Timing:** Significant costs are incurred at the beginning of forest project implementation, but the first revenue would not be yielded earlier than 2008, when carbon credits could become a commercial commodity. After 2008, however, the revenue flow could become significant for Russia ($20–30 million annually). One possible solution to this problem of cost and benefit temporal distribution may be to allow forward sales--that is, sales of credits for sequestration that will occur in a later budget period and put that money toward costs that occur in an earlier period. For instance, it may be possible to sell second commitment period credits in the first commitment period, allowing the revenue to offset part of the initial cost of the project. It may also be possible to sell a portion of unused Russian carbon credits.

- **Economic Choices vs. Ecological Choices:** Due to the high discount factor, only carbon sequestered in the first twenty years (1999-2019) has any commercial benefit; the economic value of later carbon sequestration is close to zero. Therefore, one would not choose the species with the highest sequestration capacity over its lifetime, but rather those species with the highest sequestration capacity within the first 20 years. In the Russian boreal forest, these are soft-leafed, fast-growing species such as birch and aspen, rather than the slower-growing, carbon maximizing spruce and larch. This means that carbon sequestration potential will not be maximized, as long as forests are planted, then left to grow.

  However, the economic incentives for carbon maximizing reforestation activity can be improved by the reduction of planting costs, increases in productivity, accounting for non-timber products (NTP), and land tax abatements in the first 10 years. “Soft” loans (loans at below-market terms, loan-grant combinations, etc.) to implement forest projects can have a positive impact as well.

- **Need for Established Market:** Below $25 a ton for carbon, very little new forests for sequestration are planted. At $25 reforestation projects will only occur in European Russia. In Asian Russia, the initial costs are higher. No significant planting will occur until the cost of carbon is $30 per ton or higher, due to a more difficult climactic conditions and higher

planting and access costs. However, the Asian regions may ultimately have much more carbon sequestration potential than those in the west.

Finally, the value of carbon sequestration will remain uncertain and the transaction costs in certain regions may be high. It is in the interests of both Russia and the OECD countries to pursue efforts to reduce these uncertainties and transaction costs if Russia is to maximize its forest sequestration potential.

Russian Forests for Climate Change Mitigation: An Economic Analysis

Alexander Golub*

1. Russian forests and their role in carbon sequestration: economic and institutional barriers

Of all the countries listed in Annex B to the 1997 Kyoto Protocol to the UN Framework Convention on Climate Change (FCCC), Russia has the greatest potential to sequester carbon. In the literature, estimations of annual carbon sinks vary. Natural annual sequestration by Russia's existing forests has been estimated at 262 million tons (A. Isaev, et al., 1995). This amount could be increased dramatically by additional reforestation and afforestation measures on land not currently covered by forests, including marginal agricultural lands. Apart from the existing biological constraints, however, much depends on the economic and institutional situation, which could promote or hinder use of the carbon sequestration potential of Russia's forests. The goal of this paper is to analyze the economic instruments and institutional changes needed to maximize the amount of carbon sinks by Russian forests for carbon credit production.

In this study we calculate the potential supply of "assigned amount units" (AAU) of carbon assimilation from Russian forest projects under different scenarios for international negotiations on the role of forests in carbon balances. We take into account the influence of the economic situation in Russia as well. From these factors, we construct an AAU supply function from Russia's forest sector for the first Kyoto budget period (2008–2012) and for a second hypothetical budget period (2013–2022). We then compare decisions based on economically efficient carbon sequestration projects (in light of the institutional constraints arising from the Kyoto Protocol), and those based on the criterion of maximization of carbon sequestration in the

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* Alexander Golub is a Senior Research Fellow at the Environment and Natural Resources Program, Kennedy School of Government, Harvard University.

long run. We identify the conflict between these two sets of criteria. Based on this analysis, we formulate recommendations to harmonize these criteria, and we develop a set of tools to create incentives for global climate change mitigation on the micro level.

1.1. Forests in the Kyoto Protocol

Annex B to the Kyoto Protocol established emission budgets for the developed countries for the period between 2008 and 2012. The emission budget (EB) for each country is a GHG emissions volume, defined by the Kyoto Protocol, for 2008–2012. It can be calculated by the following formula:

> EB = GHG 1990 * K * 5,
>
> where GHG 1990 is total GHG emissions in 1990;
>
> and K is a coefficient of GHG emissions reduction or increase from Annex B (e.g., K=1 for Russia, K=0.93 for USA, K=1.08 for Australia).

Each country could increase its EB by increasing carbon sinks through implementation of reforestation and afforestation projects. Unfortunately, the effectiveness of doing so depends not only on biological factors but also on specific carbon accounting rules established by the Kyoto Protocol. As a result, the most productive way to increase carbon sinks is not necessarily the most efficient way to increase the emissions budget; in other words, the Kyoto Protocol may create some perverse incentives.

The text of the Protocol does not specify what forest projects may be accounted in the national GHG budget and in what way. Article 2, paragraph 2 of the Protocol makes only a general declaration that the Protocol promotes measures to increase forest sequestration, "resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990." Article 3, paragraph 3, states that for Annex I (developed) countries, the net changes of carbon absorption by forests resulting from the human activities mentioned above will be accounted together with GHG emissions to estimate whether

each country has met its commitments. The Protocol specifies, under such commitments, a set of assigned amounts, calculated pursuant to the each country's " quantified emission limitation and reduction commitments inscribed in Annex B" of the Protocol.

The main problem is that accounting and verification rules are not defined yet. Article 4, paragraph 3 of the Protocol states that verification procedures are not agreed yet and have yet to be elaborated:

> The Conference of the Parties should … decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the Intergovernmental Panel on Climate Change [IPCC], the advice provided by the Subsidiary Body for Scientific and Technological Advice in accordance with Article 5 and the decisions of the Conference of the Parties.

It is clear that the process is going to be very complicated.

One of the most controversial issues of the Protocol is in which budget period additional sinks should be accounted. Part 2 of Article 3, paragraph 4 says: "Such [an accounting] decision shall apply in the second and subsequent commitment periods. A Party may choose to apply such a decision on these additional human-induced activities for its first commitment period, provided that these activities have taken place since 1990." This suggests the possibility of accounting all carbon sinks, even for "old" projects (started not earlier than 1990), and adding their carbon benefit to the first budget period.

That these matters — what forest projects can be counted as AAU producing; how to calculate their carbon benefit; and when forest sinks may be accounted in the national budgets — are unsettled increases the business uncertainty, and thus increases the risk of getting a return on

investments in forest projects. One of the purposes of this paper is to provide some recommendations on the issue by offering an economic analysis of the problem.

However, the same project in the forest sector could be said to generate different values for a country's emissions budget, depending on what carbon-sink accounting rules are applied. There is a potential fundamental contradiction between biological and economic criteria for forest project selection. Therefore another purpose of this paper is to examine this contradiction and to propose ways to reconcile it, to maximize the economic incentives for overall reduction of GHG.

1.2 Russian forests' carbon sequestration potential

The most reliable estimation of the potential of Russian forests to sequester carbon was presented by the International Forest Institute of the Russian Academy of Sciences, and was published in 1995 (A. Isaev, et al., 1995). It was later used by Russia's Bureau of Economic Analysis to produce the Russian National Strategy for GHG Emissions Management (referred to in this paper as the "NSS").

In the NSS study, estimates of Russia's carbon stock and its carbon annual sink were based on two main data sources:

- data on primary forest production and information on the species mix in forest areas in different climatic zones;
- information on Russia's state forest stock and data on its biomass and forest ecosystem production.

There is a database in Russia containing detailed information on the country's forested areas, the structure of productive and unproductive forest lands, and forest ages and types. That database is considered to be sufficiently reliable for carbon pool estimation.

The total area of Russia's forests is 1.18 billion hectares; the timber stock is 80.6 billion m^3. The forest vegetation total biomass has been estimated as 79.3 G t (gigatons), and its total carbon stock at 38.6 G t (NSS, 1999).

Coniferous forests dominate in the Russian forest stock. They contain more than 57 percent of the Russian carbon stock. More than 80 percent of the Russian forest vegetation is located in the Asian part of the Russian Federation. These are mostly mature forests.

The annual carbon sink in Russian forests has been estimated at 262 million tons per year. Carbon sequestration by forests was estimated by calculating the difference between biomass accumulation of carbon (in soil, trunk, roots, etc.) and loss (carbon assimilated by branches and leaves that then fall off and decompose, releasing some of their carbon). The European part of the Russian Federation contributes 45 percent of the total annual carbon sink, although it has no more than 20 percent of Russia's total forest area. This discrepancy is due to differences in the age structure and productivity of the forests. Young and middle-aged plantations, which actively produce and deposit organic substances, prevail in the European part of the Russian Federation. In the Asian part of the Russian Federation mature forests prevail; they tend to be more balanced and stable, which means that the percent of carbon incorporation and isolation are mutually balanced, and so the amount of carbon deposition is lower.

The young and middle-aged forest ecosystems result in the accumulation of phytomass and undecomposed dying-off biomass, and consequently large amounts of carbon sequestration in the forest stock of the Russian Federation. However, that is only part of the Russian forest carbon potential. Other components include carbon emissions resulting from forest fires, pests, forest pathologies, forest protection measures, forest resources utilization, and regeneration.

The main possibilities for increasing the carbon sink are:

- expansion of forested areas through afforestation and reforestation;
- increasing forest productivity; and
- improving forest age structure (forest regeneration).

In the Russian NSS, experts estimated the scale of potential forest project implementation with regard to both the areas available and the economic constraints on implementing costly

reforestation projects. It was assumed that implementation of afforestation and reforestation measures would start in 1999 and that additional increases in forest lands would be about 2 million hectares annually within the next 25 years (1.3 million hectares of reforestation and 0.7 million hectares of reconstruction). Total potential for the first budget period under the Kyoto Protocol was estimated at 100 million tons of carbon, which is about 10 percent of the total Russian potential of AAU.

We are sure, however, that Russia's potential could be increased significantly by more efficient implementation of forest projects; our analysis is intended to indicate ways to get to that result.

2. Cost-benefit analysis and biological criteria for selecting among forest projects

To make a preliminary estimation of the economic efficiency of a given forest project, we use the familiar parameters of net present value (NPV) and internal rate of return (IRR) to calculate both the total carbon sink potential of Russian forests and the costs to generate those sinks.

We use the following formula to calculate NPV of forest projects:

$$NPV = \sum_{t=0}^{T} (PtQt - Ct)\ (1+E)^{-t}$$

where

Pt is the price of AAU in year t;

Qt is carbon sequestration in year t that could be sold;

E is the discount rate;

T is the time of AAU production by the forest project, or project duration;

Ct is project costs in year t, including forest planting and maintenance. (We do not consider transaction costs at that time, because they depend on the scale of the project implementation.)

The major problem with forest projects is that the greatest expenditures are up-front, while the greatest benefits are returned only after some years. Moreover, in the first years the returns are relatively modest; they grow dramatically as the forest ages. Thus, the amount of up-front cost is a critical parameter to which all other parameters are very sensitive, as we show below.

2.1 Benefit side

The revenues are affected by the amount of carbon sequestration by the particular species of tree, the distribution of sequestration over time, and the AAU price.

2.1.1. Carbon sequestration volume

As shown in the formula above, the net revenue depends in part on the AAU price (Pt) and the volume of carbon sequestration (Qt). As noted above, we cannot count all carbon produced by the forest project as an increase in the emissions budget (EB); the share of carbon that cannot be used for this purpose has zero value, and is not included in the values for Qt.

Article 3 of the Kyoto Protocol counts only anthropogenic sequestration added after 1990 to increase EB. (See Figure 1.) In Figure 1, the shaded area between line *a* and line *b* presents this amount. The terms of the Kyoto Protocol do not clearly specify what part of the rectangle under line *a* could also be claimed as part of the EB; resolution of this question requires further development of interpretations of the Kyoto Protocol and baseline studies of the countries involved. Our analysis, therefore, concentrates on the shaded area only.

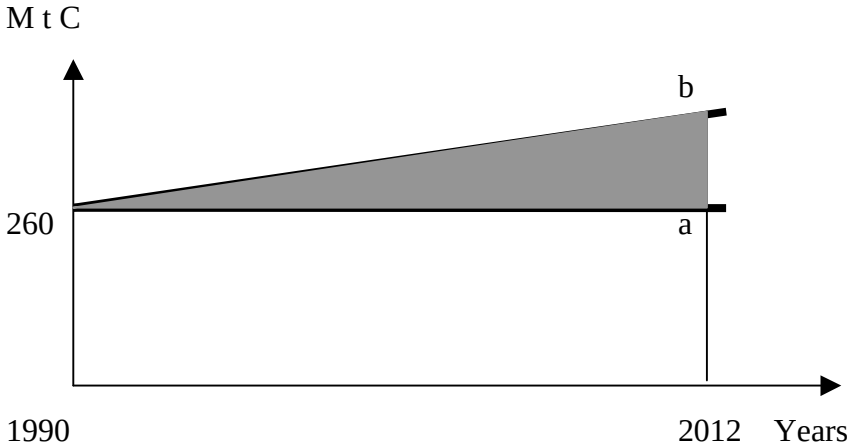


Figure 1. How Kyoto Protocol treats carbon sequestration

Thus, in this study, we consider only “new” projects that are ready for implementation in 2000 because only such projects are appropriate for analysis of the economic justification for their implementation. Investors must choose whether to implement the project or not, based on an analysis of the economic and financial parameters; we discuss these below.

We disregard “old” projects because their up-front costs have been already covered. (For major existing projects, the NPV is, of course, positive, and so there is no point in doing an economic analysis.) To evaluate these “new” projects, we consider some hypothetical examples of forest planting on one hectare, and analyze different options with regard to certain parameters of forest productivity: forest type (the main species); climate conditions; and planting and maintenance practices.

The main species

Different species have different potentials to sequester and to deposit carbon. The differences are in the speed of sequestration, the period of sequestration, and the start of decomposition. Those factors affect the biological and economic characteristics of the newly planted forest. We compare the results of planting different species in Russia to find an optimal species mix for future carbon sequestration projects. Table 1 and Figures 2 and 3 present examples of carbon sequestration by spruce, the most common species found in Russian forests.

Table 1. Average annual carbon sequestration by spruce in the European part of Russia (ton of carbon/hectare)

Age	North	Middle	South
0–10	0.27	0.33	0.57
11–20	0.49	0.61	1.22
21–30	0.69	0.98	1.81
31–40	0.97	1.28	2.11
41–50	1.20	1.55	2.16
51–60	1.28	1.59	2.31
61–70	1.21	1.47	2.31
71–80	1.21	1.42	2.10
81–90	1.13	1.33	1.86
91–100	1.02	1.18	1.59
101–110	0.88	1.00	1.32
111–120	0.72	0.82	1.05
121–130	0.61	0.68	0.87
131–140	0.55	0.60	0.74
141–150	0.48	0.53	0.67
151–160	0.44	0.48	0.59

Figure 2. Average annual carbon sequestration by spruce in the European part of Russia (ton of carbon/hectare)

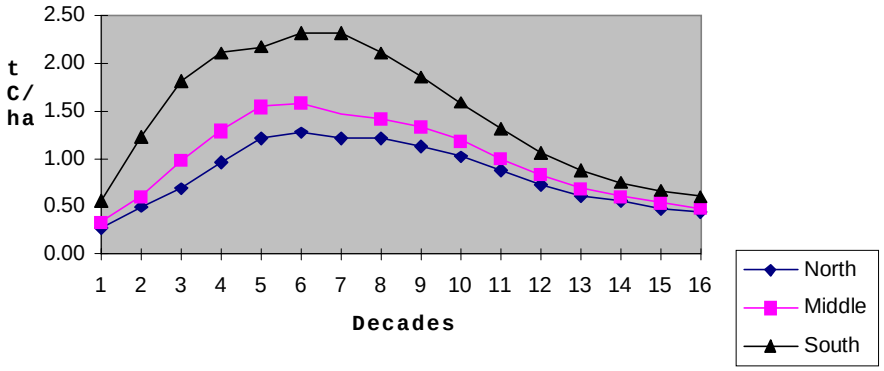
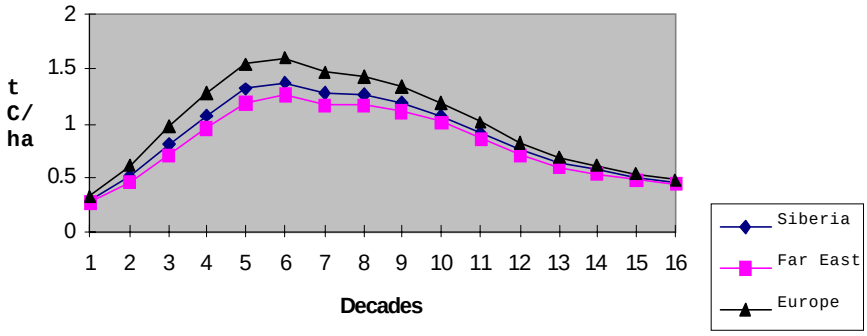


Figure 3. Average annual carbon sequestration by spruce in the regions of Russia (ton C/ha)



Climate conditions and soils

The productivity of various species will vary in different climate zones. Thus the species mix that is optimal for one zone may not be the best for another. We do not take into account all details, but we analyze some examples that are typical for some of Russia's main climate zones.

At the project level, it would be necessary to take into account all factors that will affect the growth of the trees, such as climate, soils, topography, etc. We do not do so; rather we do an analysis at the aggregate level, examining average conditions for typical climate zones. Such a

simplification seems appropriate for our goals. In the database from the International Forest Institute, information about productivity of forests is broken down by species, by region, and by soil type. This information is adequate to build the AAU supply curve. However, at the project level, more detailed data will be required (such as that found in, for example, A. Lubimov, et al., 1998; and the USSR Forest Committee, 1984). Such information is available for most Russian regions. Information required at the project level is also available (see S. Hamburg, et al., 1995).

The technique of planting and maintenance

The Russian techniques for planting and maintenance of forests are fairly complex, but the practices are far from optimal. To construct the AAU supply curve, we use the existing techniques from the Russian forest database as a baseline. However, there are substantial possibilities to increase productivity by applying modern technologies; there have been several examples of successful application of improved techniques. The best way to consider their potential impact would be to conduct an analysis on the project level. (One good example of such an economic analysis is presented in Vincent, et al., 1998.)

2.1.2. Price forecast on the AAU market

At the fourth Conference of the Parties (COP-4) of the FCCC, held in Buenos Aires in 1998, an Action Plan (known as the Buenos Aires Action Plan, or BAAP) was adopted which brought some additional certainty to discussions of various scenarios for AAU market development. We have based our analysis on the few sources available (Ellerman, et al., 1998; W. McKibbin et al., 1998; NSS, 1999).

The prices shown in Table 2 are drawn from several sources, and are based on estimates generated by the models used in each of the sources cited.

Table 2. Estimates of the price per ton of carbon (carbon dioxide) in U.S. $/t of C (figures in parentheses: per ton of CO2)

Year	MIT Annex B*	MIT Full Trading*	EPA Annex B†	EPA OECD†	Russian NSS‡	Scandinavian market§
2008					$37 ($10)	
2010	$127 ($35)	$24 ($6.5)	$61 ($17)	$112 ($30)	$55 ($15)	$202 ($55)
2012					$55 ($15)	
2020			$109 ($30)	$123 ($33.5)		

* Source: MIT: Ellerman, et al., 1998

† Source: EPA study: McKibbin, et al., 1998

‡ Source: NSS, 1999

§ Source: P. Bohm, 1997.

2.1.2.1. Carbon market development scenarios and price forecast

The main scenarios that are considered in the sources we relied upon are as follows:

- no trading;
- trading within Annex B countries (i.e., the developed countries for whom GHG targets are specified) with or without a cap on trading;
- trading with participation of non–Annex B countries (i.e., the developing countries).

Those basic scenarios could be further varied, as we show next.

NO TRADING

Usually the "no-trading" scenario is used as a baseline, to show the losses of all countries and each Party if the flexible mechanisms established in the Kyoto Protocol are not used. These losses are then compared with the costs involved in using one or other mechanism. The difference between losses and costs is interpreted as the benefit from a given flexible mechanism. This also permits evaluation of the distribution of revenues among countries that use one or another flexible mechanism. This basic scenario has not generally been used to estimate prices for AAU; we do so here.

TRADING WITHIN ANNEX B COUNTRIES

Trading among Annex B countries is the most probable scenario for the first budget period. Certain preconditions already are in place to implement it, in that the Kyoto Protocol established GHG emission quotas for the Annex B countries.

Two types of trading possible within Annex B:

- Trading without caps, which means that all countries of Annex B could participate and any share of total AAU budget of any Annex B country could be a commodity on the AAU market and could be traded; or

- Trading with caps, which means that there are limits on the volume of AAU purchases or sales by each Annex B country, or constraints on participation in the market, or further specifications that indicate which AAU are appropriate for trading.

The "no-cap" type of trading is simpler and more straightforward. Trading with caps is more complicated and has no natural preconditions for its implementation; it is designed to make trading more difficult and ultimately to reduce its scale. Two variations have been proposed. First, limits could be placed on AAU purchases: each country would be allowed to meet only part of its demand for AAU on the world market. For example, a limit of 20 percent has been discussed. This limit could double AAU prices compared to trading without caps.

A second type of limit is a sales limit, typically by AAU specification. For example, only additional emission reductions (below “business as usual”) would be permitted to become a commodity on the AAU market. In other words, not all AAU would be tradable. Therefore only part of the unused GHG emission quota generated by the additional measures of the seller could be tradable. That proposal is specifically aimed against Russia and Ukraine, which may have a significant unused GHG emission quota because of their economic decline since 1990. It also adversely affects the interests of the buyers: they would pay more for AAU and bear greater costs to implement domestic measures to limit GHG. Such a limit could double or triple prices compared to trading without caps. Any limits would increase prices and reduce trading volume. They will also increase the burden for the economies of the Annex 1 (developed) countries.

Some scenarios analyze bilateral trade, or trading among a specific subset of the Annex B countries (for example, within the so-called Umbrella Group, consisting of the United States, Japan, Canada, Russia, Ukraine, Australia, New Zealand and some other countries; or among the Scandinavian countries).

The Kyoto Protocol and the Buenos Aires Action Plan did not create any *a priori* limits on AAU purchases or sales by Annex B countries. Therefore in our analysis we will assume that trading is without caps.

TRADING WITH PARTICIPATION OF NON–ANNEX B COUNTRIES

Participation of the non–Annex B (developing) countries could increase trading volume substantially, and as a result prices for AAU would drop. We specify some hypothetical schemes for involvement of the non–Annex B countries in trading, in order to estimate the level of price changes if they are involved.

The Kyoto Protocol offers current non–Annex B countries two alternatives. Under one, they can choose to join Annex B and meet "assigned amount" obligations. Any country that does so can participate fully in a system of emissions trading just as other Annex B countries do.

Current non–Annex B countries that choose to pursue the “clean development mechanism” (CDM) diminishing their opportunity to trade with highly industrialized countries. CDM trading can only take place after the CDM itself is established, a process that might take several years of negotiation. Even after the CDM is put into operation, countries or companies seeking to trade are likely to be subject to rules and administrative requirements that will make transactions under the CDM more costly than those under Annex B. Countries in Annex B, by contrast, will not only be able to engage in GHG emissions trading sooner, but will offer a cost advantage over those countries that must conduct trading under the CDM. The first CDM projects will most likely be demonstration projects.

Adoption of commitments and emission budgets is therefore the most efficient way for non–Annex B countries to become involved in emissions trading. Thus, for example, at the fourth Conference of the Parties (COP-4) in Buenos Aires, Kazakhstan declared its intention to join Annex I of the FCCC and Annex B of the Kyoto Protocol, while Argentina announced its intention to commit to a non–Annex B emission target (a voluntary commitment to an emission cap for the whole country, without joining Annex B of the Kyoto Protocol). Other countries have considered this option but have not yet exercised it. Some countries that, in principle, would like to join Annex B are simply not yet ready for the obligations it imposes. They do not have the macroeconomic modeling capacity to identify a realistic “assigned amount,” or they do not have the institutional and technical capacity to implement and manage an allowance trading system at the national level. For these countries, early accession to Annex B would be a mistake, and their attention should focus on maximizing the benefits offered by the CDM instead. Many other countries are looking for a “third way” to accept an emission budget and to participate in emission trading. However, there is no formal procedure yet, and specific conditions for accepting an emission target are currently under discussion.

Both the CDM and voluntary adoption of emission budgets will increase supply on the AAU market and the volume of AAU transfers. By the calculations of an MIT study (Ellerman, et al., 1998), non–Annex B countries could offer up to 723 million tons of carbon for sale. They would dominate in the market and the price would drop. There is, however, some inconsistency in this

forecast. The authors of the MIT study estimated supply as the difference between “business as usual” emissions and the likely emissions following GHG reduction measures in non–Annex B countries. This difference includes the results of so-called "no-regret" or "negative costs option" implementation (projects whose benefits in addition to GHG reduction, for example because of fuel saving, are high enough to recover project costs), but it is unlikely that emission reduction obtained due to no-regret options could be credited under CDM. We adjusted the MIT forecast and estimated the AAU supply available from non–Annex B countries at 200 million tons of carbon, somewhat less than the estimates of the MIT study.

The price for a ton of carbon depends on several factors. Under the carbon market development scenarios discussed above, the total volume of sales including non–Annex B countries would be in the range of 500 million to 550 million tons of carbon. Based on the MIT forecast (see Figure 6, Ellerman, et al., 1998), the price would be in the range of $50–100 per ton of carbon. Using data from the Russian NSS instead, we estimate the price at $40–80 per ton of carbon. If we alter the MIT assumptions about non–Annex B countries by reducing their participation, as outlined above, then the results of the two forecasts are almost the same, approximately $50 per ton.

The U.S. Environmental Protection Agency (EPA) makes more conservative price estimates; they are lower because in the EPA model, energy demand is more elastic. Thus there are more substitution opportunities, therefore demand is lower, and as a result the price is lower. (McKibbin, et al., 1998).

In our analysis below, we use the price of $40 per ton of carbon or $11 per ton of carbon dioxide.

2.1.2.2. Carbon prices after 2012

The market is likely to change dramatically in the second budget period, after 2012. Both the participation level of developing countries and the AAU supply are likely to grow, resulting in a price drop to $25 for a ton of carbon. At the same time, however, demand for AAU might grow as well, putting upward pressure on the price. As a result of these two factors, the price could stay at the level of $40 per ton if Annex B countries have the same commitments as in the first budget period, and could even increase if their commitments become more stringent.

We analyze a combined scenario using a price of $40 up to 2012, and $25 per ton after 2012, to demonstrate the impact of price change on the profitability of forest projects. (However, we should note that over the long run, modeling is likely to generate increasingly incorrect results because of the multiplication of uncertainties.)

It is appropriate to assume that eventually all countries will have quantified commitments to reduce GHG emissions and that the total emissions level will be defined by the climate change mitigation goal. The difference between the costs of saving energy and the costs of other GHG reduction measures per unit of GDP will reduce due to technology transfers, harmonization of management practices, and shifts in international trade. Thus on the AAU market, the share of unused quotas from measures to increase efficiency of fuel combustion will reduce, at the same time that the share of unused quota production by carbon sequestration projects (including forest projects) will increase. Therefore the unit costs of carbon sequestration could become an important factor on the AAU market in the future.

2.1.2.3. Non-Kyoto scenario

Above we discussed the case in which the trade takes place within the framework of the Kyoto Protocol conditions: the trade is limited to the GHG quotas of Annex B countries and additional quotas produced by CDM projects. Whether these limits actually apply depends on whether the Kyoto Protocol is ratified and whether effective compliance mechanisms are introduced. Further negotiations would be needed in case a significant number of the Annex B countries whose GHG emissions are substantial do not ratify the Kyoto Protocol, or if the compliance mechanism enacted is not efficient enough. Our estimation is that the latter scenario is rather unlikely, but we do consider that scenario.

An interesting approach is taken by Nordhauz (Nordhauz, 1996), who analyzed the optimal development path with regard to the negative impact of global warming and corresponding mitigation costs for GHG reduction. He estimated much greater optimal GHG emissions than the Kyoto quotas, and therefore his carbon prices are lower than those we cite in Table 8; they are about $10 per ton of carbon. Only forest projects with other benefits such as water and soil

protection benefits would be profitable with such prices. The attractiveness of projects whose main objective is to produce carbon sequestration would be substantially reduced.

2.2. Discount rate

The discount rate is very important for calculation of NPV. Usually two options are used: E = 0.1 and E = 0.05 (J. Vincent, et al., 1998). The lower rate is associated with long-term projects. In our case it should be used if we assume that the AAU price will grow, but we have no idea what the future price level will be. (It is quite possible that AAU should be interpreted as an exhaustible resource. In that case, E = 0 from Hotelling's rule [G. Hotelling, 1931]). We use a forecast of AAU prices and a discount rate E = 0.1 or E = 0.05 in our analysis.

One issue in setting the discount rate that is not discussed by Vincent, et al. (1998) is choosing the time at which carbon benefits are estimated. For the Annex B countries, only the total balance of GHG for all 5 years of the first budget period matters. In theory, purchases could be estimated as if they all happened on December 31, 2012, just before the balances had been closed. In that case, the gap between investments and benefits would increase, and the NPV of AAU for sale would be further reduced.

In order to simplify calculations, Vincent, et al. assume that all trades happen in the middle of the first budget period, that is, in 2010, with a fixed price, defined for the first budget period. (The price is $40 per ton of carbon in our analysis.) However, that assumption is not based on their hypotheses about how the market will develop, but is rather a simplification of calculations.

If the project yields the same carbon benefit consistently throughout the budget period, then our assumptions about prices and time of trade will not influence the project NPV. In the forest projects, however, the carbon benefit will increase each year; thus our assumptions underestimate the project value. We should either account in 2010 for the total volume of carbon sequestered over the budget period, or use different prices in different years, for example, in 2008, $33 per ton of carbon; in 2009, $36.4 per ton of carbon; in 2010, $40 per ton of carbon; in

2011, $44 per ton of carbon; and in 2012, $48.4 per ton of carbon (prices are calculated by discounting from 2010 back to 2008 and forward up to 2012).

2.3. Costs side

The main elements of the cost structure of forest projects are: up-front costs for planting; operating forest maintenance costs; transaction costs; and economic rent. Each cost element has a different impact on the IRR and NPV value. Thus one should apply different amounts of effort to reduce different cost elements and increase the efficiency of the forest projects.

2.3.1. Costs of forest planting, maintenance costs, economic rent

We separate the cost analysis into two levels: first, costs as the basis for building an aggregated AAU supply curve generated by the forest sector; and second, analysis of reforestation project costs.

Estimates of the cost of planting forests vary. The range is from $150 to $1500 per hectare. The spread reflects both differences in reforestation practices and data gaps. To achieve the first goal of building an aggregate supply curve, we use averages of empirical data on the correlation between planting costs and types of forest plantations. From this, we obtain average planting costs per hectare in rubles or U.S. dollars. To analyze costs on the project level, we use information from specific reforestation projects. (Most available cost data is in current rubles; we use a purchasing power parity [PPP] coefficient instead of the exchange rate.) We also recalculate the costs, component by component, for labor, fuel, depreciation, etc.

For our preliminary calculations, we use cost estimations from the Russian NSS and from the Study on the Cost-Effectiveness of the Pilot Forest Loan in Russia (a World Bank Loan to promote sustainable forestry in Russia) (Markandya et al., 1999). We extend our analysis by considering different techniques for planting and assistance to natural regeneration techniques. This makes our analysis more accurate by incorporating the specific costs associated with those techniques.

The costs of forest maintenance also differ from project to project, but not as much as planting costs do. Several sources (S. Hamburg, et al., 1995; J. Vincent, et al., 1998; A. Isaev, 1995) present data suggesting that annual maintenance costs are $5–15 dollars per hectare. The costs vary depending on the age of the forest, reflecting differing maintenance requirements. (As one example, costs are set forth in Table 3 derived from Vincent, et al., 1998, p. 50.)

Table 3. Maintenance costs for spruce under assisted natural regeneration, Komsomolskaya zone (1997, rubles per hectare)

Year	Activity	Cost
1	Renovate fire breaks	36.00
2	Renovate fire breaks	36.00
3	Renovate fire breaks	36.00
4	Renovate fire breaks	36.00
5	Renovate fire breaks	36.00
6	Tending, renovate fire breaks	516.00
7	Renovate fire breaks	36.00
8	Tending, renovate fire breaks	516.00
9	Tending, renovate fire breaks	516.00

Source: Derived from J. Vincent, et al., 1998, p. 50.

Table 3 gives data for Komsomolskaya zone in Khabarovsky Krai in the Far East of Russia. To compare, in Vologda Oblast in European Russia, the probability of fires is much lower and the survival rate is higher; thus its maintenance costs are lower and of a different composition.

We also use an opportunity-cost approach to calculate rent (the difference between the revenue from natural resource use and the operation cost), applying this approach to an analysis of the

Vologda forest project (S. Hamburg, et al., 1995). We calculated the opportunity costs for marginal croplands proposed for reforestation purposes. We found that calculation of rent as an element of the total economic cost is not crucial for our purposes. In the next few decades, land will not be a limited resource in Russia even if relatively large areas are used for reforestation purposes. Agricultural lands are being reduced everywhere in Russia. Thus they have zero economic value.

S. Hamburg, et al. (1995) calculated maximum economic rent at $10 per hectare. This figure is relevant only if there is an alternate use for the land. In most cases in Russia, however, no such alternative use is available, and therefore the economic rent is equal to zero. At the same time, however, the possibility of economic rent collection should be considered on a project-by-project basis.

2.3.2. Transaction costs

Transaction costs require a separate analysis. The importance of this issue goes far beyond an economic analysis of the forest projects. We consider only the particular elements of transaction costs that are relevant for forest projects.

The main transaction costs are the costs for monitoring and verification of long-term projects. The major benefit of the forest projects — substantial carbon sequestration — is revealed only in the long run, but long-term projects generate more risk both for the investor and for the AAU purchaser. Thus there will be a demand for investor risk mitigation measures, such as insurance policies.

If forest projects are implemented on a rather small scale, then insurance premiums are estimated at 10 percent of the project value (we used this estimate for the Vologda project). However, the premium could be reduced by an average of up to 3–5 percent if large-scale reforestation projects are implemented. The figures would differ for each project (depending on the project type, climatic zone, legal status of the forest, etc.), and thus in each case an analysis of the particular risks is needed.

Natural risk factors are forest fires and pests. The existing data is good enough to provide an analysis of the average probable losses due to those risks. The risk varies from region to region; it is higher in Siberia and in the Far East, and lower in the European part of Russia (see Table 4).

Table 4. Probability of fires and affected area

Region	Expected forest area damaged by fires (hectares per year)	Fire probability
Leningradsky Oblast	3700	0.07%
Krasnoyarsky Kray	90,000	0.08%
Khabarovsky Kray	160,000	0.33%

Calculated from A. Markandya, et al., 1999, pp. 1, 2, 16).

We use aggregate data to build our supply curve. On the project level one should calculate a rating for each region to estimate insurance costs. If a relatively modest number or size of forest projects are implemented, then insurance costs will be higher.

We use the lower figure in our analysis. An important consideration is that reduction of transaction costs (including insurance premiums) will increase the attractiveness of the project as well as the scale of reforestation overall.

There are also sufficiently accurate and not very costly approaches to monitoring and verification. Specific research to reconcile various methods to calculate carbon absorption has been done (see S. Hamburg, 1996). This research showed that costs for monitoring and verification are not very significant, and they could be accounted for in the time period when the project starts to yield major benefits. Complicated accounting for trades, and accurate and extensive monitoring, would increase the transaction costs and reduce the profitability of the forest projects. It is important, therefore, to make a reasonable compromise, allowing some inaccuracy in exchange for increases in the scale of reforestation for carbon sequestration

purposes. Our estimation shows that total transaction costs should not be more than 5 percent of project costs.

2.3.3. Average forest project planting and maintenance costs

We use average project planting and maintenance cost estimates, differentiated for the European and Asian parts of Russia, to construct an aggregate AAU supply function. Our main source of data for up-front costs is the Submission of the Experts from the International Forest Institute to the Bureau of Economic Analysis for NSS (1998). Average forest project costs are summarized in Table 5.

Table 5. Average planting and maintenance costs per hectare (thousand rubles in 1997 prices)

	Up-front	Maintenance
Russian average	1600	260
European part	1300–1600	160–190
Asian part	1650–2000	300–400

From a survey by the Russian Forest Committee, 1999, NSS, 1999.

3. Collateral benefits from forest projects and their impact on the unit costs of AAU

Earlier, we considered just one component of the forest projects' benefits: the expected turnover from AAU sale. However, projects in the forest sector can generate a variety of additional benefits, among them biodiversity conservation, watershed protection, soil protection, land reclamation, and non-timber products (NTP) such as berries, mushrooms, herbs, and the like. These, indeed, can be substantial even for Russian forests (J. Vincent, et al., 1998, p. 49). The value of such additional benefits depends on various factors, and could easily exceed total project costs. Some specialists give an estimate of $110/hectares annually (J. Lampietti, J. Dixon, 1995, p. 23); others give a basis for more conservative estimates of around $20/hectares per year (A. Markandya, et al., 1999, p. 17). The latter source notes an additional benefit: that of job

creation, equal to $194/hectares per year. Unfortunately, the AAU producer cannot easily internalize most of these collateral benefits.

Analysis at the project level requires a careful calculation of such collateral benefits, which could give local authorities incentives to help to finance the forest project.

4. Economic evaluation of forest projects

4.1. Project duration and start time

Based on the formula we presented above for calculating the efficiency of the forest projects, we can conclude that under the present cost conditions, the preferable species are birch and aspen, which are not particularly valuable species for timber production (see Table 6). We also find that it is crucial to have the forest project live long enough; major profitability will be achieved only if the life of the project extends beyond the first budget period. However, an increase of the project life beyond the second budget period (past 2022) will not increase profitability significantly. The internal rate of return (IRR) shown in the last column of Table 6 (1999–2022) is the maximum value that can be achieved for these two species. Aspen is the only specie that can be profitable under pessimistic assumptions about the price of carbon ($ 25/ ton of carbon, IRR is 10 %). However, even if the price per ton of carbon is a relatively high $40, Siberian and Far East forests may not generate enough benefit to be commercially viable, because their productivity is lower and planting costs there are higher.

Table 6. Internal Rate of Return (IRR[1]) for different species under different assumptions about life of project

	1999–2008	1999–2012	1999–2017	1999–2022
Estimated price per ton of carbon is $40				
ASPEN	9%	13%	16%	17%
Birch	2%	9%	12%	14%
Spruce	2%	5%	8%	10%

The long period between the time investments are made and the time that benefits start to flow also makes forest projects less efficient. We analyzed several options for project start time for the planting of spruce and a price per ton of carbon equal to $40. (See Table 7.) A later start would increase the IRR of the project. However, the project life would then continue beyond 2022 (the projected end of the second budget period), which increases uncertainty dramatically. If we assume that projects will be completed in 2022, then the IRR would be in a range of 10–13 percent.

[1] IRR – internal rate of return. It is a discount rate that makes the present value of cash flows equal to the initial investment.

Table 7. IRR given different project start times and different project life (spruce; carbon price is $40/ton)

	9-year project life	14-year project life	19-year project life	23-year project life
Start in 1999	1%	6%	9%	10%
Start in 2003	4%	10%	13%	14%
Start in 2006	4%	11%	14%	15%

4.2. NPV sensitivity to different parameters

We calculate net present value (NPV) in the following way:

$$NPV = NPVc(t,E)*p - NPVz(t,E)/q$$

where:

NPVc(t,E) is discounted carbon under a constant price during time period t with discount rate E;

NPVz(t,E) is the discounted cost during time period t with discount rate E;

p is the price of carbon;

q is the exchange rate of rubles to dollars.

We consider p and q as parameters. Resource allocation condition is NPV = 0. In other words we are looking for a condition in which IRR = E. Then the following is true:

$$NPVz(t,E)/NPVc(t,E) = p/q$$

We will specify that:

$$NPVz(t,E)/NPVc(t,E) = K(t,E)$$

$K(t,E)$ is a coefficient of the cost to produce one ton of carbon. One can calculate this coefficient using existing data on forest productivity and the actual costs of standard techniques used in Russia for forest planting and maintenance. The coefficient can be calculated for different species and different land types: $K_{ij}(t,E)$ is the coefficient of costs for species "i" on land type "j."

It is easy to see that the lower the coefficient $K_{ij}(t,E)$, the higher the probability of the project implementation. We analyzed the impact of the major NPV factors upon the coefficient level, and also used the coefficient to construct the supply function.

As we can see from the formula, $K_{i,j}(t,E)$ depends on a number of parameters. However, each has a different impact. We define their impact to try to answer two questions:

- How can the economic characteristics of the forest projects be improved?
- How sensitive is the equilibrium point to changes in these parameters?

We consider a simple formula for a single region and a single species:

$$NPVz(t,E)/NPVc(t,E) = K(t,E)$$

First, we analyze the impact of productivity (a), up-front costs (I), and operating costs (C). The discount coefficient E = 10 percent.

We need to distinguish productivity in different time periods, and so "a" changes each year. Because the available data on forest growth is presented for 10-year periods, we will consider "a" for the following periods: 1–10 years; 11–20 years; 21–30 years, etc.

We assume that up-front costs are incurred in year 1. Operating costs are distributed over time, but their major part is allocated in the first 10 years; in the subsequent 10-year period, their level is one-third of the first 10-year period.

Then we rewrite the formula stated above as follows:

$$[I + C(D1 + 0.33(D2 + D3 + ...))] / [a1*D1 + a2*D2 + ...] = K$$

$$D1 = \sum_{T=1}^{10} (1 + E)^{-t}$$

$$D2 = \sum_{T=11}^{20} (1 + E)^{-t}$$

D3, D4, ... are calculated in the same way for the next 10-year periods. We present the coefficient D for different discount rates (E = 0.1 and E = 0.05) in Table 8.

Table 8. Coefficient (costs to produce one ton of carbon) for different discount factors ($/ton)

	Discount rate = 0.1%	Discount rate = 0.05%
Years 1–10	6.14	7.72
Years 11–20	2.37	4.47
Years 21–30	0.91	2.91
Years 31–40	0.35	1.79
Years 41–50	0	1.1

Incorporating D into the formula with E = 0.1 we have:

$$[I + C(D1 + 0.33(D2 + D3 + ...))] / [a1*D1 + a2*D2 + ...] = (I + 7.3C) / (6.14*a1 + 2.4*a2 + a3)$$

We could do the same for a discount rate of E = 0.05 as well. The resulting coefficients reflect the impact of deviation in the discount rate on the efficiency of forest projects. These coefficients are presented in Table 9.

Table 9. Sensitivity of coefficient K to variations in the main parameters

Parameter	Discount coefficient of 0.1	Discount coefficient of 0.05	Increase (+) or decrease (-) in NPV
ΔI	1	1	-
ΔC	7.3	11.2	-
ΔNTP	3.6	10.5	+
ΔR	9.8	18.3	-
Δa1	6.14	7.7	+
Δa2	2.4	4.7	+
Δa3	1	2.9	+
Δa4	0	1.8	+
Δa5	0	1	+

Table 9 includes figures for rent (R) and an estimate of non-timber values (NTP).

Table 9 shows that up-front investments and economic rent have the greatest impact on forest project efficiency. That is one side of the problem. From the other side, the amount (or value) of carbon sink in the first two or three ten-year periods is important as well. We will consider an

example from the European part of Russia. We have data on the average costs (see Table 11, above) when aspen is the main species. We consider a 10 percent change in the main parameters, where the basic values are I = 1500 (up-front costs), C = 175 (operating costs), R = 0 (economic rent), NTP = 0 (non-timber products), a1 = 5.4, a2 = 6.9, a3 = 2.2 (average sequestration in first, second, and third ten-year periods).

Under these assumptions, the impact of changes in the up-front costs on NPV is 5.4 percent and the impact of changes in the operating costs is 4.6 percent. That means that measures to reduce both cost components have about equal priority.

If we calculate discounted revenues from carbon sales, then a 10-percent change in a1 (carbon sequestration in the first 10-year period) will have 5 percent impact; in a2 it will have a 3.2 percent impact, and in a3 it will have 0.5 percent impact. That means that the most important periods are the first and the second 10-year periods of forest growth.

These coefficients depend on the selection of species and on the type of land chosen for reforestation. In Russian forestry terminology, all lands are assigned a quality rank called *bonitet*, and a specific growth function is specified for each land-quality ranking. These data would be useful in financial estimation of specific projects on specific lands, but so far our calculations have not taken them into account. We hope to do these calculations in a subsequent publication.

An increased investment in planting costs should increase forest productivity. We analyze that link to seek an answer to the question of what the productivity increase would be if costs increase by 10 percent. We consider only the first and second 10-year periods. Our rough estimation shows that a 10 percent growth in costs requires at least 8–9 percent productivity growth to maintain the same efficiency level. If only one cost component grows (either up-front or operating costs), then productivity should be increased by 4% to maintain the same efficiency level.

Table 10 shows that the selection of species does not depend upon the discount coefficient. This information is important to construction of the supply curve.

Table 10. Comparison of carbon sequestration by aspen and by birch

	Average annual carbon sequestration by aspen (ton C per 1 hectare) a(0)	Average annual carbon sequestration by birch (ton C per 1 hectare) a(b)	Δa = a(0)-a(b)	D(t) E = 0.1/E = 0.05	Δa*D(t;0.1)	Δa*D(t;0.05)
Years 1–10	2.7	1.7	1	6.14/7.72	6.14	7.72
Years 11–20	3.5	4.5	- 1	2.37/4.74	- 2.37	- 4.74
Years 21–30	1.1	0.8	0.3	0.91/2.91	0.27	0.87
Total					4.04	3.85

We also analyze the impact of the discount factor on the value of K (the coefficient of costs to produce a ton of carbon) for aspen. The project life is assumed to be 20 years. If the discount factor changes by one per cent (for example, it is reduced from 10 percent to 9 percent), then the coefficient K for aspen changes by 4 percent. If we interpret the discount factor E as interest on the principal, and a reduction of E as the obtaining of a soft (subsidized or below-market) loan, then we can interpret K as the profitability growth of the forest project.

5. Construction of the supply function

The supply function depends on the profitability of the forest projects. It can be characterized by the level of the coefficient $K_{ij}(t,E)$, the area of land available for reforestation, and the physical limits on development of those lands.

Using this coefficient, it is possible to estimate the profitability of a forest project on a certain site, as well as to calculate the total potential of the Russian forests under different assumptions as to carbon price and time frames. Then it is possible to construct a supply function of AAU for Russia including its forest supply.

We calculated Kij (t,E) for the whole Russia and for two major Russian areas (the European part and the Asian part). (See Table 11.) The lowest Kij (t,E) for Russia as a whole is 205. It depends on the life of the project being long enough to include the second and the third budget periods. Then, even if the prices per ton of carbon are rather low, they are still acceptable. If q = 12 (rubles to $1 U.S.), then p (the price of carbon) could drop to $17 per ton of carbon, or to $4.6 per ton of CO_2. That corresponds to the most pessimistic estimations of the AAU prices.

Table 11. Kij (t,E) where E = 0.1, given different lengths of project life

	1999–2012	1999–2022	2006–2012	2006–2022
Russia on average	300	240	270	205
European part	210	190	200	140
Asian part	540	430	470	360

If trade is limited to 2012 (that is, we only look at the first budget period in our calculation), then the marginal acceptable price at which trade will occur is $22.5 per ton of carbon. If the price is $40 (as noted above, we assume that this is a reasonable guess), then reforestation is profitable over all of Russia, including its Asian part.

It is crucial whether 2012 or 2022 is the ending date for the projects. It is much more profitable to prolong projects up to 2022 even with the same AAU price. These results are presented in Table 12.

Table 12. Reforestation projects with normal economic return (IRR ≥10%), given specified price per ton of carbon

	$12	$16	$18	$20	$23	$25	$30	$36	$40	$45
Russia										
1999–2012						+	+	+	+	+
1999–2022				+	+	+	+	+	+	+
2006–2012					+	+	+	+	+	+
2006–2022			+	+	+	+	+	+	+	+
European part										
1999–2012			+	+	+	+	+	+	+	+
1999–2022		+	+	+	+	+	+	+	+	+
2006–2012			+	+	+	+	+	+	+	+
2006–2022	+	+	+	+	+	+	+	+	+	+
Asian part										
1999–2012										+
1999–2022								+	+	+
2006–2012									+	+
2006–2022							+	+	+	+

Plus sign indicates that project would have a “normal economic return” (IRR ≥10%).

Table 12 shows that increasing the project life to 2022 will increase the potential of reforestation in Russia to produce AAU, even given relatively low prices per ton of carbon. The information

in Table 12 would also form the basis for constructing an AAU supply function for Russian forest projects.

All analysis is based on specific assumptions about reforestation costs and forest productivity. We used data based on the techniques currently used in Russia, but current technologies can be further improved, particularly as to the selection of species for reforestation, and improvement or even radical changes in forest planting techniques.

In addition, we attributed all costs to the carbon produced, but in fact, forest planting could yield many additional collateral benefits. These could also be estimated at least roughly, and brought into the calculations, resulting in reduction of AAU production costs.

6. The model of AAU production and construction of the supply curve

The Russian NSS assessed the potential of the Russian forests to produce AAU by extrapolating existing trends for various regions. For each region, current reforestation costs for each species were taken into account, assuming no change in the share of coniferous and deciduous forests and the mix of species in each forest. The forecast assumed that the existing forest structure was optimal, in the long run, from the point of view of forest quality, biodiversity, and so forth. In other words, biological criteria were dominant in the NSS study, while carbon sinks were treated as an incidental. (A comparison of the assumptions of the NSS and our calculations is presented in Table 13.)

Table 13. Comparison of the assumptions in NSS and of our model for AAU production

	NSS Study	Our Model
Criteria	Forest structure is given, priority is given to the existing species	Maximize AAU production
Dynamics of reforestation by area	Reforestation area is the same for different years	The initial area for reforestation is given. It could increase if profitability of the forest projects increase
Beginning of reforestation in the area	Consequence of reforestation is given	Reforestation starts when it is economically viable; growth of reforestation activity stops when further reforestation is unprofitable
Accounting of the costs	Implicit accounting while the program of reforestation is being established	Direct accounting, all cost factors are operating parameters
Aggregation level	Aggregated data are used	It is technically possible to use data of any disaggregation level
Possible analyses	Basic scenario is given; the only analytic possibility is to change the cycle of reforestation (rotation time)	Unlimited possibility to construct and analyze different scenarios

We showed above that reliance on economic criteria to maximize commercial benefits from forest use, excluding revenues attributable to AAU sale, while expecting to produce carbon credits, creates a contradiction. The reason is that only the first and the second 10-year periods are important in the project selection for carbon credit production for sale, and this criterion would influence the selection of species and reforestation technologies. Incorporating economic

criteria that include carbon production, we would change the structure of planting and thus change the AAU supply.

Moreover, in the NSS forecast it was assumed that the area is reforested evenly, that each year the same share of the area is reforested, and that this distribution would not change over time. (In the NSS, reforestation takes place over 25 years.) In addition, it was assumed that the European part of Russia is reforested first and that only then would reforestation start in the Asian part of Russia. We eliminate this constraint and also introduce into the model the possibility of increasing reforestation gradually, with reforestation rates that depend on the rates of the previous year and on the profitability of the reforestation project. The NSS scenario (see Table 14) offers a baseline with which to compare our results.

Table 14. Reforestation rates from NSS study (million hectares/year)

	European part	Asian part (from 2025)
Forest lands	0.083 – 0.166	1.285 – 2.57
Marginal crop lands	0.162 – 0.324	0
Areas to protect soils	0.207 – 0.441	0.014 – 0.028
Biological recultivation	0.016 – 0.032	0.028 – 0.028

6.1 Exogenous parameters of our model

As exogenous parameters, we use the productivity of various species, reforestation costs, the area available for reforestation broken out by land type and climatic zone, reforestation capacity (initial land available for reforestation due to access difficulties, machinery and labor constraints, discount coefficient, and exchange rate).

We calculate the planting area and resulting AAU production by assuming different prices (the function of annual growth of reforestation is given). We also calculate annual planting costs and

revenues from AAU sales under various values for prices, reforested area, available areas, or shortage of land for reforestation.

The model allows changing the values of the exogenous parameters. Thus we can simulate the impact of new technologies on forest productivity, as well as the impact of different scenarios for forest sector management.

6.2 The algorithm for the AAU supply function

The algorithm for the AAU supply function is meant to compare coefficients K and AAU prices to help make decisions about whether to use a certain species on certain land at a certain moment for AAU production. The model calculates optimal planting area and resulting carbon sequestration.

The algorithm includes a number of steps.

Step 1

We choose discount factor E and project life t.

Step 2

For each land type j, species i, and technology of planting k, we assume the rates of carbon accumulation calculated based on growth in timber yield.

Step 3

We assume that the starting price of AAU is p. It will change when, after calculation of AAU supply at one price, we proceed to the calculation of AAU supply at another price.

Step 4

We assume the initial time τ (for example, year 1999 or 2000) that will be changing step by step up to t-Δ (t minus delta). The selection should be done within the same price level. It is completed when time is equal to t-Δ; then we start calculations for the next price level.

Step 5

We calculate coefficients $K_{ijk}(t,E)$, which are the coefficients of costs for species i on the land type j, with planting technology k.

Step 6

For each type of land we search for the most profitable species, i.e., we calculate a maximum $K_{ijk}(t,E) = K^*_j$ for each land type.

Step 7

If K^*_j is smaller than p/q, then we calculate $S_{ijk\tau} = S_{j(\tau-1)} + F(K^*_j, p/q)$,

Where $S_{ijk\tau}$ is the reforested land by species i on the land type j, with planting technology k by the year τ ;

$S_{j(\tau-1)}$ is the reforested land of type j by the year τ ;

$F(K^*_j, p/q)$ is additional reforested land in the year τ .

If total reforested area on the land type 0 is close to the available area for reforestation S_{j0}, i.e., if

$$S_{j(\tau-1)} + F(K^*_j, p/q) > S_{j0} - S^*_{j(\tau-1)}, \text{ where}$$

$$S^*_{j(\tau-1)} = \sum_{i}^{I}\sum_{k}\sum_{t}^{K_{\tau-1}} S_{ijkt},$$

then we select $S_{ijk\tau} = S_{j0} - S^*_{j(\tau-1)}$.

Step 8

When all calculations are done for one land type, then we proceed to another land type, and so on until all types of land are analyzed.

There is the possibility of introducing a general constraint on the annually reforested area for all types of land, but that would require a more complicated model. The idea of such a constraint is that all land types are considered within one time period. Then

*calculated areas are simply added. If, after that, we violated the general constraint for the total reforestation land available, then we could calculate the rating for each land type as a function from coefficient K*j. After that, the weight of coefficients Vj = K*j x Sijkτ/Σ Sijkτ should be calculated, and the final area of reforestation is calculated as Sijkτ∗Vj.*

It could also be useful to introduce constraints on the total volume of the financial flows into the forest sector or on the labor. Then a special optimization block could be incorporated into the model.

Step 9

We obtain matrix Sijkτ. It will be the basis for calculation of AAU production in the forest sector in the year τ. τ is in the selected budget period. Therefore we use the following formula:

$\Sigma\Sigma\Sigma NPVcijk(\tau,T^b) * Sijk\tau$, where T^b is the frontier of the budget period (for example, $T^b = 2012$ if $\tau < 2012$, or $T^b = 2022$ for τ after 2012).

Step 10

Then we sum up supply for all years in the budget period. That is the total AAU supply with a given price.

Step 11

Then the price changes, and all of the calculations are repeated.

6.3 Preliminary model calculations

For preliminary analysis we used the NSS format, where all the lands were divided by geographic criteria (the European part of Russia and the Asian part including the Far East); by groups of lands for certain purposes (forest land suitable for reforestation, marginal crop lands, forest for soil conservation, biological recultivation). The area of each land group is known; they total about 23 million hectares in the European part and 65 million hectares in the Asian part.

The NSS analysis indicates that the initial capacity of Russia to produce carbon credits is between half a million and one million hectares annually. The NSS used average productivity data for the various forest types and species. The most productive were marginal croplands and soil conservation areas. The productivity of the existing forestlands is low because the species for reforestation were chosen with no regard to carbon parameters. An implicit accounting of the costs resulted in the choice to postpone development of the Asian part of Russia for 25 years. All AAU supply from the forest sector in the first budget period (2008–2012), about 100 million tons, was obtained from the European part.

It is true that reforestation in the European part of Russia is more cost-effective. However, the constraints on reforestation capacities are distributed over Russia, a condition not subject to modification, and so we assume that reforestation in the European part and Asian part could start simultaneously if it is cost-effective given certain price conditions (see Table 15).

Table 15. Russia's potential AAU supply (million tons of carbon) given different prices for carbon, by regions, and total for Russia (during first budget period, 2008–2012)

	Less than $20	$20	25	30	35	40	45	50	55	60	65	70	75	80
European part of Russia	0	25	75	100	120	135	150	160	170	180	190	200	205	210
Asian part of Russia	0	0	0	140	225	270	315	350	380	400	420	430	450	470
Total Russia	**0**	**25**	**75**	**240**	**345**	**405**	**465**	**510**	**550**	**580**	**610**	**630**	**655**	**680**

We eliminate constraints on species selection and consider deciduous trees as dominating, because our previous analysis shows that the coefficient K is much larger for deciduous forests than for coniferous forests. However, as a result we must reduce the areas available for reforestation in the Asian part, because we exclude the less productive areas and those that are unsuitable for deciduous trees.

We will use the hypothesis that any AAU produced could be sold in the first or in the second budget periods. That covers the major period of the economic repayment of the forest projects.

Our very preliminary model calculations result in the supply dynamics for different price levels shown in Table 15.

Table 15 provides the basis for constructing an AAU supply curve from Russian forests, and a supply curve for all of Russia's AAU. Russia's supply of AAU from its forest sector is presented in Figure 4 and Table 16.

Table 16. Russian AAU supply in the first budget period 2008–2012 (million tons of carbon), where carbon price is U.S.$40/ton

	$40
Russian economy without forest sector	700
Forest sector	405
Total Russia	1,105

Figure 4. Russian supply of AAU for a given price per ton of carbon

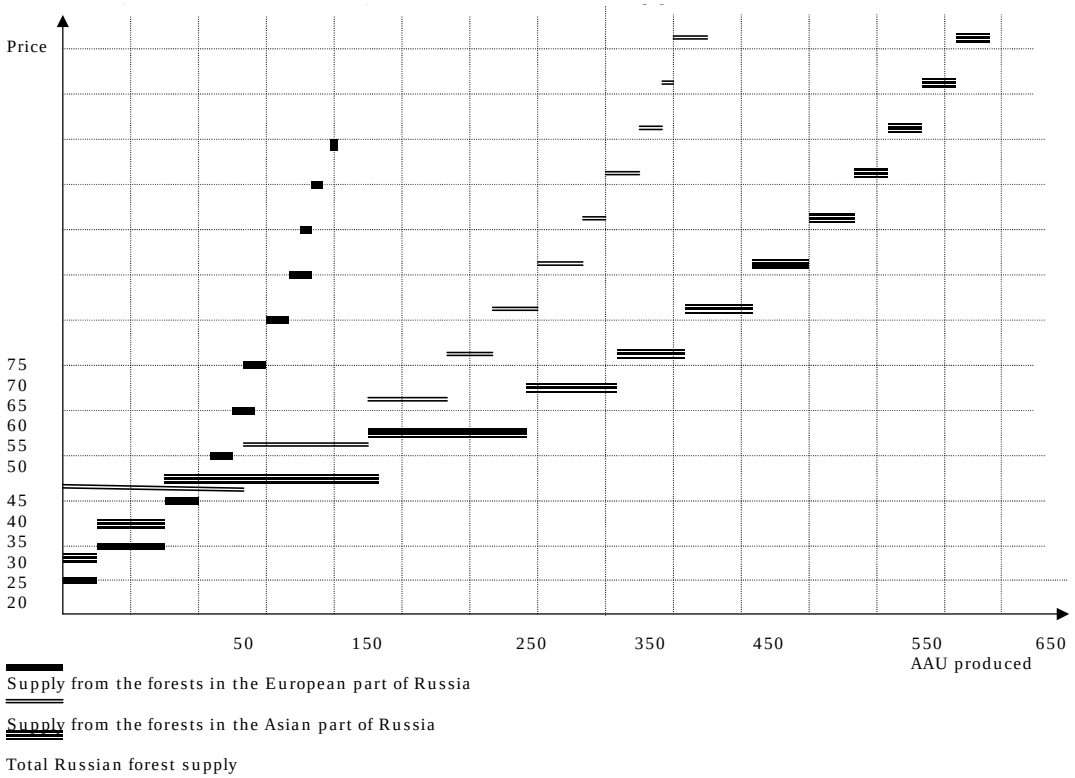


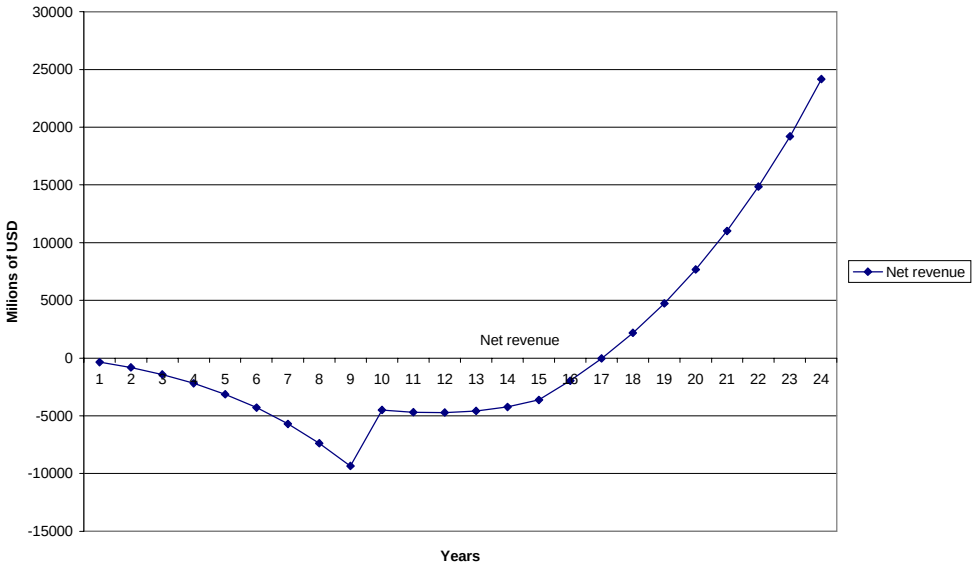
Figure 4. AAU supply from Russian forests (million tons of carbon)

There is thus no doubt that, with proper management, the forest sector could substantially increase Russia's supply on the AAU market.

7. Analysis of the financial flows

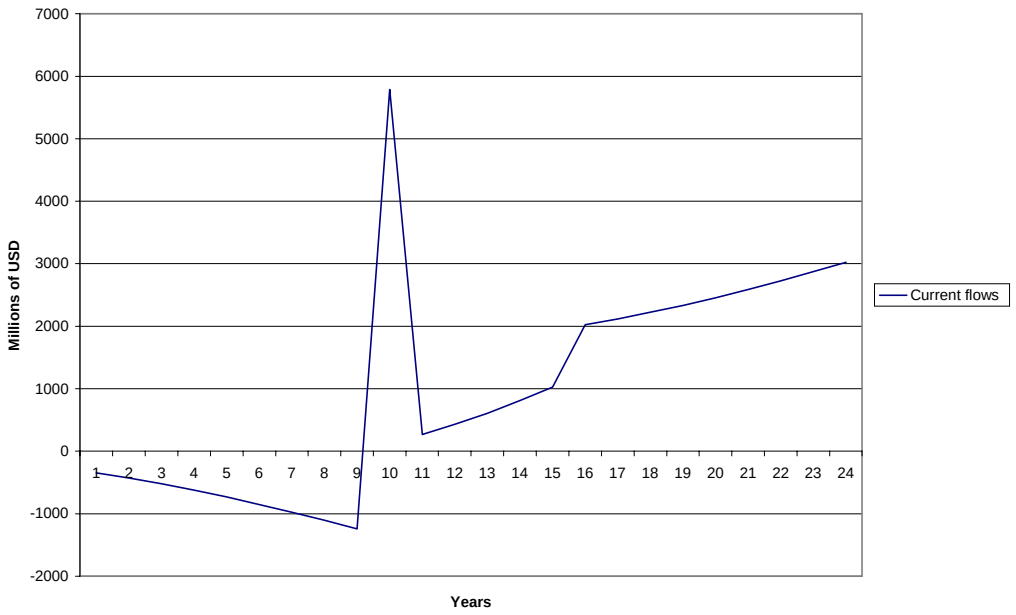
As before, we assume that in the first budget period the AAU price would be $40 per ton of carbon. The model allows us to assess financial flows into the forest sector and revenues from AAU trade. Figure 5 presents the dynamics of costs (with capitalization of interest) and revenues. Only in 2016 would all previous costs be repaid. AAU trade would then start to yield revenues, which could reach an accumulated figure of $25 billion by 2022 (with discounting back to 2016).

Figure 5. Dynamics of net income from AAU produced in forest sector - difference between costs (with capitalization of interest) and revenues from AAU sale



Current financial flows are shown in Figure 6.

Figure 6. Current financial flows (difference between current expenses and AAU sale)



Thus, the period for recouping costs is rather long for such projects; this makes it difficult to get loans. Therefore one option could be to seek soft loans or other below-market financing to cover up-front and maintenance costs.

Another option would be to reinvest revenues from forward sales of unused Russian quota (unused AAU). In Table 17 we present these calculations. From them, we can conclude that if Russia can trade its expected unused quota, then enough resources will be generated to implement reforestation projects without the need for soft loans.

Table 17. Use of forward sales of the Russian quota to support forest projects (shortfalls would determine demand for soft loans)

	1999	2000	2001	2002	2003	2004	2005	2006	2007
Price of forward contract for 1 t C*	$17	18	21	23	25	27	30	33	36
Volume of forward sales, million tons C	20	24	25	27	29	31	33	33	31
Estimated proceeds of sales	349	432	525	621	725	837	990	1089	1116
Resources needed to support forest projects ($ million) (any shortfalls affect demand for soft loans)	340	430	520	620	730	850	975	1100	1125

* We assume that price of 1 ton of carbon in 2010 is $40.

8. Theoretical analysis of the conflict between economic and climatic incentives

An analysis of reforestation projects to sequester carbon should distinguish three project selection criteria: ecological or climatic; economic; and financial. These criteria reflect the motivations of the different organizations or actors involved.

The first criterion — ecological — is based on the projected impact on global climate change. The second criterion — economic — reflects the economic impact of the project. The third — financial — reflects the impact on the revenues and expenditures of an investor. The difference

for the project selection is that in the first (ecological) case, the project is selected to maximize:

$$\sum_{t=0}^{T} Ct$$

where Ct is sequestered carbon in year t; T is project life.

In the second case (economic), the choice is to maximize: $\sum_{t=0}^{T} (PtCt+CBt)(1+E)^{-t}$

where Pt is AAU price in the year t; CBt is co-benefit in the year t.

In the third (financial) case, the firm seeks to maximize $\sum_{t=0}^{T} (PtCt + a\ CBt)(1+E)^{-t}$

where a is the share of co-benefits that the firm could internalize.

These three cases each leads to a different choice of species to plant for the forest project. In this section, we demonstrate the conflict between ecological and economic criteria for forest planting in central European Russia. Assume we have four options to use 1 hectare of the forest land: to plant pine; spruce; larch; or birch. The results are shown in Table 18.

Table 18. Economic and biological valuation of different projects planting options (per hectare)

	NPV from carbon sale	NPV of co-benefits	Total carbon sequestered (tons)
Pine	$325	$230	120
Spruce	$200	$230	**160** (preferred under ecological/climate change criteria)
Larch	$390	-	**160** (preferred under ecological/climate change criteria)
Birch	$1200	-	110
Aspen	**$1600** (preferred under economic or financial criteria)	-	90

Based on the climate change (ecological) criterion, spruce and larch are the best choices because they sequester the most total carbon. However, business would count economic or financial criteria and therefore would examine the second column of Table 2 showing NPV from carbon sale and select birch, because it gives its greatest value in the early years. Figures 7, 8, and 9 illustrate the conflict between economic and ecological characteristics (larch is not included in Figure 9, because its profitability is very low in terms of carbon sequestration).

Figure 7. NPV of the project revenues from carbon sales (price of carbon is 40 $/t)

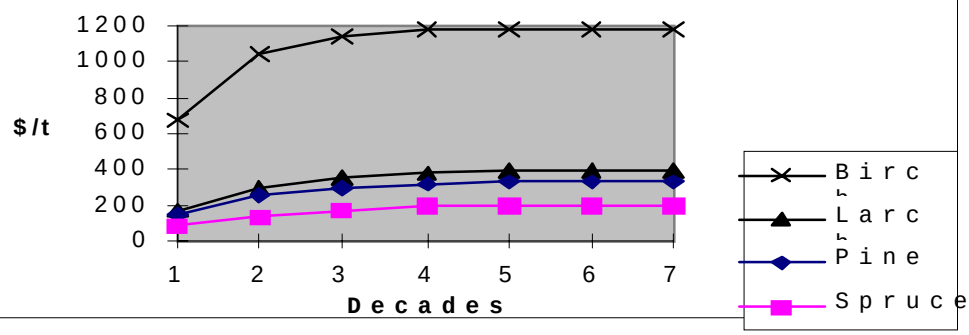
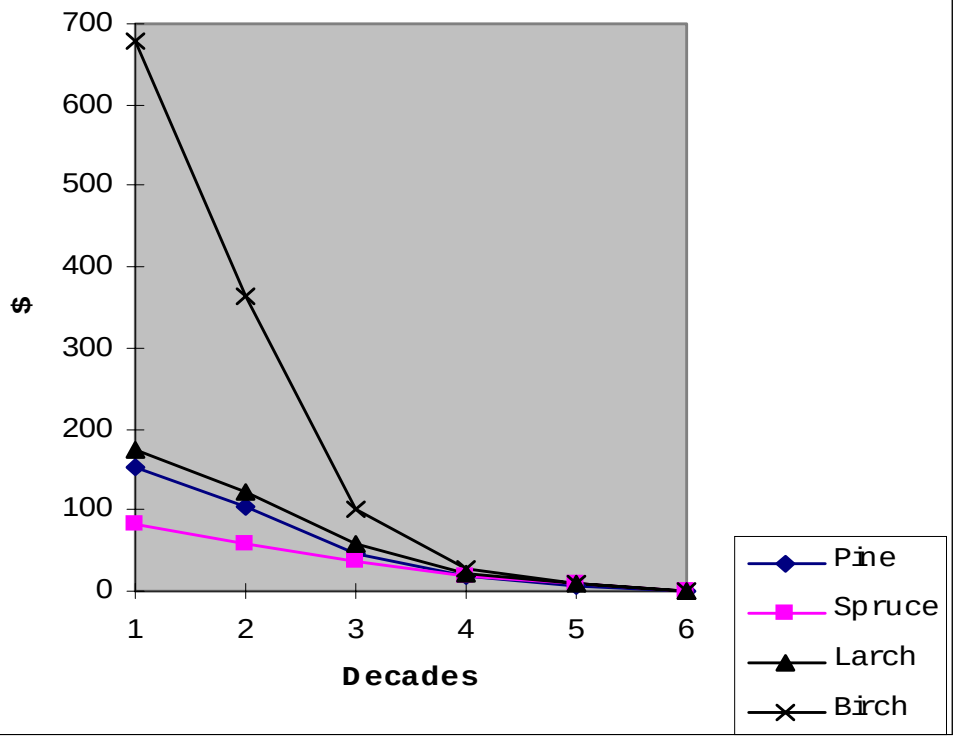
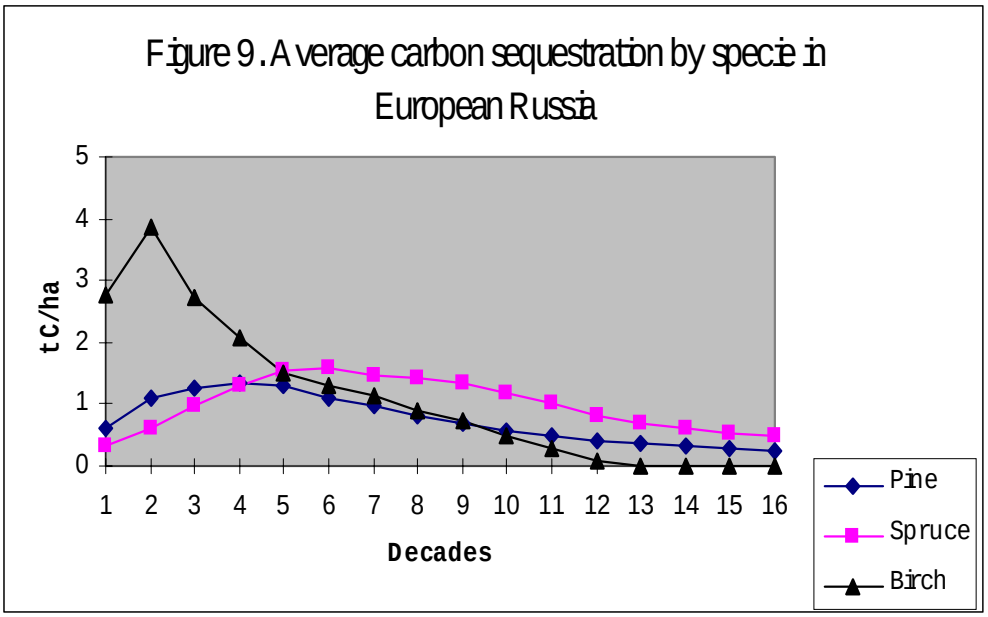


Figure 8. NPV of co-benefits with carbon sale (carbon price is 40 $/t)





Thus, the economic criterion contradicts the ecological one, a problem that arises from the wording of the Kyoto Protocol. In this section, therefore, we analyze the problem and suggest how to mitigate it.

The Kyoto Protocol established, for each of the Annex B (developed) countries, a GHG emissions limit in the period between 2008 and 2012. From an economic perspective, one could say that a new and limited resource appeared, that is, AAU. The total available amount of AAU (V_0) could be calculated with the formula

$$V_0 = \sum_{i \in \Omega} V_i$$

where Ω is the entire group of the Annex B countries; Vi is assigned amount units (its GHG emission quota) of the country i from Annex B.

Thus we can say that the Kyoto Protocol defined the process of transformation of a common good into a private good. In the past, we could apply a scarcity assumption to the assimilative capacity of the Earth, when the international community began to suffer the first consequences of global climate change and external effects related to the use of assimilative capacity appeared. The Kyoto Protocol is an attempt to internalize these external effects by establishing new commodity rules for at least some countries that use this assimilative capacity the most. Economists should provide approaches to the optimal use of this resource. Coase's theorem states that the initial distribution of AAU does not matter under an effective redistribution scheme with low transaction costs. It is our task to identify elements of such a scheme.

Emissions trading has the lowest transaction costs of the flexible mechanisms contained in the Kyoto Protocol for increasing available V_0. Under the carbon sequestration approach to reducing V_0, $V = V_0 + V_F$, that is, the quota for distribution is equal to the Kyoto target (quota) of V_0 plus additional quota V_F produced by carbon sequestration projects.

At first we consider the model with one country which is seeking to determine the optimal forest planting to increase GHG emissions quota (we call this "Model 1"). We assume a perfect market with zero transaction costs and a goal of maximizing utility function from its output. Our calculation involves the following factors: U (C), the consumption function; and C, consumption with constraints on GHG emissions and on the land available for reforestation.

This model is constructed for the first budget period and assumes only one reforestation technology (one-species planting). Later in this paper, we consider more complicated models with two budget periods and two species to plant.

Model I.

$$U(C) \rightarrow \max \qquad (1)$$

$$\text{s.t.} \quad \alpha C \leq V_0 + V_F \qquad (2)$$

$$V_F = a\, s \qquad (3)$$

$$s \leq S \qquad (4)$$

$$C \geq 0; \quad s \geq 0 \qquad (5)$$

In these calculations, C is GDP; α C i= GHG emissions; α = GHG emissions per unit of GDP; a = forest productivity (sequestration of carbon in tons per hectare); s = lands that society allocates for reforestation; S = total land available for reforestation. So far, we are not considering different land types, different species, etc.

We could set up a Lagrangian function:

$$U(C) - \lambda(\alpha C - V_0 - a\,s) - \mu(s - S) \qquad (6)$$

If C > 0 and s > 0, then

$$\frac{\partial U(C)}{\partial C} = \alpha\lambda \qquad (7)$$

$$\frac{\partial U(C)}{\partial C}\frac{a}{\alpha} = \mu \qquad (8)$$

This means that the marginal benefit from GDP growth is equal to the equilibrium price of the Kyoto Target (with regard to α), and also equal to the equilibrium price of land with regard to its productivity.

If we account for planting costs (Z), then equation (8) will transform into (9); Z = planting costs on 1 hectare.

$$\frac{\partial U(C)}{\partial C}\frac{a}{\alpha} = \mu + Z \qquad (9)$$

If we assume that the land is not a limited resource in the first budget period, that is, that $\mu = 0$, then (9) is transformed into (10):

$$\frac{\partial U(C)}{\partial C}\frac{a}{\alpha} = Z \qquad (10)$$

Then the AAU price will be fully determined by the planting costs Z.

The problem with this Model (lines 1 through 5) is that only the first budget period is considered; later potential AAU demand is not taken into account. But the decision of which specific species to plant will determine the use of the land for at least the next 100 years.

Further, as we demonstrated, selection of species based only on economic criteria does not provide a maximization of carbon sequestration over the lifetime of the forest. Maximization of economic benefits in the first budget period will increase the gap between economic and ecological criteria even further. We consider Model II to analyze this situation.

Model II

In Model II, we consider two time periods (GHG emissions budget periods) and assume that a choice between two species must be made. One species has productivity a_1 in the first budget period and a_2 in the second budget period. The other has productivity b_1 in the first budget period and b_2 in the second. Assume that $a_1 > b_1$, and $b_2 > a_2$. Also assume that $b_1 + b_2 > a_1 + a_2$. Thus the second species is more productive when its full growth period is examined. The first species, however, is more productive in the first budget period. For Russia, the first species might be aspen and the second, spruce.

$$U_1 (C_1) + U_2 (C_2)(1 + E)^{-1} \rightarrow \max \quad (11)$$

$$\text{s.t.} \quad \alpha C_1 \leq V_{01} + VF_1 \quad (12)$$

$$\alpha C_2 \leq V_{02} + VF_2 \quad (13)$$

$$VF_1 = a_1 s_{a1} + b_1 s_{b1} \quad (14)$$

$$VF_2 = a_2 s_{a1} + b_2 s_{b2} + a_1 s_{a2} + b_1 s_{b2} \quad (15)$$

$$s_{a1} + s_{b1} + s_{a2} + s_{b2} \leq S \quad (16)$$

$$C_1 \geq 0;\ C_2 \geq 0;\ s_{a1} \geq 0;\ s_{b1} \geq 0;\ s_{a2} \geq 0;\ s_{b2} \geq 0 \quad (17)$$

All planting in the first budget period influences the country quota in both the first and the second budget periods (s_{a1} is the area planted with the first species in the first budget period; s_{b1} is the area planted with the second species in the first budget period). Planting in the second budget period affects only the second budget period. For simplicity, assume that all planting happens in the first budget period, that is, $s_{a2} = s_{b2} = 0$; that the first species is productive only in the first period, i.e., $a_1 = a$, $a_2 = 0$; and that the second species is productive only in the second period, i.e. $b_1 = 0$, $b_2 = b$ ($b > a$). Then we can rewrite the model:

$$U(C_1) + U(C_2)(1 + E)^{-1} \rightarrow \max \qquad (18)$$

$$\text{s.t.} \quad \alpha C_1 \leq V_{01} + a\, s_a \qquad (19)$$

$$\alpha C_2 \leq V_{02} + b\, s_b \qquad (20)$$

$$s_b + s_a \leq S \qquad (21)$$

$$C_1 \geq 0;\ C_2 \geq 0;\ s_a \geq 0;\ s_b \geq 0 \qquad (22)$$

E is the discount factor.

The Lagrangian function for Model II (lines 18–22) is as follows:

$$U(C_1) + U(C_2)(1 + E)^{-1} - \lambda_1(\alpha C_1 - V_{01} - a\, s_a) - - \lambda_2(\alpha C_2 - V_{02} - b\, s_b) - \mu(s_a + s_b - S) \qquad (23)$$

If $C_1 > 0$; $C_2 > 0$; $s_a > 0$; $s_b > 0$, then the first-order optimality conditions are:

$$\frac{\partial U(C_1)}{\partial C_1} = \alpha\lambda_1 \qquad (24)$$

$$\frac{\partial U(C_2)}{\partial C_2} = \alpha\lambda_2 (1 + E) \qquad (25)$$

$$\lambda_1 a = \mu \qquad (26)$$

$$\lambda_2 b = \mu \qquad (27)$$

From (26) and (27), it is clear that λ_1 a = λ_2 b, and thus that $\lambda_2 < \lambda_1$. Therefore the equilibrium price of AAU is higher in the first budget period than in the second budget period. If this were not so, there would be no reason to allocate the land to the less productive species.

Assume that $\alpha = 1$, then from optimality conditions:

$$\frac{\partial U(C_1)}{\partial C_1} = \frac{\partial U(C_2)}{\partial C_2} \frac{b}{a(1+E)} \qquad (28)$$

That means that

$$\frac{b}{a(1+E)} \geq 1 \text{ or } b \geq a\,(1+E) \qquad (29).$$

From (29) one gets the next equation:

$$\frac{\partial U(C_1)}{\partial C_1} / \frac{\partial U(C_2)}{\partial C_2} = \frac{b}{a(1+E)} \qquad (30)$$

By the theorem of the implicit function one can get:

$$-\frac{\Delta C_2}{\Delta C_1} = \frac{b}{a(1+E)} \qquad (31)$$

If we apply the coefficient α again, then the meaning of the equation (31) is even clearer: from the increments of consumption we will obtain increments of the GHG emissions:

$$-\frac{\alpha}{\alpha} \frac{\Delta C_2}{\Delta C_1} = \frac{b}{a(1+E)} \qquad (32)$$

We assume that in the first budget period, due to reduction of planting and strict constraint on the line (19), GHG emissions would reduce for α (i.e., $\Delta C_1 = -1$). Then:

$$\Delta C_2 = \frac{b}{a(1+E)} \qquad (33)$$

Equation (33) should then be the basis for calculating production increases in the second period. If both species have the same productivity (a = b), then the rate of production growth is equal to the discount factor. An inequality (29), on the other hand, means that productivity of the second species is greater than the productivity of the first one by the discount factor. Then and only then should the land be allocated to the second species.

Thus the system of carbon accounting established by the Kyoto Protocol forces one to apply an economic discount factor to the tons of carbon: sequestration of one ton today is 1.1 times better than sequestration of one ton a year from now. This outcome contradicts our scientific understanding of climatic processes, and is contrary to the overall intention of the FCCC and the Kyoto Protocol. The time when sequestration occurs does matter, but it does not matter as much for climate change as it does for purely economic parameters. For purposes of mitigating climate change, the ton sequestered today is practically equivalent to the ton sequestered a year from now. Therefore while comparing different carbon sequestration strategies and estimating their climatic consequences, one should not apply an economic discount factor. At the same time we are forced to use it by the fact that we are looking for the most cost-effective strategy to implement the Kyoto Protocol (and perhaps the next Agreement reached in the post-Kyoto process).

There is only one conclusion from this contradiction: it is necessary to correct the Kyoto Protocol with regard to conditions under which countries meet their Kyoto targets. We will consider some possible changes.

Model III

Let us consider the possibility of accumulating unused AAU to use them in the next budget period. Then Model II (18) – (22) is transformed into Model III (34) – (38).

$$U(C_1) + U(C_2)(1 + E)^{-1} \rightarrow \max \qquad (34)$$

$$\text{s.t.} \quad \alpha C_1 \leq V_{01} + a\, s_a \qquad (35)$$

$$\alpha(C_1 + C_2) \leq V_{01} + V_{02} + a\, s_a + b\, s_b \qquad (36)$$

$s_b + s_a \leq S$ (37)

$C_1 \geq 0$; $C_2 \geq 0$; $s_{a1} \geq 0$; $s_{b1} \geq 0$; $s_{a2} \geq 0$; $s_{b2} \geq 0$ (38)

Then the Lagrangian function is:

$U(C_1) + U(C_2)(1 + E)^{-1} - \lambda_1(\alpha C_1 - V_{01} - a s_a) - - \lambda_2(\alpha (C1 + C_2) - V_{01} - V_{02} - a s_a - b s_b) - \mu(s_a + s_b - S)$ (39)

If we assume $\alpha = 1$, then:

$$\frac{\partial U(C_1)}{\partial C_1} = \lambda_1 + \lambda_2 \qquad (40)$$

$$\frac{\partial U(C_2)}{\partial C_2}(1 + E)^{-1} = \lambda_2 \qquad (41)$$

$a(\lambda_1 + \lambda_2) = \mu$ (42)

$\lambda_2 b = \mu$ (43)

If $\lambda_1 > 0$ and $\lambda_2 > 0$, then the results will be the same as in the previous case; see (33). $\lambda_1 > 0$ means that there is no reservation of AAU in the first budget period to use in the second one, and that it is most profitable to use all of the Kyoto quota V_{01} and additional carbon as_a in the first budget period.

If $\lambda_1 = 0$ and part of quota from the first budget period is reserved to be used in the second period, and if all land available is used to plant the more productive species, i.e., s_a=0, then we can determine λ_2 as $\lambda_2 = \lambda$. After transformation of (40)–(43), we obtain:

$$\frac{\partial U(C_1)}{\partial C_1}(1 + E) = \frac{\partial U(C_2)}{\partial C_2} \qquad (44)$$

From (44) we can see that the marginal utility of carbon consumption grows at a rate equal to the discount factor. Rewriting (44) and after we restore α, we obtain Hotelling's equation:

$$\alpha \frac{\partial U(C_t)}{\partial C_t} = \lambda(1+E)^t = P_t \qquad (45)$$

$\alpha \frac{\partial U(C_t)}{\partial C_t}$ is the price of AAU, which grows at a rate equal to the discount factor.

Then instead of (42) we can write (46):

$$a\lambda\, s_a = \mu S \qquad (46)$$

The land equilibrium price $\mu = P_0$; in other words it is equal to the price of the commodity produced (in our case, it is the AAU price). If we account for planting costs (Z), then:

$$\mu = P_0\, b - Z \qquad (47)$$

If land is unlimited $\mu = 0$, then $P_0\, b = Z$ or:

$$P_0 = \frac{Z}{b} \qquad (48)$$

See Figure 10. In the marginal case, the price of AAU will be determined by the unit cost for carbon sequestration by the most productive species.

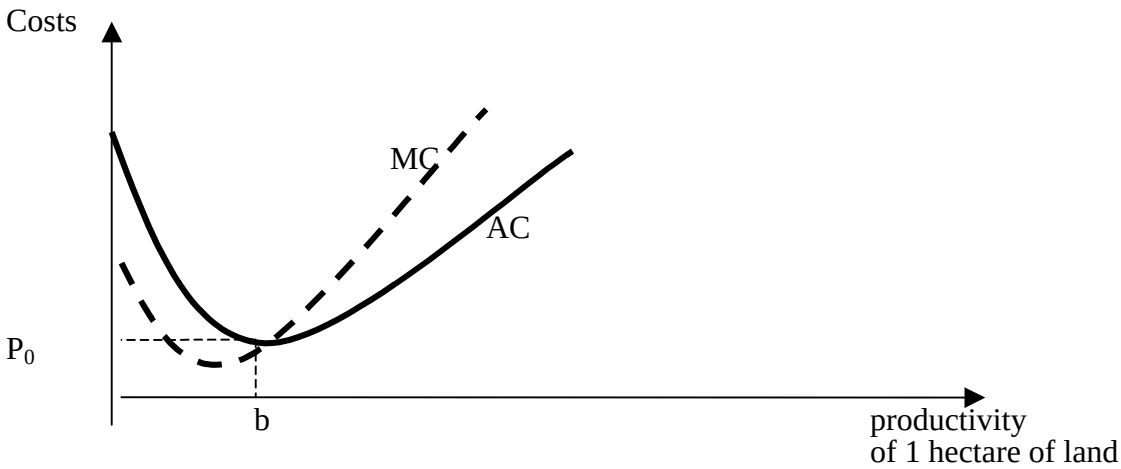


Figure 10. AAU pricing. MC – marginal planting costs; AC – average planting costs; P_0 – AAU price; b – productivity of the most productive species.

Figure 10 shows what happens if Z = Z(b). In the models analyzed in this paper, Z=const; b = const. For demonstration purposes we could overcome this constraint. Based on the assumptions formulated above, we obtained exponential price growth:

$$P_t = P_0 (1 + E)^t \qquad (49)$$

Then the carbon price should double in the second budget period, quadruple in the third one, etc., to make it profitable to plant the less productive species in the first budget period. However, we are not anticipating this, for two main reasons. The first is technical progress in Annex B countries: the growth rate of demand will be less than the economic growth rate, and so the growth rate of the AAU price will be less as well. Second, there will be an increasing supply of AAU, due to growing participation of developing countries in emissions trading.

Therefore it would be unrealistic to assume that (35) is strict inequality and $\lambda_1 = 0$. Thus $\lambda_2 > 0$ and $s_a > 0$. So part of the land will be used to plant the first less productive species. As a result, total carbon sequestration will be less and unit carbon sequestration costs will be higher. In other

words, the international community will have allocated resources (assimilative capacity) with diminished cost-efficiency because of the accounting/distribution AAU rules proposed under the Kyoto Protocol. The lands available for reforestation would be allocated to plant less productive species that have a more rapid yield. Because there will be a shortage of available lands in future, the world will have to pay more to increase assimilative capacity or to reduce its burden.

Model IV

There are presently intensive discussions on many levels of issues concerning compliance and sanctions for noncompliance with Kyoto targets. One useful idea was proposed: if one country exceeds its Kyoto target, then the difference is subtracted from the second budget period target. In other words, the country is treated as borrowing AAU from its future GHG emissions budget. There are no consequences to the global environment from such borrowing. If a country is weighing two options for the same time period, then under this idea, it would be preferable to accept the one with less total GHG emissions. If a country is considering two options of forest planting, then it becomes preferable to choose the one with greater total carbon sequestration. Thus any additional GHG emissions in the first budget period will be offset by additional sequestration in the second period.

Based on this idea, then, for modeling purposes, we will exclude species with productivity a. We will assume that species with higher productivity b will always dominate and will be selected for planting.

The model is:

$$U(C_1) + U(C_2)(1 + E)^{-1} \rightarrow \max \quad (50)$$

$$\text{s.t.} \quad \alpha C_1 \leq V_{01} + bs_b \quad (51)$$

$$\alpha C_2 \leq V_{01} + V_{02} + bs_b \quad (52)$$

$$\alpha(C_1 + C_2) \leq V_{01} + V_{02} + bs_b \quad (53)$$

$$s_b \leq S \quad (54)$$

$C_1 \geq 0$; $C_2 \geq 0$; $s_b \geq 0$ (55)

Additional sequestration bs_b achieved in the second budget period could be used in either the first period (inequality [51]) and in the second period (inequality [52]). Any given ton of carbon could not be used twice (inequality [53]). The Kyoto target of the second budget period could not be used in the first budget period, but any AAU unused in the first period could be used in the second one. Inequality (54) ensures that one ton is not used twice in this case. Inequalities (51) and (52) cannot both be equalities in the optimum; one or the other of them must remain an inequality.

If (52) is an equality, then there are carbon reserves from the first period to use in the second one. We analyzed this situation in Model III. Now we consider the situation when (51) is equality in the optimum, i.e., carbon sequestered in the second period is used in the first one. Again let $\alpha = 1$; we get the following optimality condition:

$$\frac{\partial U(C_1)}{\partial C_1} = \lambda_1 + \lambda_3 \qquad (56)$$

$$\frac{\partial U(C_2)}{\partial C_2}(1+E)^{-1} = \lambda_3 \qquad (57)$$

$$\lambda_1 b + \lambda_3 b = \mu \qquad (58)$$

If land is an unlimited resource (μ=0), then with regard to planting costs Z, (58) will transform into (59):

$$(\lambda_1 + \lambda_2)\, b = Z \qquad (59)$$

or $$\frac{\partial U(C_1)}{\partial C_2} = \frac{Z}{b} \qquad (60)$$

As in Model III:

$$P_0 = \frac{Z}{b}, \text{ but } \quad P_1 = \frac{\partial U(C_2)}{\partial C_2} = \frac{Z - \lambda_1}{b}(1 + E) \text{ and } \lambda_1 > 0$$

then $P_1 < P_0 (1 + E)$ (61)

It seems that (61) is a non-Hotelling equation. However, that is just a development of Hotelling's situation. The land available is Hotelling's resource. Borrowing of carbon from future budgets makes it possible to optimize land use dynamically, thus maximizing land productivity.

The growth rate of AAU prices is lower than the discount factor; that is, economic growth can be ensured under relatively moderate limits on use of the global assimilative capacity. The international community thus increases the sequestration potential of the ecosystem and total allowable GHG emissions volume, while establishing preconditions to select more productive species for reforestation purposes. The non-Hotelling character of (61) does not contradict Hotelling's theory. The explanation is that the land is the Hotelling resource in this situation.

Model V

Now we consider land scarcity more precisely. Assume that there is planting of a species having productivity *a* in the second budget period. Then the sequestration it produces could be used only in the second period (remember that we have only two periods in our simplified model). Then Model V is:

$U(C_1) + U(C_2)(1 + E)^{-1} \rightarrow \max$ (62)

s.t. $\alpha C_1 \leq V_{01} + bs_b$ (63)

$\alpha C_2 \leq V_{02} + as_a$ (64)

$s_b + s_a \leq S$ (65)

$C_1 \geq 0$; $C_2 \geq 0$; $s_a \geq 0$; $s_b \geq 0$ (66)

If we assume again that $\alpha = 1$, we get the following optimality conditions:

$$\frac{\partial U(C_1)}{\partial C_1} = \lambda_1 \qquad (67)$$

$$\frac{\partial U(C_2)}{\partial C_2}(1+E)^{-1} = \lambda_2 \qquad (68)$$

$$b\,\lambda_1 = \mu \qquad (69)$$

$$a\,\lambda_2 = \mu \qquad (70)$$

(69) and (70) cannot both be feasible, because a > b, and thus $P_1 > P_0(1+E)$. Therefore redistribution of AAU in favor of the second budget period is needed, and thus $s_a = 0$. All planting to produce AAU in both the first and the second periods must be completed in the first period. In spite of the fact that the international community is borrowing from the second budget period, it is establishing in the first period the necessary preconditions to repay the debt, i.e., it is planting beforehand. From an institutional point of view, it is necessary to provide the physical and financial incentives to preserve those new plantations. There are several ways to do it (such as a fund with a fixed capital, insurance, etc.). We do not consider them here, because our task was to prove the economic effectiveness and acceptability, from the perspective of mitigating global climate change, of borrowing AAU from the future. The results, as we demonstrated, are that:

- AAU price will be lower;
- Total carbon sequestration potential will be increased;
- Economic growth with be facilitated;
- There will be a real possibility to select updated technologies and to minimize coefficient α.

If the land is a limited resource then the land price is:

$$\mu = P_0 b - Z \qquad (71)$$

If the model is more general, with more budget periods, and borrowing is allowed only from the next period, then we will get Hotelling's formula for the price of land:

$$\mu_t = \mu_0 (1 + E)^t \qquad (72)$$

We can obtain the same Hotelling formula for the land price from our Model V. If the costs are substantially lower in the second period, then

$$P_1 a - Z_1 = (P_0 b - Z_0) (1 + E) \qquad (73)$$

Assume the price is constant and equal to P, then after some algebra applied to (73), obtain:

$$P (b - a) + P E b = Z_1 - Z_0 (1+E) \qquad (74)$$

$$P (b (1 - E) - a) = Z_1 - Z_0 (1+E) \qquad (75)$$

There is another situation applicable to Model V: this is when the land is used for planting in both periods. That could happen if planting capacities are also limited in the first budget period. Then the carbon price in the first budget period consists of three components: planting costs, land price, and the equilibrium price of the planting assets. Hotelling's equation should be relevant for land in this case, as well.

9. Conclusions

We can now formulate a number of preliminary ideas about the economic aspects of reforestation projects for AAU production.

Forest project for sequestration will have commercial value if AAU trade is settled for the first and the second budget period. For the first budget period only, it is hard to find economically viable projects. Forward sale of AAU should be for the period from 2008 up to 2022.

It is expedient to start forest planting in the nearest future, so that in the first budget period it will be possible to sell AAU accumulated before.

Starting from the price of $25 per ton of C, the scale of AAU from forest projects could be substantial. Supply in the first budget period could reach 75 million t C. If the price is $40 per ton of carbon, then supply in the first budget period might reach 400 million t C. That is over one-third of the potential Russian supply on the AAU market.

The Asian part of Russia has the largest potential, but unit costs are higher there. A rapid pace of reforestation there could be achieved at the price $30 per t C.

The most important factor to guarantee commercial viability of the project is the value of the carbon sequestration coefficient in the first and the second 10-year period. Based on economic criteria, it will be preferable to use species with the most rapid growth in the first 20 years. If maximum sequestration over the total lifetime of the species were not a crucial condition, then free areas would be used for fast-growing species, which would lead to a future deficit of available lands. Thus there is a contradiction between economic and biological criteria of species selection. Eventually, this would mean that maximum sequestration is not assured, if land available for reforestation is limited.

Significant up-front funds are needed at the beginning of forest project implementation. The first revenue will be yielded not earlier than 2008, when AAU will become a commercial commodity. Forest planting is capital-intensive in Russia. Only after 2008 will the revenue flow be significant ($20–30 million annually). The Russian forest sector cannot generate the resources to pay all up-front costs itself. However, there is a possibility to obtain necessary funds from forward sales of the unused Russian quota; sufficient revenue for up-front costs of implementation could be raised from forward sale of 200–250 million t C.

It is also very important to ensure accurate accounting and internalization of revenues from other forest products (NTP); this will improve the economic parameters of AAU production by the forest projects significantly, and will reduce the incremental costs of AAU production.

To have commercially viable projects on marginal croplands, it is important to refrain from rent collection at least in the first 10–15 years. Otherwise economic barriers will prevent use of such lands for AAU production.

Our study leads us to conclude that, with some institutional changes and accurate economic analysis, the necessary incentives can be identified to maximize Russia's production of tradable carbon on the AAU market, adding both to Russia's own financial benefit and to mitigation of global climate change.

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