Optimal continuous cover forest management: - Economic and environmental effects and legal considerations

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BIT's 5th Low Carbon Earth Summit

(LCES 2015 & ICE-2015)

Theme: "Take Actions for Rebuilding a Clean World"

September 24-26, 2015

Venue: Xi'an, China

Optimal continuous cover forest management:
- Economic and environmental effects and legal considerations
Professor Dr Peter Lohmander

Abstract

Forest management can be performed in many different ways. Decisions in forestry affect economic results, the flow of bioenergy raw materials, the CO2 balance of the world, species diversity, recreation options for humans and much more. Technological development sequentially and rapidly changes most of the parameters of relevance to forestry. Some of the fundamental decision problems concern: Continuous Cover Forestry (CCF) or Plantation Forestry (PF), the Stand Density (SD), the Harvest Interval (HI), Single Species Forestry (SSF) or Multi Species Forestry (MSF). With present prices, costs, technology and initial forest conditions in many dominating forest countries, CCF is often a better choice than PF when we optimize the economic present values. CCF is also a better choice than PF from several environmental perspectives. The optimal levels of SD and HI are affected by all parameters. MSF can give environmental benefits in relation to SSF. MSF can also give economically valuable options to sequentially adjust forest production to future market changes. MSF is less sensitive to species specific damages and is more flexible to changing environmental conditions. Therefore, the expected present value of MSF is often higher than the expected present value of SSF. The forest laws in different countries, also neighbour countries such as Finland and Sweden, with almost the same prices, costs, technology and forest conditions, are very different with respect to the fundamental decisions: CCF or PF, SD, HI and SSF or MSF. The economic and environmental development of the world would benefit from more rational forest management. Several forest laws need to be adjusted in order to make rational decisions legal.

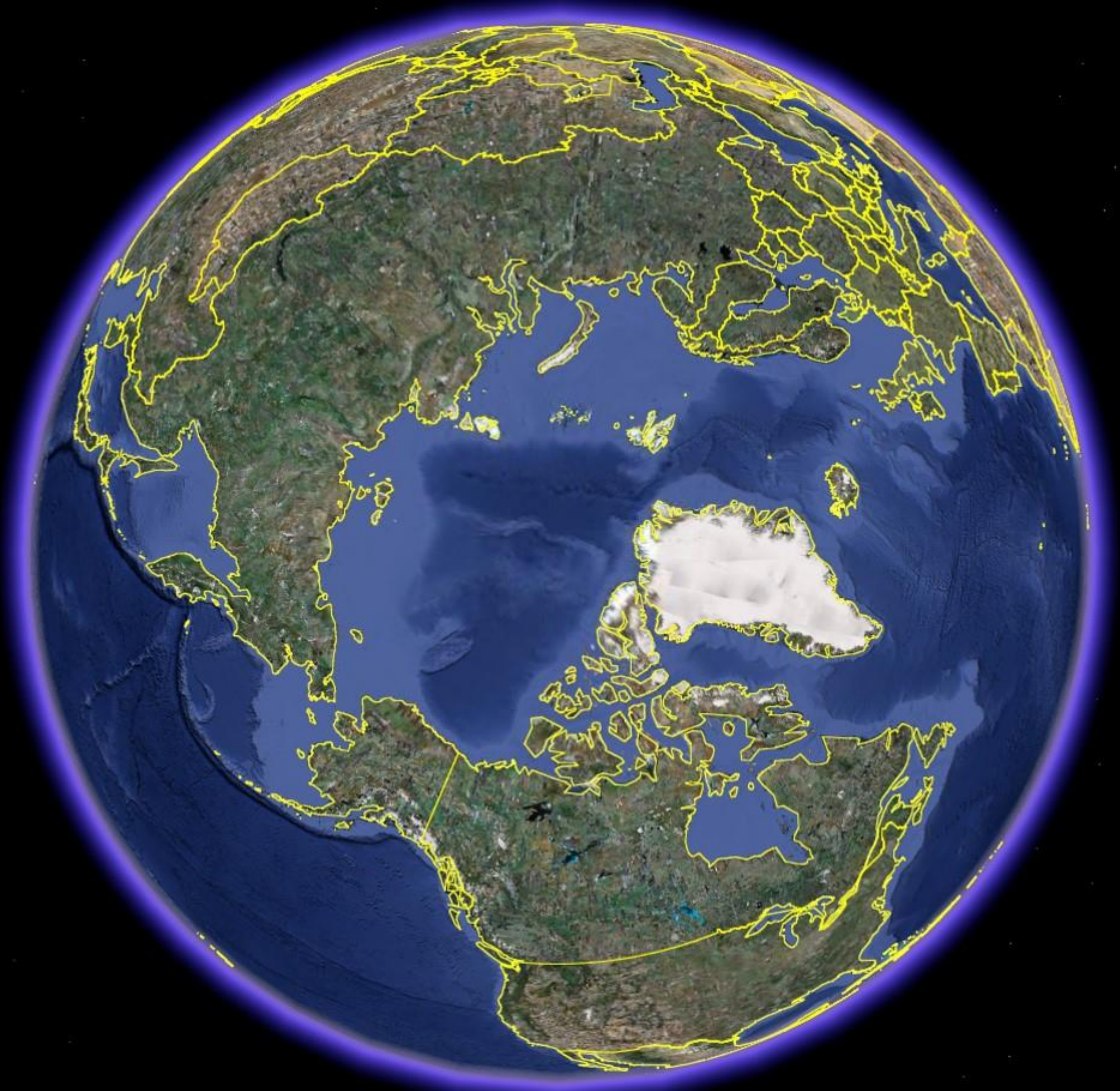
Background:

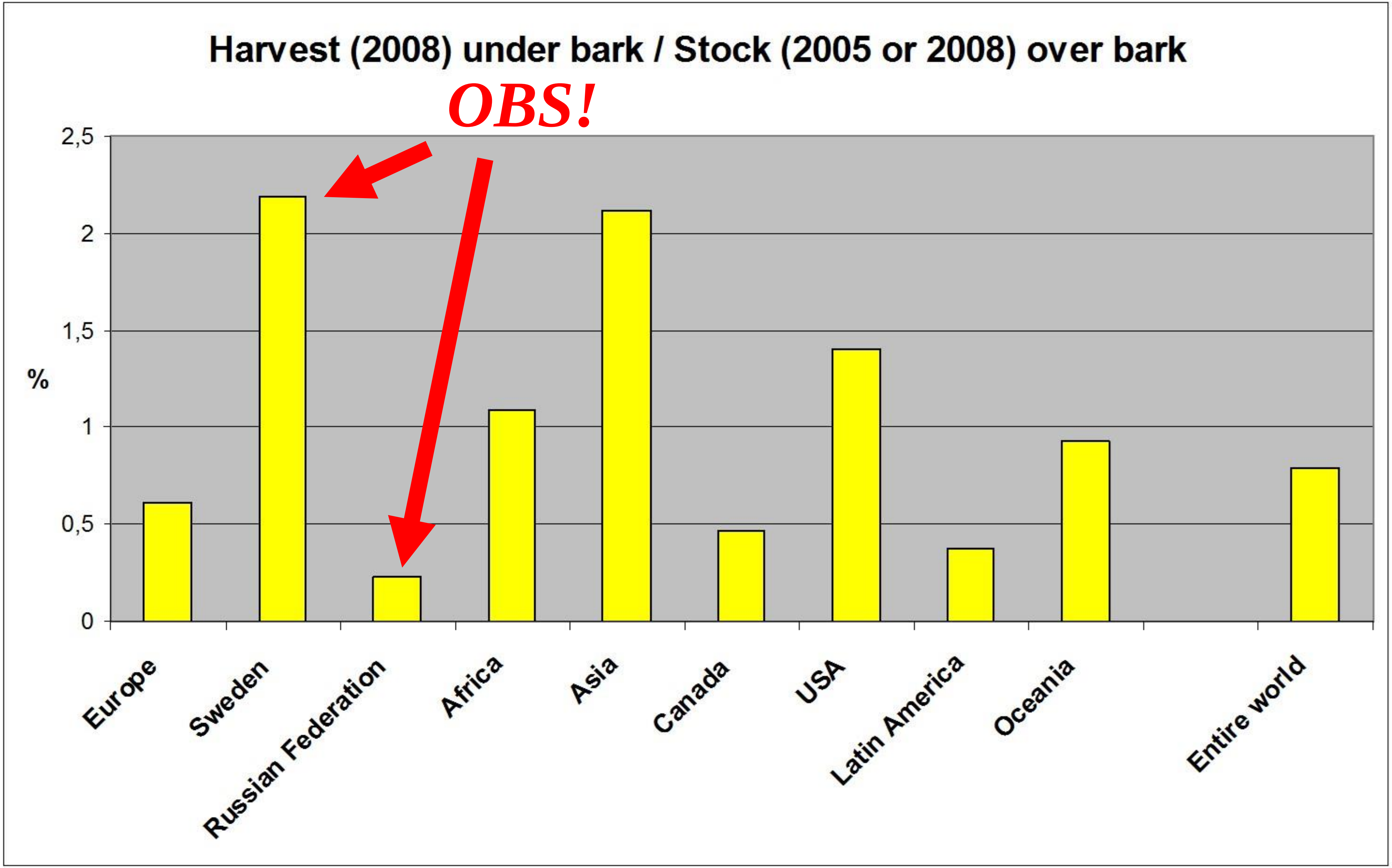
In order to solve the global warming problem and other environmental and economic problems with global implications,

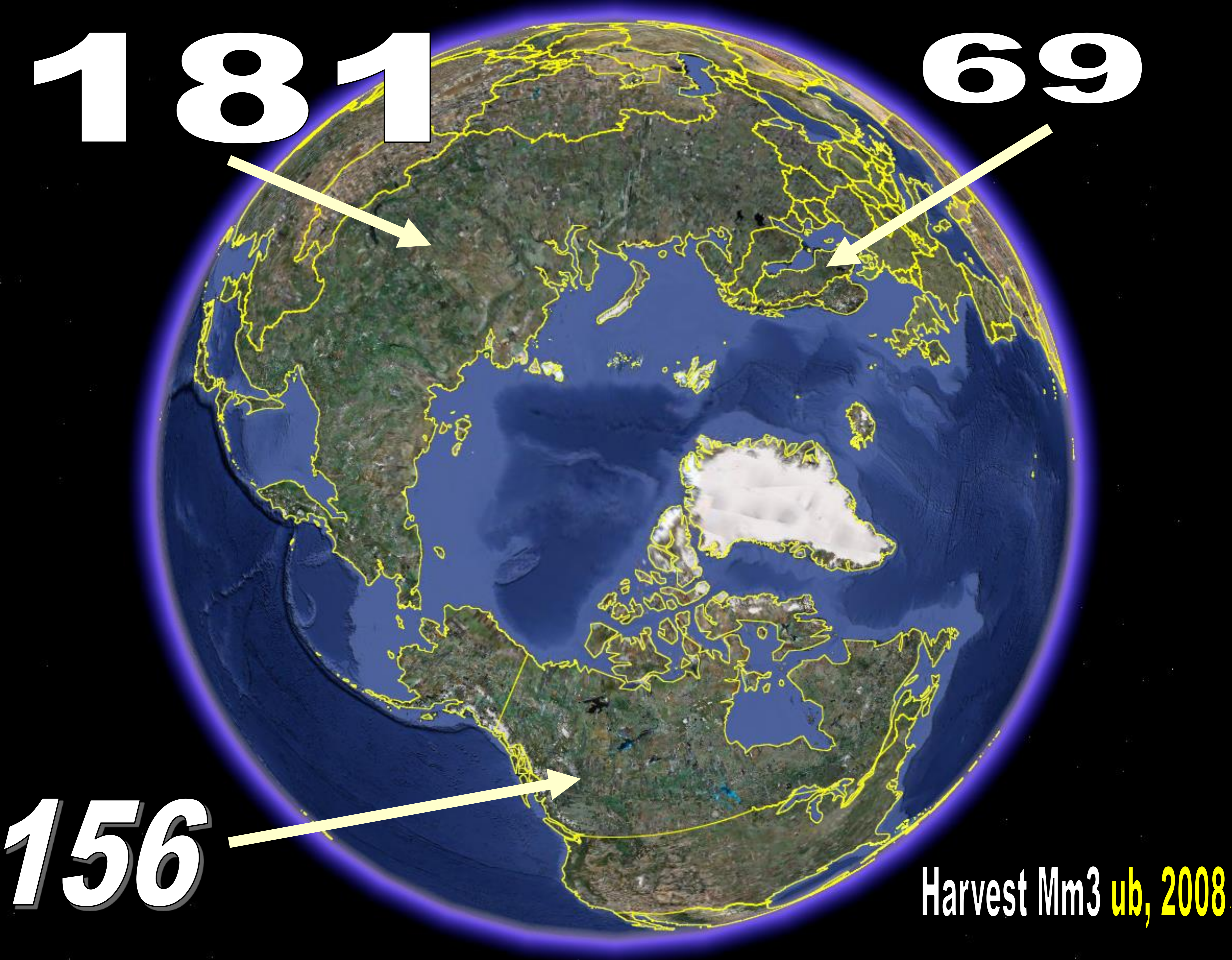
it is necessary that the most relevant and important sustainable management options are well investigated and formulated.

The forests are of particular importance, since they store large amounts of carbon and can produce a sustainable flow of biomass.

The most important sustainable management options are found where we presently have very large forest resources with low degrees of utilization.




Harvest (2008) under bark / Stock (2005 or 2008) over bark
OBS!
2,5
2
1,5
1
0,5
0
%
Europe
Sweden
Russian Federation
Africa
Asia
Canada
USA
Latin America
Oceania
Entire world

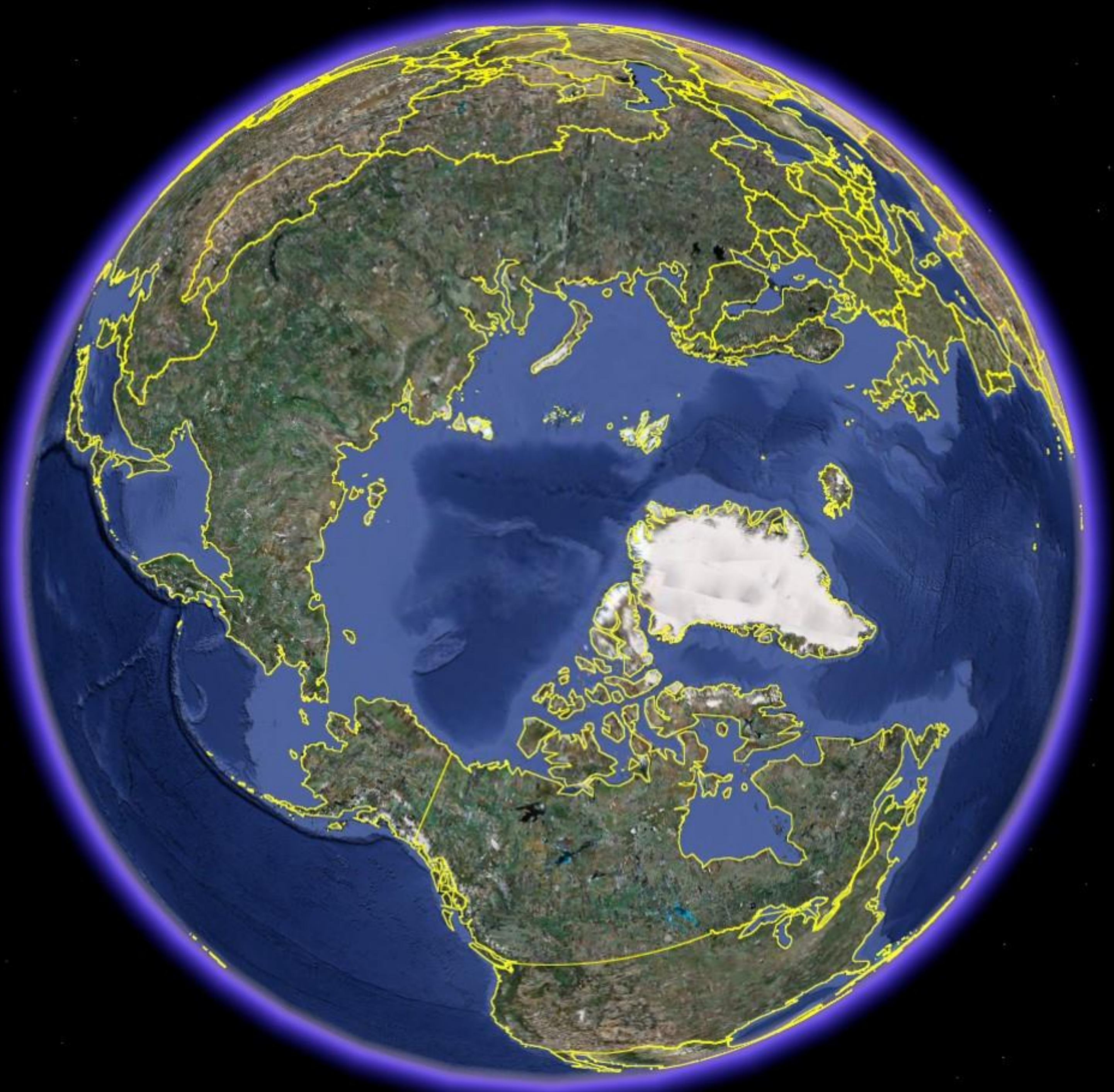

181
69
156
Harvest Mm3 ub, 2008

A simple calculation based on official statistics shows that the sustainable forest production potential in Russian Federation is more than 2900 million cubic metres (over bark) per year.

The harvest (year 2008) was only 181 million cubic metres (under bark).

- *http://www.lohmander.com/RuMa09/Lohmander_Presentation.ppt*
- http://www.iiasa.ac.at/Research/FOR/forest_cdrom/english/for_fund_en.html

Very large forest areas in the north, in particular in Russian Federation and Canada, are covered by more or less natural forests, where trees of different sizes and ages grow together.



Many species prefer continuous cover forests to plantation forests.

The environmental values may be high also with stand densities that periodically are rather low.

Forest growth model development should focus on growth in forests, where trees of different sizes and ages grow together.

The models should be robust and flexible and make it possible to investigate the effects of alternative dynamic controls (harvest volumes over time).

Optimal forest management

Forest management can be performed in many different ways.

Decisions in forestry affect economic results, the flow of bioenergy raw materials, the CO_2 balance of the world, species diversity, recreation options for humans and much more.

<u>Some of the fundamental decision problems concern:</u>

Continuous Cover Forestry (CCF) or Plantation Forestry (PF),

the Stand Density (SD),

the Harvest Interval (HI),

Single Species Forestry (SSF) or Multi Species Forestry (MSF).

With present prices, costs, technology and initial forest conditions in many dominating forest countries, CCF is often a better choice than PF when we optimize the economic present values.

CCF is also a better choice than PF from several environmental perspectives.

The optimal levels of SD and HI are affected by all parameters.

MSF can give environmental benefits in relation to SSF.

MSF can also give economically valuable options to sequentially adjust forest production to future market changes.

MSF is less sensitive to species specific damages and is more flexible to changing environmental conditions.

Therefore, the expected present value of MSF is often higher than the expected present value of SSF.

Similar countries with very different forest laws

The forest laws in different countries, also neighbour countries such as Finland and Sweden, with almost the same prices, costs, technology and forest conditions, are very different with respect to the fundamental decisions: CCF or PF, SD, HI and SSF or MSF.

The economic and environmental development of the world would benefit from more rational forest management.

Several forest laws need to be adjusted in order to make rational decisions legal.

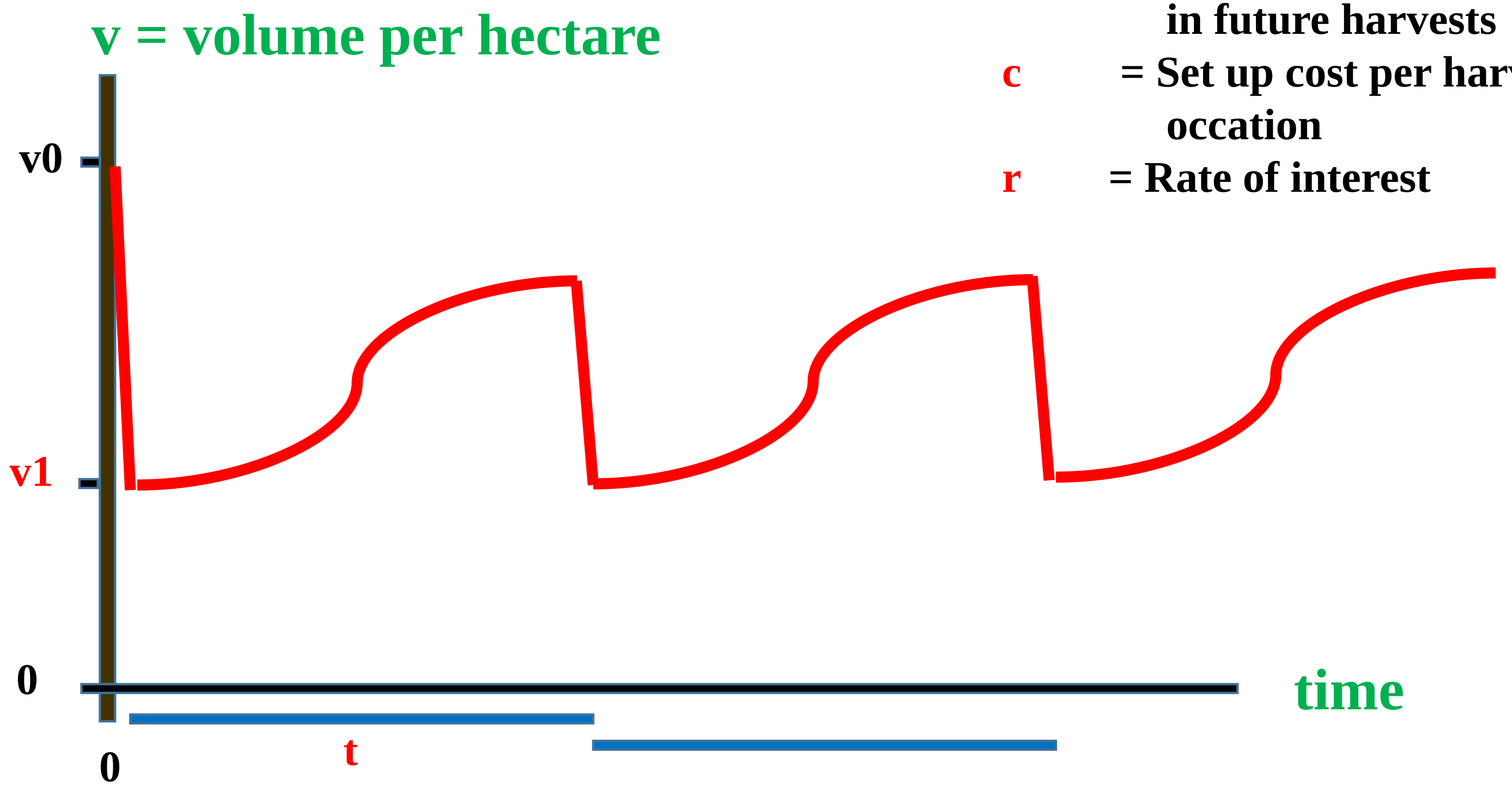
Present value

$$\max \pi = R(h) + \frac{P(v_1,t)Q(v_1,t) - c}{e^{rt} - 1}$$

$$s.t.$$

$$h = v_0 - v_1$$

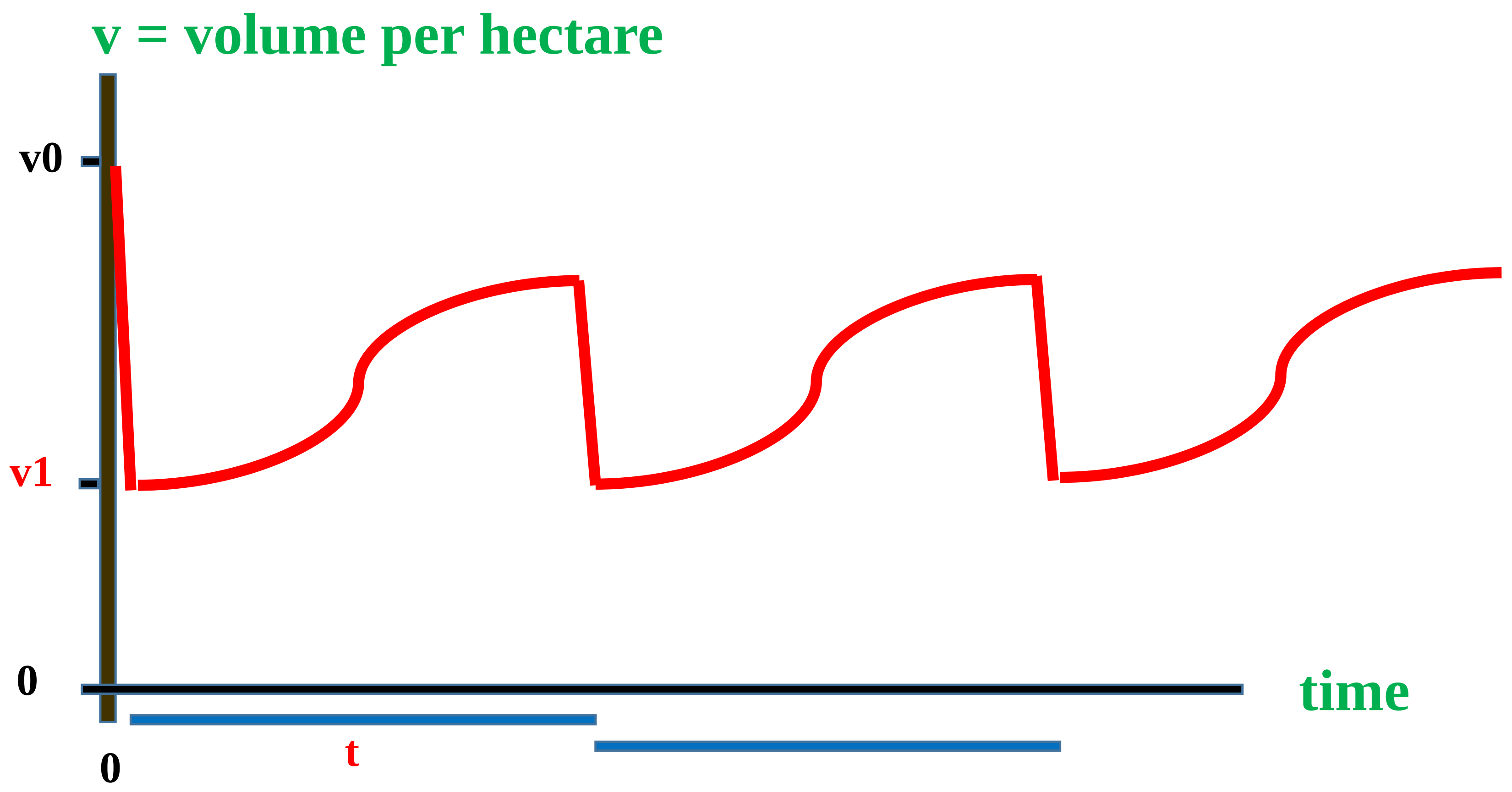
h = The first harvest volume
R(h) = Profit from the first harvest
P(.) = Price per cubic metre (reduced by variable cost per cubic metre) in future harvests
Q(.) = Harvest volume per hectare in future harvests
c = Set up cost per harvest occation
r = Rate of interest



In Finland, continuous cover forest management can be optimized without constraints.

In Sweden, there are several constraints in the forest act. For instance, the volume always has to stay above a specified lower limit. If the volume is below the limit, you have to make a clearcut.

WITH Swedish constraints, forestry with clearcuts often is the economically optimal choice.
WITHOUT Swedish constraints, continuous cover forestry is very often the economically optimal choice.



$$\max \pi = R(h) + \frac{P(v_1, t)Q(v_1, t) - c}{e^{rt} - 1}$$

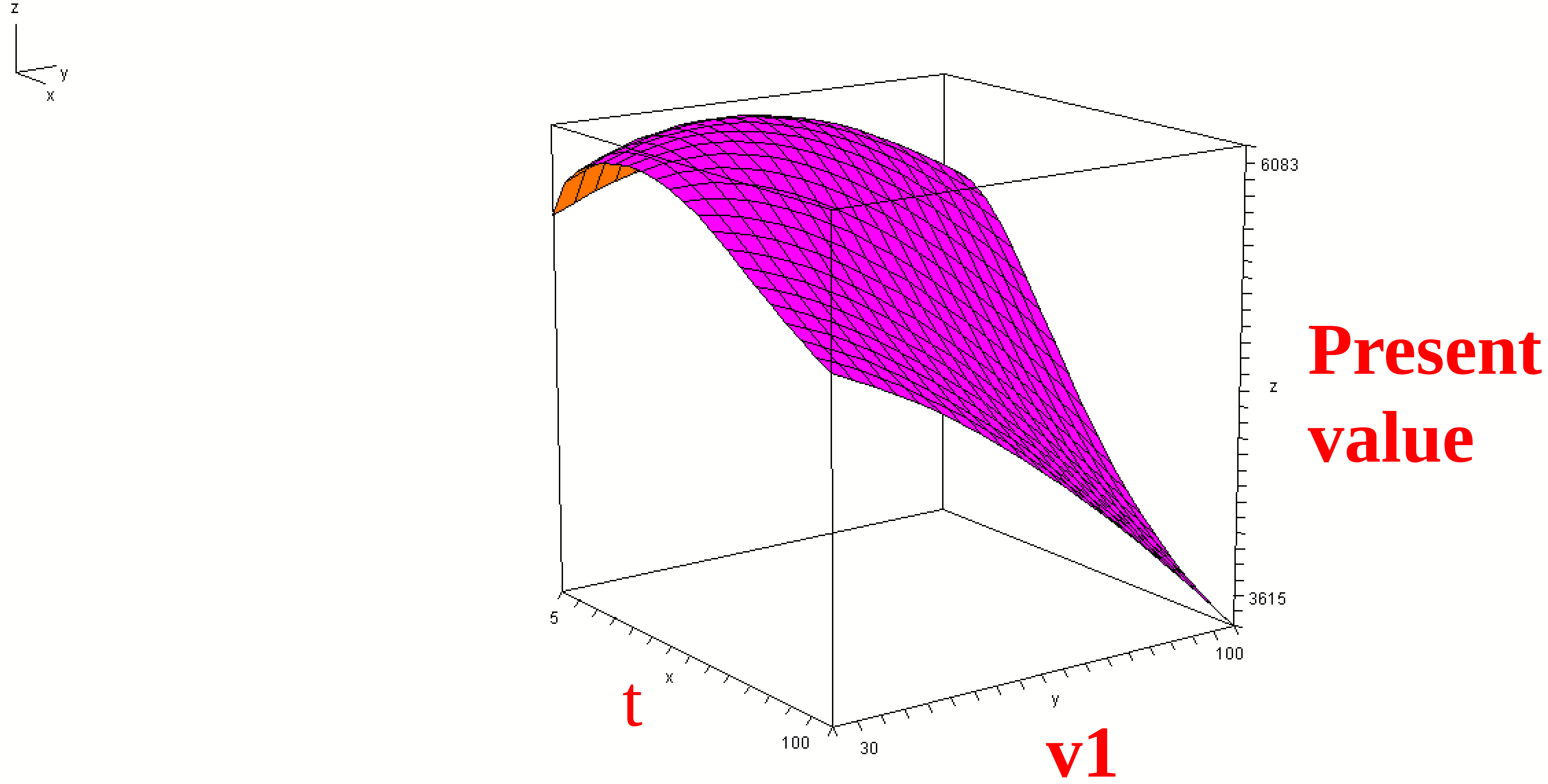
$$s.t.$$

$$h = v_0 - v_1$$

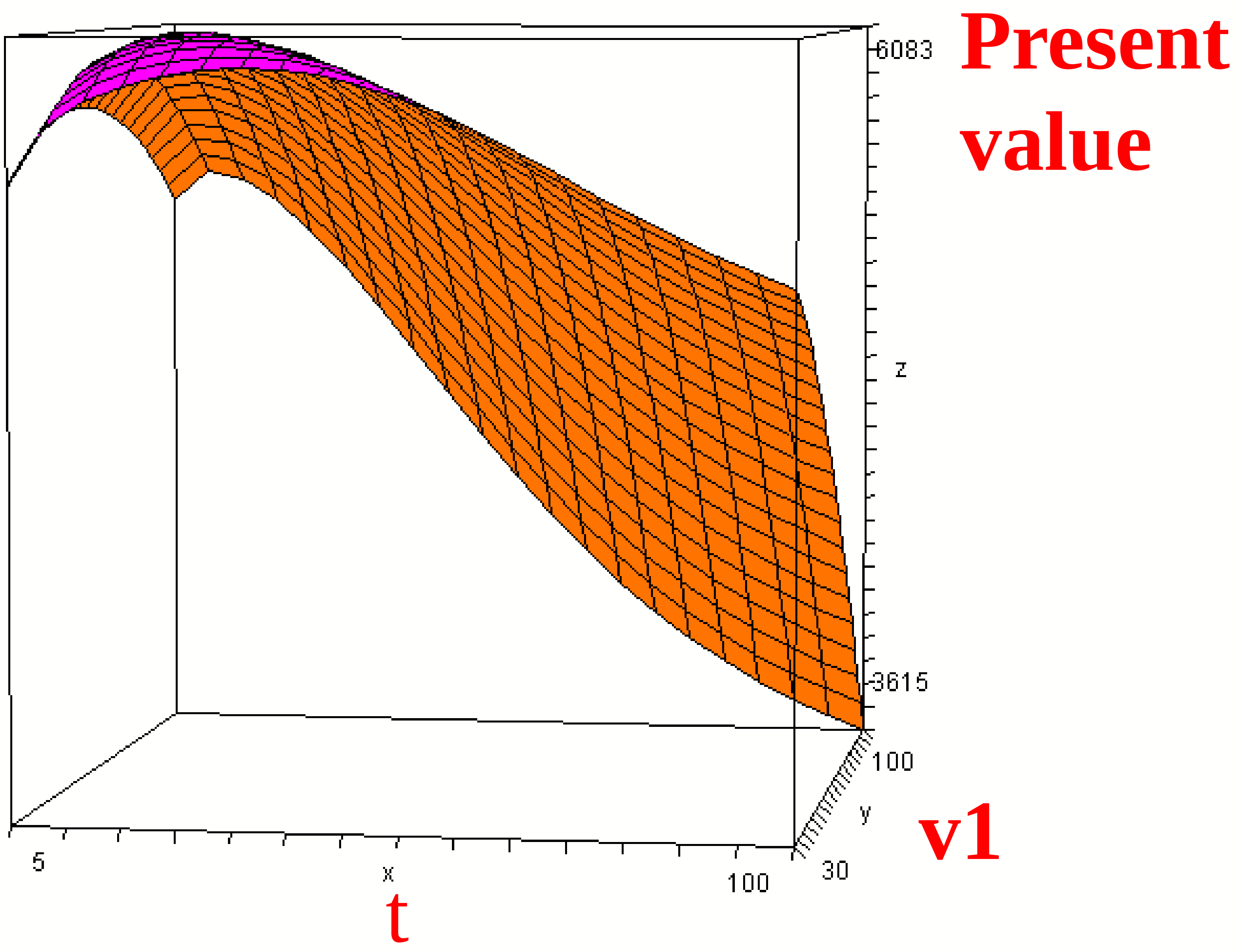
Example:

Graphical illustrations based on specified functions and parameters

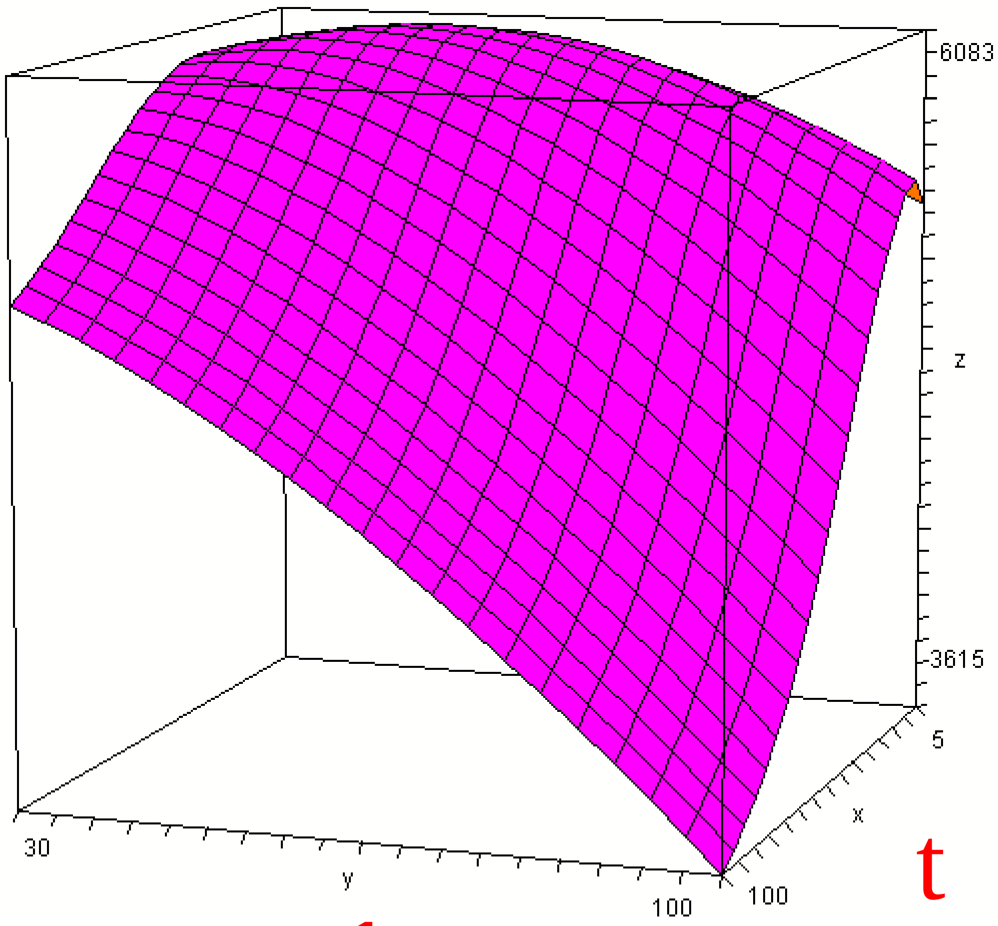
$$\frac{\left(30\cdot(200-v)+\frac{0.1833333}{2}\cdot(200-v)\cdot(200-v)-\frac{0.001666667}{3}\cdot(200-v)\cdot(200-v)\cdot(200-v)-50\right)+20\cdot\left(\frac{1}{\frac{1}{400}+\left(\frac{1}{v}-\frac{1}{400}\right)\cdot\mathrm{EXP}(-0.05\cdot t)}-v\right)-50}{\mathrm{EXP}(0.03\cdot t)-1}$$



z
y
x
6083
z
3615
5
x
100
30
y
100
Present value
t
v1



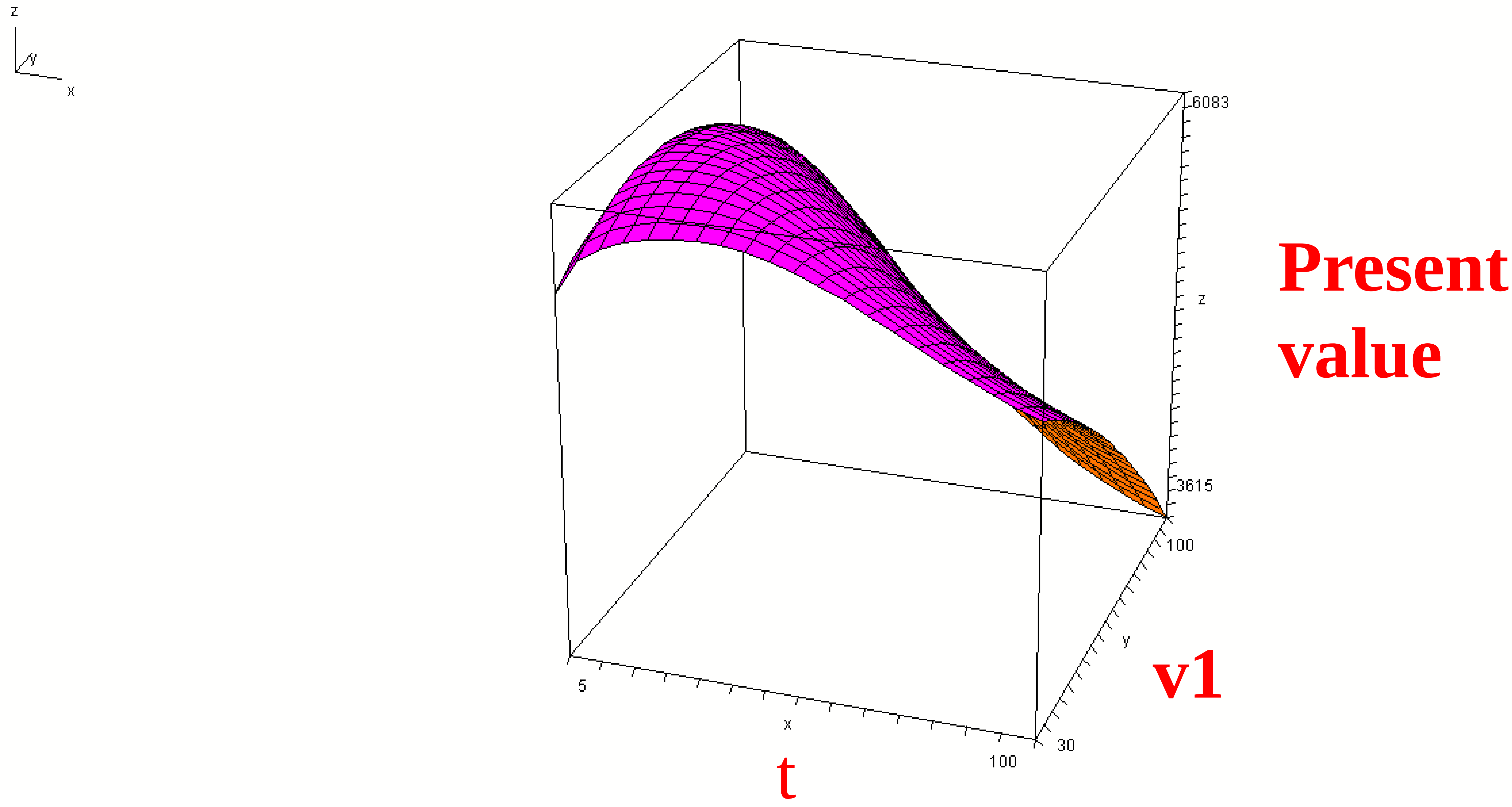
Present value
v1
t
6083
3615
z
100
y
30
5
x
100



Present value

t

v1


z
y
x
6083
z
3615
100
y
30
5
x
100
Present value
v1
t

Numerical Analysis

Peter Lohmander 150812

Case 0:

```
! OPT CCF 150812;
! Peter Lohmander;

v0 = 200;
p = 20;
c = 50;
r = 0.03;
m0 = 30;
c0 = 50;

max = Y;
Y = R0 + (p*Q-c)/(@exp(r*t)-1);
h = v0-v1;
h < v0;
h > 1;

mp = m0 - a*h-b*h*h;
R0 = m0*h-a/2*h*h-b/3*h*h*h-c0;
Q = 1/(1/400+(1/v1-1/400)*@exp(-0.05*t))-v1;

! Derivation of initial marginal price function;
150*a+(150)^2*b= 10;
200*a+(200)^2*b = 30;
@free(a);
@free(b);
```

```
Local optimal solution found.
  Objective value:                              6084.286
  Infeasibilities:                              0.000000
  Total solver iterations:                            34
```

Variable	Value	Reduced Cost
V0	200.0000	0.000000
P	20.00000	0.000000
C	50.00000	0.000000
R	0.3000000E-01	0.000000
M0	30.00000	0.000000
C0	50.00000	0.000000
Y	6084.286	0.000000
R0	4651.524	0.000000
Q	71.17267	0.000000
T	22.40775	0.1339671E-08
H	150.7051	0.000000
V1	49.29487	0.000000
MP	19.77588	0.000000
A	-0.1833333	0.000000
B	0.1666667E-02	0.000000

Maximum present value

The optimal value of V1 is far below the Swedish constraint.

Optimal continuous cover forest management

First, we study:

One dimensional optimization in the time interval dimension (of relevance when the stock level after harvest is determined by law or can not be determined for some other reason)

$$\max \pi = R(h) + \frac{P(v_1, t)Q(v_1, t) - c}{e^{rt} - 1}$$

$$s.t.$$

$$h = v_0 - v_1$$

$$\frac{d\pi}{dt}=\frac{e^{rt}}{\left(e^{rt}-1\right)^{2}}\left(\left(\frac{dP}{dt}Q+P\frac{dQ}{dt}\right)\left(1-e^{-rt}\right)-\left(PQ-c\right)r\right)=0$$

$$\left(\frac{dP}{dt}Q+P\frac{dQ}{dt}\right)\left(1-e^{-rt}\right)-\left(PQ-c\right)r=0$$

$$\left(M(.)=0\right)\Rightarrow$$

Optimal principle in the time dimension:

$$\frac{\dfrac{dP}{dt}Q + P\dfrac{dQ}{dt}}{PQ + \dfrac{\left(-c + e^{-rt}PQ\right)}{1 - e^{-rt}}} = r$$

How is the optimal time interval affected if the parameter c marginally increases (ceteres paribus)?

$$\frac{d\pi}{dt} = 0$$

$$d\left(\frac{d\pi}{dt}\right) = \frac{d^2\pi}{dt^2}dt^* + \frac{d^2\pi}{dtdc}dc = 0$$

$$\frac{dt^*}{dc} = \frac{-\left(\frac{d^2\pi}{dtdc}\right)}{\left(\frac{d^2\pi}{dt^2}\right)}$$

A unique maximum is assumed in the time interval dimension

$$\frac{d^2\pi}{dt^2} < 0$$

$$\frac{d^2\pi}{dtdc} = k(.)r > 0$$

$$\frac{dt^*}{dc} = \frac{-\left(\dfrac{d^2\pi}{dtdc}\right)}{\left(\dfrac{d^2\pi}{dt^2}\right)} > 0$$

Conclusion:

The optimal time interval is a strictly increasing function of c.

How is the optimal time interval affected if the parameter r marginally increases (ceteres paribus)?

$$\frac{dt^*}{dr} = \frac{-\left(\dfrac{d^2\pi}{dtdr}\right)}{\left(\dfrac{d^2\pi}{dt^2}\right)} < 0$$

Conclusion:

The optimal time interval is a strictly decreasing function of the parameter r.

How is the optimal time interval affected if the future prices marginally increase (ceteres paribus)?

$$\max \pi = R(h) + \frac{pQ(v_1, t) - c}{e^{rt} - 1}$$

$$\frac{dt^*}{dp} = \frac{-\left(\dfrac{d^2\pi}{dtdp}\right)}{\left(\dfrac{d^2\pi}{dt^2}\right)} < 0$$

Conclusion:

The optimal time interval is a strictly decreasing function of the parameter p.

Optimal continuous cover forest management

Now, we study:

One dimensional optimization in the volume dimension (of relevance when the time interval is determined by law or can not be determined for some other reason)

$$\max \pi = R(h) + \frac{P(v_1, t)Q(v_1, t) - c}{e^{rt} - 1}$$

$$s.t.$$

$$h = v_0 - v_1$$

$$\frac{d\pi}{dv_1} = \frac{dR}{dh}\frac{dh}{dv_1} + \frac{1}{e^{rt}-1}\left(\frac{dP}{dv_1}Q(.) + P\frac{dQ}{dv_1}\right) = 0$$

$$\frac{dh}{dv_1} = -1$$

Optimal principle in the volume dimension:

$$\frac{dR}{dh} = \frac{1}{e^{rt}-1}\left(\frac{dP}{dv_1}Q(.) + P\frac{dQ}{dv_1}\right)$$

How is the optimal volume affected if one parameter marginally increases (ceteres paribus)?

- **The optimal volume is not affected by changes of c.**
- **The optimal volume is a strictly decreasing function of r.**
- **The optimal volume is a strictly increasing function of p.**

Observation:

- If the volume is constrained (by law or something else), we may study the effects of the volume constraint on the optimal time interval, via one dimensional optimization.

$$\frac{d^2\pi}{dv_1 dt} < 0$$

$$\frac{dt^*}{dv_1} = \frac{-\left(\dfrac{d^2\pi}{dt dv_1}\right)}{\left(\dfrac{d^2\pi}{dt^2}\right)} < 0$$

Observation (extended):

- If the time interval is constrained (by law or something else), we may study the effects of the time interval constraint on the volume, via one dimensional optimization.

$$\frac{d^2\pi}{dv_1 dt} < 0$$

$$\frac{dv_1^*}{dt} = \frac{-\left(\dfrac{d^2\pi}{dv_1 dt}\right)}{\left(\dfrac{d^2\pi}{dv_1^2}\right)} < 0$$

Optimal continuous cover forest management

Now, we study:

Two dimensional optimization in the volume AND time interval dimensions

$$\max \pi = R(h) + \frac{pQ(v_1, t) - c}{e^{rt} - 1}$$

$$s.t.$$

$$h = v_0 - v_1$$

The first order optimum conditions:

$$\begin{cases} \dfrac{d\pi}{dv_1} = 0 \\ \dfrac{d\pi}{dt} = 0 \end{cases}$$

$$\begin{cases} \dfrac{dR}{dh}\dfrac{dh}{dv_1} + \left(\dfrac{1}{e^{rt}-1}\right) p \dfrac{dQ}{dv_1} = 0 \\ \dfrac{e^{rt}}{\left(e^{rt}-1\right)^2}\left(p\dfrac{dQ}{dt}\left(1-e^{-rt}\right) - \left(pQ-c\right)r \right) = 0 \end{cases}$$

Assumption: A unique maximum exists. The following conditions hold:

$$\left|\frac{d^2\pi}{dv_1{}^2}\right| < 0, \qquad \left|\frac{d^2\pi}{dt^2}\right| < 0, \qquad \begin{vmatrix} \dfrac{d^2\pi}{dv_1{}^2} & \dfrac{d^2\pi}{dv_1 dt} \\ \dfrac{d^2\pi}{dt dv_1} & \dfrac{d^2\pi}{dt^2} \end{vmatrix} > 0$$

$$\left(|D| = \begin{vmatrix} \dfrac{d^2\pi}{d{v_1}^2} & \dfrac{d^2\pi}{dv_1 dt} \\ \dfrac{d^2\pi}{dt dv_1} & \dfrac{d^2\pi}{dt^2} \end{vmatrix} > 0 \right) \Rightarrow \frac{d^2\pi}{d{v_1}^2}\frac{d^2\pi}{dt^2} - \frac{d^2\pi}{dt dv_1}\frac{d^2\pi}{dv_1 dt} > 0$$

$$\frac{d^2\pi}{d{v_1}^2}\frac{d^2\pi}{dt^2} > \frac{d^2\pi}{dt dv_1}\frac{d^2\pi}{dv_1 dt} = \left(\frac{d^2\pi}{dv_1 dt} \right)^2$$

Comparative statics analysis based on two dimensional optimization:

$$\begin{bmatrix} \dfrac{d^2\pi}{dv_1^{\,2}} & \dfrac{d^2\pi}{dv_1 dt} \\ \dfrac{d^2\pi}{dt dv_1} & \dfrac{d^2\pi}{dt^2} \end{bmatrix} \begin{bmatrix} dv_1^{\,*} \\ dt^* \end{bmatrix} = \begin{bmatrix} -\dfrac{d^2\pi}{dv_1 dc}dc - \dfrac{d^2\pi}{dv_1 dp}dp - \dfrac{d^2\pi}{dv_1 dr}dr \\ -\dfrac{d^2\pi}{dt dc}dc - \dfrac{d^2\pi}{dt dp}dp - \dfrac{d^2\pi}{dt dr}dr \end{bmatrix}$$

$$\begin{bmatrix} \dfrac{d^2\pi}{d{v_1}^2} & \dfrac{d^2\pi}{dv_1 dt} \\ \dfrac{d^2\pi}{dt dv_1} & \dfrac{d^2\pi}{dt^2} \end{bmatrix} \begin{bmatrix} d{v_1}^* \\ dt^* \end{bmatrix} = \begin{bmatrix} -\dfrac{d^2\pi}{dv_1 dc} dc \\ -\dfrac{d^2\pi}{dt dc} dc \end{bmatrix}$$

$$\frac{dv_1^{\ *}}{dc} = \frac{\begin{vmatrix} 0 & \dfrac{d^2\pi}{dv_1 dt} \\ -\dfrac{d^2\pi}{dtdc} & \dfrac{d^2\pi}{dt^2} \end{vmatrix}}{|D|} = \frac{\dfrac{d^2\pi}{dtdc}\dfrac{d^2\pi}{dv_1 dt}}{|D|} < 0$$

$$\frac{dt^*}{dc} = \frac{\begin{vmatrix} \dfrac{d^2\pi}{dv_1{}^2} & -\dfrac{d^2\pi}{dv_1 dc} \\ \dfrac{d^2\pi}{dtdv_1} & -\dfrac{d^2\pi}{dtdc} \end{vmatrix}}{\begin{vmatrix} \dfrac{d^2\pi}{dv_1{}^2} & \dfrac{d^2\pi}{dv_1 dt} \\ \dfrac{d^2\pi}{dtdv_1} & \dfrac{d^2\pi}{dt^2} \end{vmatrix}} = \frac{\begin{vmatrix} \dfrac{d^2\pi}{dv_1{}^2} & 0 \\ \dfrac{d^2\pi}{dtdv_1} & -\dfrac{d^2\pi}{dtdc} \end{vmatrix}}{|D|} = \frac{-\dfrac{d^2\pi}{dv_1{}^2}\dfrac{d^2\pi}{dtdc}}{|D|} > 0$$

$$\frac{dv_1^{\,*}}{dp}=\frac{\begin{vmatrix}-\dfrac{d^2\pi}{dv_1dp} & \dfrac{d^2\pi}{dv_1dt}\\[2ex] -\dfrac{d^2\pi}{dtdp} & \dfrac{d^2\pi}{dt^2}\end{vmatrix}}{|D|}=\frac{-\dfrac{d^2\pi}{dv_1dp}\dfrac{d^2\pi}{dt^2}+\dfrac{d^2\pi}{dtdp}\dfrac{d^2\pi}{dv_1dt}}{|D|}>0$$

$$\frac{dt^*}{dp} = \frac{\begin{vmatrix} \dfrac{d^2\pi}{dv_1{}^2} & -\dfrac{d^2\pi}{dv_1 dp} \\ \dfrac{d^2\pi}{dtdv_1} & -\dfrac{d^2\pi}{dtdp} \end{vmatrix}}{|D|} = \frac{-\dfrac{d^2\pi}{dv_1{}^2}\dfrac{d^2\pi}{dtdp} + \dfrac{d^2\pi}{dtdv_1}\dfrac{d^2\pi}{dv_1 dp}}{|D|} < 0$$

$$\frac{dv_1^{\ *}}{dr} = \frac{\begin{vmatrix} -\dfrac{d^2\pi}{dv_1 dr} & \dfrac{d^2\pi}{dv_1 dt} \\ -\dfrac{d^2\pi}{dt dr} & \dfrac{d^2\pi}{dt^2} \end{vmatrix}}{|D|} = \frac{-\dfrac{d^2\pi}{dv_1 dr}\dfrac{d^2\pi}{dt^2} + \dfrac{d^2\pi}{dt dr}\dfrac{d^2\pi}{dv_1 dt}}{|D|} < 0$$

$$\frac{dt^*}{dr} = \frac{\begin{vmatrix} \dfrac{d^2\pi}{dv_1^2} & -\dfrac{d^2\pi}{dv_1 dr} \\ \dfrac{d^2\pi}{dt dv_1} & -\dfrac{d^2\pi}{dt dr} \end{vmatrix}}{\begin{vmatrix} \dfrac{d^2\pi}{dv_1^2} & \dfrac{d^2\pi}{dv_1 dt} \\ \dfrac{d^2\pi}{dt dv_1} & \dfrac{d^2\pi}{dt^2} \end{vmatrix}} = \frac{-\dfrac{d^2\pi}{dv_1^2}\dfrac{d^2\pi}{dt dr} + \dfrac{d^2\pi}{dt dv_1}\dfrac{d^2\pi}{dv_1 dr}}{|D|} < 0$$

Conclusions:

The forest laws in different countries, also neighbour countries such as Finland and Sweden, with almost the same prices, costs, technology and forest conditions, are very different.

If constraints that make continuous cover forest management less profitable than clear cut forestry are removed, we can expect better economic results and environmental improvements.

The analyses have shown how optimal decisions in forestry can be determined and how these optimal decisions are affected by parameter changes.

Several laws need to be adjusted in order to make rational forestry decisions legal.

The economic and environmental development of the world would benefit from more rational forest management.

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There is a mathematical appendix available that contains all of the derivations.

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