HIGH RESOLUTION ADAPTIVE OPTIMIZATION OF CONTINUOUS COVER SPRUCE FOREST MANAGEMENT IN SOUTHERN SWEDEN

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METHODOLOGY and MOTIVATION

- Stochastic dynamic programming, SDP, can be used, and has often been used, to optimize forest management decisions under the influence of stochastic disturbances.
- If the number of decision variables is large and the optimal decisions are dependent on detailed information in a state space of large dimensionality, SDP can however not be applied.
- For this reason, **optimal control functions for local decisions are defined and the parameters are determined via stochastic full system simulation and multidimensional regression analysis**.

Structure of the analysis:

A multidimensional loop with different adaptive control function parameter value combinations is created.

For each parameter combination:

10 stochastic simulations of the complete system during 200 years with estimation of the expected present value.

A table with expected present values for different adaptive control function parameter value combinations is created.

A multidimensional nonlinear approximation of the expected present value, as a function of the adaptive control function parameters, is derived via regression analysis.

The adaptive control function parameters are analytically determined via the first order optimum conditions and the second order maximum conditions.

The maximum expected present value is determined via the determined control function parameter values.

METHODOLOGY and MOTIVATION

- All local harvest decisions are based on locally relevant state space information within stochastic dynamic and spatially explicit forest production.
- The expected present value of all harvests, over time and space, in a forest area, is maximized.
- Each tree is affected by competition from neighbor trees.
- **The harvest decisions, for each tree, are functions of the prices in the stochastic market, the dimension and quality of the individual tree, and the local competition.**

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METHODOLOGY and MOTIVATION

- The market value of a tree is a function of size, quality and stochastic price variations.
- The variable harvesting cost of a tree is size dependent.
- The random quality differences are defined via the effects on the timber prices.

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METHODOLOGY and MOTIVATION

- **The adaptive control function, a limit diameter function**, to be used in this forest is determined, that **gives the maximum of the total expected present value of all activities over time**.
- If the diameter of a particular tree is larger than the limit diameter, then the tree should be instantly harvested.
- Otherwise, it should be left for continued production.

The optimal limit diameter function:

Diameter of tree n1

Local competition of tree n1

Timber quality of tree n1

1.0

Real timber price (of average timber quality) minus expected real equilibrium price

IF d(n1) > (dlim_0 + dlim_c * c(n1) + dlim_q * qual(n1) + dlim_p * SigmaK * pdev(nums, t)) THEN h(n1) = 1

? ? ? ?

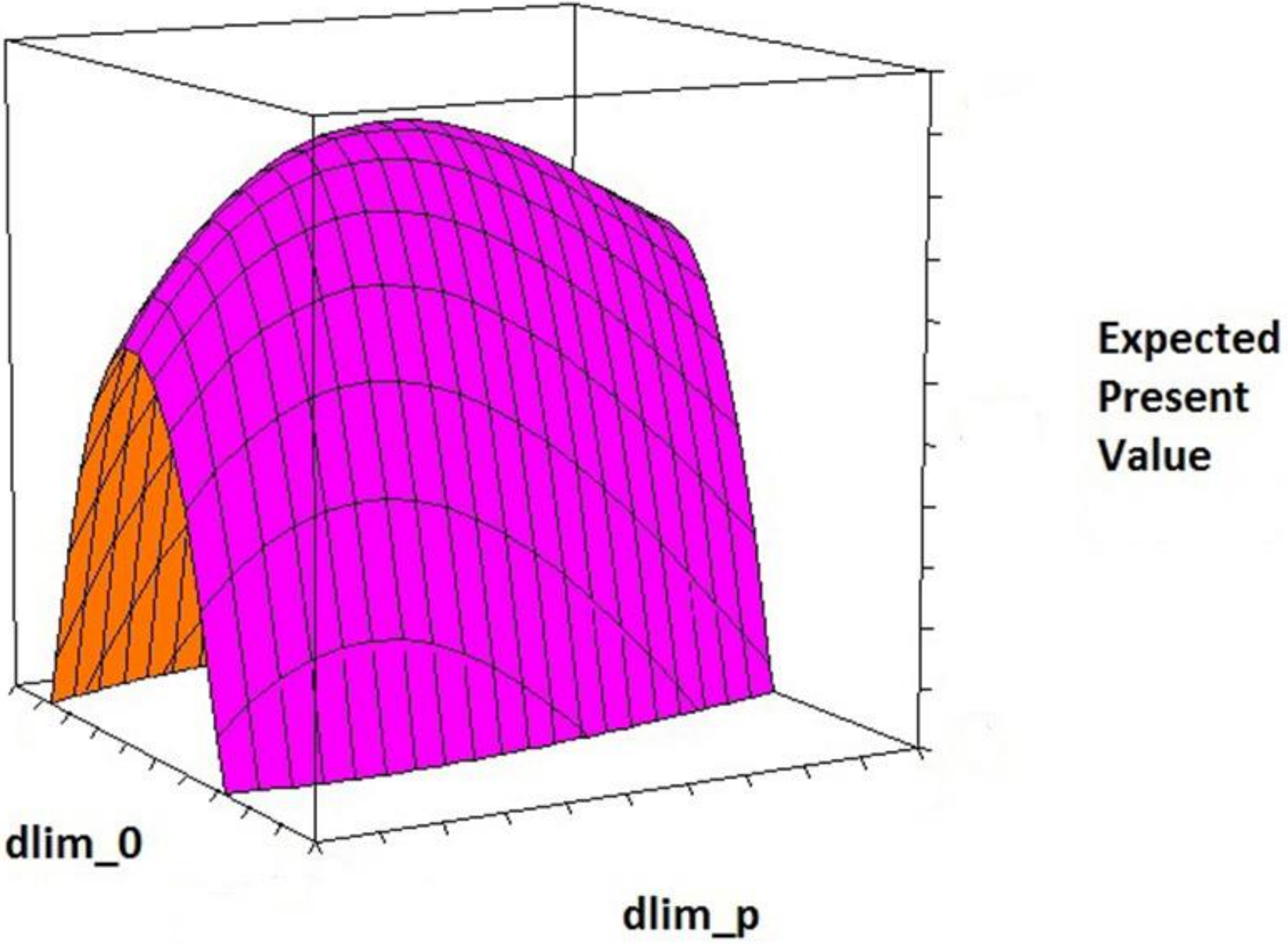
These four parameters, in the control function, should be optimized (for real rate of interest 3%) .

If h(n1)=0 (default value), then the tree should not be instantly harvested.
If h(n1) = 1, then the tree should be instantly harvested.

Partial objective function surface

The expected present value as a function of the values of two parameters in the limit diameter (= adaptive harvest control) function.

(The other parameters are assumed to have the optimal values.)



HIGH RESOLUTION ADAPTIVE OPTIMIZATION OF CONTINUOUS COVER SPRUCE FOREST MANAGEMENT IN SOUTHERN SWEDEN

APPLICATION

Economically optimal forest management decisions are determined within the continuous cover framework, in forests of Norway spruce in southern Sweden.

The general methodological approach can also be applied to other species and in other regions.

This study is based on a new growth function for individual trees of Norway spruce in southern Sweden managed with a continuous cover system.

The function determines the basal area increment of individual trees based on the state of the tree itself, i.e. current basal area, and local competition in the neighborhood of each tree.

The model set includes a stochastic timber quality sub model that assigns qualities to the trees.

The software:

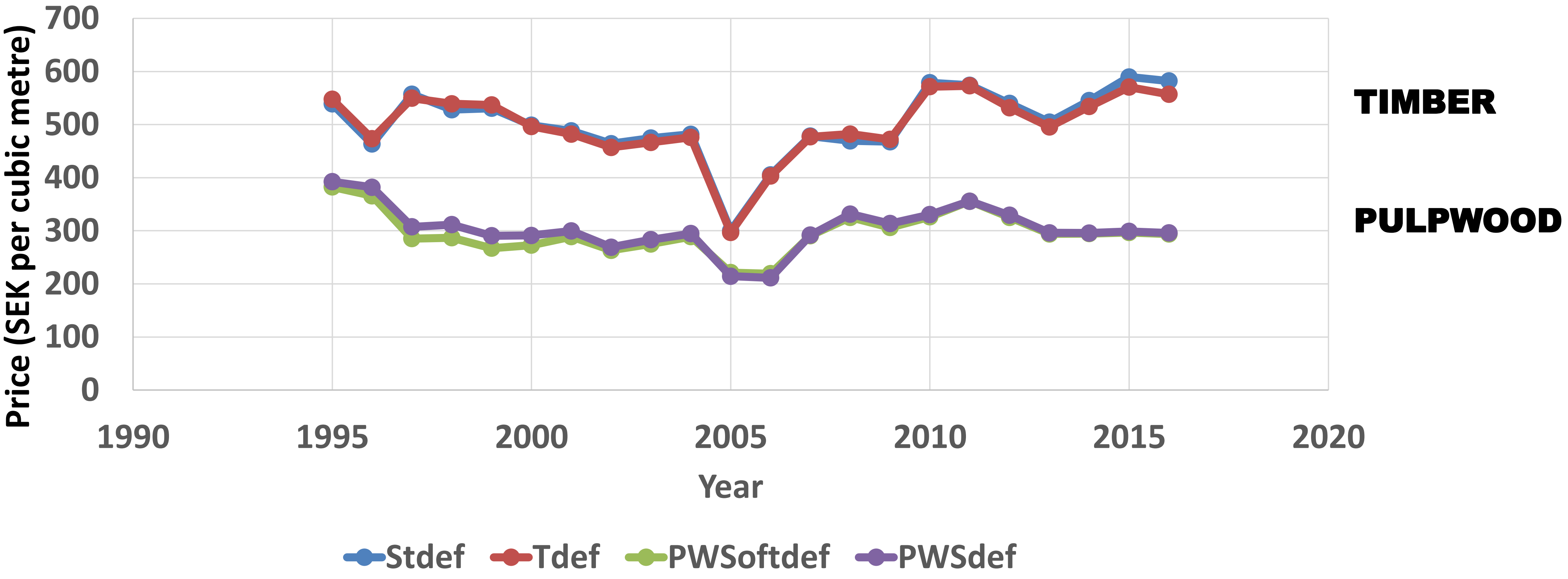
In the end of this presentation, the complete software is documented and followed by a few lines of a typical output file.

The software estimates, via repeated stochastic simulations, the total expected present value of all activities during 200 years, for different control function parameter value combinations.

Some of the empirical background and derived functions used in the optimization, are briefly described on the following pages.

All statistics concerning prices, costs and forests, concern ”Southern Sweden”.

”REAL PRICES” (Prices deflated by consumer price index to the price level of 2016)



Stdef = Real price of spruce timber, **Tdef** = Real price of timber, **PWSoftdef** = Real price of pulpwood from softwoods, **PWSdef** = Real price of pulpwood from spruce. (Spruce = Norway spruce = Picea abies. All prices concern southern Sweden.) Sources: Swedish Forest Agency and SCB.

Regression statistics	
Multipel-R	0,992636
R2	0,985325
Adjusted R2	0,937706
Standard error	38,03903
Observations	22

ALMOST a perfect and very simple function:

PWSdef = 0.60*Stdef

(Pulpwood price = 0.6 * Timber price)

ANOVA

	fg	*KvS*	*MKv*	*F*	*p-value of F*
Regression	1	2040284	2040284	1410,041	5,08E-20
Residual	21	30386,33	1446,968		
Total	22	2070670			

	Coefficient	*Standard error*	*t-ratio*	*p-value*
Constant	0			
Stdef	0,600793	0,016	37,55051	9,72E-21

Deflated price of spruce timber year t as a function of the deflated price of spruce timber year t-1.

Regression statistics	
Multipel-R	0,515774551
R2	0,266023388
Adjusted R2	0,22739304
Standard error	59,02778581
Observations	21

First order autoregressive process:

$$P(t) = 236 + 0.531*P(t-1) + s(t)$$

stdev = 59

ANOVA

	fg	*KvS*	*MKv*	*F*	*p-value of F*
Regression	1	23994,08455	23994,08455	6,886383417	0,016699293
Residual	19	66201,31046	3484,279498		
Total	20	90195,39502			

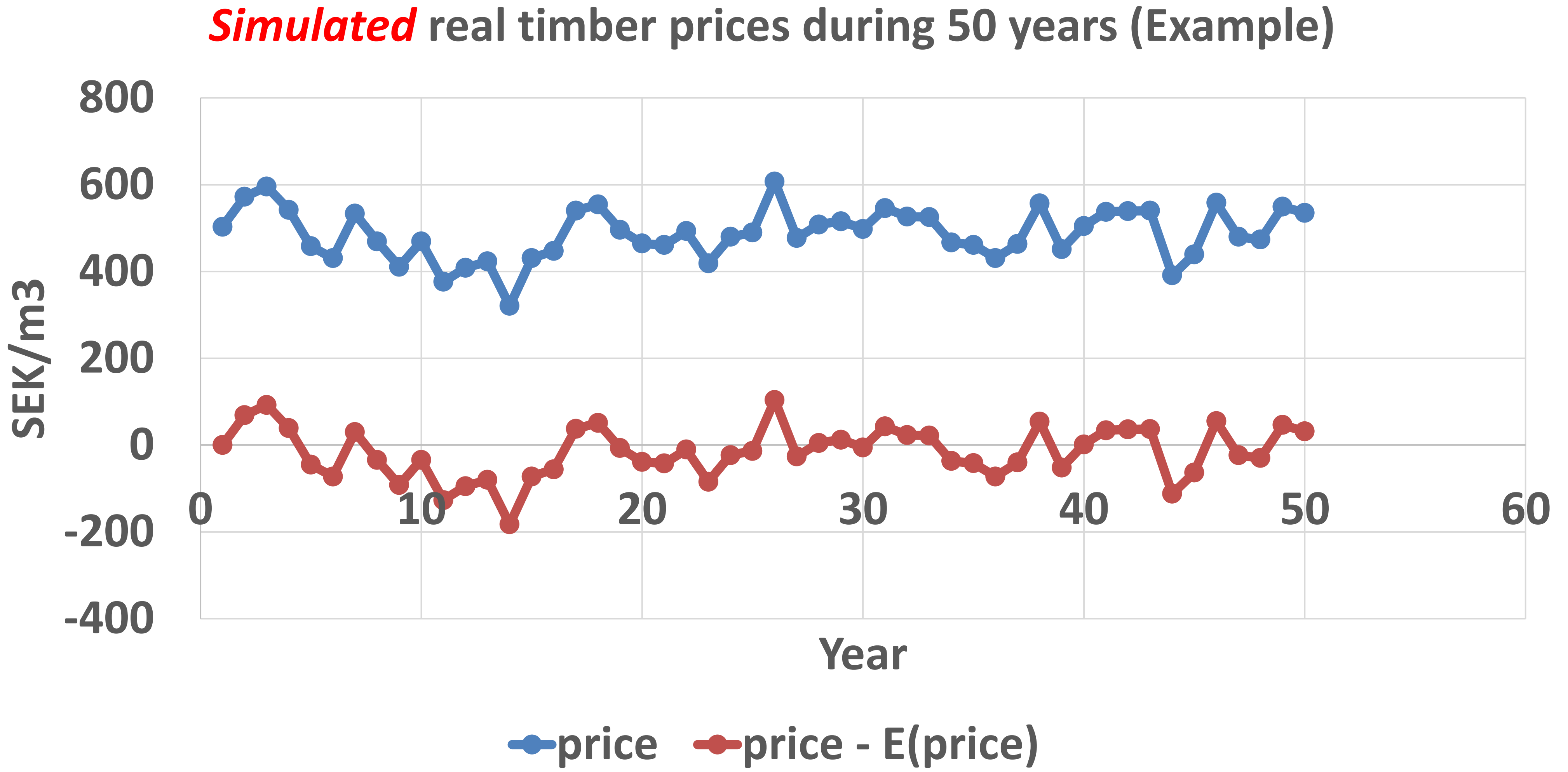
	Coefficient	*Standard error*	*t-ratio*	*p-value*
Constant	235,9102296	101,8500004	2,316251632	0,031871867
STP0	0,531329826	0,202473689	2,624191955	0,016699293

Observation	PREDICTED PRICE	Residual	YEAR OF PREDICTED PRICE	
1	522,2832849	-58,76277704	1996	
2	482,1925005	74,91123053	1997	
3	531,9160583	-3,71189486	1998	
4	516,560856	14,29613738	1999	
5	517,9703837	-19,11065991	2000	
6	500,96928	-12,87807824	2001	
7	495,2476431	-31,27403606	2002	
8	482,4332457	-7,958919878	2003	
9	488,0125907	-6,340850039	2004	
10	491,8367919	-191,65712	2005	OBS
11	395,4046425	9,846641678	2006	
12	451,2323241	26,9363104	2007	
13	489,9754871	-20,50414552	2008	
14	485,354356	-17,56255864	2009	
15	484,4619641	94,25895467	2010	
16	543,4019149	30,66914444	2011	
17	540,9313059	-1,127104713	2012	
18	522,7243021	-17,94359137	2013	
19	504,115277	40,94899941	2014	
20	525,5191369	64,22115349	2015	
21	549,2568357	32,7431643	2016	

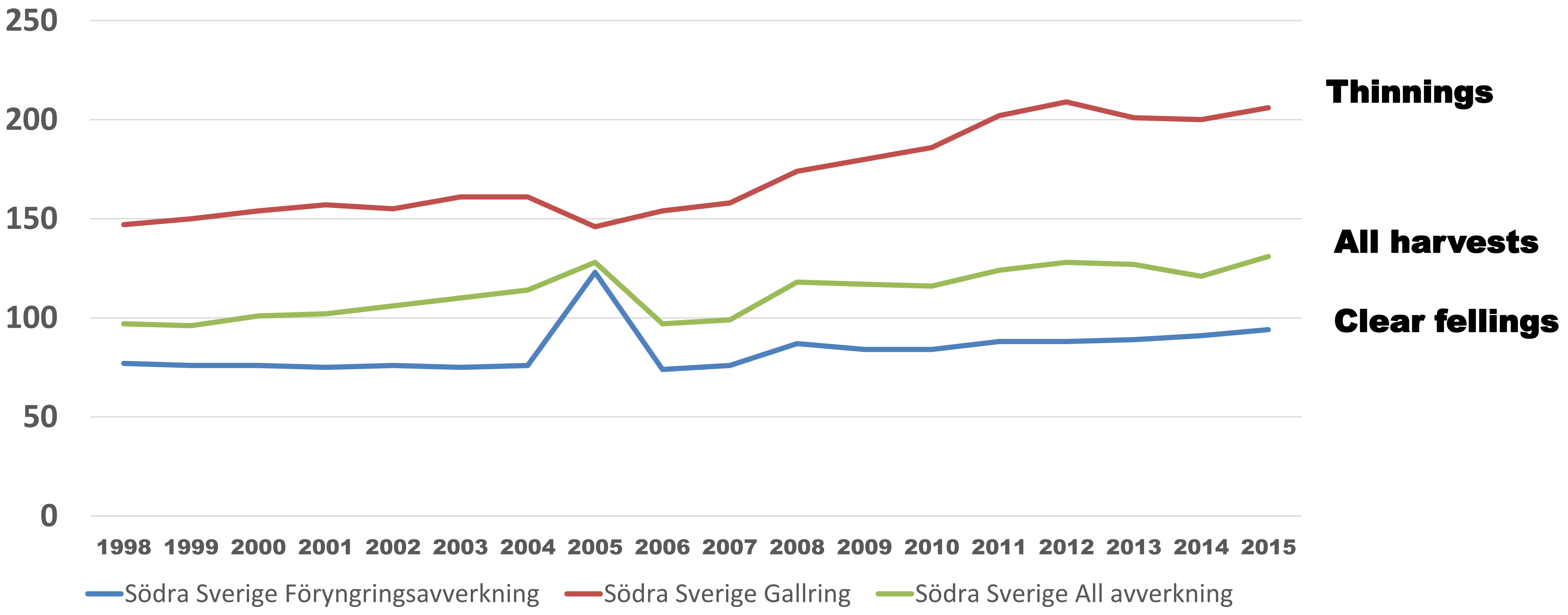
The storm Gudrun came in 2005

First order autoregressive process:

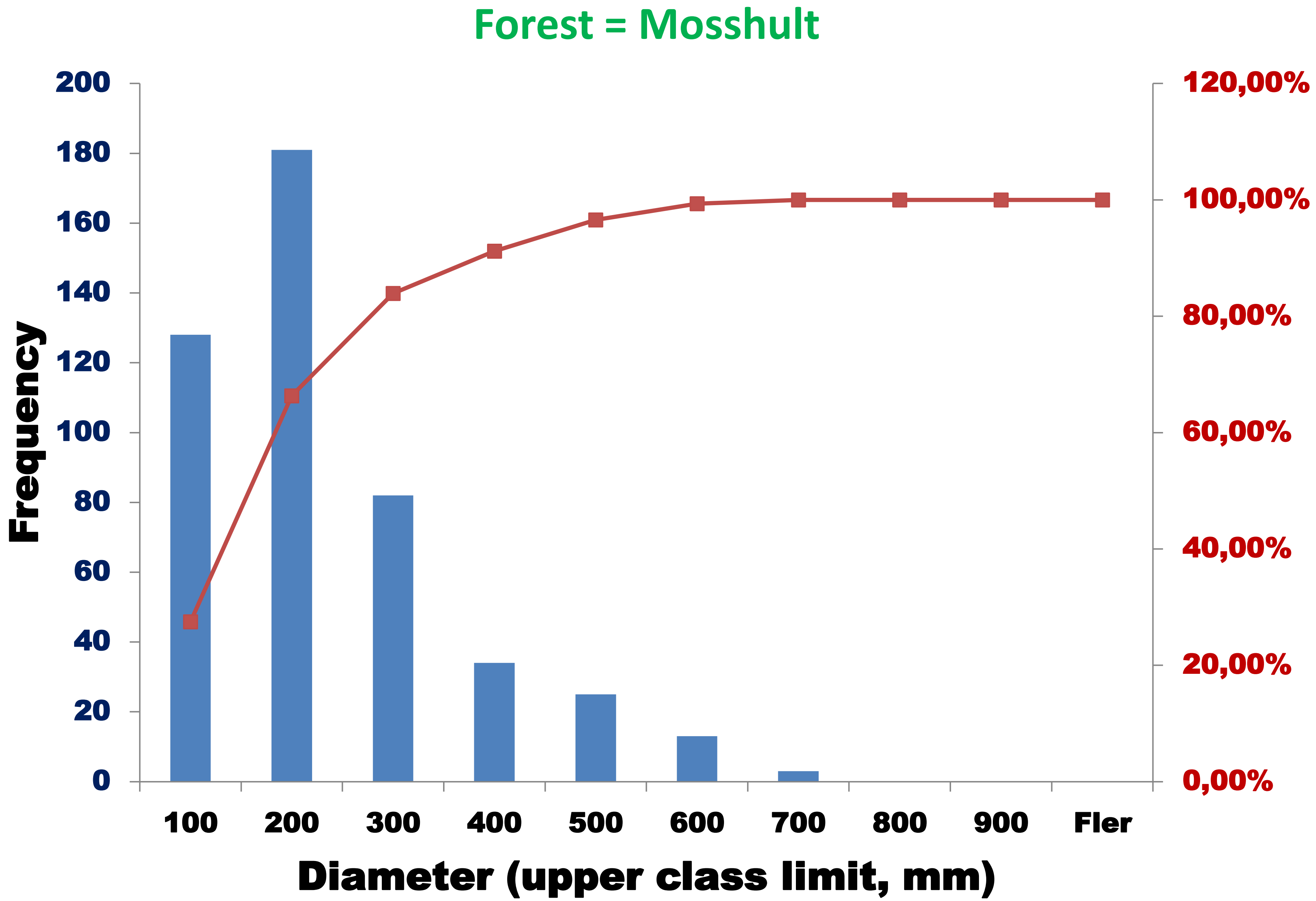
P(t) = 236 + 0.531*P(t-1) + s(t) **(stdev = 59)**



Harvesting costs, SEK per m3 solid, in large scale forestry, in Southern Sweden.



Diameter frequency distribution (Initial conditions)

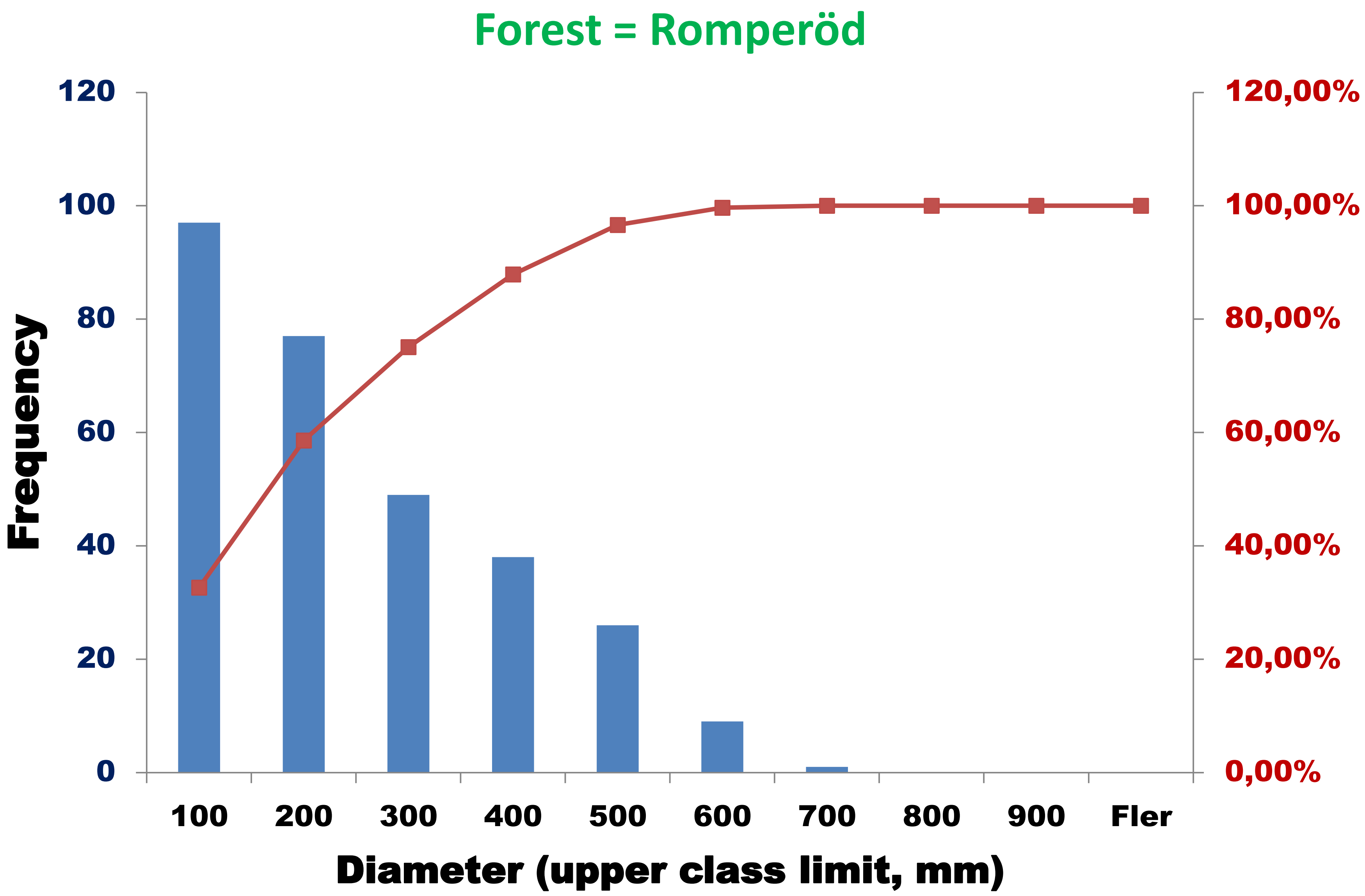


Diameter frequency distribution (Initial conditions)

Forest = Mosshult

Diameter *(upper class limit, mm)*	***Frequency***	***Cumulative percentage***
100	128	27,47%
200	181	66,31%
300	82	83,91%
400	34	91,20%
500	25	96,57%
600	13	99,36%
700	3	100,00%
800	0	100,00%
900	0	100,00%

Diameter frequency distribution (Initial conditions)



Diameter frequency distribution (Initial conditions)

Forest = Romperöd

Diameter *(upper class limit, mm)*	***Frequency***	***Cumulative percentage***
100	97	32,66%
200	77	58,59%
300	49	75,08%
400	38	87,88%
500	26	96,63%
600	9	99,66%
700	1	100,00%
800	0	100,00%
900	0	100,00%

Basal area increment function with motivation

This basal area increment function was motivated and analyzed by Lohmander (2017) :

$$\frac{dx}{dt} = a\sqrt{x}\,(1-bx)$$

$$\boxed{\frac{dx_i}{dt} = a_1 x_i^{0.5} + a_2 x_i^{1.5}} \quad +$$

$$\boxed{+\,a_{3,AT}\left(\sum_{i\neq j}\left(\frac{x_j}{x_i}\right)^{k2} x_j \cdot e^{-\left(\frac{R_{i,j}}{k3}\right)^{k4}}\right)^{k1} x_i^{0.5} + a_{3,S}\left(\sum_{i\neq j}\left(\frac{x_{S,j}}{x_i}\right)^{k2} x_{S,j} \cdot e^{-\left(\frac{R_{i,j}}{k3}\right)^{k4}}\right)^{k1} x_i^{0.5}}$$

Basal area increment is negatively affected by competition
from other trees. Relative size, size and distance affect the degree of influence.

Basal area increment function with more details concerning competition from different species

$$\frac{dx_i}{dt} = a_1 x_i^{0.5} + a_2 x_i^{1.5} \quad +$$

$$\boxed{+\, a_{3,AT}\left(\sum_{i\neq j}\left(\frac{x_j}{x_i}\right)^{k2} x_j \cdot e^{-\left(\frac{R_{i,j}}{k3}\right)^{k4}}\right)^{k1} x_i^{0.5}} + \boxed{a_{3,S}\left(\sum_{i\neq j}\left(\frac{x_{S,j}}{x_i}\right)^{k2} x_{S,j} \cdot e^{-\left(\frac{R_{i,j}}{k3}\right)^{k4}}\right)^{k1} x_i^{0.5}}$$

Competition from "AT" = "ALL TREE SPECIES"

Competition from "S" = "SPRUCE"

Basal area increment function with more details concerning competition

Basal area of competing tree

Distance to competing tree

$$\frac{dx_i}{dt} = a_1 x_i^{0.5} + a_2 x_i^{1.5} \quad +$$

$$+ a_{3,AT}\left(\sum_{i \neq j}\left(\frac{x_j}{x_i}\right)^{k2} x_j \cdot e^{-\left(\frac{R_{i,j}}{k3}\right)^{k4}}\right)^{k1} x_i^{0.5} + a_{3,S}\left(\sum_{i \neq j}\left(\frac{x_{S,j}}{x_i}\right)^{k2} x_{S,j} \cdot e^{-\left(\frac{R_{i,j}}{k3}\right)^{k4}}\right)^{k1} x_i^{0.5}$$

The effect of competition on increment is proportional to increment for low values of basal area.

Basal area increment function used in the optimization

Parameters derived in two different areas

$$\frac{dx_i}{dt} = \left(\frac{a_{1,M} + a_{1,R}}{2}\right) x_i^{0.5} + \left(\frac{a_{2,M} + a_{2,R}}{2}\right) x_i^{1.5} +$$

$$+ a_{3,AT} \left(\sum_{i \neq j} \left(\frac{x_j}{x_i}\right)^{k2} x_j \cdot e^{-\left(\frac{R_{i,j}}{k3}\right)^{k4}} \right)^{k1} x_i^{0.5} + a_{3,S} \left(\sum_{i \neq j} \left(\frac{x_{S,j}}{x_i}\right)^{k2} x_{S,j} \cdot e^{-\left(\frac{R_{i,j}}{k3}\right)^{k4}} \right)^{k1} x_i^{0.5}$$

Estimated basal area increment function

$$\frac{dx_i}{dt} = a_{1,M}\, x_{M,i}{}^{0.5} + a_{2,M}\, x_{M,i}^{1.5} + a_{1,R}\, x_{R,i}{}^{0.5} + a_{2,R}\, x_{R,i}^{1.5} +$$

$$+ a_{3,AT}\left(\sum_{i \neq j}\left(\frac{x_j}{x_i}\right)^{k2} x_j \cdot e^{-\left(\frac{R_{i,j}}{k3}\right)^{k4}}\right)^{k1} x_i^{0.5} + a_{3,S}\left(\sum_{i \neq j}\left(\frac{x_{S,j}}{x_i}\right)^{k2} x_{S,j} \cdot e^{-\left(\frac{R_{i,j}}{k3}\right)^{k4}}\right)^{k1} x_i^{0.5}$$

Parameter	Optimized Value
$a_{1,M}$	88.50
$a_{2,M}$	-154.71
$a_{1,R}$	73.03
$a_{2,R}$	-85.33
$a_{3,AT}$	-83.16
$a_{3,S}$	-55.96
k_1	1.1768
k_2	0.1515
k_3	5.630
k_4	2 (*)

(= The value of k_4 was not optimized.)*

Height function

$$H = a_0 + a_1 \cdot D + a_2 \cdot D^{1.5}$$

Symbol	Explanation
H	Tree height (dm)
D	Tree diameter at breast height (1.3 meters) (mm)

Parameter	Value
a_0	13
a_1	1.4743
a_2	-0.037864

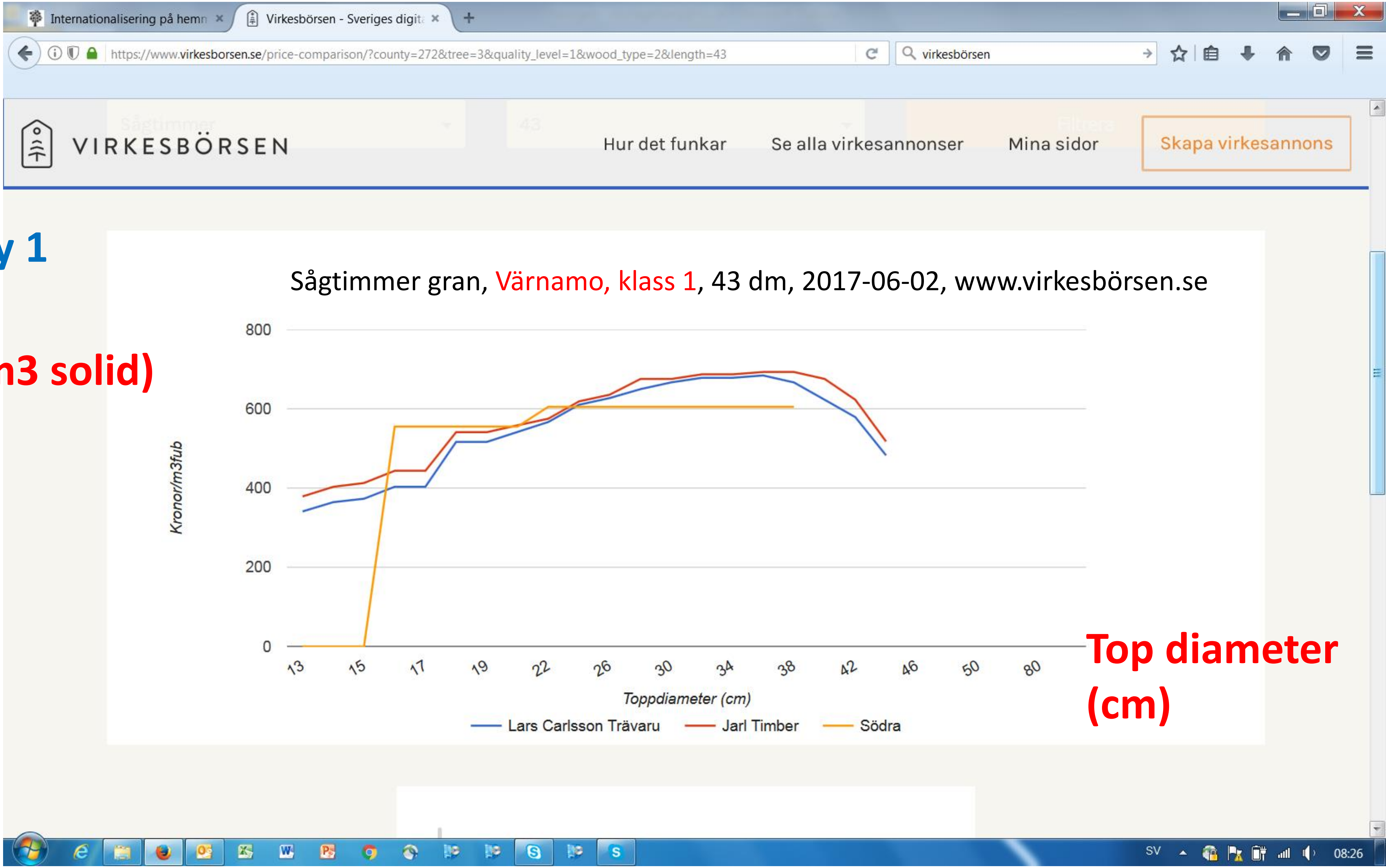
On the importance of quality and size in the timber price lists

- Different sawmills pay for timber in different ways.
- Some sawmills pay much more for the highest quality compared to the lower qualities.
- Some sawmills pay much more for timber with large diameter than for timber with low diameter.

Quality 1

Price

(SEK/m3 solid)

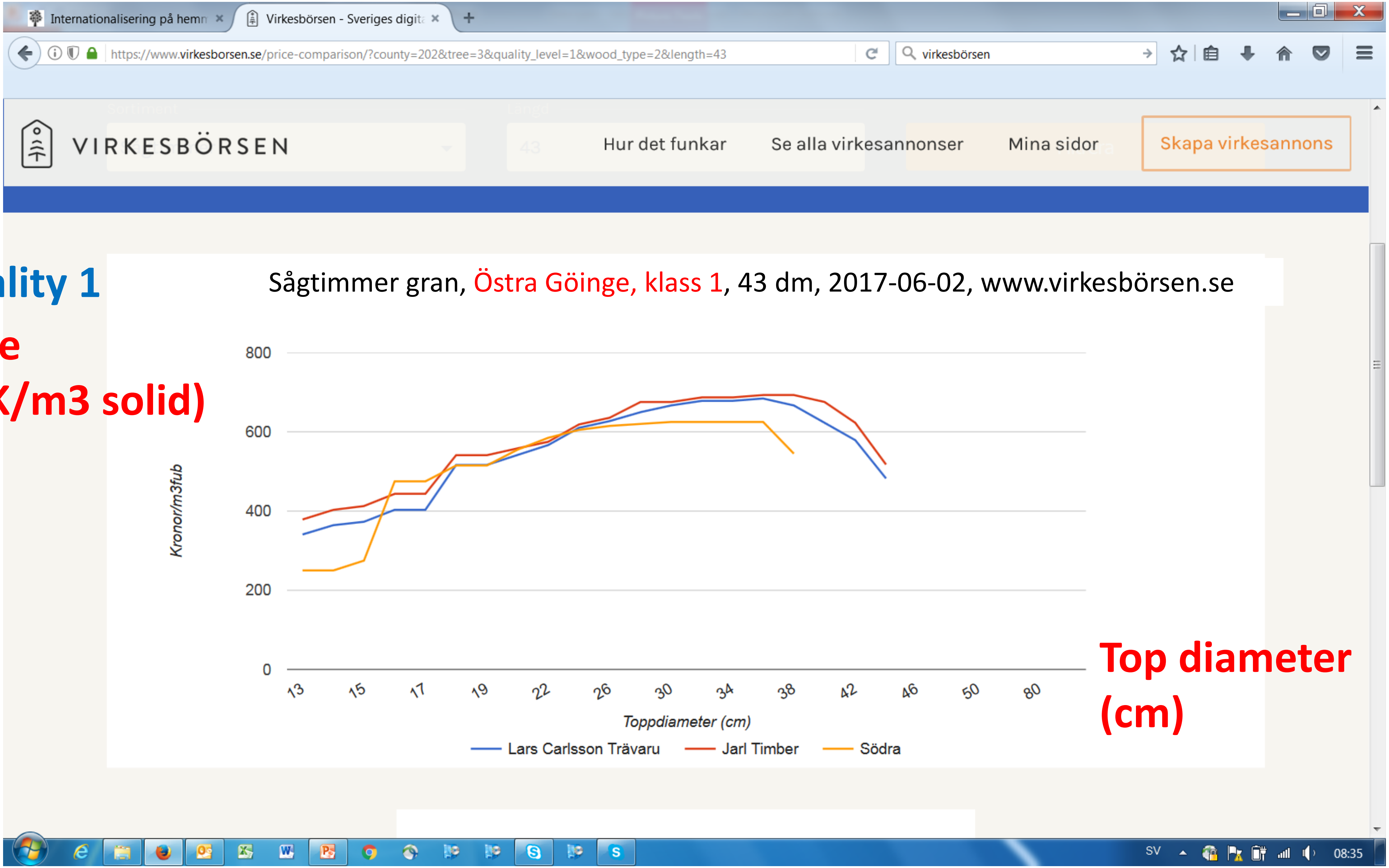


Top diameter

(cm)

Quality 1

Price (SEK/m3 solid)

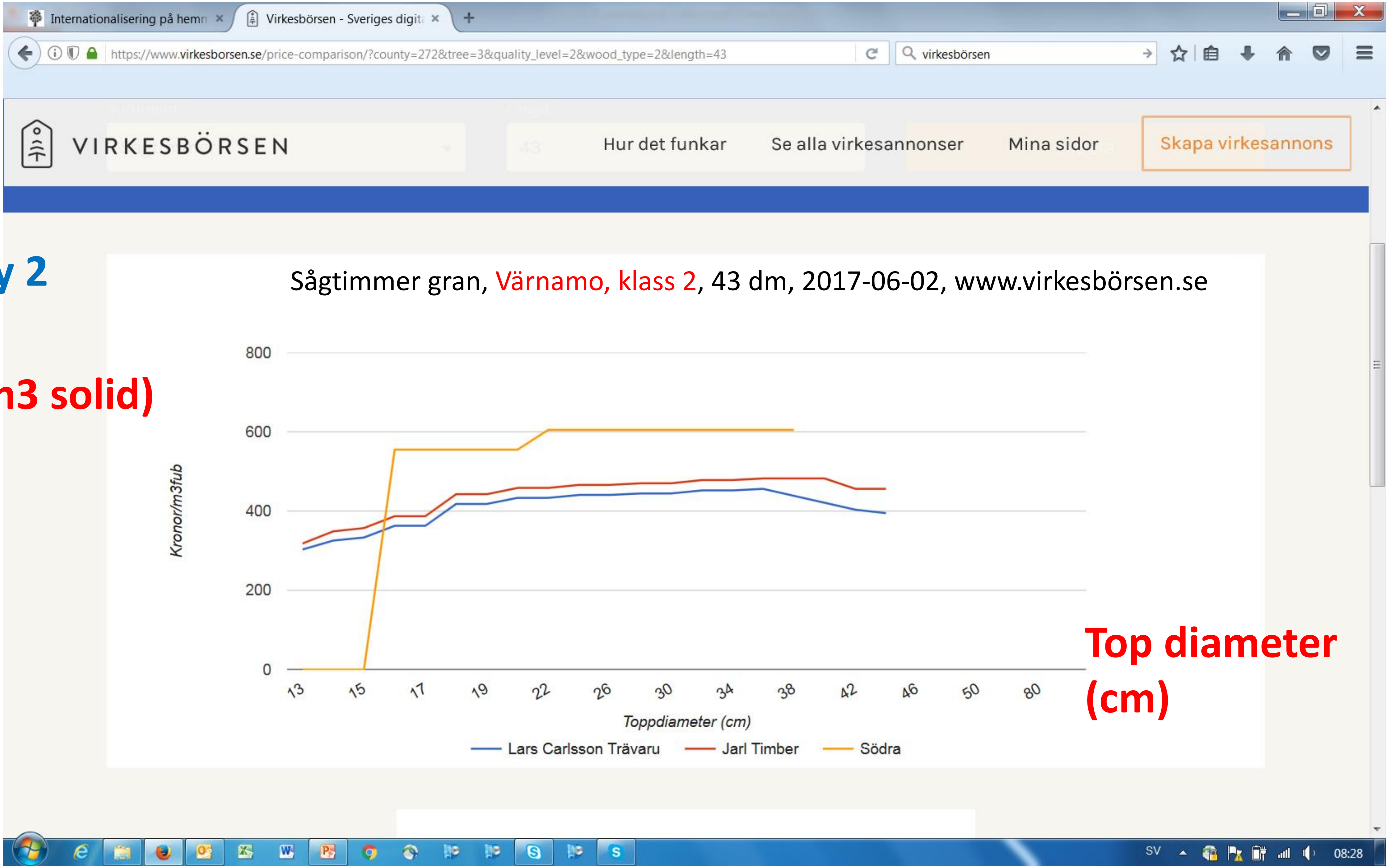


Top diameter (cm)

Quality 2

Price

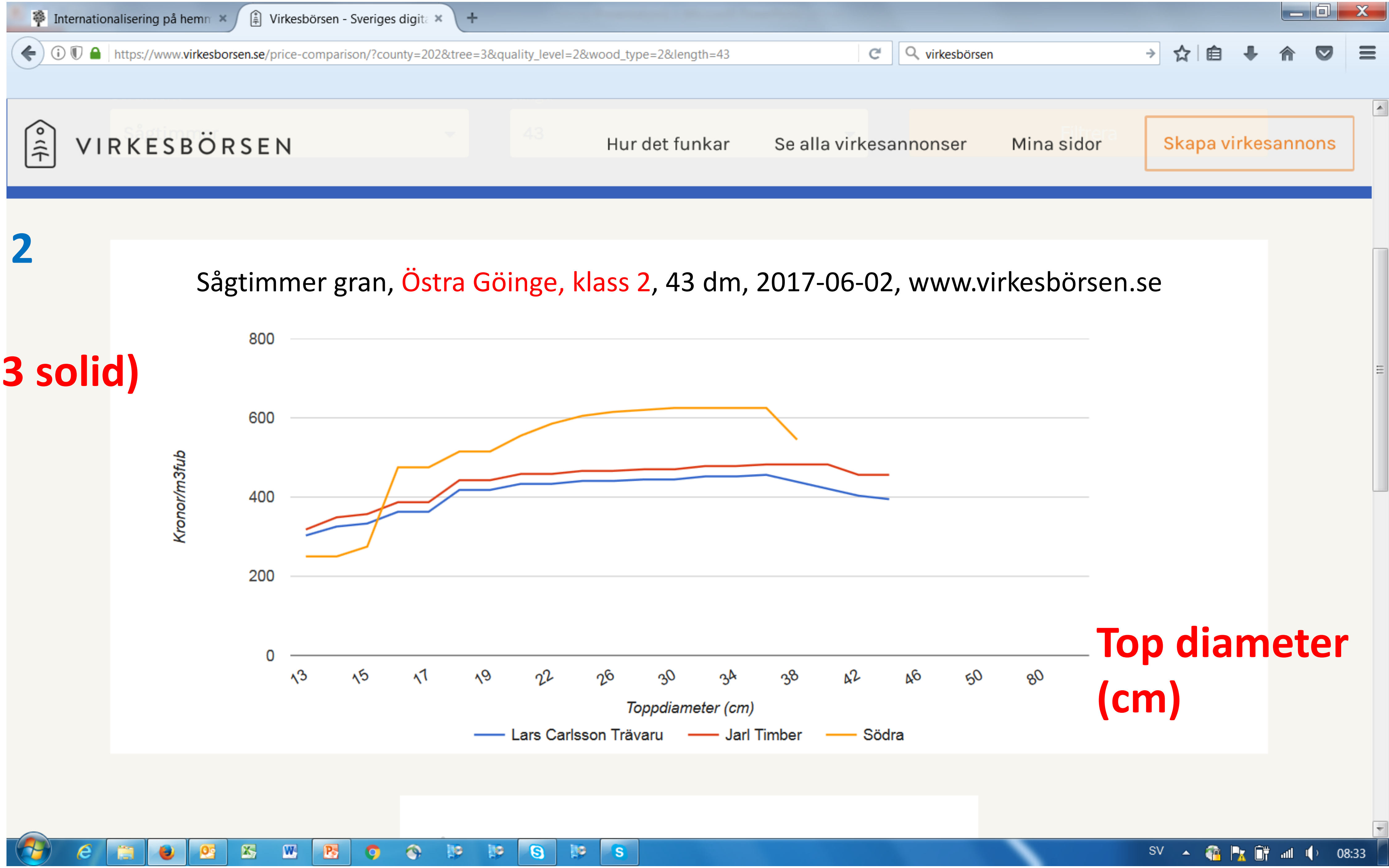
(SEK/m3 solid)



Top diameter (cm)

Quality 2

Price (SEK/m3 solid)



Top diameter (cm)

The long list of results from the software has been used to estimate ”smooth function approximations” of the total expected present value function (the objective function) as a function of the control function parameters. Such approximations are found on the following pages.

REG SSAFR 18 170709_2253

regres 1

THE APPROXIMATION IS VERY GOOD!

Regression statistics	
Multipel-R	0,996060268
R2	0,992136058
Adjusted R2	0,989761492
Standard error of estimate	14,5934915
Number of observations	448

ANOVA

	fg	*KvS*	*MKv*	*F*	*p-value for F*
Regression	7	11849170,53	1692738,647	7948,24949	0
Residual	441	93919,76743	212,9699942		
Total	448	11943090,3			

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regres 1

	Coefficient	*Standard error*	*t-ratio*	*p-value*
Constant	0			
x	92,23657812	1,637862818	56,31520363	1,6304E-203
xx	-15,12419474	0,379080306	-39,89707323	1,9827E-148
xy	-3,971394886	0,168170542	-23,61528261	2,69321E-80
yyy	0,162419153	0,012052529	13,4759396	6,60883E-35
z	-10,87340641	2,854717482	-3,80892557	0,000159361
zz	-1,247730986	0,598599346	-2,084417556	0,037697081
xz	1,272859441	0,561028884	2,268794845	0,023763276

dlim_0 = 0.1*x
dlim_p = 0.001*y
dlim_c = 0.001*z

The estimated parameter values have reliable t-values and make sence.

Then, via analytical derivations,
the optimal control function
parameter combination was determined.

This is found on the following pages.

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The expected present value

```
Below, we have the approximation of the objective function.
The unit is "kSEK/ha". The following transformations and
rescalings have been made to avoid numerical problems:
dlim_0 = 0.1*x
dlim_p = 0.001*y
dlim_c = 0.001*z
```

$$92.237 \cdot x - 15.124 \cdot x \cdot x - 3.9714 \cdot x \cdot y + 0.16242 \cdot y \cdot y \cdot y - 10.873 \cdot z - 1.2477 \cdot z \cdot z + 1.2729 \cdot x \cdot z$$

OBS: dlim_q is assumed to be constant, at an already determined value, in this process.

The expected present value, π , as a function of the rescaled control function parameters:

$$\pi = 92.237x - 15.124x^2 - 3.9714xy + 0.16242y^3$$
$$-10.873z - 1.2477z^2 + 1.2729xz$$

First order optimum conditions:

$$\begin{cases} \dfrac{d\pi}{dx} = 92.237 - 30.248x - 3.9714y + 1.2729z = 0 \\ \dfrac{d\pi}{dy} = -3.9714x + 0.48726y^2 = 0 \\ \dfrac{d\pi}{dz} = -10.873 + 1.2729x - 2.4954z = 0 \end{cases}$$

Here, we have a nonlinear component in the equation system.

$$\frac{d\pi}{dy} = -3.9714x + 0.48726y^2 = 0$$

$$3.9714x = 0.48726y^2$$

$$\boxed{x = 0.12269y^2}$$

$$\frac{d\pi}{dz} = -10.873 + 1.2729x - 2.4954z = 0$$

$$2.4954z = -10.873 + 1.2729x$$

$$\boxed{x = 0.12269y^2}$$

$$z = -4.3572 + 0.51010x$$

$$\boxed{z = -4.3572 + 0.062584y^2}$$

$$\frac{d\pi}{dx} = 92.237 - 30.248x - 3.9714y + 1.2729z = 0$$

$$x = 0.12269y^2 \qquad z = -4.3572 + 0.062584y^2$$

$$92.237 - 30.248\left(0.12269y^2\right) - 3.9714y + 1.2729\left(-4.3572 + 0.062584y^2\right) = 0$$

$$92.237-30.248\left(0.12269y^2\right)-3.9714y+1.2729\left(-4.3572+0.062584y^2\right)=0$$

$$-3.6315y^2-3.9714y+86.691=0$$

$$y^2+1.0936y-23.872=0$$

$$y^2+py+q=0$$

$$y=-\frac{p}{2}\pm\sqrt{\left(\frac{p}{2}\right)^2-q}$$

$$y = -\frac{1.0936}{2} \pm \sqrt{\left(\frac{1.0936}{2}\right)^2 + 23.872}$$

$$y = -0.5468 \pm 4.9164$$

$$\boxed{(y_1, y_2) = (4.3639, -5.4632)}$$

We want to investigate the second order maximum conditions.
We have a three-variable quadratic form.

$$\begin{vmatrix} \pi_{xx} & \pi_{xy} & \pi_{xz} \\ \pi_{yx} & \pi_{yy} & \pi_{yz} \\ \pi_{zx} & \pi_{zy} & \pi_{zz} \end{vmatrix} = \begin{vmatrix} -30.248 & -3.9714 & 1.2729 \\ -3.9714 & 0.97452y & 0 \\ 1.2729 & 0 & -2.4954 \end{vmatrix}$$

Note that you find y in one place!

Second order maximum conditions of the three principal minors

$$\left|\pi_{xx}\right| < 0$$

$$\begin{vmatrix} \pi_{xx} & \pi_{xy} \\ \pi_{yx} & \pi_{yy} \end{vmatrix} > 0$$

$$\begin{vmatrix} \pi_{xx} & \pi_{xy} & \pi_{xz} \\ \pi_{yx} & \pi_{yy} & \pi_{yz} \\ \pi_{zx} & \pi_{zy} & \pi_{zz} \end{vmatrix} < 0$$

$$\left|\pi_{xx}\right| = \left|-30.248\right| = -30.248 < 0$$

Maximum condition always satisfied.

$$\begin{vmatrix} \pi_{xx} & \pi_{xy} \\ \pi_{yx} & \pi_{yy} \end{vmatrix} = \begin{vmatrix} -30.248 & -3.9714 \\ -3.9714 & 0.97452y \end{vmatrix} > 0$$

$$\begin{vmatrix} -30.248 & -3.9714 \\ -3.9714 & 0.97452y \end{vmatrix} = -30.248(0.97452y) - (-3.9714)^2 > 0$$

$$-29.477 - 15.772y > 0$$

$$29.477 + 15.772y < 0$$

$$15.772y < -29.477$$

$$\boxed{y < -0.53506}$$

Maximum condition satisfied if
y<-0.53506

$$\begin{vmatrix} \pi_{xx} & \pi_{xy} & \pi_{xz} \\ \pi_{yx} & \pi_{yy} & \pi_{yz} \\ \pi_{zx} & \pi_{zy} & \pi_{zz} \end{vmatrix} = \begin{vmatrix} -30.248 & -3.9714 & 1.2729 \\ -3.9714 & 0.97452y & 0 \\ 1.2729 & 0 & -2.4954 \end{vmatrix} < 0$$

$$\begin{vmatrix} \pi_{xx} & \pi_{xy} & \pi_{xz} \\ \pi_{yx} & \pi_{yy} & \pi_{yz} \\ \pi_{zx} & \pi_{zy} & \pi_{zz} \end{vmatrix} = 39.357 + 71.979y < 0$$

$$71.979y < -39.357$$

$$\boxed{y < -0.54678}$$

Maximum condition satisfied if $y<-0.54678$

$$\left(\begin{vmatrix} \pi_{xx} & \pi_{xy} \\ \pi_{yx} & \pi_{yy} \end{vmatrix} > 0 \right) \Rightarrow \left(y < -0.53506 \right)$$

Maximum!

$$\left(\begin{vmatrix} \pi_{xx} & \pi_{xy} & \pi_{xz} \\ \pi_{yx} & \pi_{yy} & \pi_{yz} \\ \pi_{zx} & \pi_{zy} & \pi_{zz} \end{vmatrix} < 0 \right) \Rightarrow \left(y < -0.54678 \right)$$

$$\left(y_1, y_2 \right) = (4.3639, -5.4632)$$

$$y^* = -5.4632$$

$$x^* = 0.12269\left(y^*\right)^2 \approx 3.6619$$

$$z^* = -4.3572 + 0.062584\left(y^*\right)^2 \approx -2.4893$$

$$\boxed{(x^*, y^*, z^*) = (3.6619,\ -5.4632,\ -2.4893)}$$

The optimal values of x, y and z, calculated with more decimals, are:

$x = 3.661887475$

$y = -5.463160161$

$z = -2.489293673$

If we use the calculated values of x, y and z, we get the optimal objective function value:

92.237·3.661887475 - 15.124·3.661887475·3.661887475 - 3.9714·3.661887475·(-5.463160161) + 0.16242·(-5.463160161)·(-5.463160161)·(-5.463160161) - 10.873·(-2.489293673) - 1.2477·(-2.489293673)·(-2.489293673) + 1.2729·3.661887475·(-2.489293673)

195,6554283 (kSEK/ha)

EXPECTED PRESENT VALUE MAXIMUM

Note that this is a unique maximum!

- It is possible to get the same solution via a standard nonlinear programming software (Lingo), if we already have the correct nonlinear approximation of the expected present value function.

```
! contopt;
! Peter Lohmander 170711;

f = 92.237*x-15.124*x*x-3.9714*x*y+0.16242*y*y*y - 10.873*z -
1.2477*z*z + 1.2729*x*z;

x<10;
x>1;

@free(y);
y<-1;
y>-10;

@free(z);
z<-1;
z>-10;

max = f;
```

```
Local optimal solution found.
  Objective value:                    195.6554
  Infeasibilities:                    0.000000
  Extended solver steps:                     5
  Total solver iterations:                  95
  Elapsed runtime seconds:                0.28
```

Variable	Value	Reduced Cost
F	195.6554	0.000000
X	3.661887	0.000000
Y	-5.463160	0.000000
Z	-2.489294	0.000000

OBS!!! EXACTLY THE SAME VALUES VIA THIS METHOD!

The optimal limit diameter function:

Diameter of tree n1

Local competition of tree n1

Timber quality of tree n1

1.0

Real timber price (of average timber quality) minus expected real equilibrium price

IF d(n1) > (dlim_0 + dlim_c * c(n1) + dlim_q * qual(n1) + dlim_p * SigmaK * pdev(nums, t)) THEN h(n1) = 1

0.366

-0.00249

0.00600

-0.00546

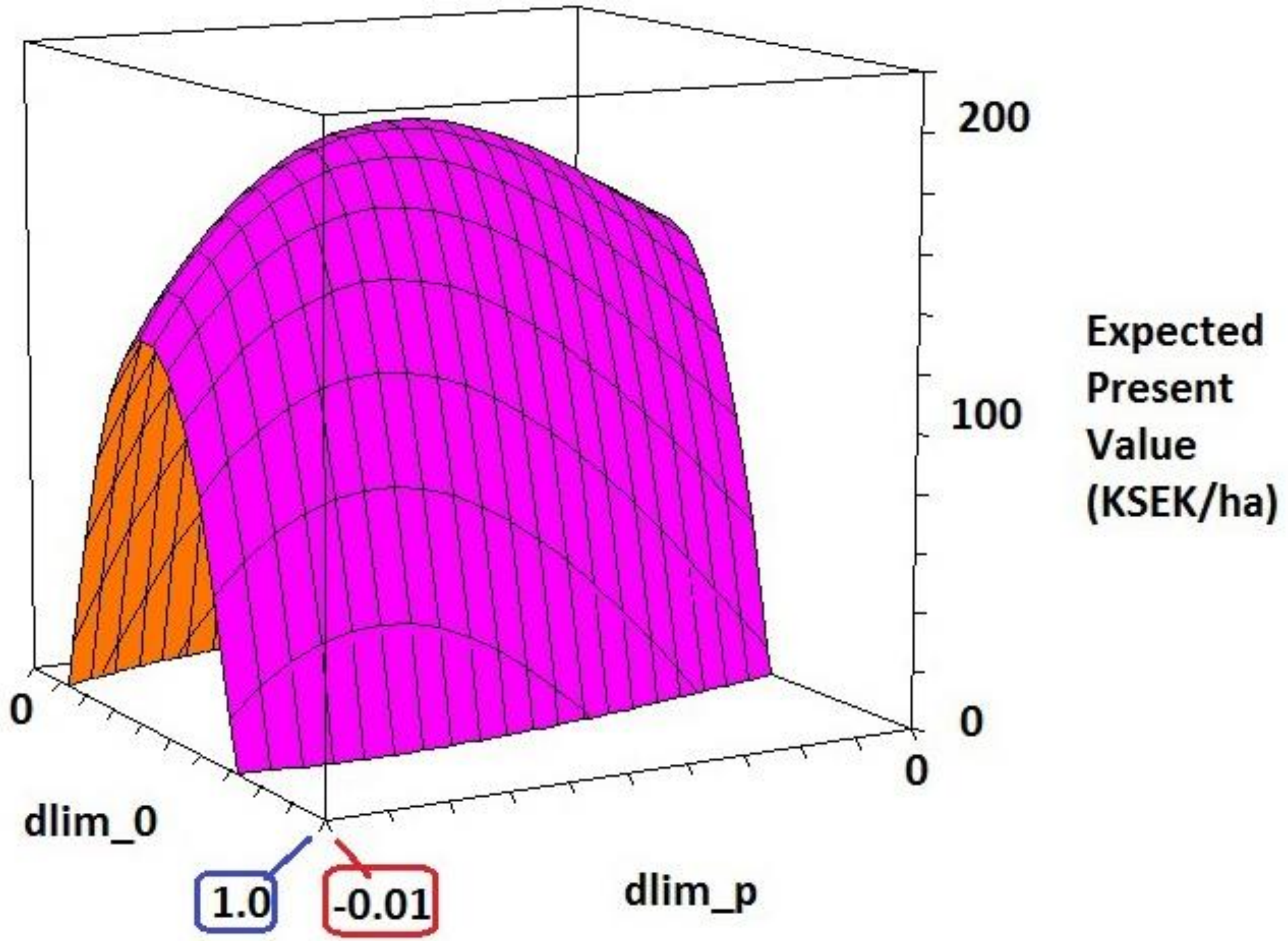
These four parameters, in the control function, have been optimized (for real rate of interest 3%) .

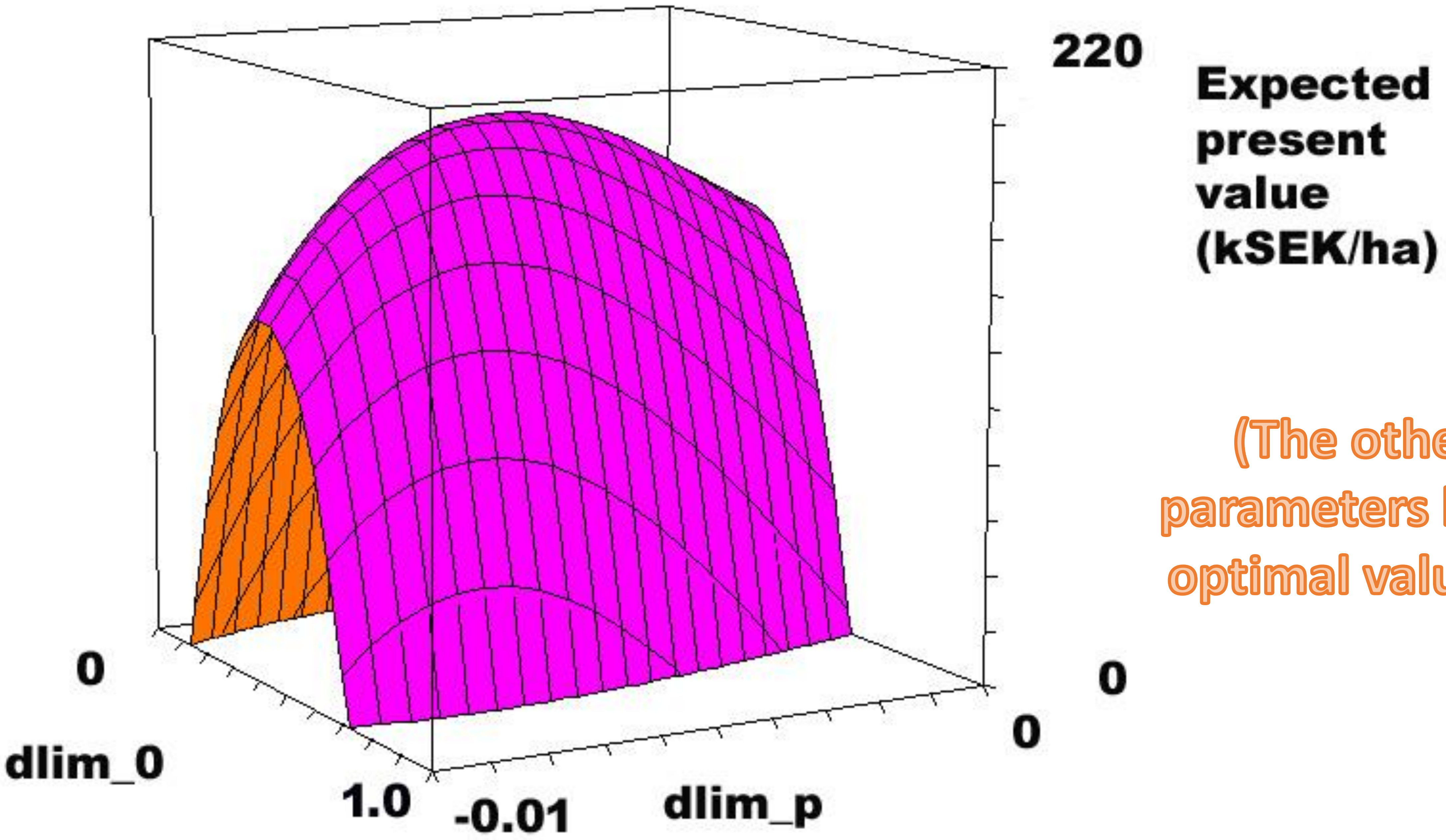
If h(n1)=0 (default value), then the tree should not be instantly harvested.
If h(n1) = 1, then the tree should be instantly harvested.

Partial objective function surface

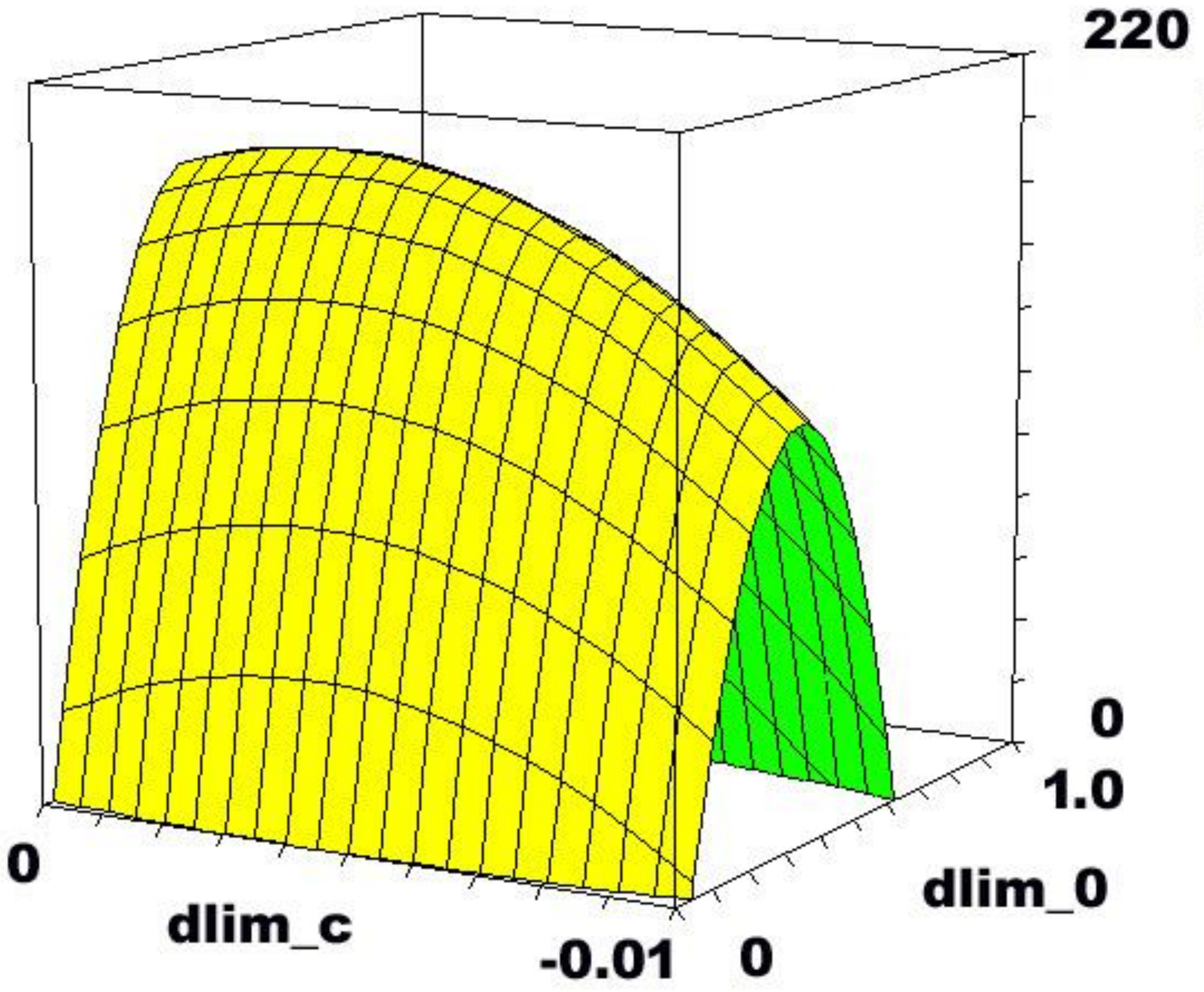
The expected present value as a function of the values of two parameters in the limit diameter (= adaptive harvest control) function.

(The other parameters are assumed to have the optimal values.)

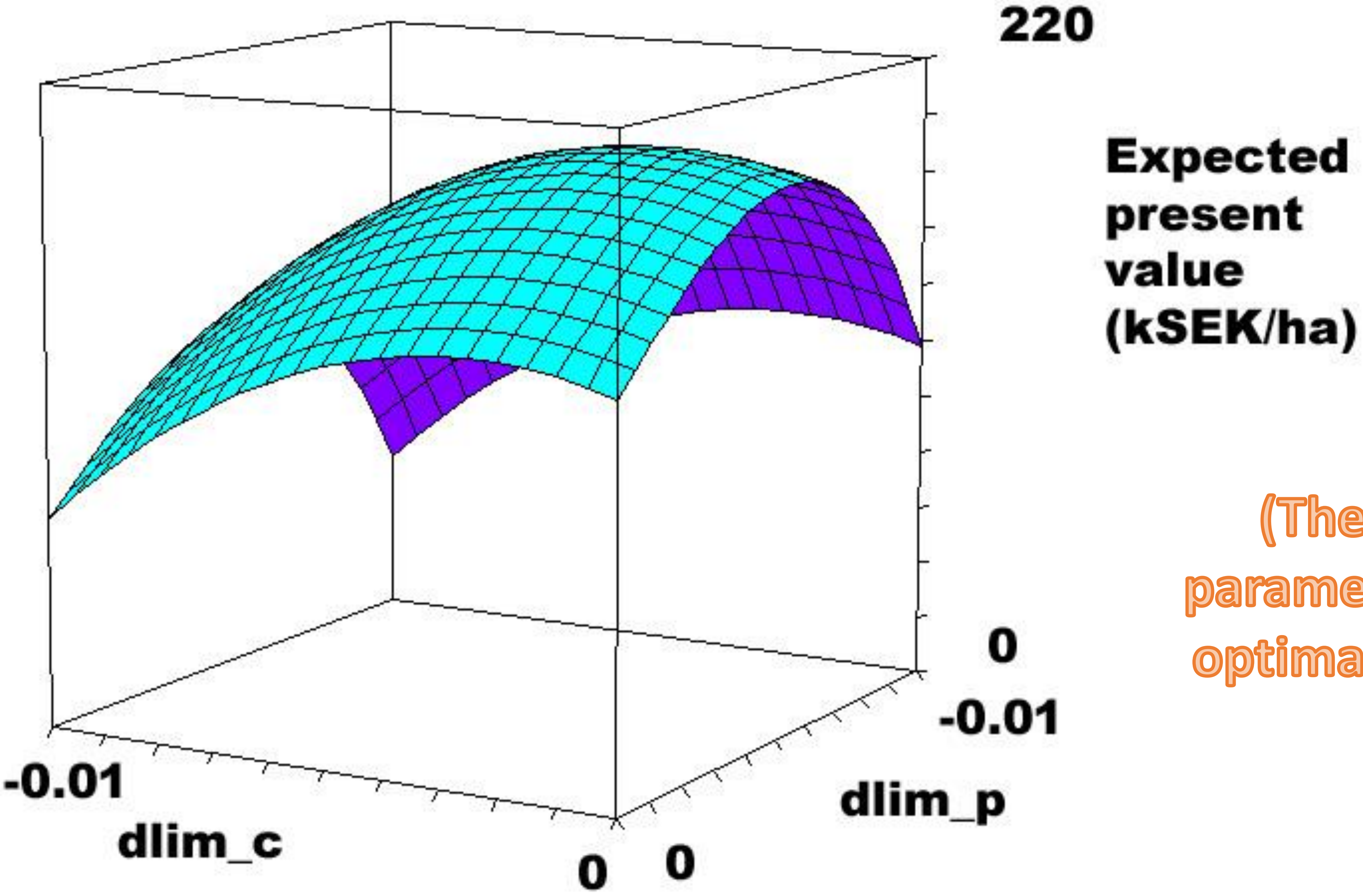




(The other parameters have optimal values.)



(The other parameters have optimal values.)



(The other parameters have optimal values.)

GENERAL CONCLUSIONS

- Three general forest management conclusions can be made:
- A tree should be harvested at a smaller diameter, if the local competition from other trees is high than if it is low.
- A tree should be harvested at a larger diameter, if the wood quality of the tree is high than if it is low.
- A tree should be harvested at a smaller diameter, if the market net price for wood is high than if it is low.

PARTICULAR CONCLUSIONS

#1:
The optimal expected present value is 195,655 kSEK/hectare.

#2: The optimal limit diameter function is:

Diameter of tree n1

Local competition of tree n1

Timber quality of tree n1

1.0

Real timber price (of average timber quality) minus expected real equilibrium price

IF d(n1) > (dlim_0 + dlim_c * c(n1) + dlim_q * qual(n1) + dlim_p * SigmaK * pdev(nums, t)) THEN h(n1) = 1

0.366

-0.00249

0.00600

-0.00546

These four parameters, in the control function, have been optimized (for real rate of interest 3%) .

If h(n1)=0 (default value), then the tree should not be instantly harvested.
If h(n1) = 1, then the tree should be instantly harvested.

HIGH RESOLUTION ADAPTIVE OPTIMIZATION OF CONTINUOUS COVER SPRUCE FOREST MANAGEMENT IN SOUTHERN SWEDEN

FUTURE OPTIONS

- The growth functions are preliminary and based on a limited sample. For this reason, the particular numerical results should not be considered as final.
- Future data collection from continuous cover managed stands will increase the precision and widen the scope of the growth function, covering the range of site fertility relevant in southern Sweden.
- The general approach, however, can be used also with updated growth functions, derived via larger datasets.

THE SOFTWARE:

```
REM
REM SSAFR18.bas   Large loop model including (dlim_0, dlim_c, dlim_p).
REM Peter Lohmander 170708_2200

REM Software references:
REM tutorial: https://www.youtube.com/watch?v=GjrSxMUb9F8
REM http://www.qb64.net/wiki/index.php/COLOR

DIM x(1000), y(1000), d(1000), a(1000), c(1000), dist(1000, 1000)
DIM h(1000), vol(1000), p(1000), net(1000), csmall(1000), qual(1000)
DIM pdev(100, 200), height(1000), dadt(1000)
CLS

OPEN "a_OutSSAFR18.txt" FOR OUTPUT AS #2
PRINT #2, "Results from SSAFR18.bas by Peter Lohmander 170708"
PRINT "Results from SSAFR18.bas by Peter Lohmander 170708"

PRINT #2, "       r  SigmaK  dlim_0  dlim_c  dlim_q  dlim_p   avHARV    TotalPV"
PRINT "       r  SigmaK  dlim_0  dlim_c  dlim_q  dlim_p   avHARV    TotalPV"

REM parameters
PI = 3.1415926536
```

```
dmax = 10
hacorr = 10000 / (PI * (dmax / 2) ^ 2)
formnumb = 0.5
setupc = 1000
r = 0.03
TMAX = 200

REM Harvest parameter definitions
harvt = 5

REM Generation of random market price deviations
randseed = 1
RANDOMIZE randseed
```

```
Numser = 10
PEQU = 503.3
SigmaP = 59.03

FOR nums = 1 TO Numser
   Price_t = PEQU
   pdev(nums, 0) = 0
   FOR t = 1 TO 200
      REM Generation of Random Number N(0,1):
      epsilon = 0
      FOR ii = 1 TO 12
         epsilon = epsilon + RND
      NEXT ii
      epsilon = (epsilon - 6)
      Price_t = 235.9 + 0.5313 * Price_t + SigmaP * epsilon
      pdev(nums, t) = Price_t - PEQU
   NEXT t

NEXT nums
```

```
REM Here the loop starts with alternative values of
REM some important exogenous parameters.

REM FOR r = 0.02 TO 0.041 STEP 0.01
r = 0.03
REM FOR SigmaK = 0.5 TO 1.51 STEP 0.5
SigmaK = 1

REM Here is the loop where all total system simulations are
made
REM with different control function parameter values
```

```
FOR dlim_0 = 0.20 TO 0.51 STEP .050

  FOR dlim_c = 0.0000 TO -0.0036 STEP -0.0005

    REM FOR dlim_q = 0.00 TO 0.061 STEP 0.02
    dlim_q = 0.0600

    FOR dlim_p = -0.0070 TO 0.0001 STEP 0.001

      Detail = 0
      sum_Totharv = 0
      sum_Totpresv = 0
      FOR nums = 1 TO Numser
        GOSUB Subroutine_SDOC
        sum_Totharv = sum_Totharv + Totharv
        sum_Totpresv = sum_Totpresv + Totpresv
      NEXT nums
```

```
PRINT #2, USING "###.####"; r;
          PRINT #2, USING "###.####"; SigmaK;
          PRINT #2, USING "###.####"; dlim_0;
          PRINT #2, USING "###.####"; dlim_c;
          PRINT #2, USING "###.####"; dlim_q;
          PRINT #2, USING "###.####"; dlim_p;

          PRINT #2, USING "####.####"; sum_Totharv / 200 /
Numser;
          PRINT #2, USING "#######.###"; sum_Totpresv /
Numser

          PRINT USING "###.####"; r;
          PRINT USING "###.####"; SigmaK;
          PRINT USING "###.####"; dlim_0;
          PRINT USING "###.####"; dlim_c;
          PRINT USING "###.####"; dlim_q;
          PRINT USING "###.####"; dlim_p;

          PRINT USING "####.####"; sum_Totharv / 200 / Numser;
          PRINT USING "#######.###"; sum_Totpresv / Numser
```

```
 NEXT dlim_p
       REM NEXT dlim_q
   NEXT dlim_c
NEXT dlim_0
REM NEXT SigmaK
REM NEXT r

CLOSE #2
END
REM Here the main program ends.
```

```
REM Here, the subroutine starts, where all of the full system simulations are made
Subroutine_SDOC:

IF Detail = 1 THEN SCREEN _NEWIMAGE(800, 800, 256)
IF Detail = 1 THEN COLOR 30, 15

REM Initial conditions via diameter frequences
REM The following data are relevant to the Romperod forest area.
REM In Rompedod, there are 825 trees per hectare. Here, however, we
REM assume that there are 1000 trees per hectare, but with the same
REM relative frequency distribution.
```

```
randseed = 1
RANDOMIZE randseed

FOR N = 1 TO 1000
   x(N) = 100 * RND
   y(N) = 100 * RND
   dialim = 0
   random1 = RND
   IF random1 > 0.3266 THEN dialim = 0.1
   IF random1 > 0.5859 THEN dialim = 0.2
   IF random1 > 0.7508 THEN dialim = 0.3
   IF random1 > 0.8788 THEN dialim = 0.4
   IF random1 > 0.9663 THEN dialim = 0.5
   IF random1 > 0.9966 THEN dialim = 0.6
   d(N) = dialim + RND * 0.1
   a(N) = PI * (d(N) / 2) ^ 2
   qual(N) = 0
   IF RND > .3 THEN qual(N) = 1
NEXT N
```

```
FOR n1 = 1 TO 1000
    FOR n2 = 1 TO 1000
        dist(n1, n2) = ((x(n1) - x(n2)) ^ 2 + (y(n1) - y(n2)) ^ 2) ^ .5
    NEXT n2
NEXT n1
```

```
Totharv = 0
Totpresv = 0
FOR t = 1 TO TMAX
   IF Detail = 1 THEN CLS
   IF Detail = 1 THEN COLOR 3: PRINT ""
   IF Detail = 1 THEN COLOR 3: PRINT "  t = "; t

   harvper = 0
   IF (INT(t / harvt) = t / harvt) THEN harvper = 1
   IF harvper = 1 AND Detail = 1 THEN PRINT "  This year, harvest is possible."
```

```
REM Calculation of competition for individual n1.
  REM Only trees closer than dmax are considered.
  REM
  FOR n1 = 1 TO 1000
     sumAT = 0
     sumS = 0
     FOR n2 = 1 TO 1000
        IF n2 = n1 THEN GOTO 100
        IF dist(n1, n2) > dmax THEN GOTO 100
        sumAT = sumAT + (a(n2) / a(n1)) ^ 0.1515 * a(n2) * EXP(-dist(n1, n2) / 5.630) ^ 2
        sumS = sumS + (a(n2) / a(n1)) ^ 0.1515 * a(n2) * EXP(-dist(n1, n2) / 5.630) ^ 2
     100 NEXT n2
     c(n1) = 83.16 * sumAT ^ 1.1768 + 55.96 * sumS ^ 1.1768
  NEXT n1
```

```
REM Harvest decisions
   IF harvper = 0 THEN GOTO 200
   FOR n1 = 1 TO 1000
      h(n1) = 0
      IF d(n1) > (dlim_0 + dlim_c * c(n1) + dlim_q * qual(n1) + dlim_p * SigmaK * pdev(nums, t)) THEN h(n1) = 1
   NEXT n1
```

```
REM Harvest volumes and values etc
   Hvolume = 0
   Hnet = 0
   Hpresv = 0
   FOR n1 = 1 TO 1000
      IF h(n1) = 0 THEN GOTO 500

      diam_mm = d(n1) * 1000
      IF diam_mm > 674 THEN diam_mm = 674
      hojd_dm = 13 + 1.4743 * diam_mm - 0.037864 * diam_mm ^ 1.5
      height(n1) = hojd_dm / 10
      vol(n1) = (PI * (d(n1) / 2) ^ 2) * height(n1) * formnumb
      Hvolume = Hvolume + vol(n1)
```

```
p(n1) = (PEQU + SigmaK * pdev(nums, t) + 150 * (qual(n1) - 0.5) + 2 * (d(n1) - 40)) * (0.8 * 1.0 + 0.2 * 0.6) - 206

      net(n1) = p(n1) * vol(n1)
      Hnet = Hnet + net(n1)
      500 REM
   NEXT n1
   Totharv = Totharv + Hvolume
   Hpresv = EXP(-r * t) * (-setupc + Hnet)
   Totpresv = Totpresv + Hpresv
```

```
IF Detail = 1 THEN PRINT "  Harvest volume this year = "; Hvolume;
    IF Detail = 1 THEN PRINT "  Present value of activitites this year = "; Hpresv
    IF Detail = 1 THEN PRINT "  Total harvest volume= "; Totharv;
    IF Detail = 1 THEN PRINT "  Total present value = "; Totpresv

    REM Consequences after harvesting:
    REM In case n1 has been harvested, the individual n1
    REM is removed and a individual with random coordinates
    REM appears in the list with small size
    FOR n1 = 1 TO 1000
        IF h(n1) = 0 THEN GOTO 300
        x(n1) = 100 * RND
        y(n1) = 100 * RND
        d(n1) = 0.1 * RND
        a(n1) = PI * (d(n1) / 2) ^ 2
        qual(n1) = 0
        IF RND > .5 THEN qual(n1) = 1
        300 REM
    NEXT n1
```

```
REM Calculation of new distances between n1 and n2
  REM in case at least one of them has been harvested.
  FOR n1 = 1 TO 1000
     FOR n2 = 1 TO 1000
        newdist = h(n1) + h(n2)
        IF newdist < 1 THEN GOTO 400
        dist(n1, n2) = ((x(n1) - x(n2)) ^ 2 + (y(n1) - y(n2)) ^ 2) ^ .5
        400 REM
     NEXT n2
  NEXT n1
```

```
200 REM

  REM Calculation of growth of all individuals n.
  REM first, the basal area increment dadt(n) (m2/year), is calculated.
  REM Then, the basal area after growth, a(n) (m2) is calculated.
  REM Finally, the diameter after growth, d(n) (m), is calculated.
  FOR N = 1 TO 1000
     dadt(N) = (88.50 + 73.03) / 2 * a(N) ^ 0.5 + (-154.71 - 85.33) / 2 * a(N) ^ 1.5
     dadt(N) = dadt(N) - c(N) * a(N) ^ 0.5
     dadt(N) = dadt(N) / 10000
     IF dadt(N) < 0 THEN dadt(N) = 0
     a(N) = a(N) + dadt(N)
     d(N) = (4 * a(N) / PI) ^ 0.5
  NEXT N
```

```
IF Detail = 0 THEN GOTO 600

   FOR N = 1 TO 1000
      CIRCLE (INT(6 * x(N) + 100), INT(6 * y(N) + 100)), INT(100 * d(N) / 5), 0
   NEXT N
   LINE (100, 100)-(700, 100), 3
   LINE (100, 100)-(100, 700), 3
   LINE (700, 100)-(700, 700), 3
   LINE (100, 700)-(700, 700), 3
   SLEEP
   600 REM

NEXT t

RETURN
```

Results from SSAFR18.bas by Peter Lohmander 170708

r	SigmaK	dlim_0	dlim_c	dlim_q	dlim_p	avHARV	TotalPV
0.0300	1.0000	0.2000	0.0000	0.0600	-0.0070	9.2169	168574.641
0.0300	1.0000	0.2000	0.0000	0.0600	-0.0060	9.1339	164125.391
0.0300	1.0000	0.2000	0.0000	0.0600	-0.0050	9.4153	171340.875
0.0300	1.0000	0.2000	0.0000	0.0600	-0.0040	9.4504	165719.969
0.0300	1.0000	0.2000	0.0000	0.0600	-0.0030	9.7598	166267.719
0.0300	1.0000	0.2000	0.0000	0.0600	-0.0020	10.3343	163299.469
0.0300	1.0000	0.2000	0.0000	0.0600	-0.0010	11.7373	161918.297
0.0300	1.0000	0.2000	0.0000	0.0600	0.0000	13.0930	146660.469

(This is just the start of the very long list …)