Optimization of adaptive control functions in multidimensional forest management via stochastic simulation and grid search

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Optimization of adaptive control functions in multidimensional forest management via stochastic simulation and grid search

Peter Lohmander

Abstract

A dynamic multidimensional production system, with several interdependent processes, is adaptively controlled under the influence of stochastic market changes. An adaptive control function with low dimensionality that makes it possible to directly and indirectly control all parts of the interdependent processes is determined. Discrete parameter value combinations are investigated. Grid search is applied to find optimal control function parameter values via stochastic simulation, where the complete production system is simulated 100 times, during 200 years. The 100 time series of random numbers, each representing 200 years, used to represent stochastic market changes, are the same for every control function parameter combination. The optimal control function is determined for beech stands in Germany, as an adaptive harvest diameter rule, for different rates of interest and for different levels of market risk. With a uniform price probability density function with price variation within the interval -40 to +40 EURO/m3, 3% rate of interest and optimal control, the expected present value was 62% higher than without risk. Without risk the optimal harvest diameter was 55 cm and with risk, (115 – 2 $\delta(t)$) cm, where $\delta(t)$ denotes wood price deviation in period t from the expected wood price (EURO/m3).

Keywords:

Adaptive control function; Stochastic system optimization; Forest management

A dynamic multidimensional production system, with several interdependent processes, is adaptively controlled under the influence of stochastic market changes.

$$i(k) = \max\left\{\left(b_0 + b_1 LN(d_k) + b_2\left(C(k)\right)^3\right), 0\right\}$$

$i(k)$	diameter increment per year of trees in diameter class k
d_k	average diameter before increment of trees in diameter class k
$C(k)$	total basal area per hectare of trees with diameter larger than d_k

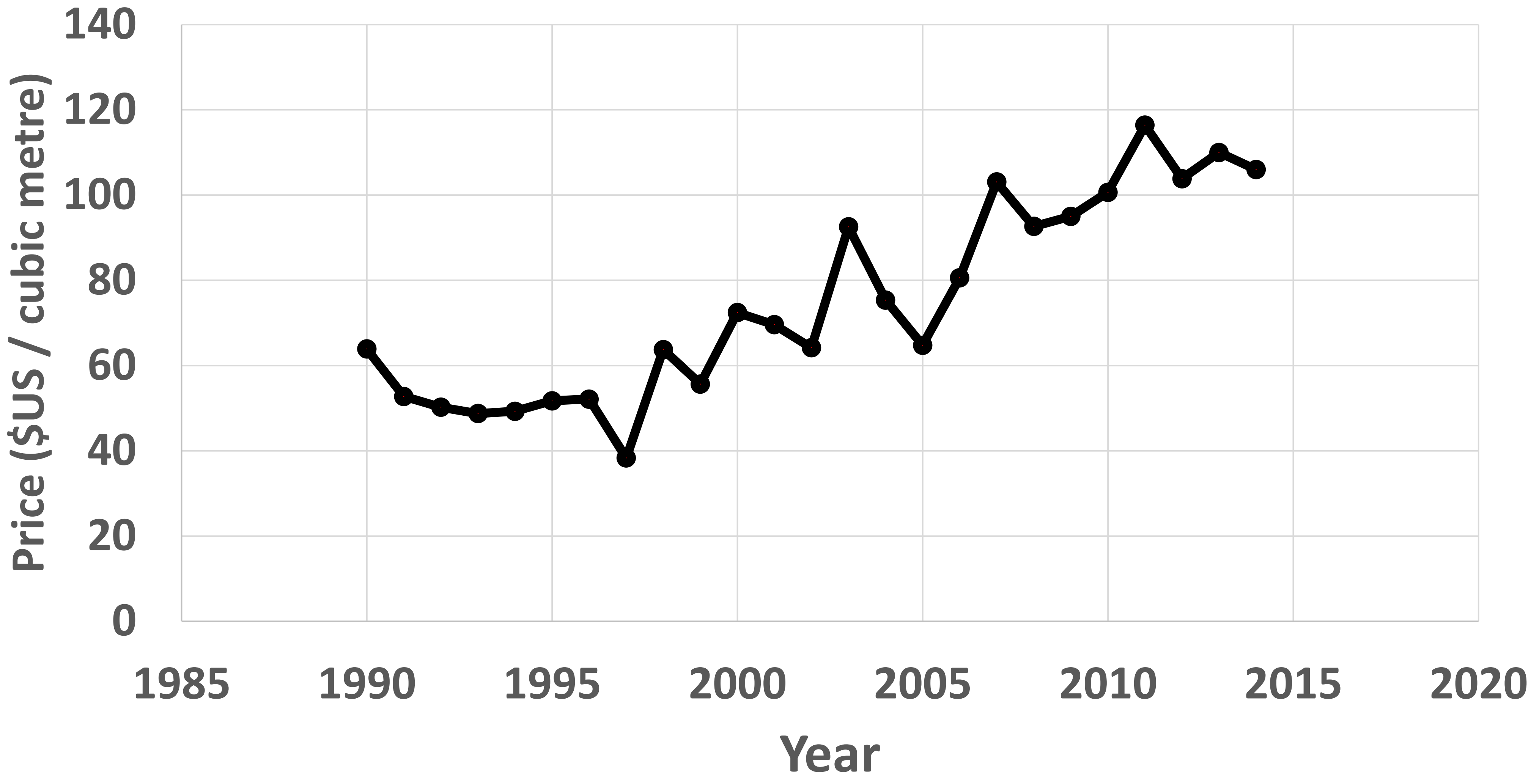
$$b_0 = 1.506969;\ b_1 = 0.94255;\ b_2 = -0.000183455$$

Source:

Schütz, J-P. (2006) Modelling the demographic sustainability of pure beech plenter forests in Eastern Germany, Ann.For.Sci. 63 (2000), 93-100, http://dx.doi.org/10.1051/forest:2005101

Export Unit Price, Roundwood, Germany

Source: UNECE/FAO TIMBER database, September 2015.
http://www.unece.org/forests/output/prices.html



$$D_L(t) = \alpha + \beta\delta(t)$$

$D_L(t)$ denotes “limit diameter” at time t,

All trees with diameters exceeding the limit diameter should be harvested, in case the total stock level per hectare exceeds the lowest feasible stock level. Otherwise, the largest trees with diameters exceeding the limit diameter are harvested until the lowest feasible stock level is reached.

α and β are parameters that should be optimized

$\delta(t)$ stochastic market price deviation from the expected market price in period t.

$$n_{t+1}(k) = n_t(k) + P_t(k-1)n_t(k-1) - P_t(k)n_t(k) - h_t(k)$$

$n_t(k)$ denotes the number of trees per hectare in diameter class k in period t.

$P_t(k)$ is the probability for trees in diameter class k to move up to the next diameter class in period t.

$h_t(k)$ denotes the number of trees harvested (via optimal control) in diameter class k in period t.

Of course, $P_t(k)$ is a function of $i(k)$, described in (2). $h_t(k)$ is a function of the adaptive control parameters found in (1), the random development of the exogenous market conditions and the dynamically changing availability of trees in different diameter classes.

Observations:

$$\delta(t) = \delta(t, P(t))$$

$$h_t(k) = h(t, k, n_t(1), ..., n_t(K), \delta(t))$$

An adaptive control function with low dimensionality that makes it possible to directly and indirectly control all parts of the interdependent processes is determined.

$$D_L(t) = \alpha + \beta\delta(t)$$

Discrete parameter value combinations, (α, β)
are investigated.

Grid search is applied to find optimal control function parameter values via stochastic simulation, where the complete production system is simulated 100 times, during 200 years.

The 100 time series of random numbers, each representing 200 years, used to represent stochastic market changes, are the same for every control function parameter combination.

Calculation of the ”Market price adjusted diameter limit” ”DlimitADJ” in the computer code:

```
REM Price adaptive diameter limit adjustment

DlimitADJ = x + (y - 10) / 1 * PDEV(NumS, t)
```

(α, β) $\delta(t)$

```
REM Dlimit limitation

IF DlimitADJ < 10 THEN DlimitADJ = 10
IF DlimitADJ > 100 THEN DlimitADJ = 100
```

”Expected present values - 6000” (EURO/ha)

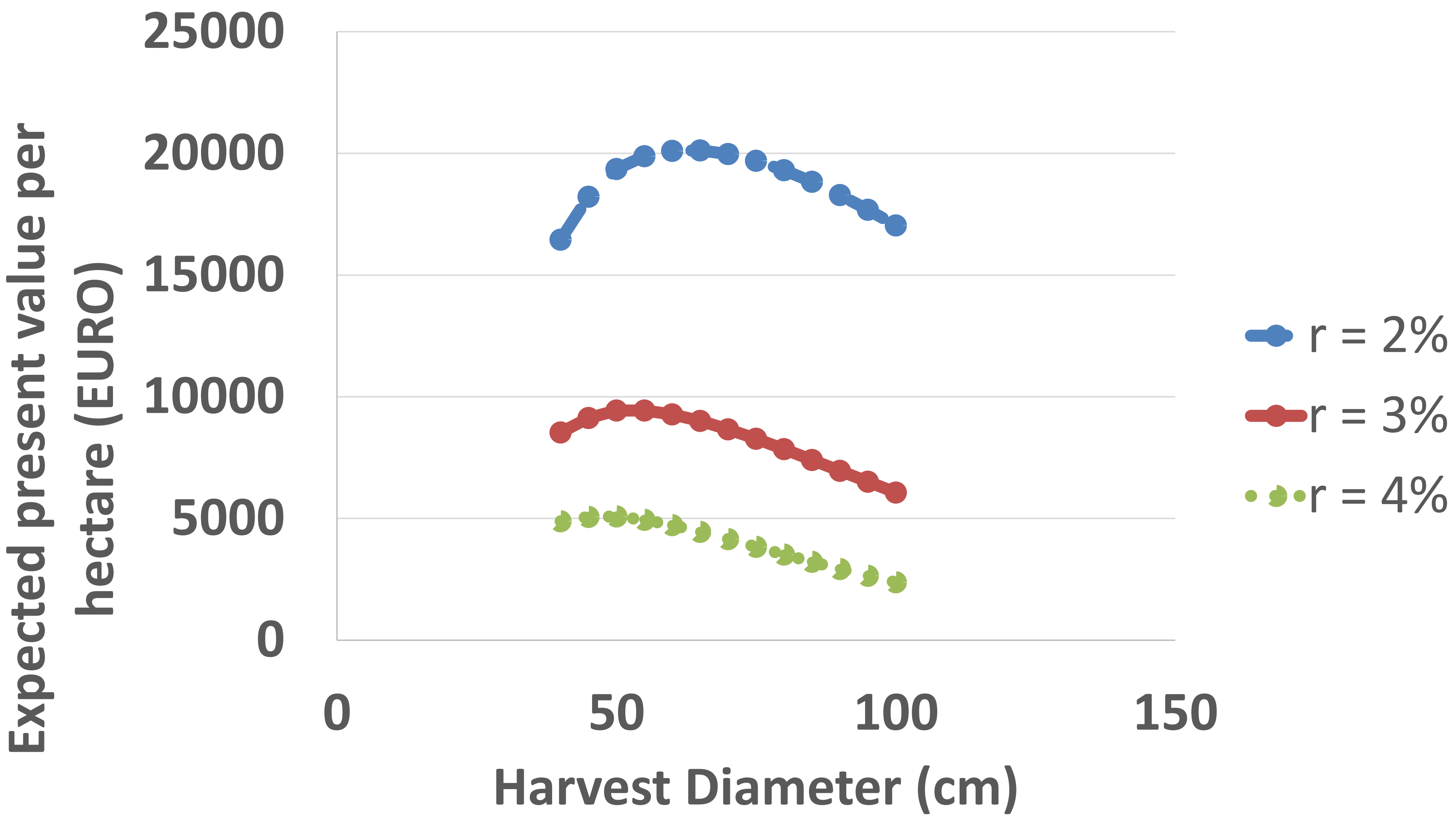
β

α	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
40	6269	6262	6253	6243	6231	6202	6162	6107	5966	5615	2536
45	6314	6311	6308	6304	6302	6294	6280	6263	6212	6081	3126
50	6367	6367	6368	6369	6382	6397	6411	6438	6469	6558	3432
55	6427	6437	6447	6462	6483	6515	6545	6609	6710	7048	3437
60	6487	6506	6530	6551	6573	6622	6679	6768	6945	7552	3273
65	6554	6569	6591	6624	6663	6722	6796	6915	7218	8024	3006
70	6602	6628	6654	6698	6743	6814	6903	7079	7487	8477	2664
75	6653	6686	6722	6763	6821	6905	7019	7270	7743	8864	2271
80	6702	6742	6778	6829	6900	6989	7158	7455	7978	9133	1847
85	6752	6790	6836	6892	6966	7090	7304	7631	8221	9197	1405
90	6796	6840	6892	6955	7045	7206	7441	7803	8458	8936	955
95	6842	6886	6942	7018	7134	7326	7578	7970	8698	8433	507
100	6884	6933	6995	7093	7234	7436	7704	8130	8910	7781	65
105	6930	6980	7055	7176	7338	7543	7833	8298	9085	7040	65
110	6970	7032	7128	7263	7430	7650	7962	8462	9212	6247	65
115	7015	7093	7199	7351	7520	7749	8074	8618	9276	5416	65
120	7066	7152	7278	7423	7606	7857	8198	8781	9237	4514	65
125	7123	7220	7356	7501	7694	7960	8330	8927	9020	3485	65
130	7180	7292	7421	7576	7772	8053	8464	9039	8571	2272	65

Assumptions:
Uniform price probability density function with price variation within the interval -40 to +40 EURO/m3, Rate of interest 3%.

The optimal control function is determined for beech stands in Germany, as an adaptive harvest diameter rule, for different rates of interest and for different levels of market risk.

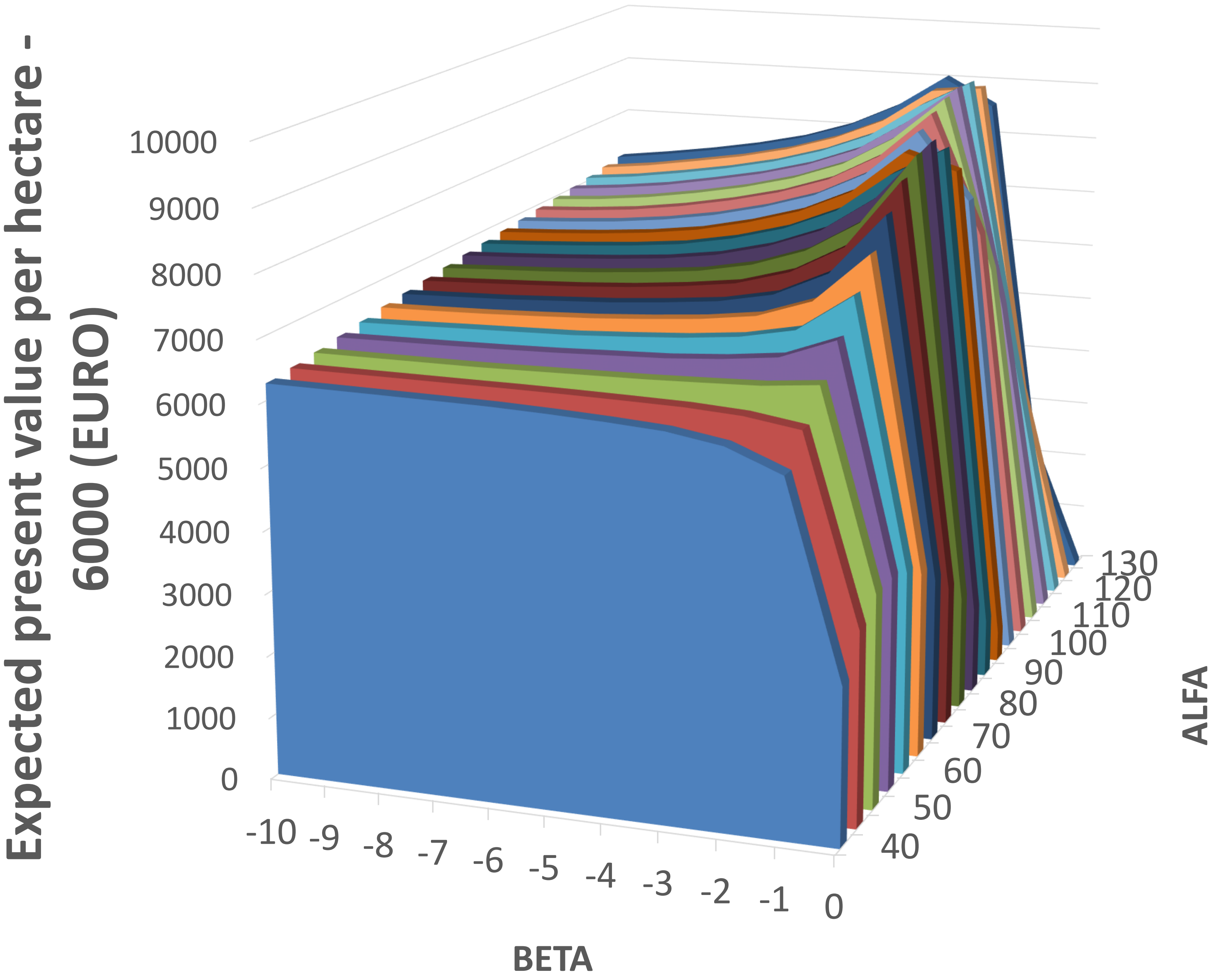
THE DETERMINISTIC CASE



Example:

With a uniform price probability density function with price variation within the interval -40 to +40 EURO/m3, 3% rate of interest and optimal control, the expected present value was 62% higher than without risk.

(The expected present value is a strictly increasing function of the degree of price variation.)



Expected present value per hectare - 6000 (EURO)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
BETA
40
50
60
70
80
90
100
110
120
130
ALFA

Example with 3% rate of interest:

Without risk, the optimal limit diameter was 55 cm.

With risk (*), the optimal limit diameter was (115 – 2 $\delta(t)$) cm.

(*) = Prices distributed according to a uniform price probability density function with price variation within the interval -40 to +40 EURO/m3

250
200
150
100
50
0
Limit Diameter (cm)
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
Stochastic Price Deviation from Average Price (EURO/m3)
Limit Diameter with risk
Limit Diameter without risk

Detailed numerical analysis:

CCF9 (Optimization software)

by Peter Lohmander
in QB64

```
REM
REM CCF9.bas
REM Peter Lohmander
REM 160106
REM Date of first version of this software 090416
REM http://www.Lohmander.com
REM Peter@Lohmander.com
REM
REM A dynamic diameter distribution model for numerical economic
REM optimization of continuous cover forest management
REM
REM Acknowledgements:
REM My thanks go to Prof. Dr. Jean-Philippe Schutz.
REM Several of the equations in this preliminary computer model
REM were obtained from his article found below. Furthermore, he
REM showed me interesting experiments in Switzerland.
REM
REM References:
REM Schutz, J-P. (2006) Modelling the demographic sustainability
REM of pure beech plenter forests in Eastern Germany,
REM Ann.For.Sci. 63 (2000), 93-100
REM http://dx.doi.org/10.1051/forest:2005101
REM
```

Parameters inputs and generation of the random price deviation series:

```
CLS
DIM PDEV(100, 200)
INPUT "Risk multiplier = ", rmp
INPUT "Rate of interest = ", r
INPUT "Random number seed = ", randseed
INPUT "Number of time series = ", NumSer
RANDOMIZE randseed

FOR t = 0 TO 200
   FOR NumS = 1 TO NumSer
      PDEV(NumS, t) = rmp * (2 * RND - 1)
   NEXT NumS
NEXT t
```

```
OPEN "CCF9optout.txt" FOR OUTPUT AS #2
PRINT #2, "CCF Optimization (CCF9)"
PRINT #2, "with market adaptive adjustment of diameter limit."
PRINT #2, "Peter Lohmander 160106"
PRINT #2, ""
PRINT #2, "Risk multiplier = ", rmp
PRINT #2, "Rate of interest = ", r
PRINT #2, "Random seed = ", randseed
PRINT #2, "Number of time series = ", NumSer
PRINT #2, ""
PRINT #2, "  Alfa                   Beta (Columns) "
PRINT #2, "       "
PRINT #2, " (Rows) "
PRINT #2, "       ";
FOR y = 0 TO 10
   PRINT #2, USING "###.##"; (y - 10) / 1;
NEXT y
PRINT #2, ""
PRINT #2, ""
```

The main program:

```
FOR x = 40 TO 200 STEP 5
   PRINT #2, USING "###"; x;
   PRINT #2, "     ";
   FOR y = 0 TO 10
      AveTotPV = 0
      FOR NumS = 1 TO NumSer
         GOSUB Subroutine_CCF
         AveTotPV = AveTotPV + TotPV
      NEXT NumS
      AveTotPV = AveTotPV / NumSer
      PRINT #2, USING "######"; AveTotPV;
   NEXT y
   PRINT #2, " "
NEXT x
CLOSE #2

END
```

The subroutine is called.

The subroutine starts here:

```
Subroutine_CCF:
DIM n(20), i(20), p(20), e(20), gcum(20), sapt(20), v(20), h(20), np(20)
DIM nnext(20), nharv(20), npADJ(20)
pi = 3.141593

p0 = 25
p1 = 2.5

Stockmin = 150

TotPV = 0
TotHarv = 0
```

```
b0 = 1.506969
b1 = .94255
b2 = -.000183455#

FOR k = 1 TO 20
    d = k * .05
    h(k) = 3 * k - (k / 8) ^ 2
    n(k) = .1
    i(k) = 0
    p(k) = 0
    e(k) = 0
    sapt(k) = pi * (d / 2) ^ 2
    v(k) = .5 * sapt(k) * h(k)
    np(k) = p0 + p1 * k
NEXT k
```

```
REM ******************** Time loop ********************
FOR t = 1 TO 200
    disc = 1 / (1 + r) ^ t
    n(2) = 100

    Stock = 0
    FOR k = 1 TO 20
        Stock = Stock + n(k) * v(k)
    NEXT k

    StDif = 0
    IF Stock > Stockmin THEN StDif = Stock - Stockmin
```

```
REM Price adaptive diameter limit adjustment

    DlimitADJ = x + (y - 10) / 1 * PDEV(NumS, t)

    REM Dlimit limitation

    IF DlimitADJ < 10 THEN DlimitADJ = 10
    IF DlimitADJ > 100 THEN DlimitADJ = 100
    KlimitADJ = INT(DlimitADJ / 5)
```

```
REM Price adaptive profit function adjustment

    FOR k = 1 TO 20
        npADJ(k) = np(k) + PDEV(NumS, t)
    NEXT k
```

```
FOR k = 20 TO KlimitADJ STEP -1
        e(k) = 0
        volk = v(k) * n(k)
        hshare = StDif / (volk + .001)
        e(k) = hshare
        IF hshare > 1 THEN e(k) = 1

        StDif = StDif - e(k) * volk

        nharv(k) = n(k) * e(k)
        n(k) = n(k) * (1 - e(k))
    NEXT k
```

```
harv = 0
prof = 0
    FOR k = 20 TO KlimitADJ STEP -1
        prof = prof + nharv(k) * npADJ(k) * v(k)
        harv = harv + nharv(k) * v(k)
    NEXT k

    TotPV = TotPV + disc * prof
    TotHarv = TotHarv + harv
```

```
FOR k = 1 TO 20
      gcum(k) = 0
NEXT k
```

REM **Calculation of GCUM**

```
FOR k = 1 TO 20
   FOR j = k + 1 TO 20
      gcum(k) = gcum(k) + n(j) * sapt(j)
   NEXT j
NEXT k
```

```
REM Calculation of diameter increments

  FOR k = 1 TO 20
    d = k * 50
    i(k) = b0 + b1 * LOG(d) + b2 * gcum(k) ^ 3
    IF i(k) < 0 THEN i(k) = 0
  NEXT k
```

```
REM Calculation of the probabilities to move up

    FOR k = 1 TO 20
        p(k) = i(k) / 50
    NEXT k
```

```
FOR k = 2 TO 20
    nnext(k) = n(k) + p(k - 1) * n(k - 1) - p(k) * n(k)
NEXT k

FOR k = 2 TO 20
    n(k) = nnext(k)
NEXT k
```

```
    IF t < 200 GOTO 100

    YearHarv = TotHarv / 200

    100 REM

NEXT t

RETURN
```

Case 1:

No price variation.

CCF Optimization (CCF9)
with market adaptive adjustment of diameter limit.
Peter Lohmander 160106

Risk multiplier = 0
Rate of interest = .03
Random seed = 3
Number of time series = 10

Alfa (Rows), Beta (Columns)

Alfa (Rows)	-10.00	-9.00	-8.00	-7.00	-6.00	-5.00	-4.00	-3.00	-2.00	-1.00	0.00
40	8526	8526	8526	8526	8526	8526	8526	8526	8526	8526	8526
45	9138	9138	9138	9138	9138	9138	9138	9138	9138	9138	9138
50	9439	9439	9439	9439	9439	9439	9439	9439	9439	9439	9439
55	9449	9449	9449	9449	9449	9449	9449	9449	9449	9449	9449
60	9292	9292	9292	9292	9292	9292	9292	9292	9292	9292	9292
65	9035	9035	9035	9035	9035	9035	9035	9035	9035	9035	9035
70	8699	8699	8699	8699	8699	8699	8699	8699	8699	8699	8699
75	8310	8310	8310	8310	8310	8310	8310	8310	8310	8310	8310
80	7888	7888	7888	7888	7888	7888	7888	7888	7888	7888	7888
85	7447	7447	7447	7447	7447	7447	7447	7447	7447	7447	7447
90	6996	6996	6996	6996	6996	6996	6996	6996	6996	6996	6996
95	6545	6545	6545	6545	6545	6545	6545	6545	6545	6545	6545
100	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
105	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
110	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
115	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
120	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
125	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
130	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
135	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
140	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
145	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
150	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
155	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
160	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
165	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
170	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
175	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
180	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
185	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
190	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
195	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
200	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099

CCF Optimization (CCF9)
with market adaptive adjustment of diameter limit.

Peter Lohmander 160106

Risk multiplier =	0
Rate of interest =	.03
Random seed =	3
Number of time series =	10

Optimal expected present value

=

9 449 EURO/ha

Alfa (Rows)	Beta (Columns) -10.00	-9.00	-8.00	-7.00	-6.00	-5.00	-4.00	-3.00	-2.00	-1.00	0.00
40	8526	8526	8526	8526	8526	8526	8526	8526	8526	8526	8526
45	9138	9138	9138	9138	9138	9138	9138	9138	9138	9138	9138
50	9439	9439	9439	9439	9439	9439	9439	9439	9439	9439	9439
55	9449	9449	9449	9449	9449	9449	9449	9449	9449	9449	9449
60	9292	9292	9292	9292	9292	9292	9292	9292	9292	9292	9292
65	9035	9035	9035	9035	9035	9035	9035	9035	9035	9035	9035
70	8699	8699	8699	8699	8699	8699	8699	8699	8699	8699	8699
75	8310	8310	8310	8310	8310	8310	8310	8310	8310	8310	8310
80	7888	7888	7888	7888	7888	7888	7888	7888	7888	7888	7888
85	7447	7447	7447	7447	7447	7447	7447	7447	7447	7447	7447
90	6996	6996	6996	6996	6996	6996	6996	6996	6996	6996	6996
95	6545	6545	6545	6545	6545	6545	6545	6545	6545	6545	6545
100	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
105	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
110	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
115	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
120	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
125	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
130	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
135	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
140	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
145	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
150	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
155	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
160	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
165	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
170	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
175	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
180	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
185	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
190	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
195	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099
200	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099	6099

Case 2:

Price variation within the interval -20 to +20 EURO/m3

CCF Optimization (CCF9)
with market adaptive adjustment of diameter limit.
Peter Lohmander 160106

Risk multiplier = 20
Rate of interest = .03
Random seed = 3
Number of time series = 100

Alfa (Rows) \ Beta (Columns)	-10.00	-9.00	-8.00	-7.00	-6.00	-5.00	-4.00	-3.00	-2.00	-1.00	0.00
40	10424	10416	10403	10390	10373	10339	10298	10236	10112	9791	8531
45	10474	10470	10466	10461	10458	10446	10431	10408	10363	10265	9132
50	10530	10535	10538	10544	10553	10564	10571	10592	10623	10753	9436
55	10594	10603	10611	10626	10646	10672	10702	10759	10893	11256	9443
60	10652	10666	10683	10704	10732	10775	10831	10952	11176	11716	9283
65	10706	10722	10747	10777	10813	10876	10982	11149	11448	12051	9020
70	10757	10777	10805	10846	10903	10998	11132	11333	11717	12052	8681
75	10806	10829	10869	10930	11009	11120	11276	11516	11956	11806	8291
80	10852	10890	10947	11021	11113	11234	11410	11697	12139	11410	7867
85	10908	10961	11028	11108	11211	11350	11552	11872	12217	10920	7426
90	10973	11033	11104	11196	11308	11462	11690	12028	12076	10367	6976
95	11039	11103	11180	11274	11403	11576	11831	12147	11741	9780	6526
100	11101	11169	11250	11358	11494	11687	11957	12212	11278	9173	6082
105	11160	11235	11324	11435	11592	11807	12064	12170	10734	8534	6082
110	11220	11294	11396	11515	11688	11909	12144	11943	10141	7802	6082
115	11275	11360	11460	11601	11778	11999	12189	11550	9514	6917	6082
120	11336	11422	11532	11687	11873	12077	12173	11046	8850	6082	6082
125	11394	11481	11609	11764	11957	12138	12043	10471	8134	6082	6082
130	11448	11546	11687	11849	12024	12175	11752	9850	7356	6082	6082
135	11504	11617	11754	11923	12086	12166	11318	9196	6594	6082	6082
140	11561	11686	11823	11988	12133	12092	10788	8508	6082	6082	6082
145	11622	11747	11896	12039	12160	11910	10197	7786	6082	6082	6082
150	11684	11804	11954	12089	12157	11578	9565	7073	6082	6082	6082
155	11739	11871	12007	12127	12110	11116	8900	6459	6082	6082	6082
160	11792	11930	12051	12148	11991	10566	8215	6082	6082	6082	6082
165	11854	11981	12093	12150	11757	9960	7529	6082	6082	6082	6082
170	11911	12024	12125	12114	11385	9318	6894	6082	6082	6082	6082
175	11953	12058	12141	12029	10894	8652	6389	6082	6082	6082	6082
180	11996	12093	12141	11864	10324	7984	6082	6082	6082	6082	6082
185	12031	12121	12112	11595	9704	7344	6082	6082	6082	6082	6082
190	12059	12135	12048	11196	9056	6785	6082	6082	6082	6082	6082
195	12091	12134	11934	10689	8401	6348	6082	6082	6082	6082	6082
200	12116	12113	11731	10110	7766	6082	6082	6082	6082	6082	6082

CCF Optimization (CCF9)
with market adaptive adjustment of diameter limit.

Peter Lohmander 160106

Risk multiplier =	20
Rate of interest =	.03
Random seed =	3
Number of time series =	100

Optimal expected present value

=

12 217 EURO/ha

Alfa (Rows) \ Beta (Columns)	-10.00	-9.00	-8.00	-7.00	-6.00	-5.00	-4.00	-3.00	-2.00	-1.00	0.00
40	10424	10416	10403	10390	10373	10339	10298	10236	10112	9791	8531
45	10474	10470	10466	10461	10458	10446	10431	10408	10363	10265	9132
50	10530	10535	10538	10544	10553	10564	10571	10592	10623	10753	9436
55	10594	10603	10611	10626	10646	10672	10702	10759	10893	11256	9443
60	10652	10666	10683	10704	10732	10775	10831	10952	11176	11716	9283
65	10706	10722	10747	10777	10813	10876	10982	11149	11448	12051	9020
70	10757	10777	10805	10846	10903	10998	11132	11333	11717	12052	8681
75	10806	10829	10869	10930	11009	11120	11276	11516	11956	11806	8291
80	10852	10890	10947	11021	11113	11234	11410	11697	12139	11410	7867
85	10908	10961	11028	11108	11211	11350	11552	11872	12217	10920	7426
90	10973	11033	11104	11196	11308	11462	11690	12028	12076	10367	6976
95	11039	11103	11180	11274	11403	11576	11831	12147	11741	9780	6526
100	11101	11169	11250	11358	11494	11687	11957	12212	11278	9173	6082
105	11160	11235	11324	11435	11592	11807	12064	12170	10734	8534	6082
110	11220	11294	11396	11515	11688	11909	12144	11943	10141	7802	6082
115	11275	11360	11460	11601	11778	11999	12189	11550	9514	6917	6082
120	11336	11422	11532	11687	11873	12077	12173	11046	8850	6082	6082
125	11394	11481	11609	11764	11957	12138	12043	10471	8134	6082	6082
130	11448	11546	11687	11849	12024	12175	11752	9850	7356	6082	6082
135	11504	11617	11754	11923	12086	12166	11318	9196	6594	6082	6082
140	11561	11686	11823	11988	12133	12092	10788	8508	6082	6082	6082
145	11622	11747	11896	12039	12160	11910	10197	7786	6082	6082	6082
150	11684	11804	11954	12089	12157	11578	9565	7073	6082	6082	6082
155	11739	11871	12007	12127	12110	11116	8900	6459	6082	6082	6082
160	11792	11930	12051	12148	11991	10566	8215	6082	6082	6082	6082
165	11854	11981	12093	12150	11757	9960	7529	6082	6082	6082	6082
170	11911	12024	12125	12114	11385	9318	6894	6082	6082	6082	6082
175	11953	12058	12141	12029	10894	8652	6389	6082	6082	6082	6082
180	11996	12093	12141	11864	10324	7984	6082	6082	6082	6082	6082
185	12031	12121	12112	11595	9704	7344	6082	6082	6082	6082	6082
190	12059	12135	12048	11196	9056	6785	6082	6082	6082	6082	6082
195	12091	12134	11934	10689	8401	6348	6082	6082	6082	6082	6082
200	12116	12113	11731	10110	7766	6082	6082	6082	6082	6082	6082

Case 3:

Price variation within the interval -40 to +40 EURO/m3

CCF Optimization (CCF9)
with market adaptive adjustment of diameter limit.
Peter Lohmander 160106

Risk multiplier = 40
Rate of interest = .03
Random seed = 3
Number of time series = 100

Alfa (Rows); Beta (Columns)

Alfa	-10.00	-9.00	-8.00	-7.00	-6.00	-5.00	-4.00	-3.00	-2.00	-1.00	0.00
40	12269	12262	12253	12243	12231	12202	12162	12107	11966	11615	8536
45	12314	12311	12308	12304	12302	12294	12280	12263	12212	12081	9126
50	12367	12367	12368	12369	12382	12397	12411	12438	12469	12558	9432
55	12427	12437	12447	12462	12483	12515	12545	12609	12710	13048	9437
60	12487	12506	12530	12551	12573	12622	12679	12768	12945	13552	9273
65	12554	12569	12591	12624	12663	12722	12796	12915	13218	14024	9006
70	12602	12628	12654	12698	12743	12814	12903	13079	13487	14477	8664
75	12653	12686	12722	12763	12821	12905	13019	13270	13743	14864	8271
80	12702	12742	12778	12829	12900	12989	13158	13455	13978	15133	7847
85	12752	12790	12836	12892	12966	13090	13304	13631	14221	15197	7405
90	12796	12840	12892	12955	13045	13206	13441	13803	14458	14936	6955
95	12842	12886	12942	13018	13134	13326	13578	13970	14698	14433	6507
100	12884	12933	12995	13093	13234	13436	13704	14130	14910	13781	6065
105	12930	12980	13055	13176	13338	13543	13833	14298	15085	13040	6065
110	12970	13032	13128	13263	13430	13650	13962	14462	15212	12247	6065
115	13015	13093	13199	13351	13520	13749	14074	14618	15276	11416	6065
120	13066	13152	13278	13423	13606	13857	14198	14781	15237	10514	6065
125	13123	13220	13356	13501	13694	13960	14330	14927	15020	9485	6065
130	13180	13292	13421	13576	13772	14053	14464	15039	14571	8272	6065
135	13244	13361	13486	13658	13865	14151	14581	15142	13946	6983	6065
140	13306	13417	13548	13724	13953	14250	14701	15218	13208	6065	6065
145	13366	13477	13617	13794	14035	14355	14827	15261	12398	6065	6065
150	13417	13535	13690	13876	14106	14462	14930	15258	11528	6065	6065
155	13469	13592	13750	13950	14193	14559	15020	15185	10592	6065	6065
160	13518	13660	13808	14021	14284	14651	15096	15001	9585	6065	6065
165	13572	13717	13881	14083	14375	14758	15165	14647	8523	6065	6065
170	13628	13768	13948	14151	14464	14857	15218	14097	7484	6065	6065
175	13686	13819	14007	14228	14548	14934	15246	13397	6618	6065	6065
180	13733	13885	14068	14306	14620	15007	15248	12598	6065	6065	6065
185	13782	13946	14121	14384	14692	15067	15208	11729	6065	6065	6065
190	13831	13997	14185	14459	14785	15116	15114	10807	6065	6065	6065
195	13890	14053	14250	14536	14869	15168	14944	9846	6065	6065	6065
200	13946	14103	14320	14599	14935	15211	14646	8877	6065	6065	6065

CCF Optimization (CCF9)
with market adaptive adjustment of diameter limit.

Peter Lohmander 160106

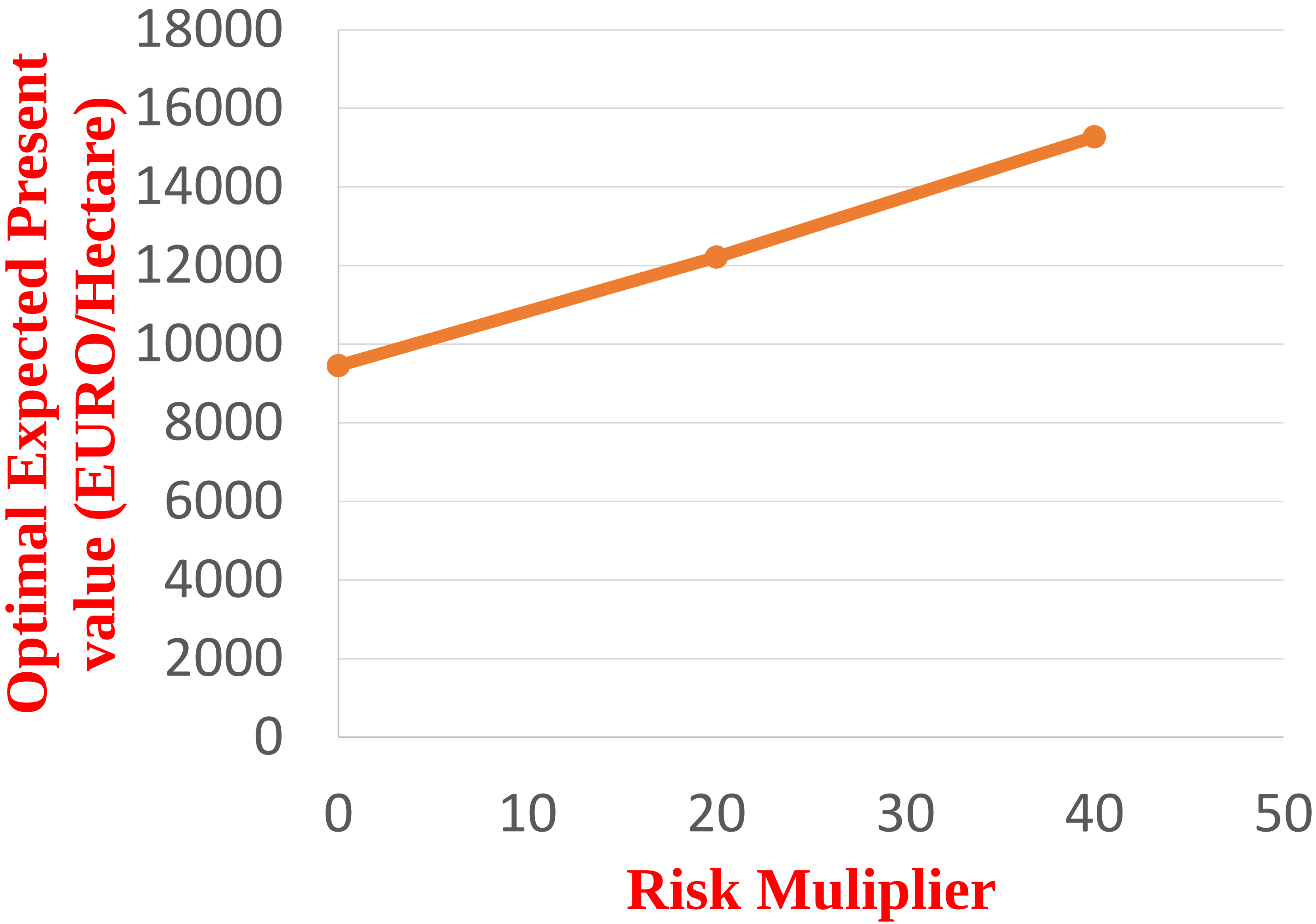
Risk multiplier =	40
Rate of interest =	.03
Random seed =	3
Number of time series =	100

Optimal expected present value

=

15 276 EURO/ha

Alfa (Rows)	Beta (Columns) -10.00	-9.00	-8.00	-7.00	-6.00	-5.00	-4.00	-3.00	-2.00	-1.00	0.00
40	12269	12262	12253	12243	12231	12202	12162	12107	11966	11615	8536
45	12314	12311	12308	12304	12302	12294	12280	12263	12212	12081	9126
50	12367	12367	12368	12369	12382	12397	12411	12438	12469	12558	9432
55	12427	12437	12447	12462	12483	12515	12545	12609	12710	13048	9437
60	12487	12506	12530	12551	12573	12622	12679	12768	12945	13552	9273
65	12554	12569	12591	12624	12663	12722	12796	12915	13218	14024	9006
70	12602	12628	12654	12698	12743	12814	12903	13079	13487	14477	8664
75	12653	12686	12722	12763	12821	12905	13019	13270	13743	14864	8271
80	12702	12742	12778	12829	12900	12989	13158	13455	13978	15133	7847
85	12752	12790	12836	12892	12966	13090	13304	13631	14221	15197	7405
90	12796	12840	12892	12955	13045	13206	13441	13803	14458	14936	6955
95	12842	12886	12942	13018	13134	13326	13578	13970	14698	14433	6507
100	12884	12933	12995	13093	13234	13436	13704	14130	14910	13781	6065
105	12930	12980	13055	13176	13338	13543	13833	14298	15085	13040	6065
110	12970	13032	13128	13263	13430	13650	13962	14462	15212	12247	6065
115	13015	13093	13199	13351	13520	13749	14074	14618	15276	11416	6065
120	13066	13152	13278	13423	13606	13857	14198	14781	15237	10514	6065
125	13123	13220	13356	13501	13694	13960	14330	14927	15020	9485	6065
130	13180	13292	13421	13576	13772	14053	14464	15039	14571	8272	6065
135	13244	13361	13486	13658	13865	14151	14581	15142	13946	6983	6065
140	13306	13417	13548	13724	13953	14250	14701	15218	13208	6065	6065
145	13366	13477	13617	13794	14035	14355	14827	15261	12398	6065	6065
150	13417	13535	13690	13876	14106	14462	14930	15258	11528	6065	6065
155	13469	13592	13750	13950	14193	14559	15020	15185	10592	6065	6065
160	13518	13660	13808	14021	14284	14651	15096	15001	9585	6065	6065
165	13572	13717	13881	14083	14375	14758	15165	14647	8523	6065	6065
170	13628	13768	13948	14151	14464	14857	15218	14097	7484	6065	6065
175	13686	13819	14007	14228	14548	14934	15246	13397	6618	6065	6065
180	13733	13885	14068	14306	14620	15007	15248	12598	6065	6065	6065
185	13782	13946	14121	14384	14692	15067	15208	11729	6065	6065	6065
190	13831	13997	14185	14459	14785	15116	15114	10807	6065	6065	6065
195	13890	14053	14250	14536	14869	15168	14944	9846	6065	6065	6065
200	13946	14103	14320	14599	14935	15211	14646	8877	6065	6065	6065


Optimal Expected Present value (EURO/Hectare)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
Risk Muliplier

Conclusions:

- It is possible to use the described method to improve the control of large stochastic systems of very different kinds.
- In many cases, there are no alternative approaches available that can solve the relevant problems in reasonable time.
- The concrete numerical results presented in this study should be considered as illustrations of what is possible to derive in similar problems.

- One of the important modelling topics that is fundamental to work of this nature is definition and estimation of stochastic processes representing market prices and other stochastic disturbances of particular application relevance.
- In Lohmander [1], we find that alternative specifications of price processes and damage probability functions can lead to drastically different types of optimal resource control functions.
- For instance, autocorrelation functions and stationarity are important concepts to consider and estimate before detailed resource control models are developed and solved.
- In the present analysis, stationary and independently distributed market prices were assumed in all periods. Of course, in other cases, the process properties may be different.

- Furthermore, expected prices minus costs for harvesting and terrain transport in different size classes, were assumed to follow a diameter dependent net price function.
- Several examples of stochastic price processes in the round wood markets have been described and analysed in Lohmander [1].
- In Finland, Sweden and Norway, these prices could be described as stationary first order autoregressive processes.

- In future applications of the optimization method described in this paper, it is suggested that the relevant price process parameters are first estimated from available historical tables and that the simulations of the 100 random price series are based on these parameters.
- It is also important to be aware of the fact that historical price series data are not always relevant to analysis of optimal decisions, at the present and in the future.
- New technologies, new demand structures and new discoveries of natural resources may change the fundamental structures and parameters also of stochastic market price processes.
- Relevant analysis has to explicitly take these things into account.

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Optimization of adaptive control functions in multidimensional forest management via stochastic simulation and grid search

Version 160408

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