Analysing production trajectories with the exponential model

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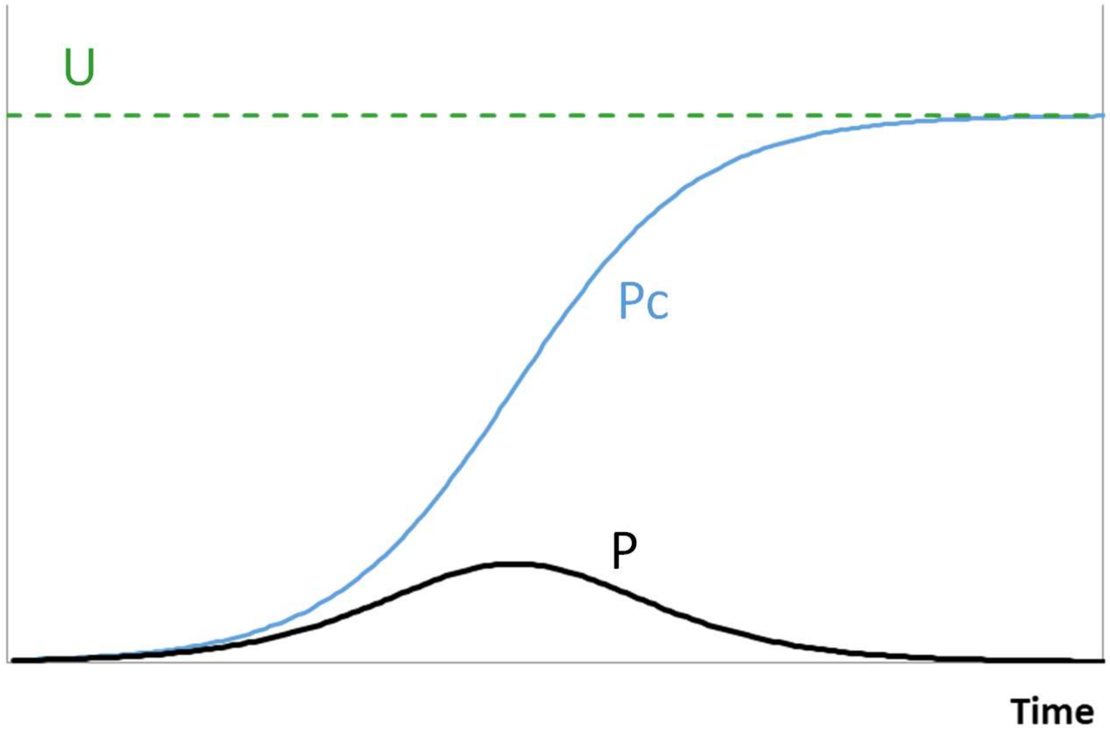

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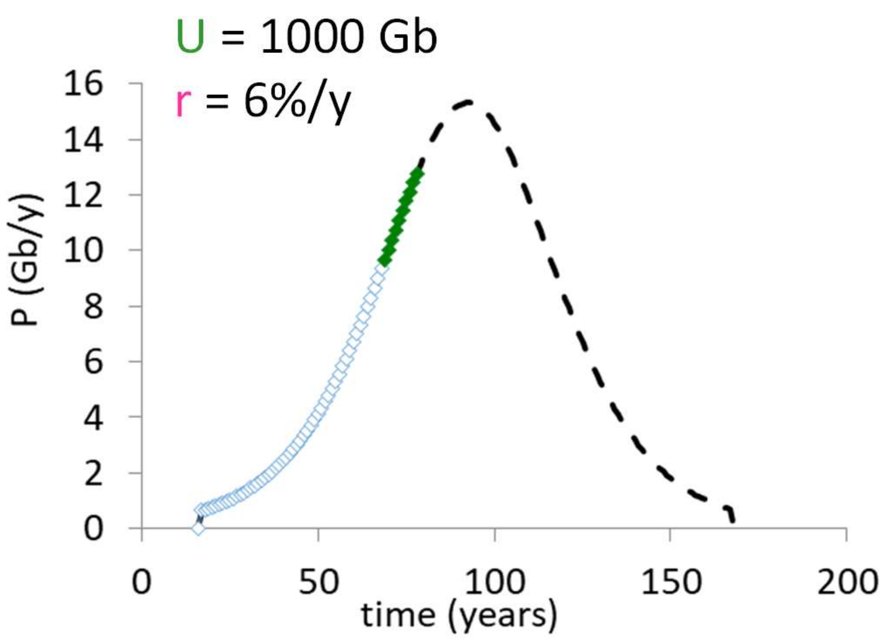
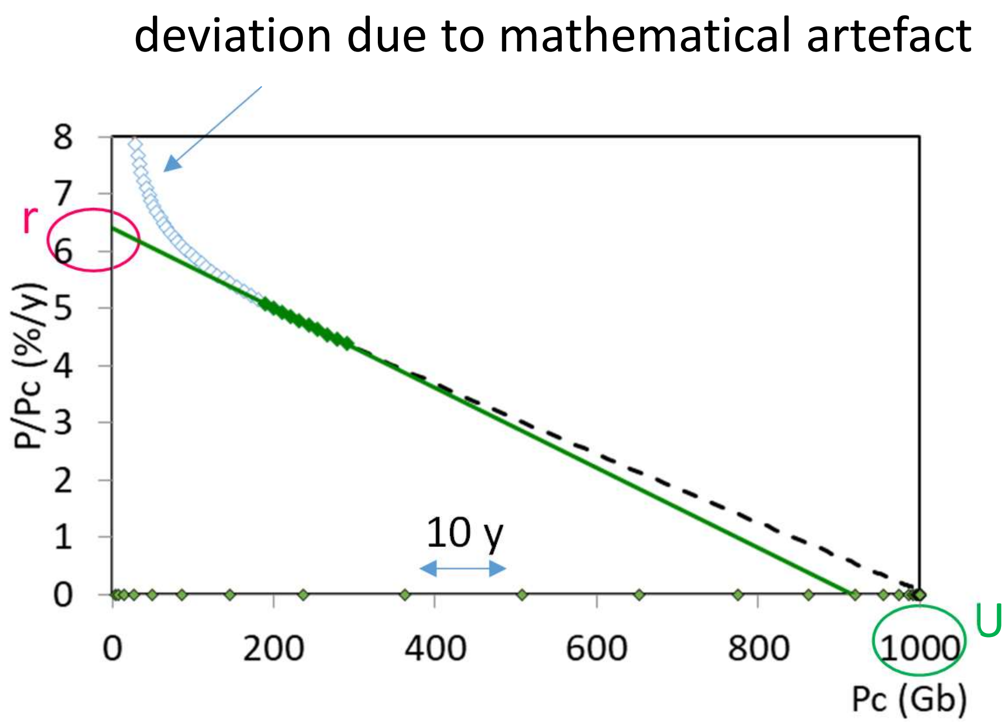
Hubbert linearization used to estimate U and r

$$P_c = \frac{U}{1 + (\frac{U}{P_{c0}} - 1)e^{-rt}} \quad \Rightarrow \quad \frac{P}{P_c} = -\frac{r}{U} P_c + r$$





Early in the cycle

$$P_c = \frac{U}{1 + (\frac{U}{P_{c0}} - 1)e^{-rt}}$$

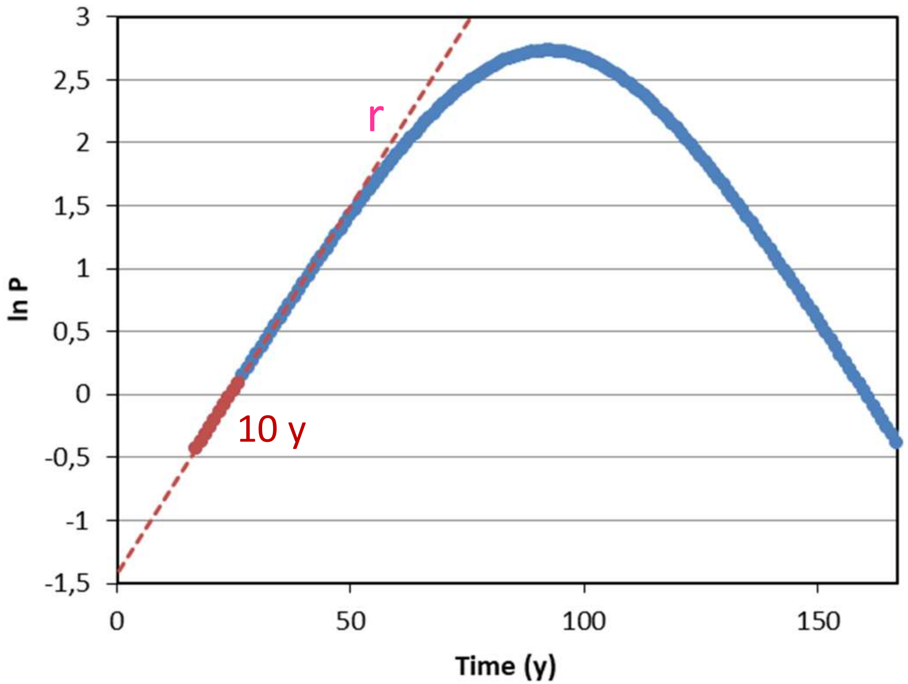
$$P_c \sim P_{c0}\, e^{rt}$$

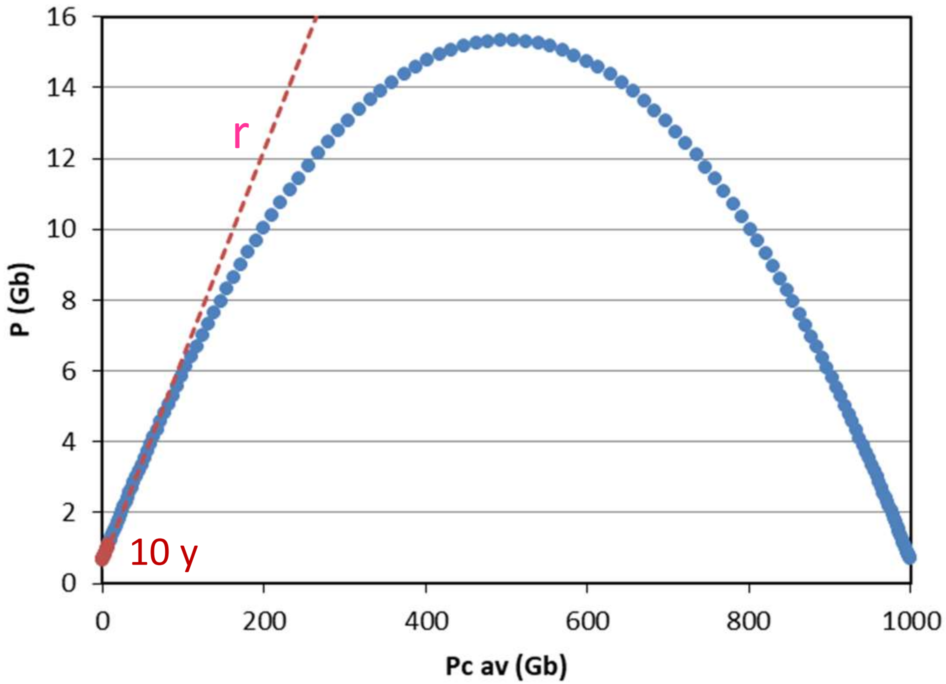
$$P = \frac{dPc}{dt}$$

$$P \sim P_{c0}\, r e^{rt}$$

$$lnP \sim rt + lnrP_{c0}$$

$$P \sim rPc$$



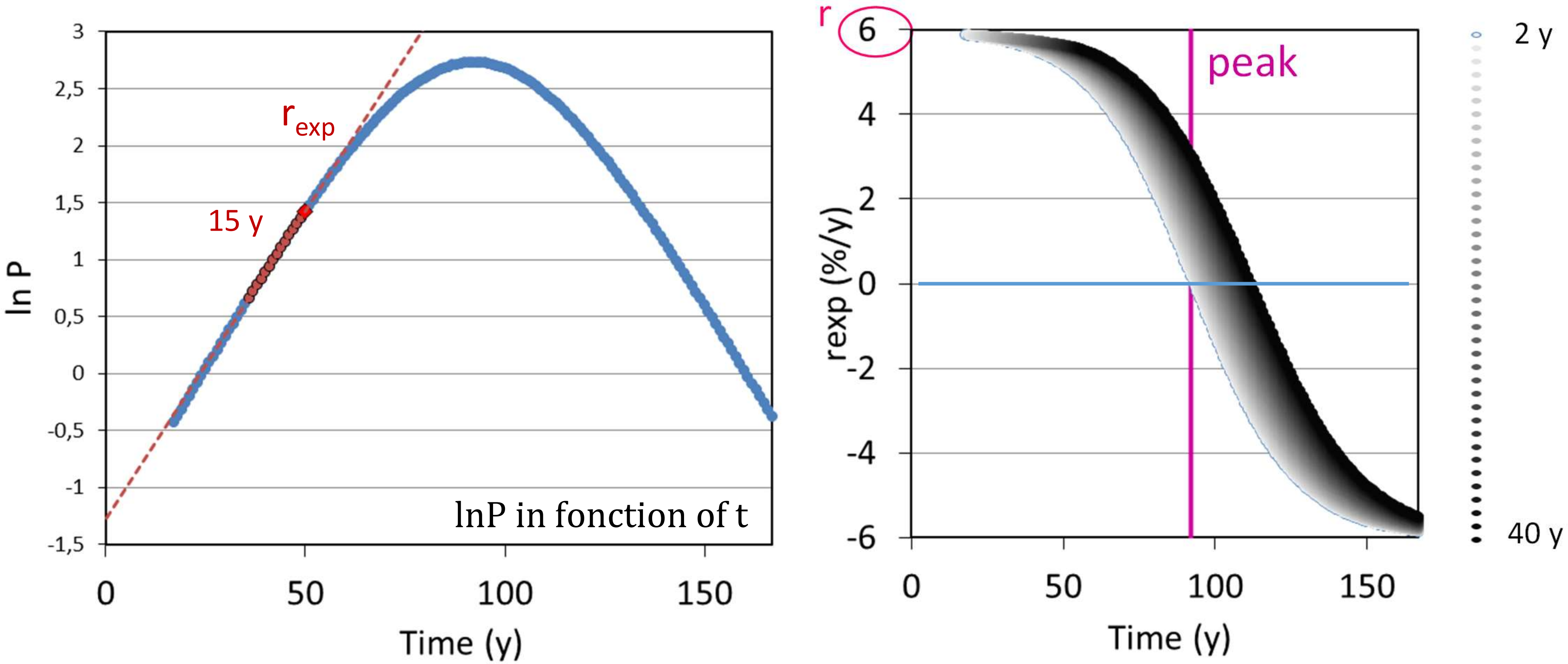


No mathematical artefact

1) backward regressions, evolution of r_{exp} in function of time

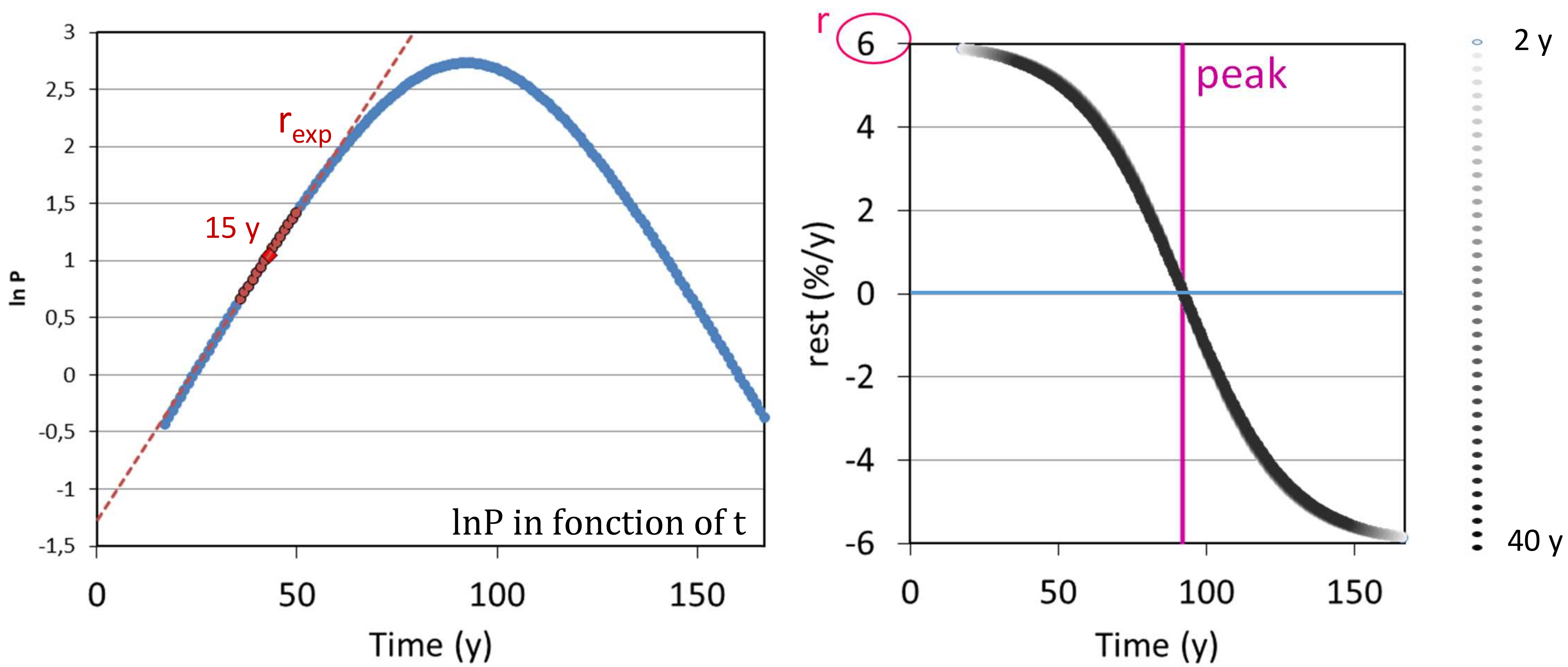
$$r_{simple} = e^{r_{exp}} - 1$$

$$\sim r_{exp} \quad (e^r = 1 + r \text{ pour } r << 1)$$



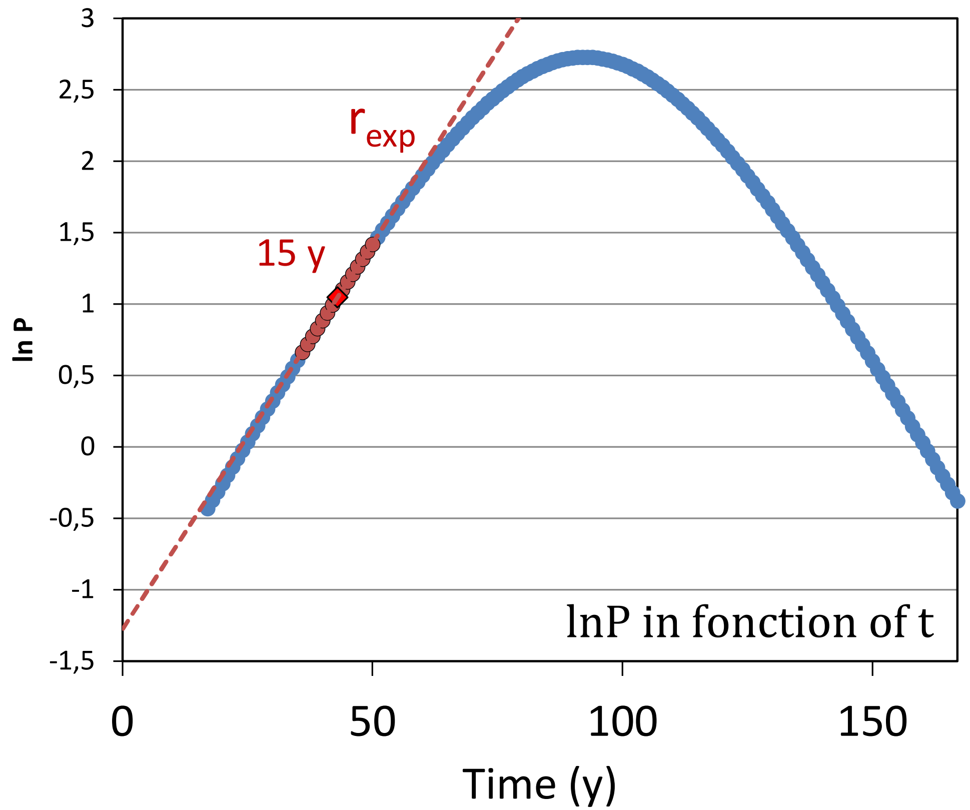
Useful representation to detect onset of trend changes

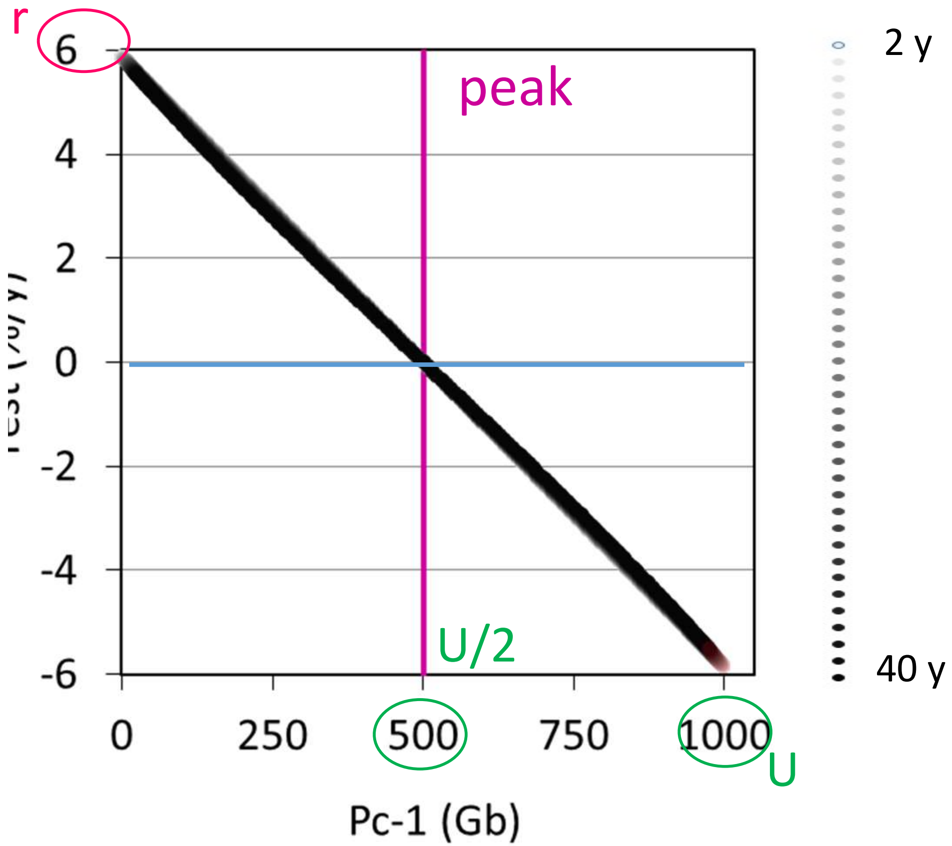
2) central regressions, evolution of r_{exp} in function of time



Peak reached when r_{exp} values cross the zero treshold

3) central regressions, evolution of r_{exp} in function of Pc

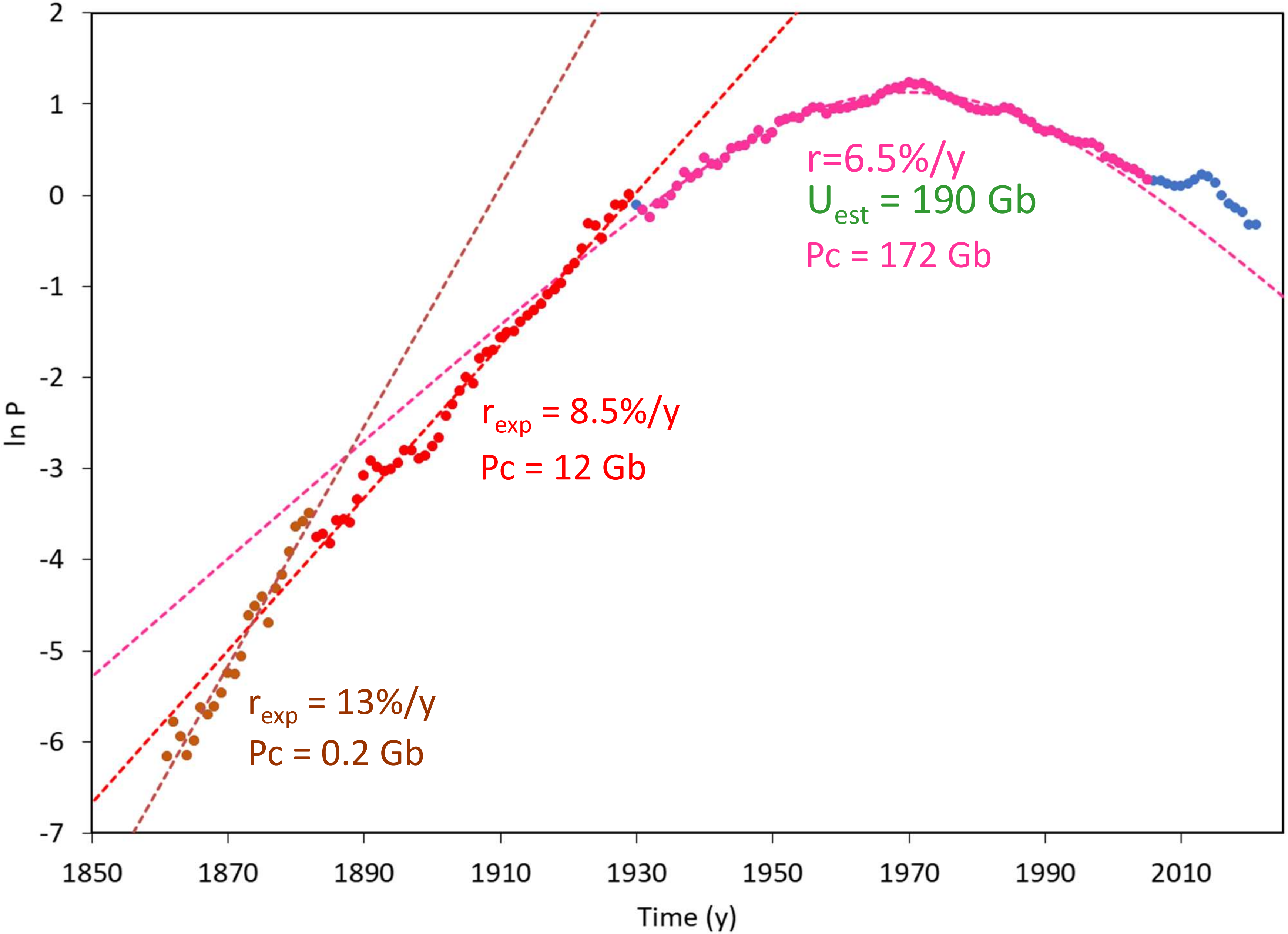




r_{exp} values form a straight line crossing the vertical axis at r

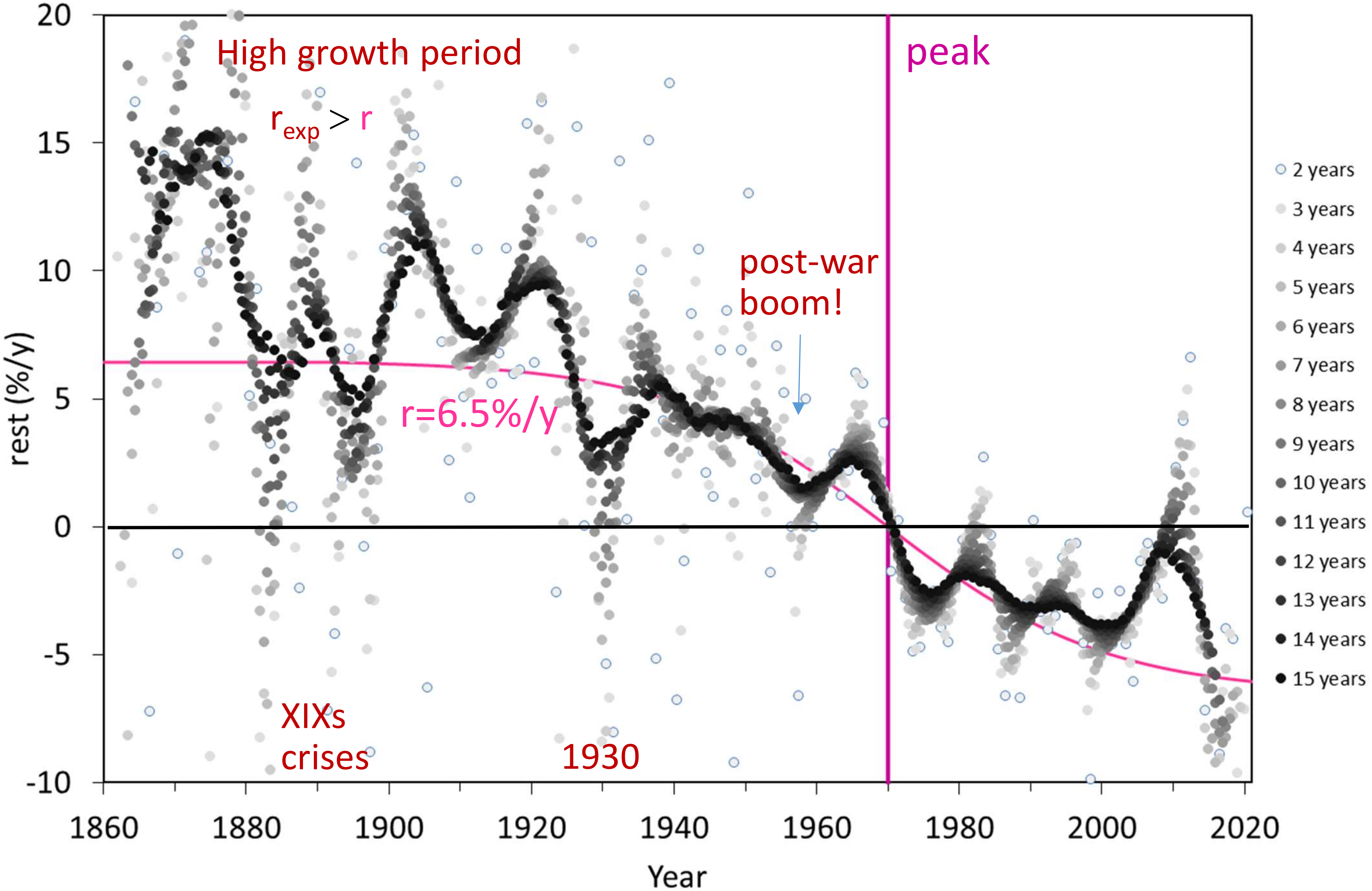
horizontal axis at U/2

USA lower-48



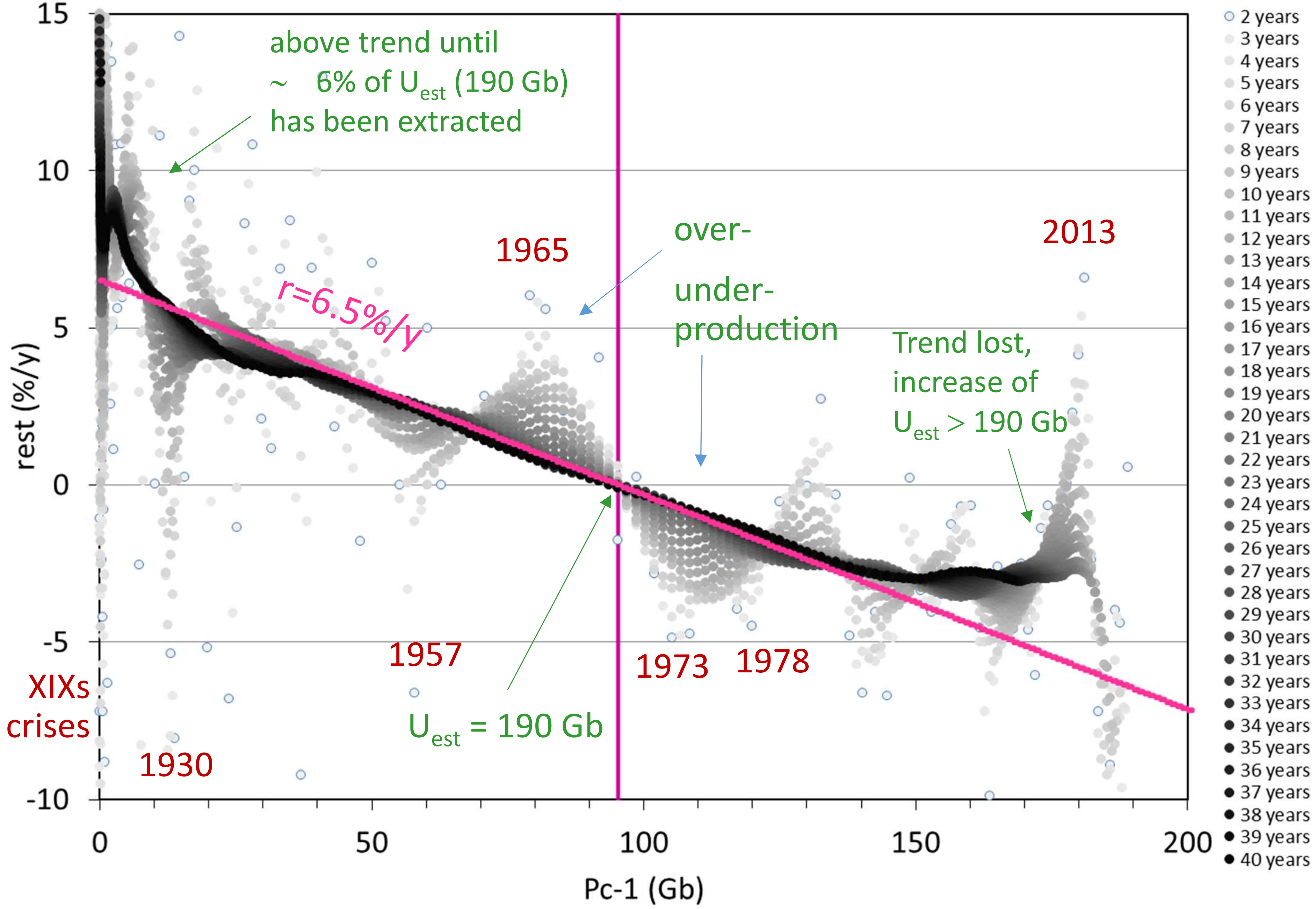
2
1
0
-1
-2
-3
-4
-5
-6
-7
ln P
1850
1870
1890
1910
1930
1950
1970
1990
2010
Time (y)
r=6.5%/y
U est = 190 Gb
Pc = 172 Gb
r exp = 8.5%/y
Pc = 12 Gb
r exp = 13%/y
Pc = 0.2 Gb

USA lower-48



High growth period
r_{exp} > r
peak
post-war boom!
r=6.5%/y
XIXs crises
1930
20
15
10
5
0
-5
-10
rest (%/y)
1860
1880
1900
1920
1940
1960
1980
2000
2020
Year
2 years
3 years
4 years
5 years
6 years
7 years
8 years
9 years
10 years
11 years
12 years
13 years
14 years
15 years

USA lower-48



15
10
5
0
-5
-10
rest (%/y)
0
50
100
150
200
Pc-1 (Gb)
above trend until
~ 6% of U est (190 Gb)
has been extracted
r=6.5%/y
1965
over-
under-
production
2013
Trend lost,
increase of
U est > 190 Gb
1957
1973
1978
XIXs
crises
1930
U est = 190 Gb
2 years
3 years
4 years
5 years
6 years
7 years
8 years
9 years
10 years
11 years
12 years
13 years
14 years
15 years
16 years
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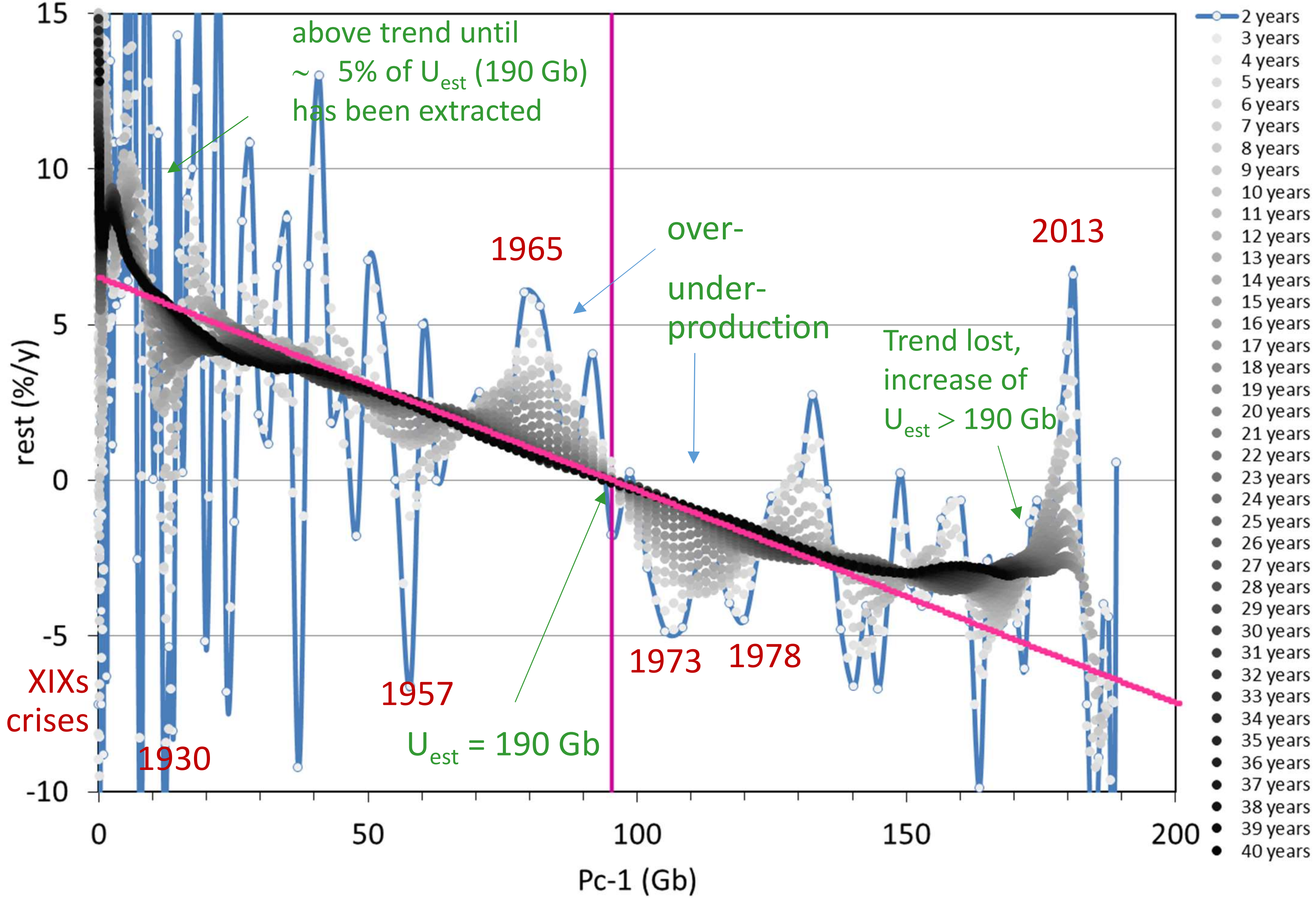
38 years
39 years
40 years

USA lower-48


15
10
5
0
-5
-10
rest (%/y)
0
50
100
150
200
Pc-1 (Gb)
above trend until
~ 5% of U_est (190 Gb)
has been extracted
1965
over-
under-
production
2013
Trend lost,
increase of
U_est > 190 Gb
XIXs
crises
1930
1957
U_est = 190 Gb
1973
1978
2 years
3 years
4 years
5 years
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7 years
8 years
9 years
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