SPRUCE BUDWORM AND OIL PRICE: A BIOPHYSICAL ANALOGY

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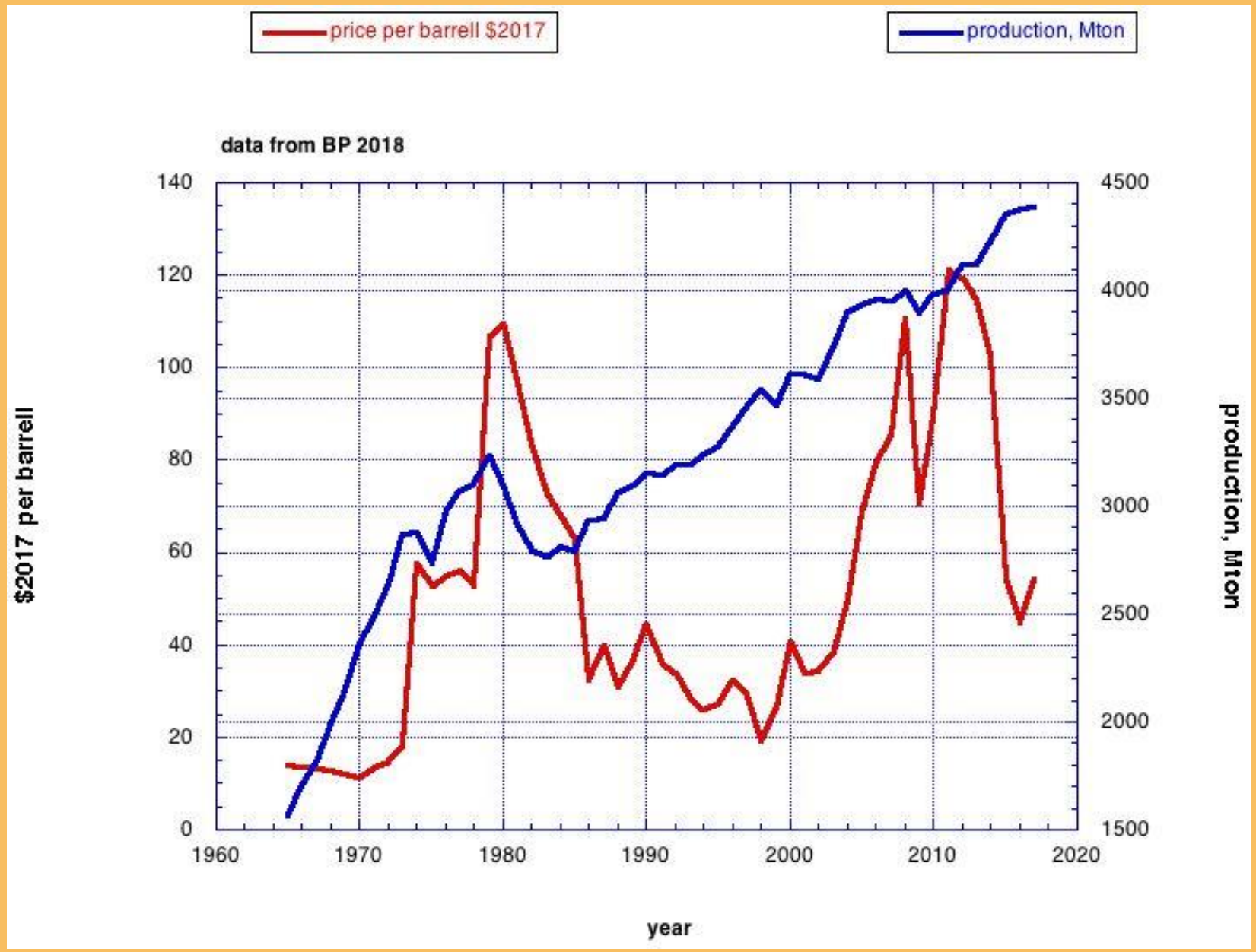
NATURAL OR ECONOMIC SYSTEMS DEPENDING ON TIME APPEAR TO HAVE A COMPLEX HISTORY



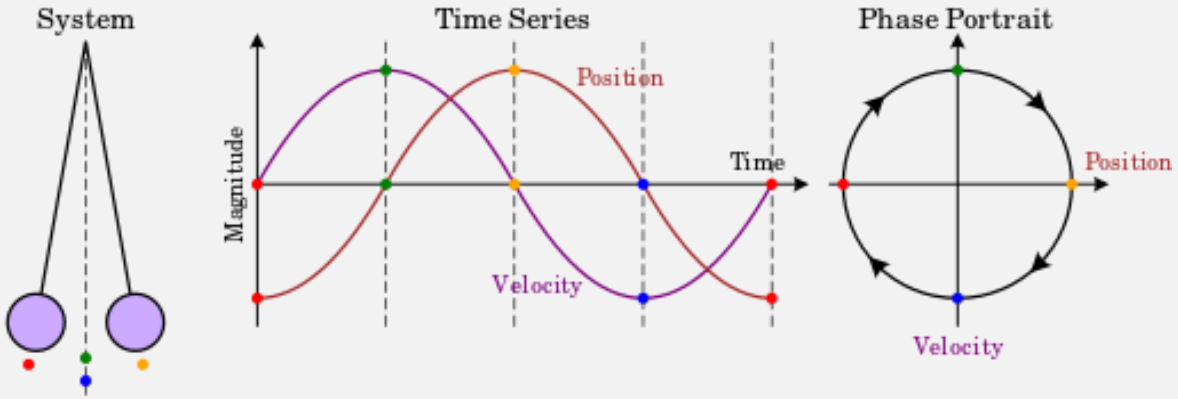
Unfortunately there
is no accepted general
criterion of evolution

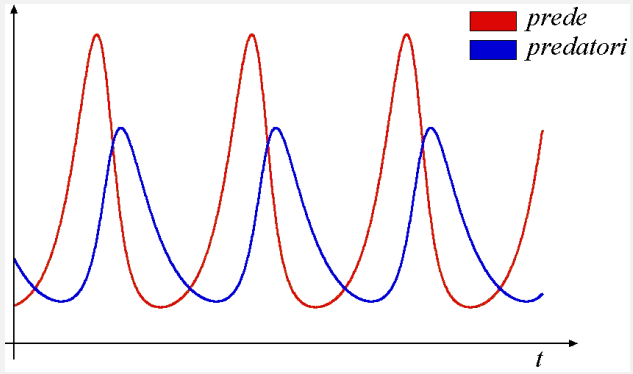
What are the possible approaches?

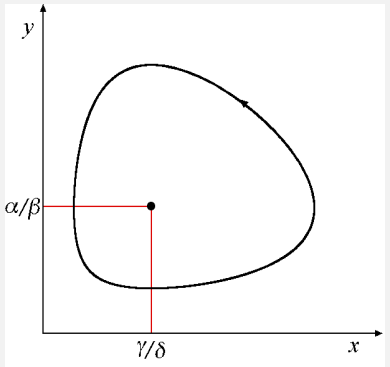
A possible answer consists
in changing the point of view:
the phase plot or portrait ,
i.e. to neglect the time variable
and consider
the relation between
the main variables as commonly
done in mechanics: e.g.: pendulum

Phase portraits may help to simplify and better understand

Mechanics, ecology, climate…







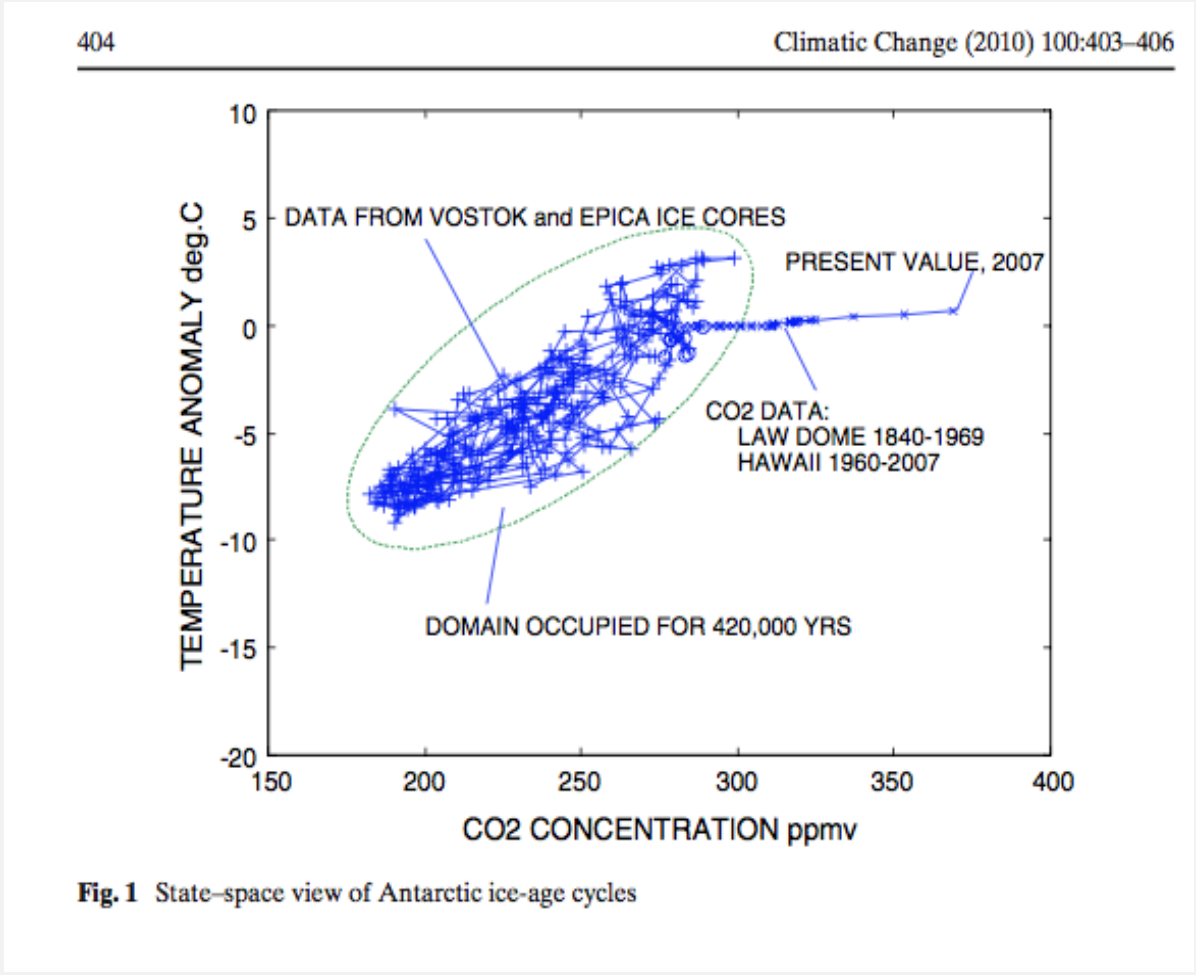
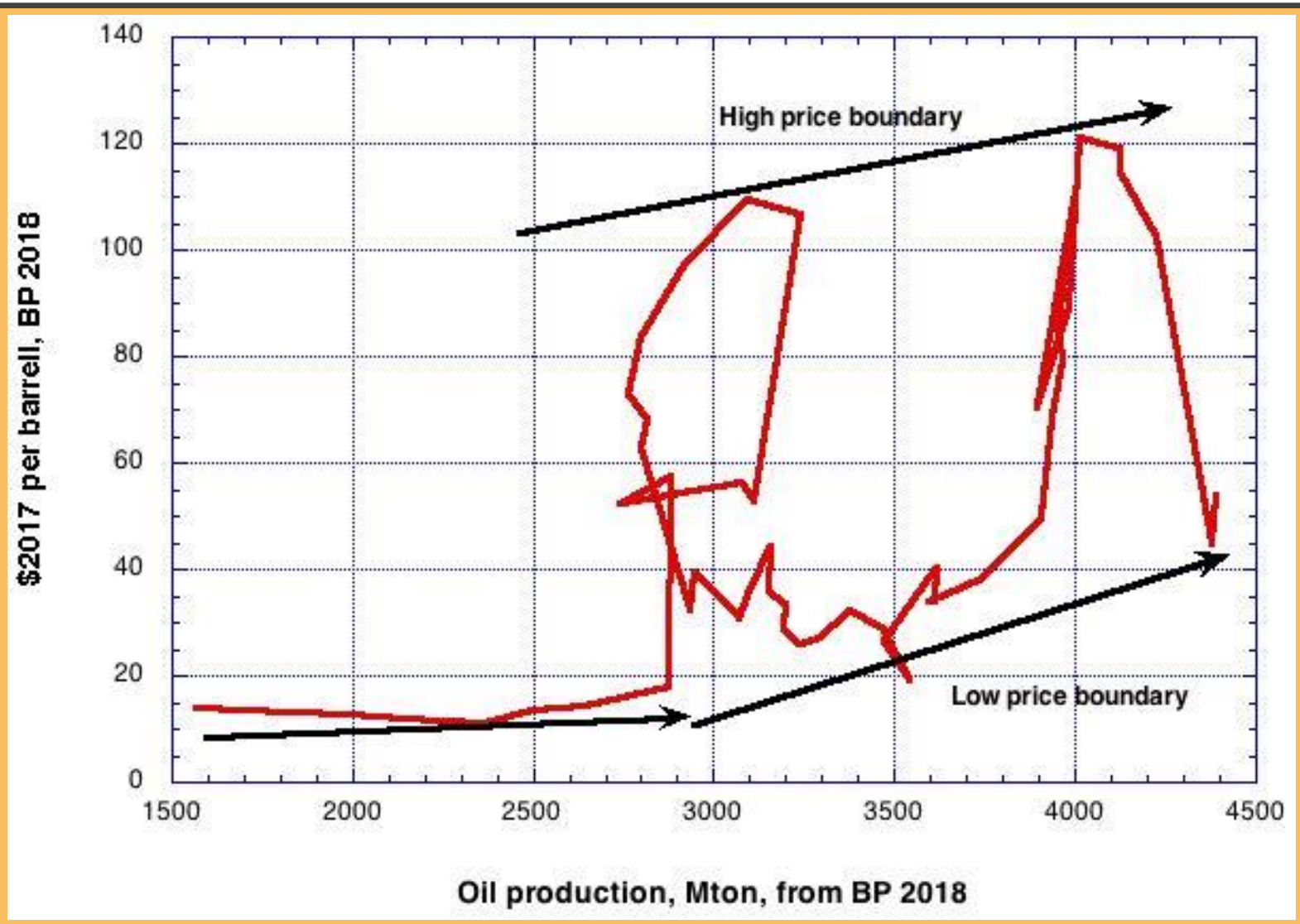


Fig. 1 State–space view of Antarctic ice-age cycles

PHASE PORTRAIT OF THE OIL MARKET

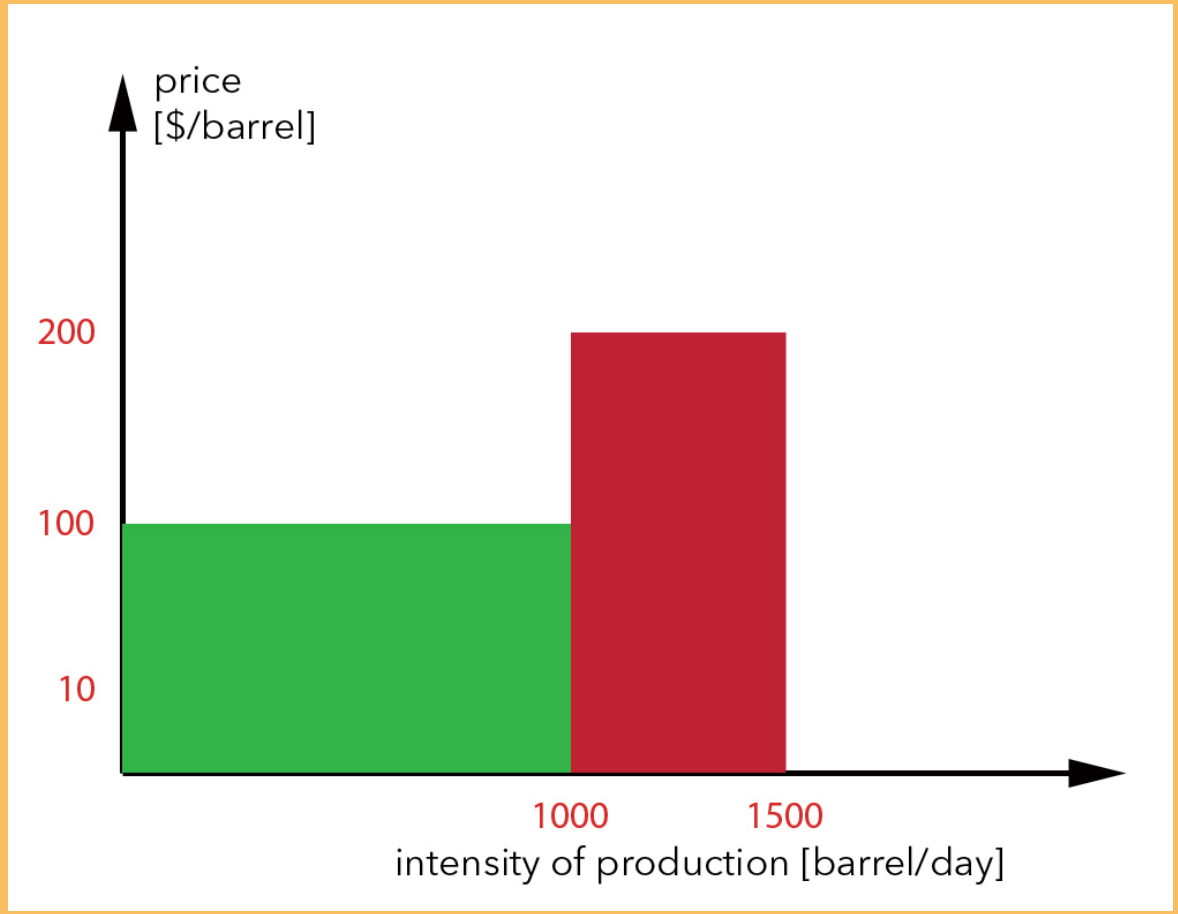
The phase portrait of the oil market shows two boundaries, one at high and one at low price.
The lower boundary is probably related to the increasing EROEI.
While the higher one is the limit which can be supported by the market and stimulate a strong investment.



Phase plot oil production vs. price, years 1965-2017 , redline is a timeline, arrows indicate boundary prices .

SCHEMATIC ORIGIN OF THE TWO BOUNDARIES

This is only a scheme,
In fact there are
many intermediate
levels of price
and intensity of
productions
which may work as
boundaries
in different conditions.



Intensity of oil production vs. price.

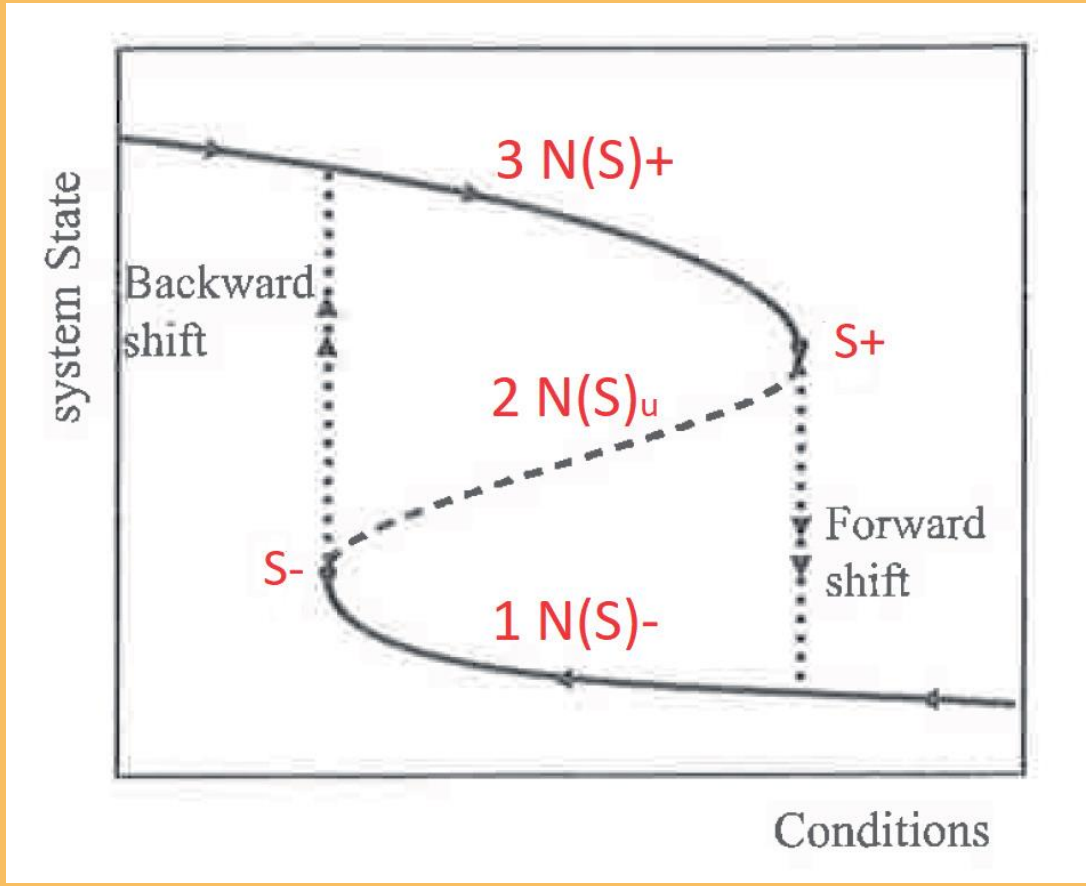
GOING FORWARD

- Economic and ecological systems are typically close to equilibrium conditions.

- Therefore, by assuming that an economic or ecological system can be described as a dynamical system, with appropriate dynamic variables and model parameters, regular behaviors are typically expected (e.g., limit cycles around a stable equilibrium).

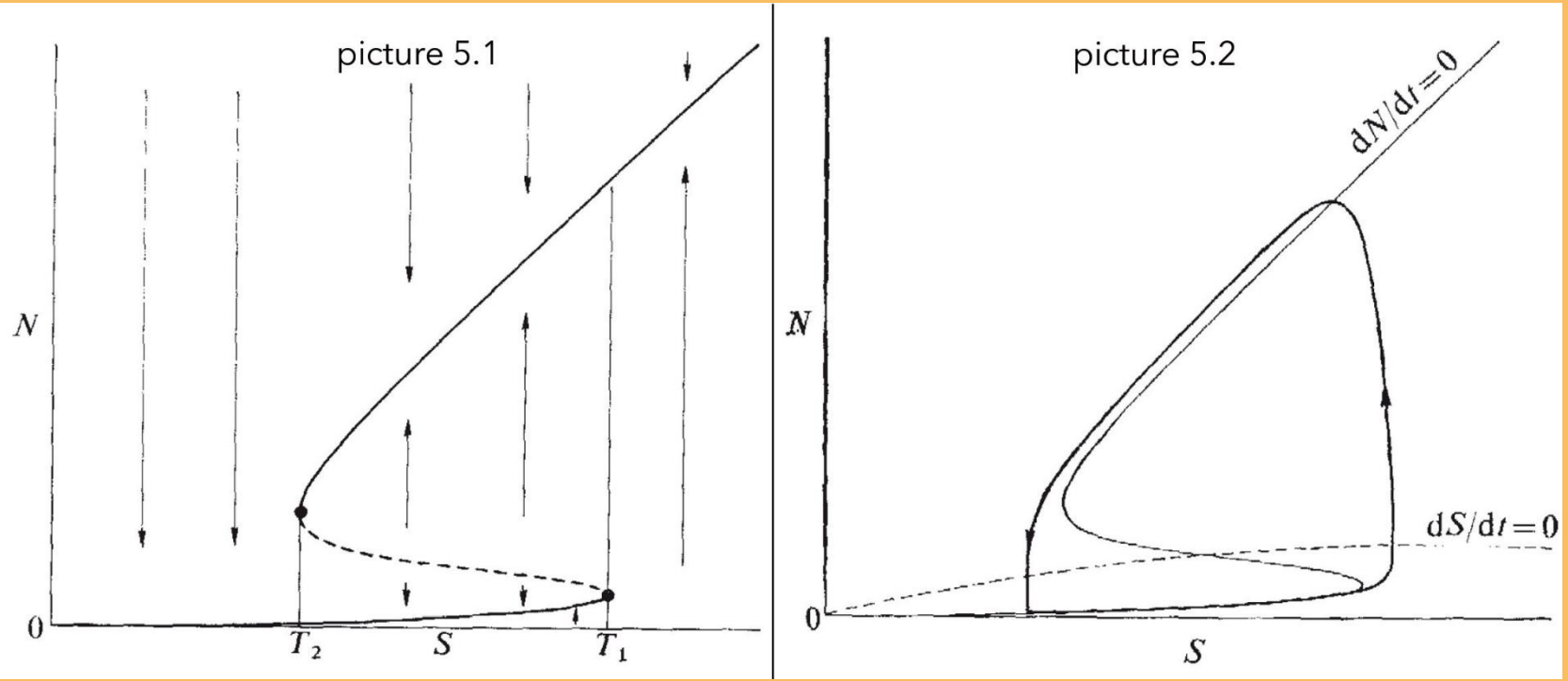
- Whenever sudden changes in the regular behavior of the system occur, due to slow variations of the parameters, some phenomenon related to bifurcation and catastrophe theory is likely to be involved.

CRITICAL PARAMETERS IN A SYSTEM



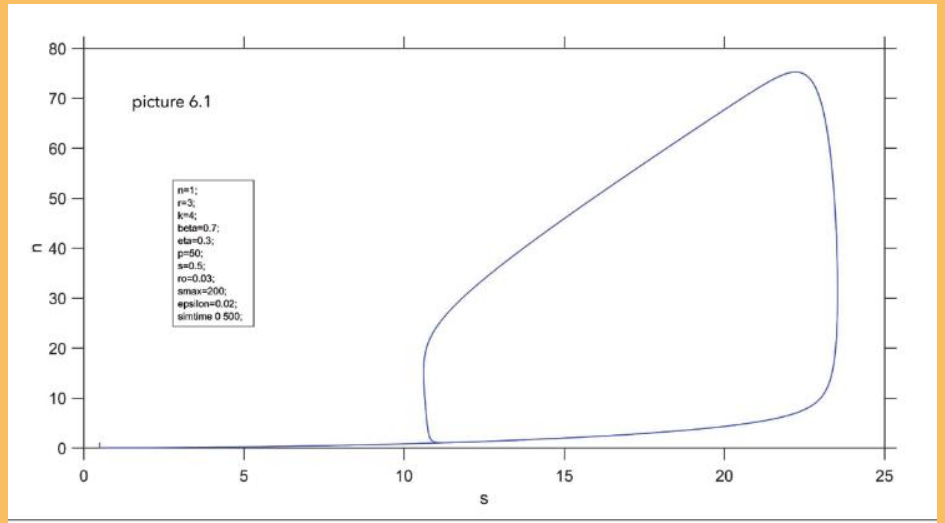
Equilibria of the system – from Scheffer (2009).

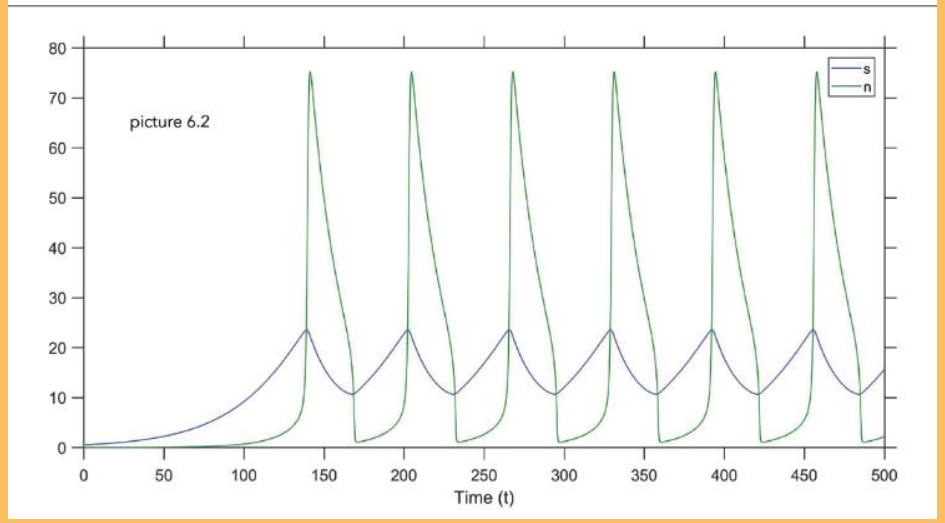
THE ECOLOGICAL CASE: THE AMERICAN SPRUCE BUDWORM



5.1: *The equilibrium budworm population. N, shown as a function of the average leaf area per tree, S.*
5.2: *The (solid dN/dt=0) equilibrium curve for budworms. N, as a function of foliage S (as indicated in 5.1, where the dashed line is the non-equilibrium range $N(S)_u$) – from May (1977).*

THE ECOLOGICAL CASE: THE AMERICAN SPRUCE BUDWORM





6.1: *The Matlab simulation for the phase plot caterpillars' population vs. spruces foliage and* (**6.2**) *the same values in time.*

EQUATIONS FOR THE SPRUCE BUDWORM

$$\begin{cases} \dfrac{dN}{dt} = rN\left(1 - \dfrac{N}{kS}\right) - \beta P \dfrac{N^2}{\eta^2 S^2 + N^2} \\ \dfrac{dS}{dt} = \rho S\left(1 - \dfrac{S}{S_{max}}\right) - \varepsilon N \end{cases}$$

N = population of budworms
S = spruce biomass is a parameter whose maximum value is denoted with S_max
ε = loss parameter for spruce due to budworm density
ρ = intrinsic growth rate of spruces
r = intrinsic growth rate of budworms
k =carrying capacity due to the mean leaf area per tree
β = predator attack rate per predator
P = number of predators of budworms
η = budworm density per unit leaf area

CHOOSING THE CORRESPONDING VARIABLES

- Considering a sudden variation, the vertical variable N can only be related to the oil price due to "rigid" character of EROEI
- While the price may suddenly vary the same is not true for EROEI, because of the necessary complex research and investments
- When EROEI is very low this is associated with a fast increase of mean prices, due to the difficulty to extract the resource at contained energy costs; on the contrary a very high EROEI will favour high production levels and will have the role of decreasing the prices.
- These observations suggest to identify:
- population N of budworms with the oil mean price N;
- Biomass S of spruces with the reciprocal of EROEI, a variable which is low when EROEI is high and viceversa. It may be considered as an index of energetic cost, necessary to extract a unit of useful energy.

EQUATIONS FOR THE OIL MARKET

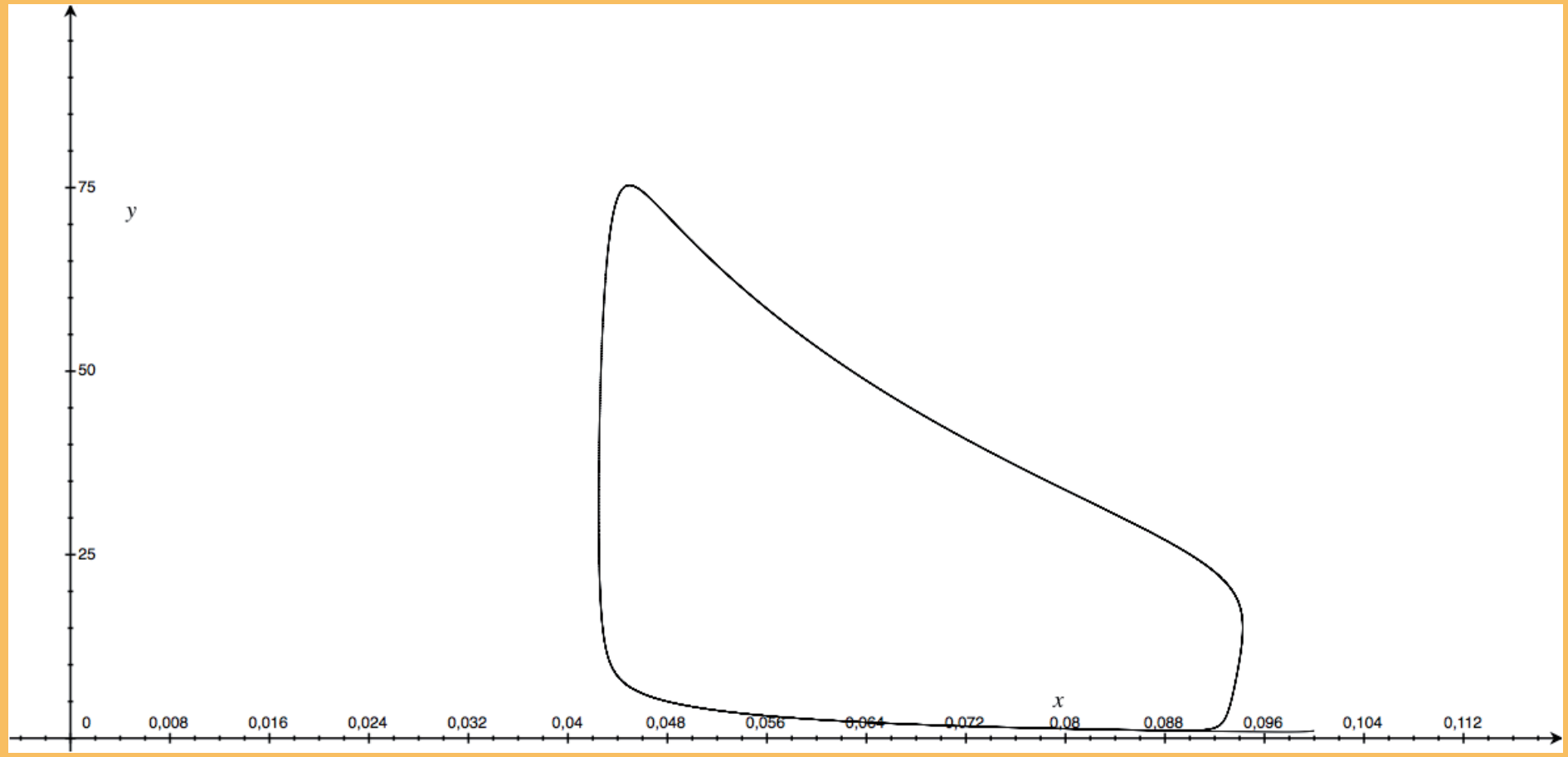
$$\begin{cases} \frac{dN}{dt} = rN\left(1 - \frac{N}{kS}\right) - \beta P \frac{N^2}{\eta^2 S^2 + N^2} \\ \frac{dS}{dt} = \rho S\left(1 - \frac{S}{S_{max}}\right) - \varepsilon N \end{cases}$$

OR

$$\begin{cases} \frac{dN}{dt} = rN\left(1 - \frac{1}{k}NE\right) - \beta P \frac{N^2}{\eta^2/E^2 + N^2} \\ \frac{dE}{dt} = \rho\left(\frac{1}{S_{max}} - E\right) + \varepsilon N E^2 \end{cases}$$

- E= EROEI or 1/S and N=price
- *rN* : shows the "natural" tendence of the price to increase due to the intrisic limits of the resource
- *1-NkS* : the price cannot go above a limit kS(the highest boundary). This maximum price is proportional to 1/EROEI, increases while the EROEI decreases.
- *- βPN ^{2}/(η^2/(E2+N2))* : when N/S = PRICE * EROEI ("Money Return on Energy Investment") is high the investments are stimulated, production increases and puts a limit on mean price. This effect has a limit at *-bP*. It is reasonable to model an increase in time of bP to represent the non cyclic behaviour of the process (after all the resource is limited and thus the cycle is not perfectly reproducible.
- If N/S = PRICE * EROEI is low, finantial support for investments is reduced and the effect on the price is minimum.
- *rS* : the variable1/EROEI spontaneously increases or equivalently the EROEI decreases (in the mean).
- *1-S/Smax* the variable 1/EROEI cannot go above S_{max} or equivalently EROEI cannot go below1/ S_{max}, otherwise the resource is not useful.
- S_{max} could increase in time to show the non perfectly cyclic behaviour of the resource
- *-εN* : high price levels have a depressive effect on 1/EROEI, they favour the increase of EROEI bacuse may push direct investments for a better exploitation of the resource.

THE OIL CASE: THE PHYSICAL QUANTITIES ANALOGY



Limit cycle for y axis N=price and x axis E=Eroei, the cycle is clockwise.

COMPARISON WITH THE COURT-FIZAINE EROEI

- Is the EROEI accepted behaviour compatible with our proposal?
- The only data of EROEI with a global character are those by Court and Fizaine(2017) : they consider a hyperbola-like function for the relationship of price and EROEI
- This hyperbola-like function is similar to that foreseeble on the basis of the catastrophe theory; but there is an important difference:
- There are at least two different hyperbola-like constants or functions, one for increasing EROEI/diminishing price situation and a different one for the opposite case
- So in conclusion with a limited variation this point of view may be in agreement with the most recent results on EROEI history

CONCLUSIONS

- The behaviour of some economic complex system may be reasonably interpreted using the general results obtained from dynamic system theory
- In particular the oil market shows a phase portrait with two price levels reasonably connected with different EROEI levels
- This observation suggest a similarity with a prey-predator system, in which the price and the EROEI (or the EROEI reciprocal) have the role respectively of the predator and the prey as it appears in the case of the budworm and spruce;
- The fast variation of the price is equivalent to explosive growth of the budworm which destroy the spruce foliage (the reciprocal of EROEI) when leaves density is sufficiently high;
- The hyperbola-like correlation between price and EROEI, suggested by Court and Fizaine appears confirmed but two different constants should be used for decreasing price and for increasing price situations.
- NONE of these effects should be considered as a direct cause-effect but alternatively as a feedback mechanism
- A set of differential equations has been written and used to model the system

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