Macroscale Modeling Linking Energy and Debt

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RESEARCH QUESTION

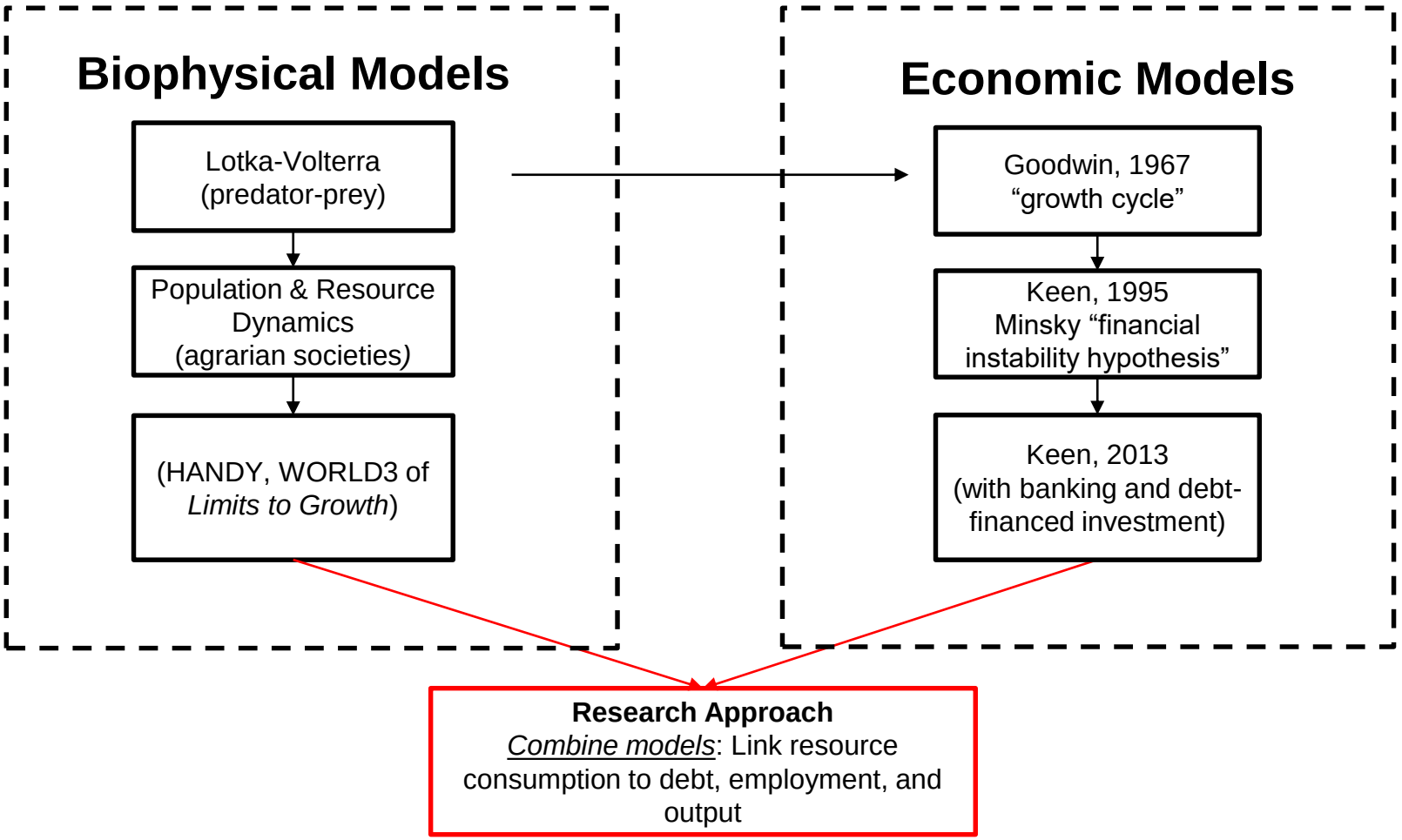
To understand how energy/resource extraction are linked with long-term economic outcomes, including the accumulation of debt in the economy

PROBLEM STATEMENT

Many economic models implicitly assume that energy resources are not constraints on the economy.

These energy-related constraints have to be introduced if we are to effectively understand long-term debt and natural resource interactions.

Goal: Merge "simple" Biophysical and "simple" Economic/Finance Models



Biophysical Model: "HANDY"

A 4-variable thought-experiment model for interaction of humans and nature developed on the concepts of the Predator-Prey Model

i. Rate of change of commoner's population

$$\frac{d}{dt}x_c = \text{Births - Deaths}$$

iii. Rate of change of nature available for extraction

$$\frac{d}{dt}\mathrm{y} = \text{Regeneration of Nature – Extraction of Nature by Commoners}$$

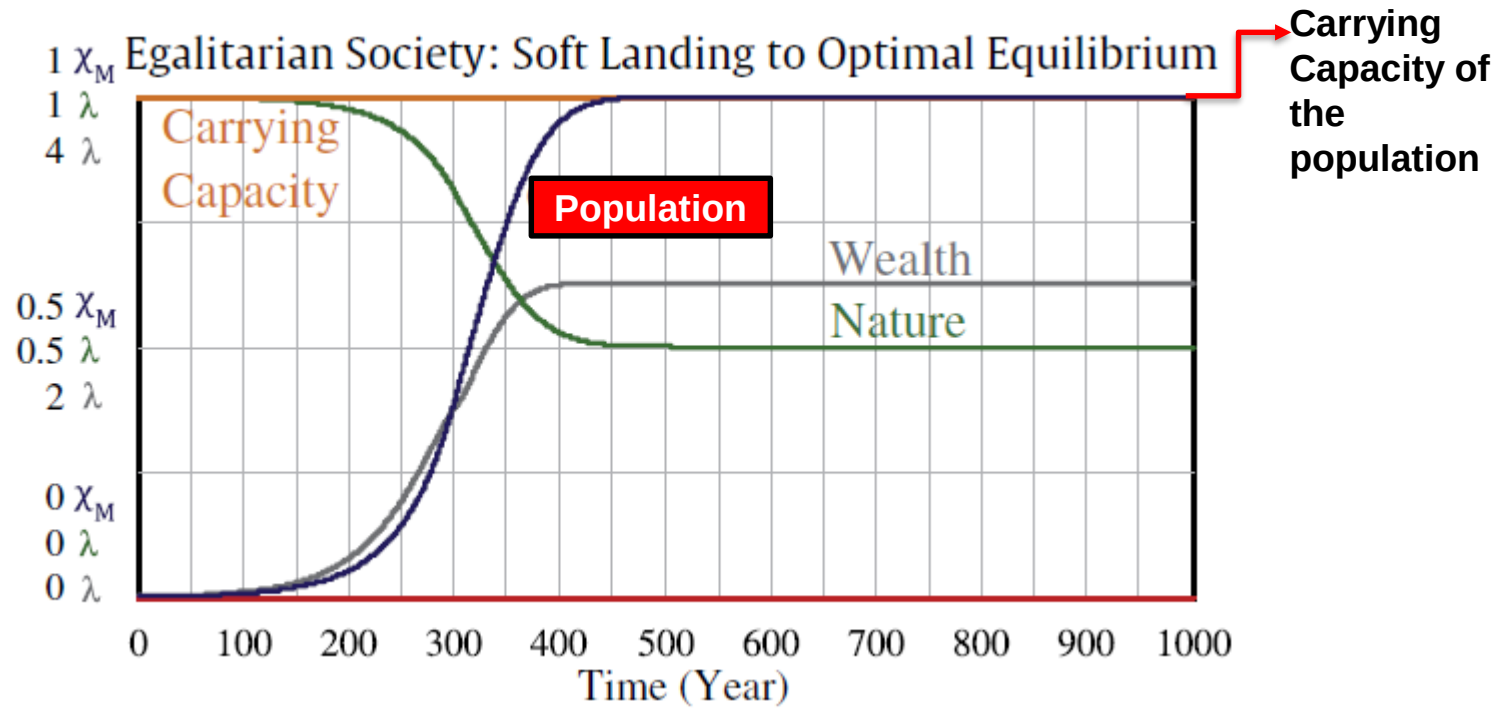
iv. Rate of change of wealth accumulated due to extraction of nature

$$\frac{d}{dt}\mathrm{w} = \text{Extracted Nature – Consumption by the population}$$

***Source**: Mothesharrei, S., Rivas, J. & Kalnay, E. 2014. Human and nature dynamics (HANDY): Modeling inequality and use of resources in the collapse or sustainability of societies. Ecological Economics, 101, 90-102.*

Biophysical Model: "HANDY"

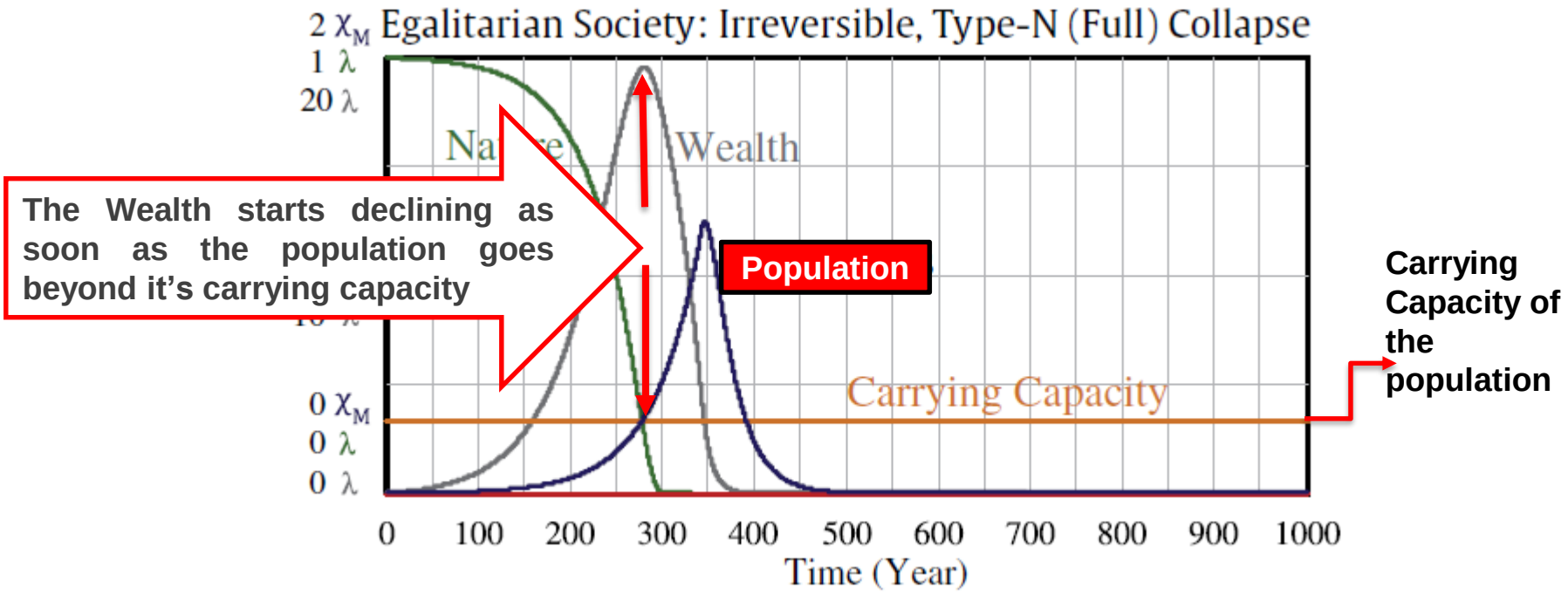
A sustainable steady state occurs if nature extraction is equal to nature's regeneration rate



(Mothesharrei, et al., 2014)

Biophysical Model: "HANDY"

A high enough rate of extraction leads to total depletion of nature and eventually a collapse in the population



(Mothesharrei, et al., 2014)

Economic Model: "The Goodwin Model"

1. The Goodwin model is one of the first models that described cyclical behavior of the economy.

2. Goodwin's model describes the relationship between employment and wages of national income.

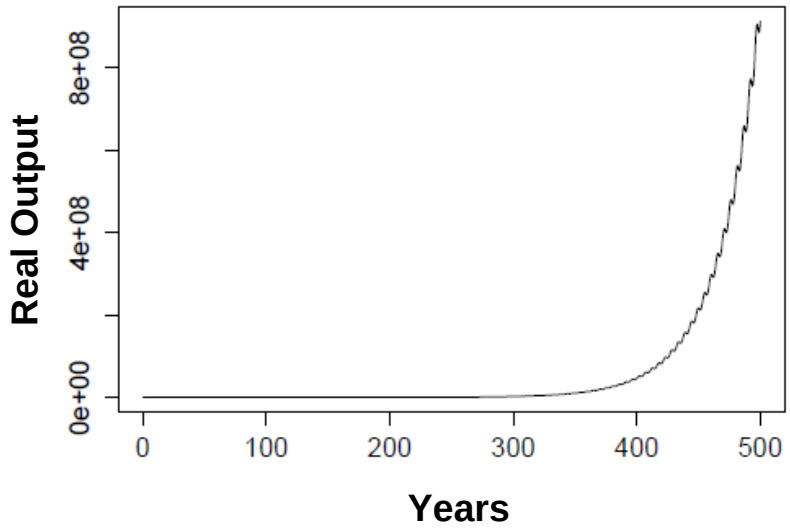
3. Keen's 1995 paper introduces debt in the Goodwin model to address Minsky's idea of the Financial Instability Hypothesis.

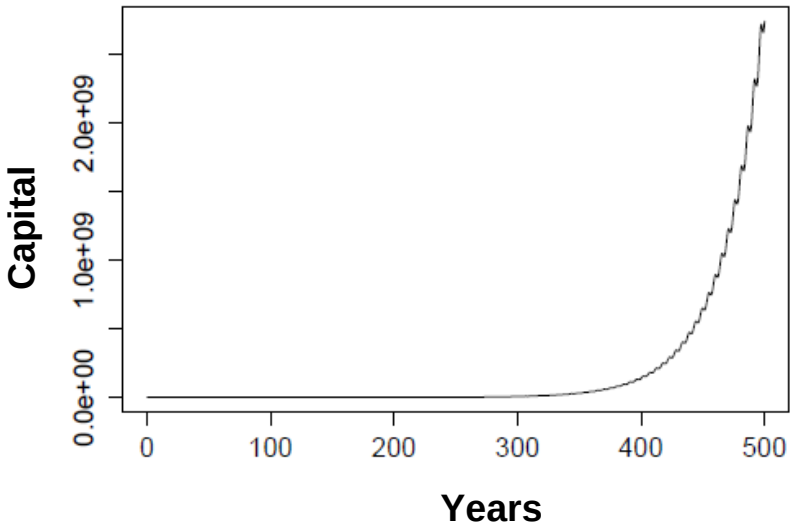
Simulating the Goodwin Model (per Keen 1995)

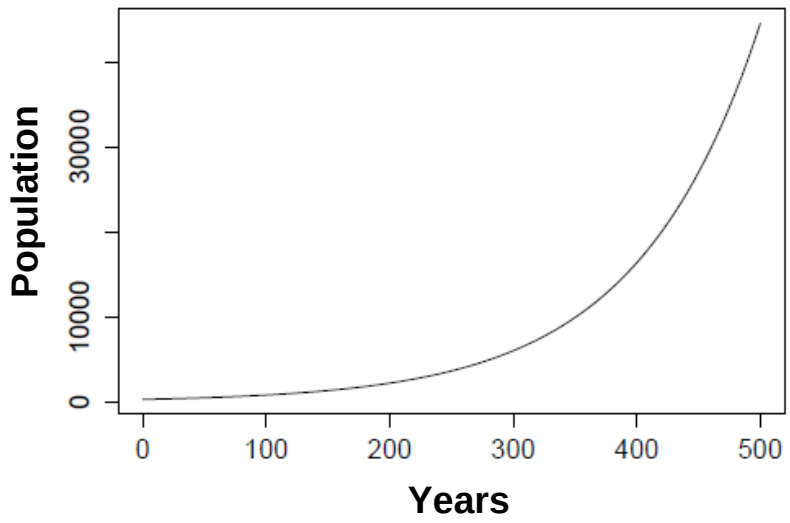
Goodwin Model assumes full capital utilization and Leontief production function: $Y = aL = \frac{K}{v}$;

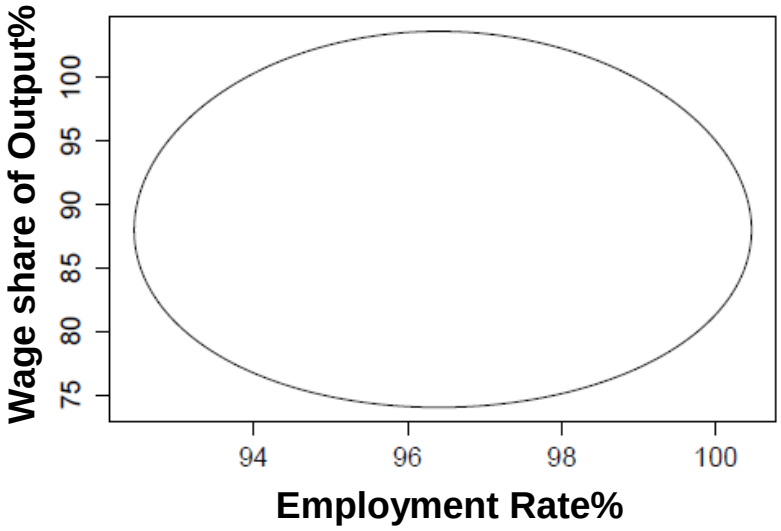
1. Output: **Investments – Depreciation**
2. Real Wages: **Change in wages as a function of employment rate**
3. Labor Productivity: **Exponential growth in labor productivity**
4. Population: **Exponential growth in population**

Results from the Goodwin Model









Merging "Goodwin Model" with "HANDY"

HANDY EQUATIONS

1. $\frac{d}{dt}x_c = \beta_c x_c - \alpha_c x_c$
2. $\frac{d}{dt}y = \gamma\, y\,(\lambda - y) - \delta x_c y$
3. $\frac{d}{dt}w = \delta x_c y - C_c - C_e$

GOODWIN EQUATIONS

1. $\frac{dY}{dt} = Y\left(\frac{I\left(\frac{\Pi}{vY}\right)}{v} - \gamma\right)$
2. $\frac{dw}{dt} = w\,(\lambda)w$
3. $\frac{da}{dt} = \alpha a$

Merged Equations

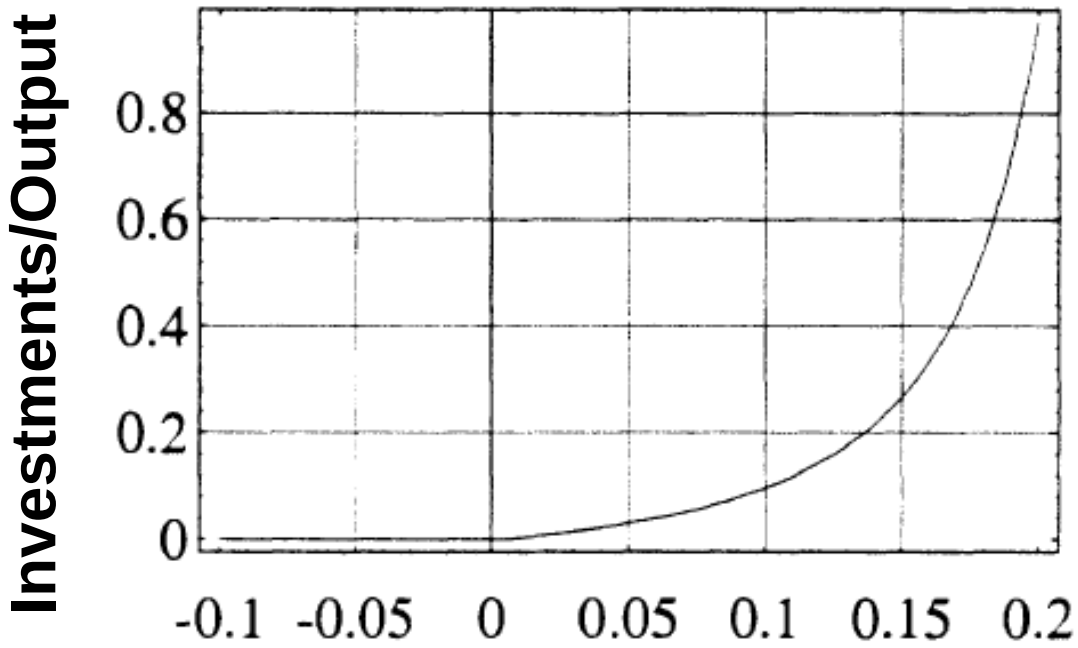
1. $\frac{d}{dt}x_{hc} = \beta_{hc}x_{hc} - \alpha_{hc}x_{hc}$
2. $\frac{d}{dt}y_h = \gamma_h y_h(\lambda_h - y_h) - \delta_h L y_h I\left(\frac{\Pi}{vY}\right)$
3. $\frac{d}{dt}w_h = \delta_h L y_h I\left(\frac{\Pi}{vY}\right) - C_{hc} - \gamma_h w_h$
4. $\frac{dY}{dt} = Y\left(\frac{I\left(\frac{\Pi}{vY}\right)}{v} - \gamma\right)$
5. $\frac{dw}{dt} = w\,(\lambda)w$
6. $\frac{da}{dt} = \alpha a$

Instead of having the total population extracting nature and generating wealth, we just have the labor in the merged model

Rate of extraction of nature as a function of investment function

The Idea behind the investment function in Keen 1995 was to incorporate Minsky's idea of Financial Instability Hypothesis

Investment is zero at and below zero profit, rising to equal profits when the profit share is 10 percent, and exceeding profits for higher profit shares



(Keen, et al., 1995)

Merging "Goodwin Model" with "HANDY" and "Debt"

HANDY EQUATIONS

1. $\frac{d}{dt}x_c = \beta_c x_c - \alpha_c x_c$
2. $\frac{d}{dt}y = \gamma\, y\,(\lambda - y) - \delta x_c y$
3. $\frac{d}{dt}w = \delta\, x_c y - C_c - C_e$

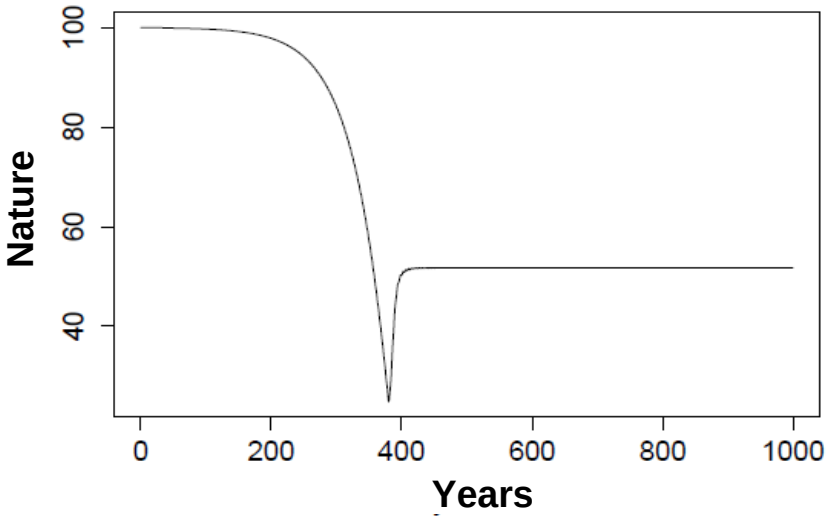
KEEN-GOODWIN EQUATIONS

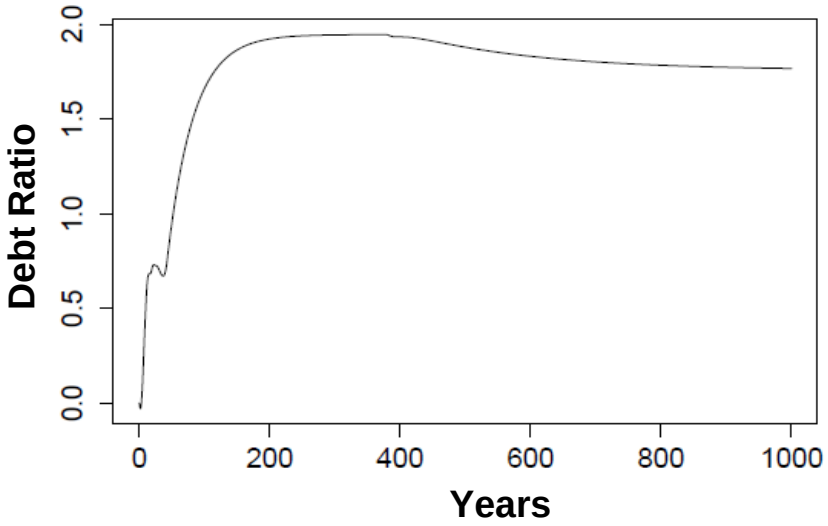
1. $\frac{dY}{dt} = Y\left(\frac{I\left(\frac{\Pi}{v \cdot Y}\right)}{v} - \gamma\right)$
2. $\frac{dw}{dt} = w\,(\lambda)w$
3. $\frac{da}{dt} = \alpha a$
4. $\frac{dD}{dt} =$ **Investment - Profit**

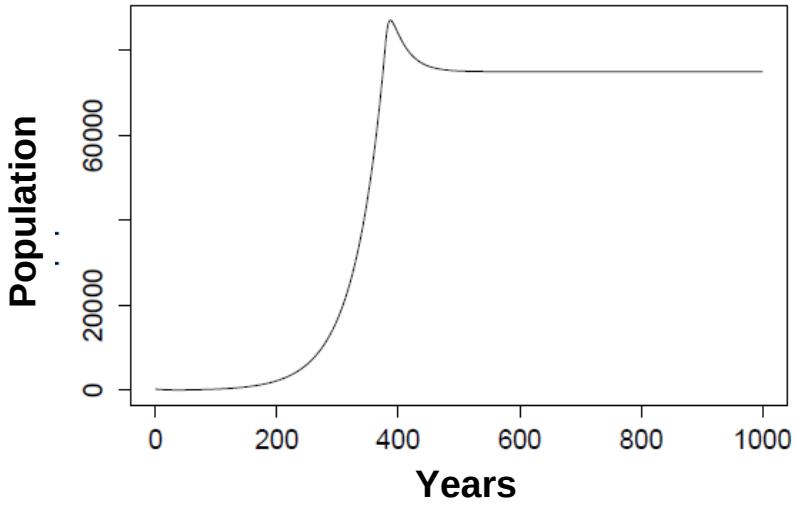
Merged Equations

1. $\frac{d}{dt}x_{hc} = \beta_{hc}x_{hc} - \alpha_{hc}x_{hc}$
2. $\frac{d}{dt}y_h = \gamma_h y_h(\lambda_h - y_h) - \delta_h L y_h I\left(\frac{\Pi}{vY}\right)$
3. $\frac{d}{dt}w_h = \delta_h L y_h I\left(\frac{\Pi}{vY}\right) - C_{hc} - \gamma_h w_h$
4. $\frac{dY}{dt} = Y\left(\frac{I\left(\frac{\Pi}{vY}\right)}{v} - \gamma\right)$
5. $\frac{dw}{dt} = w\,(\lambda)w$
6. $\frac{da}{dt} = \alpha a$
7. $\frac{dD}{dt} = I\left(\frac{\Pi}{vY}\right)Y - \Pi$

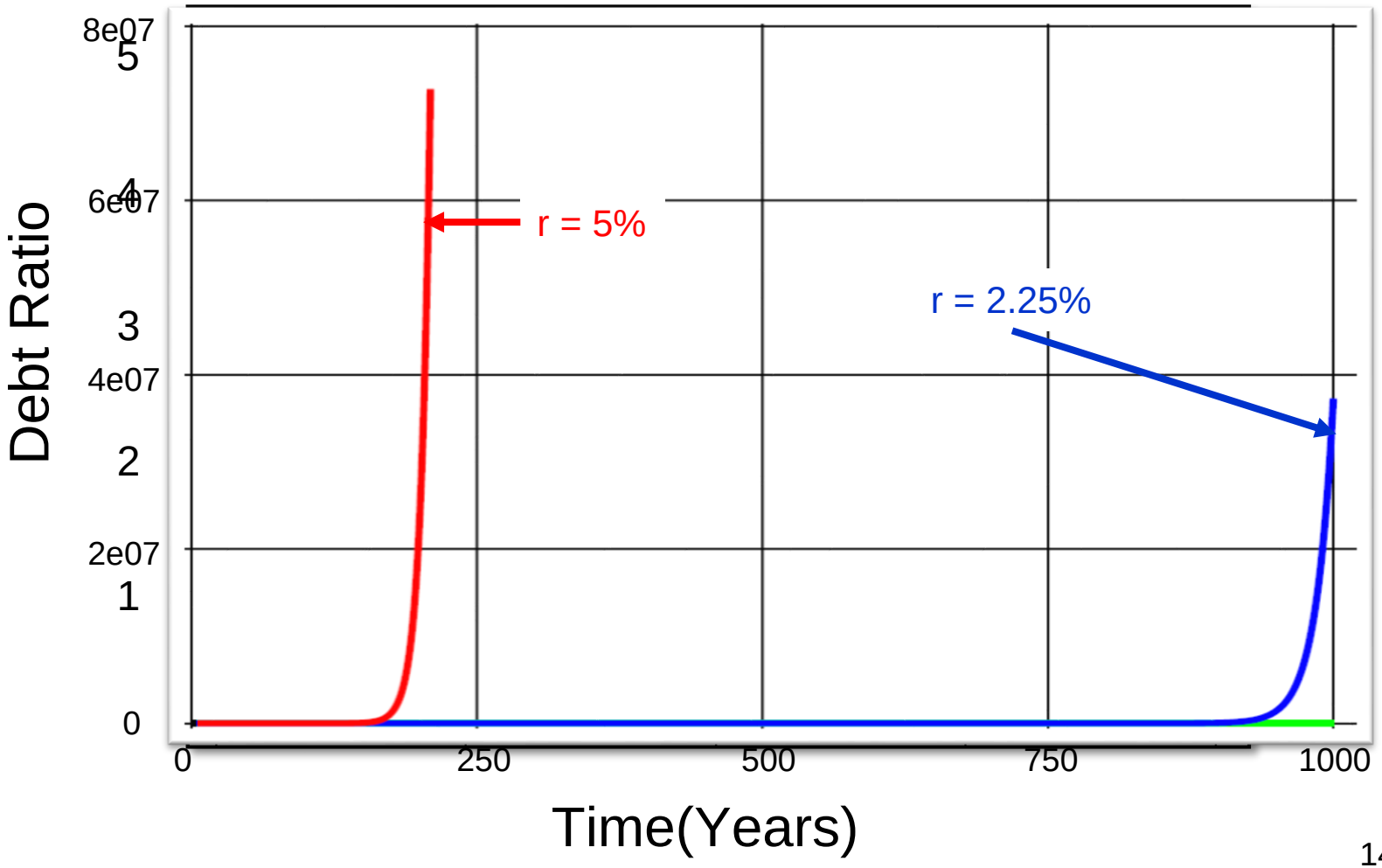
Simulating steady state in the merged model at a “low” interest rate “r=1.5%” and a “low” extraction rate of nature “δ”



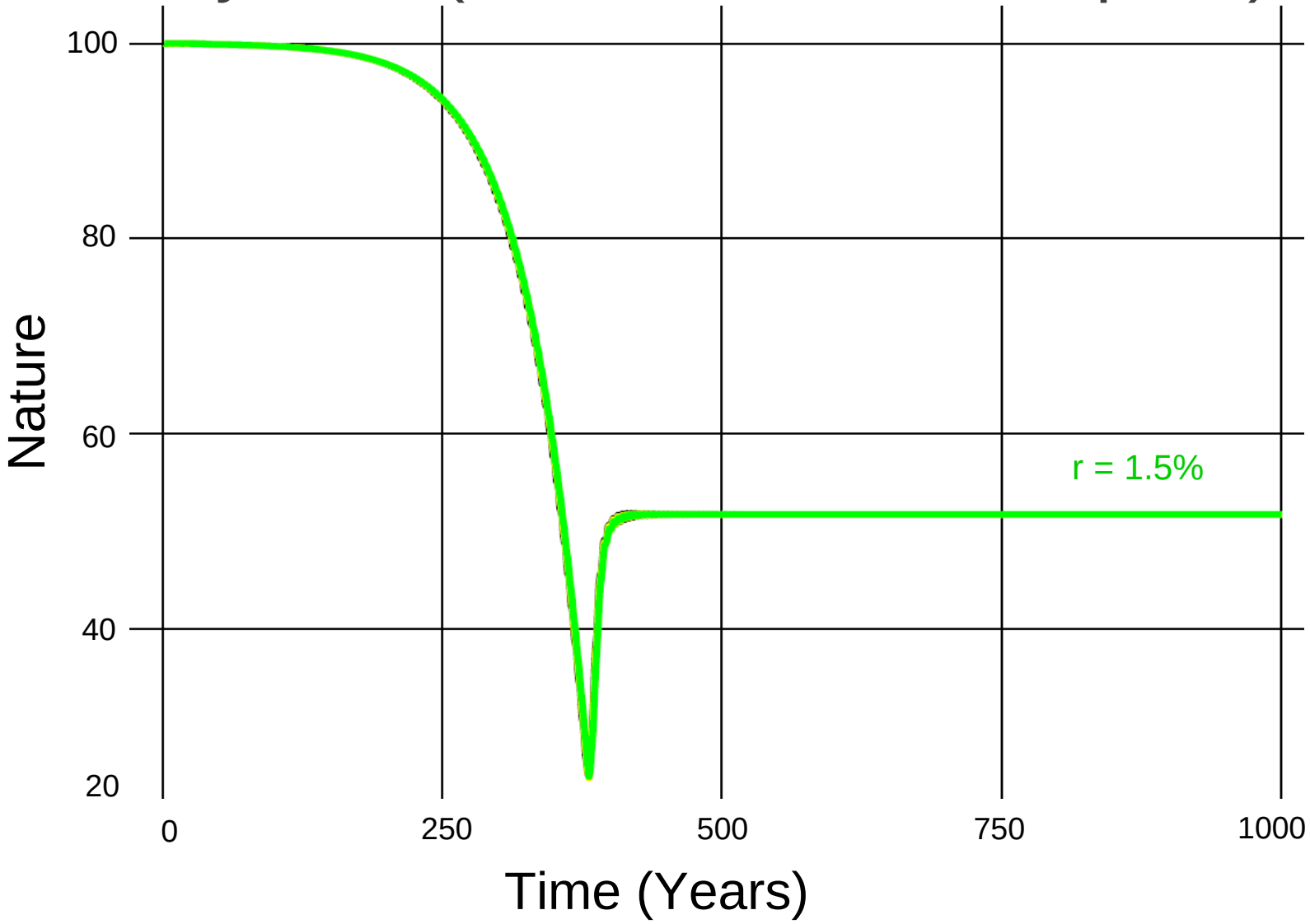




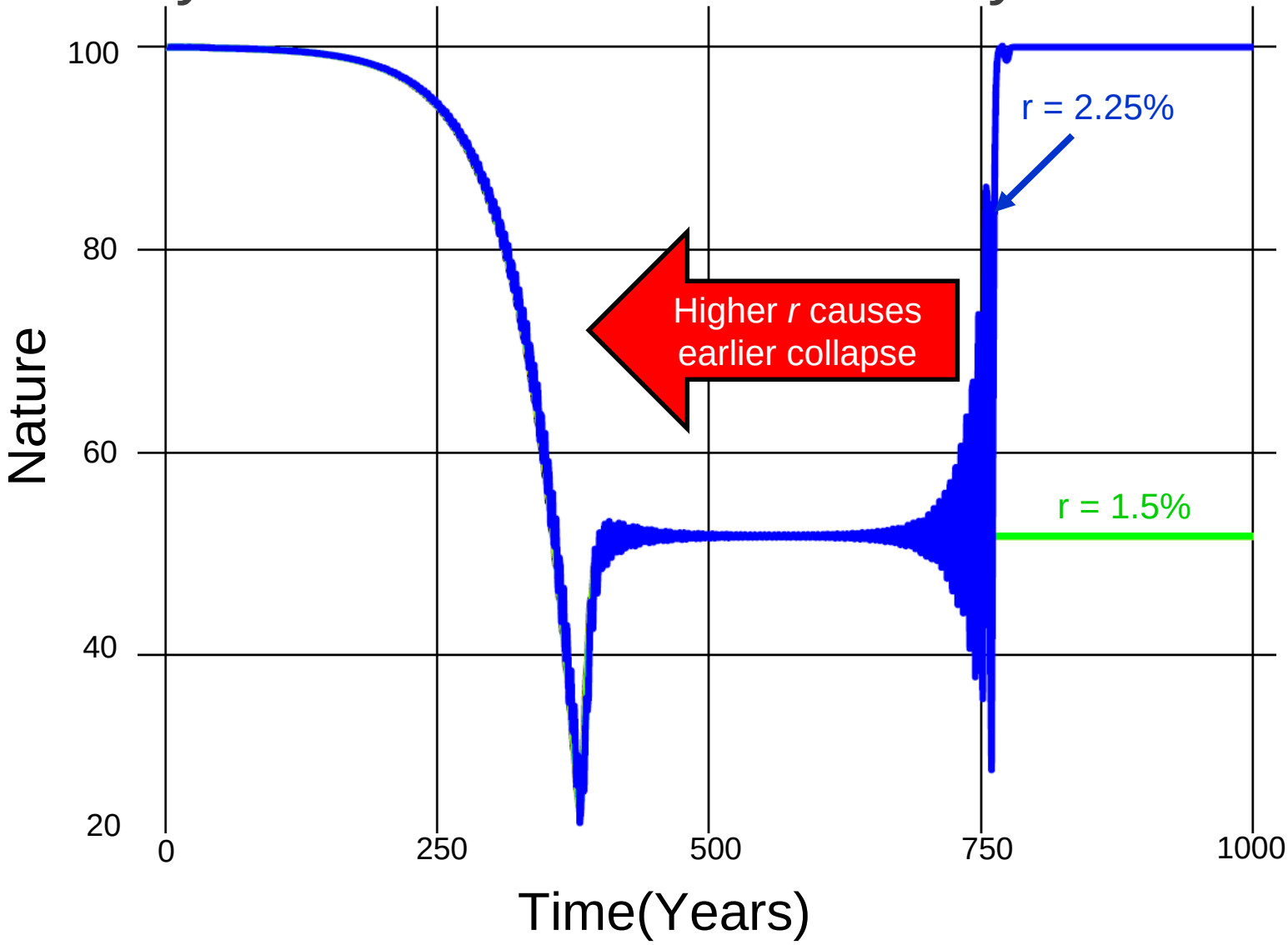
Debt Ratio (Debt/Output) increases continuously for interest rate > 2%



At “low” interest rate Nature reaches a stable steady state (extraction = consumption)



A “high enough” interest rate (e.g., r > 2%) eventually causes financial instability and collapse



Keen (1995) "Minsky model" shows eventual instability at high interest rates

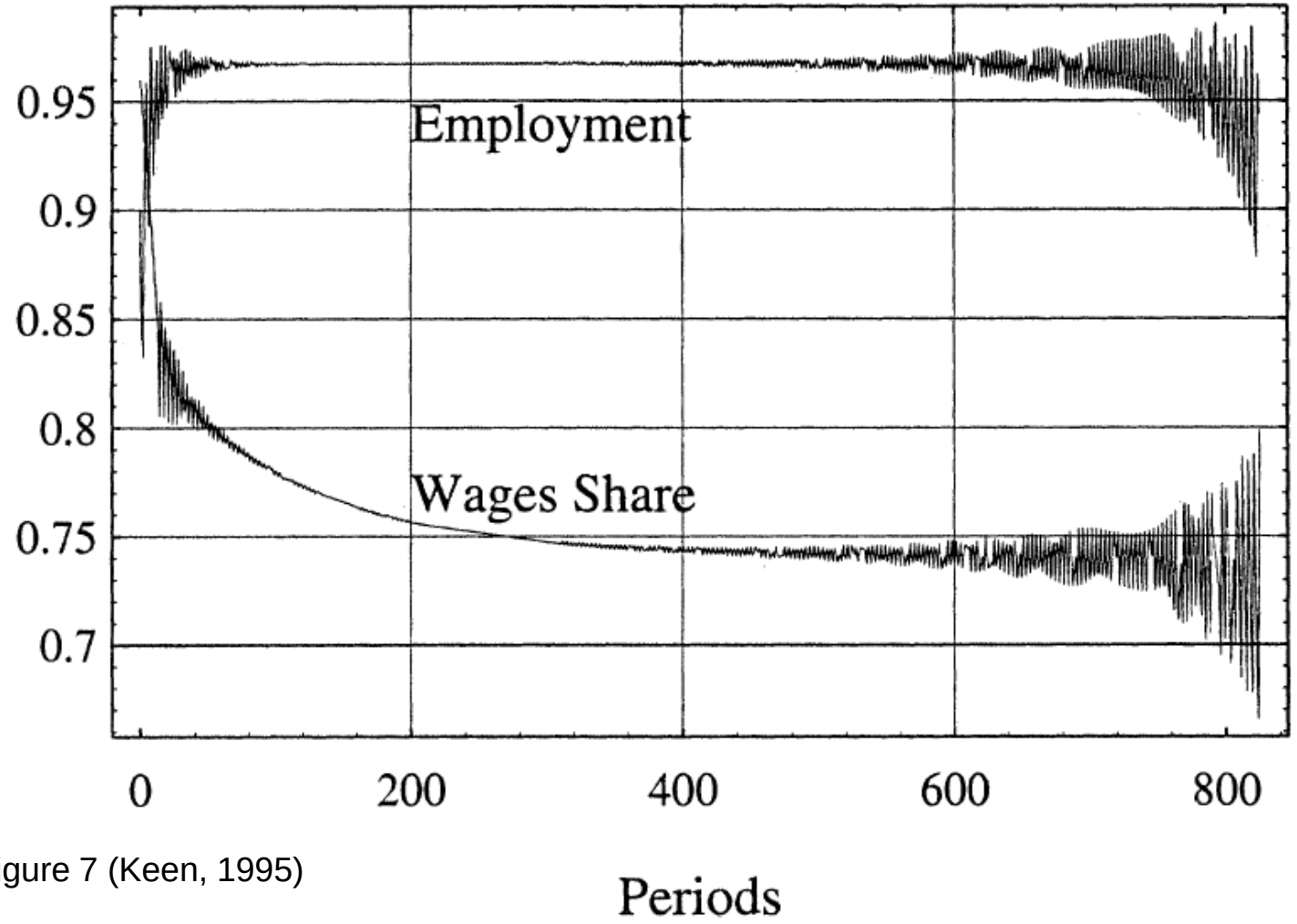
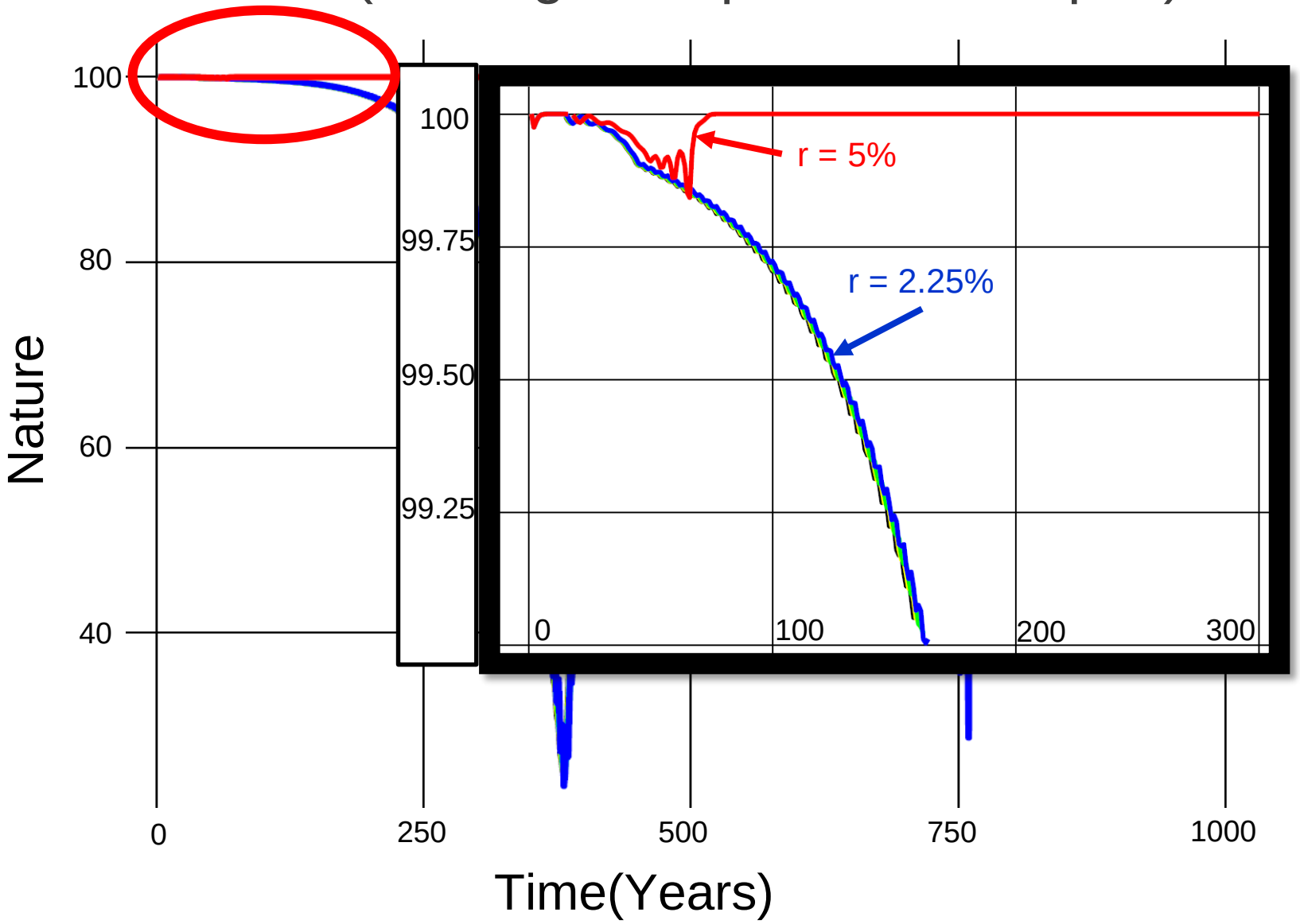
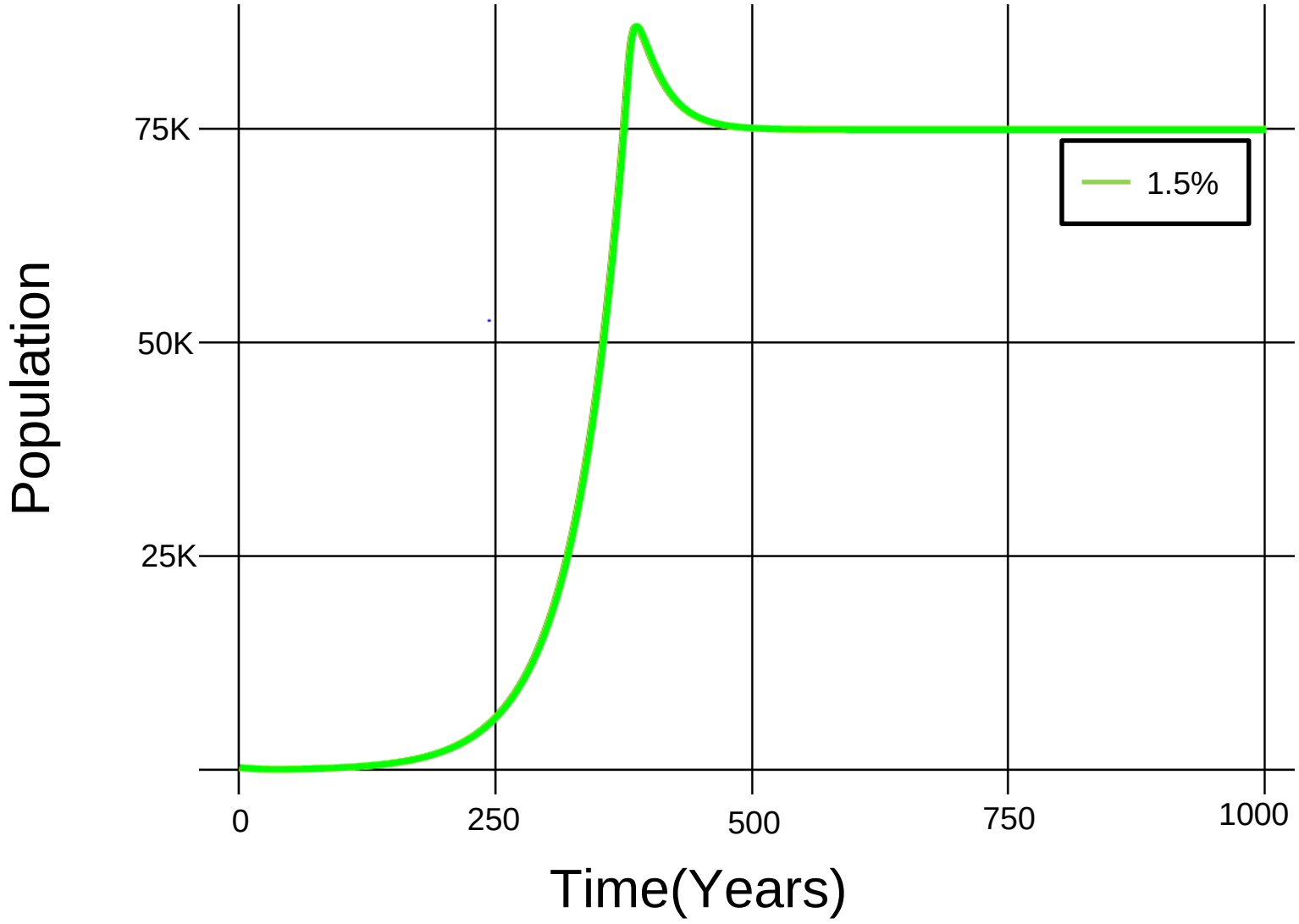


Figure 7 (Keen, 1995)

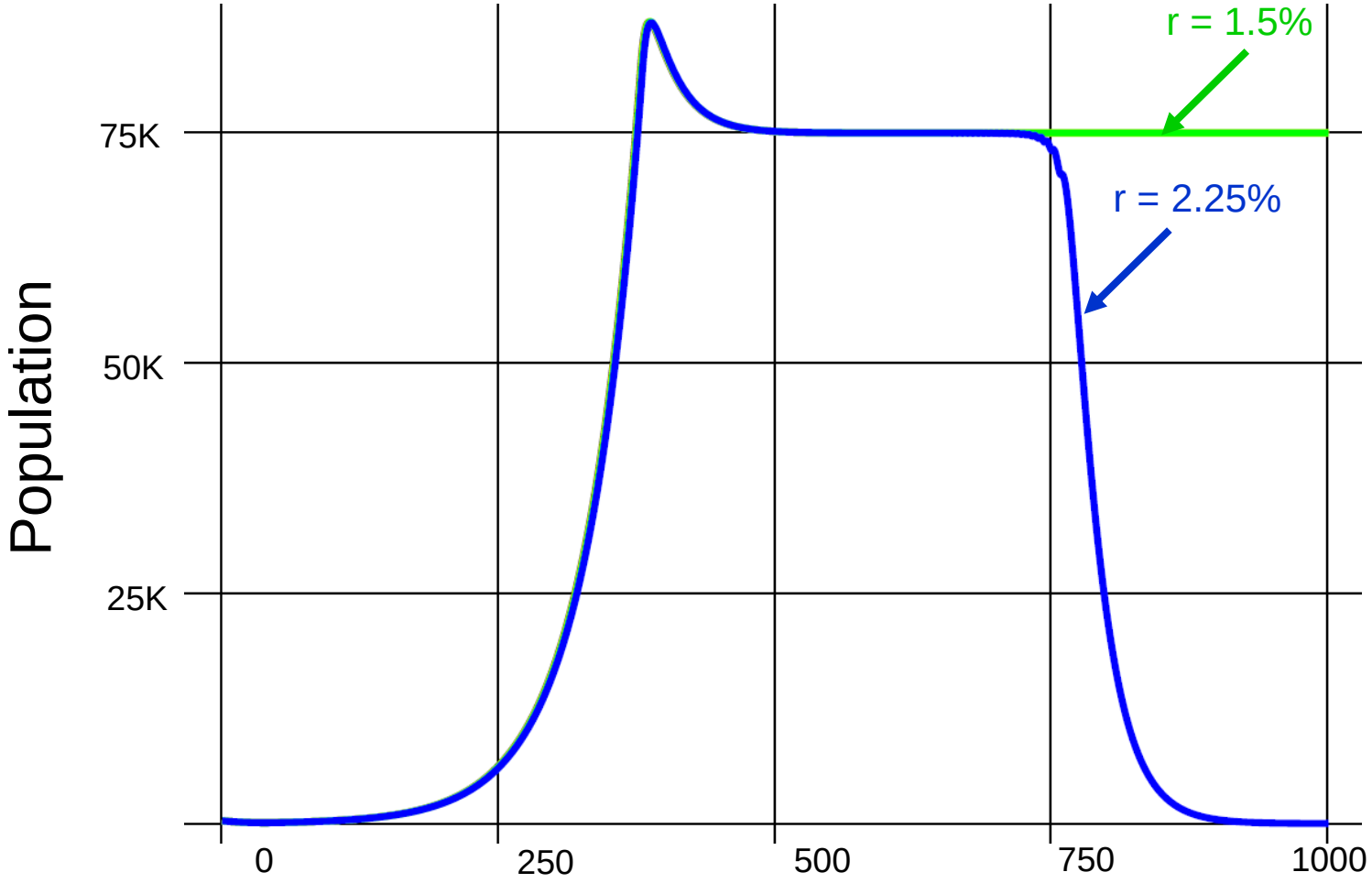
A “very high” interest rate prohibits long-term Nature extraction (leading to Population collapse)



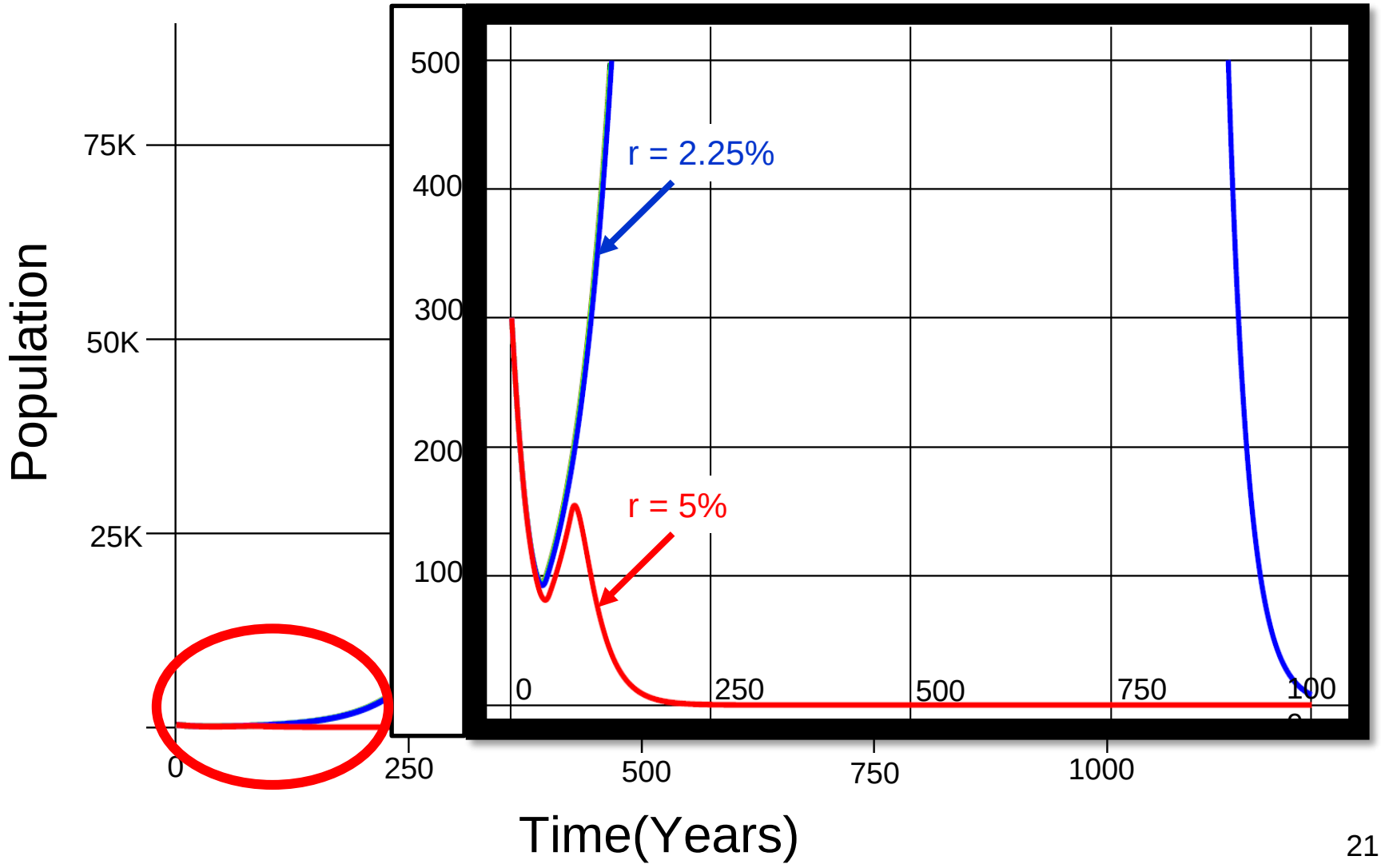
At “low” interest rate Population reaches a stable steady state



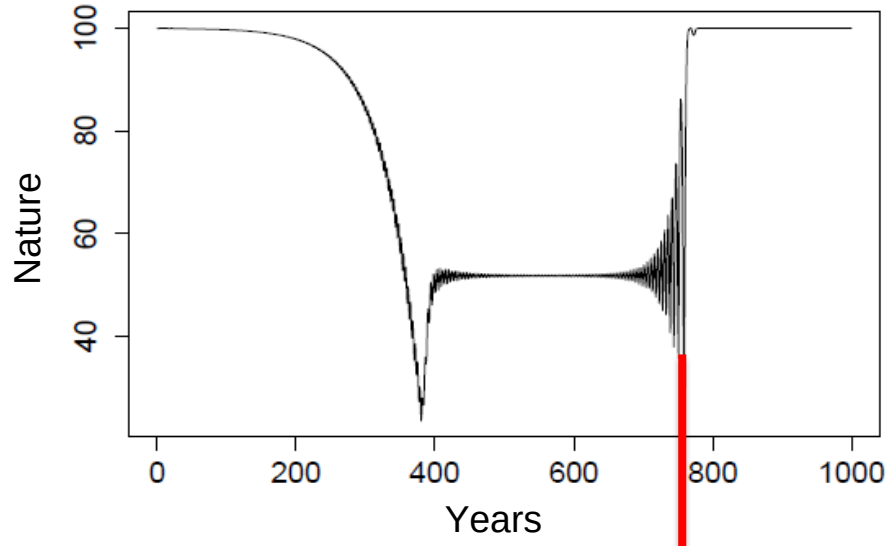
At “high” enough interest rate (> ~2%) Population eventually collapses

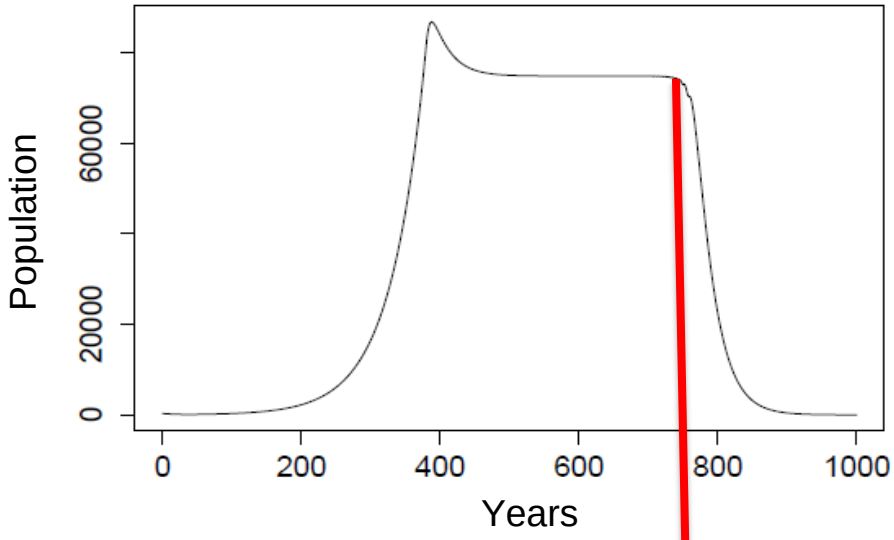


A “very high” interest rate prohibits long-term resource extraction leading to Population collapse

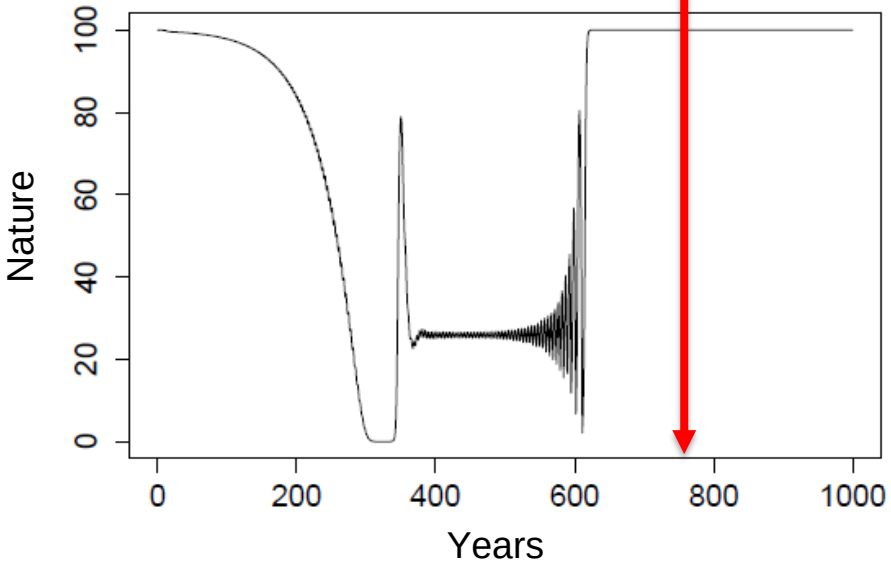


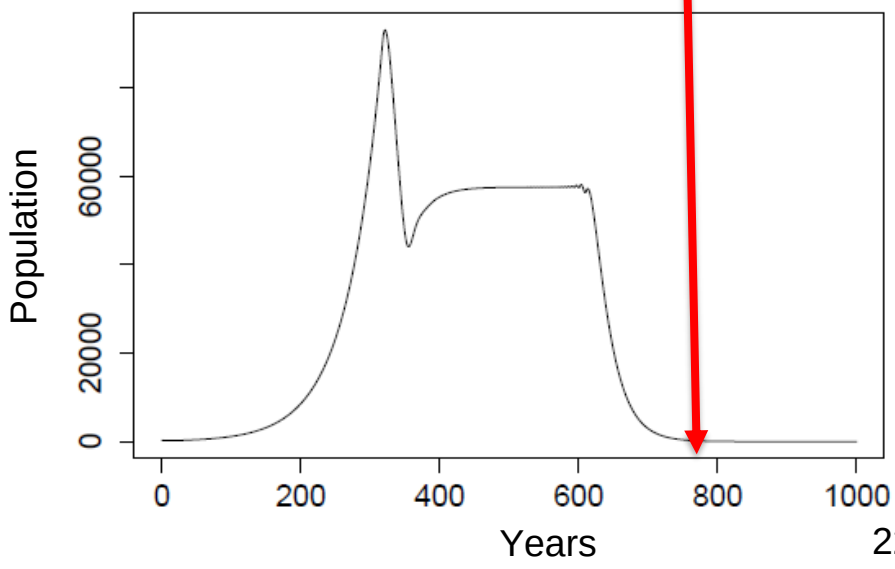
Population and Nature at a constant extraction rate: δ





Population and Nature at twice the extraction rate: 2δ





Conclusions

1. The merged model maintains the characteristics of both the biophysical and the economic/finance model

2. Earlier collapse in population can be caused by 2 factors in the model
    1. Higher (constant) interest rates
    2. Higher rate of extraction

Future Work

1. Introduce additional parameters as in Keen, 1995
    1. Variable rate of Interests
    2. Taxation
2. Introduce a bank/financial institution in the model (per Keen, 2013) and classify debt into different types (e.g., household, firms, government)
3. Incorporate different production functions
    1. E.g., Cobb-Douglas instead of Leontief
4. Include different types of Nature (or energy) resources
    1. Fossil
    2. Renewables from flows (e.g., solar insolation)

Thank You

Questions?

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