A MERGED BIOPHYSICAL AND MONETARY MODEL LINKING NATURAL RESOURCES AND DEBT

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Overview

Monetary models of finance and debt often assume that energy resources and technology are not constraints on the economy. Energy transition scenario models often assume that economic growth, finance and debt will not be constraints on the energy transition. These assumptions must be eliminated, and the modeling concepts must be integrated if we are to properly understand the dynamic interactions between energy and financial sectors.

Methodology

Here the research integrates macro-scale system dynamics models of money, debt, and employment (specifically the Goodwin and Minsky models of (Keen, 1995, Keen, 2013)) with system dynamics model of (Motesharrei et al., 2014)). Tables 1 and 2 outline the equations that have been derived from both models, and merged into one set. The goal is to have an integrated model that has the capability for simulating both a debt-induced and/or natural resources depletion-induced "collapse" (e.g., population, output).

Table 1. State equations for the merged biophysical and monetary economic models. M2014: equation from Motesharrei et al. (2014). Keen: equation from Keen (1995) or Keen (2013).

State Equations for Merged Biophysical and Monetary Economic Model	Interpretations of State Equations
1) $\dot{x} = \beta x - \alpha(w_h)x$, Population **[M2014]**	1) $\dot{x} =$ births – deaths
2) $\dot{y} = \gamma y(y_{max} - y) - y_{ext}$, Nature **[M2014]**	2) $\dot{y} =$ nature regeneration – nature extraction
3) $\dot{w_h} = y_{ext} - C(w_h) - \gamma_w w_h - v_I \kappa\left(\frac{\Pi}{Y}\right)Y$, Wealth **[M2014]**	3) $\dot{w_h} =$ nature extraction – consumption – depreciation – wealth requirement for investment
4) $\dot{a} = \alpha_a a_o$, Labor Productivity **[Keen]**	4) $\dot{a} =$ labor productivity is exogenous and grows exponentially at rate α_o
5) $\dot{Y} = \left(\frac{\kappa\left(\frac{\Pi}{Y}\right)}{Yv} - \gamma_K\right)Y$, Real (aggregate) Output **[Keen]**	5) $\dot{Y} = \frac{\dot{K}}{v}$ = (investment – depreciation of capital)/v
6) $\dot{D} = \kappa\left(\frac{\Pi}{Y}\right)Y - \Pi$, Debt **[Keen]**	6) $\dot{D} =$ investment – profits
7) $\dot{w} = f_{gen}(\lambda)w$, Real Wages **[Keen]**	7) $\dot{w} =$ (nonlinearly increasing function of employment, λ)×(current wages, w)

Table 2. Constraining expressions for the merged biophysical and monetary economic models.

Additional Constraining Equations	Interpretations of Constraining Equations
8) $C(w_h) = \min\left(1, \frac{w_h}{w_{h,th}}\right) sx$, Consumption **[M2014]**	8) Per capita consumption of wealth is constant, at s, above a threshold level of wealth, $w_{h,th}$, and declines linearly thereafter.
9) $\alpha(w_h) = \alpha_m + \max(0, 1 - \frac{C}{sx})(\alpha_M - \alpha_m)$, Death Rate **[M2014]**	9) Death rate is constant, at minimum α_m, and increases linearly to maximum α_M, as per capita consumption declines below s.
10) $Y = \frac{K}{v} = La$, Real Output **[Keen]**	10) Output is represented by a Leontief production function (L = labor, K = capital, v = capital/output ratio)
11) $\Pi = Y - wL - rD$, Profits **[Keen]**	11) Profits of firms = output – wages – interest payments. r is the interest rate.
12) $\lambda = {}^{L}/_{x}$, Employment **[Keen]**	12) Employment is labor force divided by population.
13) $f_{gen}(\lambda) = -y_{min} e^{\left(\frac{s_W}{y_{min}}(\lambda - \lambda_o)\right)} + y_{min}$, **[Keen]**	13) A general exponential expression such that wages are constant at λ_o, increase if $\lambda > \lambda_o$, and decrease if $\lambda < \lambda_o$.
14) $\kappa\left(\frac{\Pi}{Y}\right) = (\kappa_o - \kappa_{min}) e^{\left(\frac{s_K}{(\kappa_o - \kappa_{min})}\left(\frac{\Pi}{Y} - \left(\frac{\Pi}{Y}\right)_o\right)\right)} + \kappa_{min}$, **[Keen]**	14) A general exponential expression such that at a nominal profit share, investment as a fraction of output (κ) is equal to profit share ($\pi = \Pi/Y$), or $I_o = Y\kappa_o = Y\kappa\left(\frac{\Pi}{Y}\right)_o = \Pi_o$ at $(\Pi/Y)_o$.
15) (a) $y_{ext,L} = \delta_L Ly$; (b) $y_{ext,K} = \delta_K Ky$; (c) $y_{ext,w_h} = \delta_{w_h} w_h y$, **[this research]**	15) Various explored production functions for describing nature extraction, y_{ext}.

Results

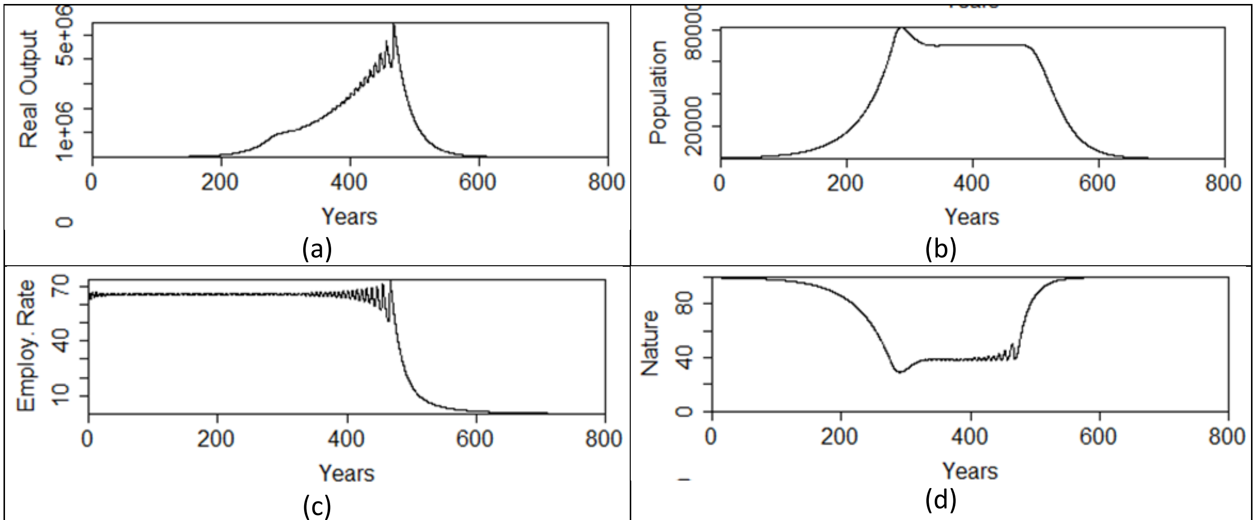

Figure 1. Result from the merged biophysical and monetary model when nature extraction is assumed a function of labor only (yext = δ_LLy) indicating an eventual debt-induced collapse before nature is depleted state: (a) real output, (b) population, (c) employment rate (%), and (d) the stock of nature.

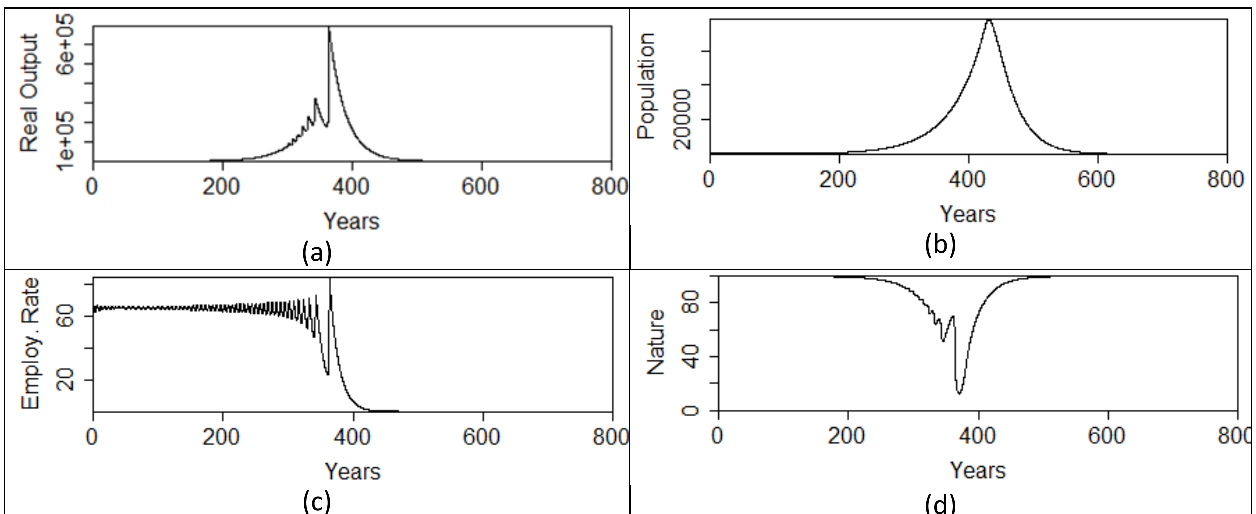

Figure 2. Result from the merged biophysical and monetary model when nature extraction is assumed a function of labor only (yext = δ_KKy) indicating an eventual debt-induced collapse before nature is depleted: (a) real output, (b) population, (c) employment rate (%), and (d) the stock of nature.

Conclusions

The merged biophysical "HANDY" model of Motesharrei et al. (2014) with the Goodwin-Keen model of Keen (1995, 2013) maintains the properties of both models. It has the capability of simulating a "collapse" due to both nature depletion (not shown) when nature is extracted too quickly and debt accumulation (Figures 1 and 2) because interest payments eventually do not enable the firms to be profitable and all workers are fired (subfigures (c)).

References

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