Examining the impact of debt-based economic systems on natural resources: An Agent-based modelling approach

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Abstract. The current economic crisis draws renewed attention to the underlying mechanisms of our economic system and its increasing effects on the environment. The interest rates associated with debt stocks forces society to create an increasing income flow, resulting on the accumulation of more and more debt to finance the economic growth [1]. The impact on the environment is not factored in to this cycle of interest, debt, growth, thus driving the decoupling process between the economic and resource systems and preventing a more sustainable development. We build a conceptual ABM implemented in NetLogo [2], which integrates a resource system into Steve Keen's [3] pure credit economic model. We test the hypothesis that there is a built-in bias in our debt-bearing economic system towards unsustainable use of natural resources. This paper describes our model using Grimm et al.'s [4,5] ODD (Overview, Design concepts and Details) model description protocol.

Keywords: Agent-based model (ABM) · sustainable development · social-ecological system · natural resources · monetary debt

1. Introduction

Over the last decades, there has been increasing evidence that resource use from human activities is eroding the integrity of our ecological life support systems. This has produced several discussions which highlight the impossibility of continuous economic growth within the ecological boundaries of our planet [6]. Moreover, the financial crisis has emphatically confirmed that the dominant neoclassical models of macroeconomics and finance are seriously in fault. Thus, we do not only need economic models that replicate the actual nature of the economy [3], but also crossdisciplinary models that address their impact on natural systems.

A popular critique of the financial system is that because commercial banks create money in the form of interest-bearing debt, the system necessarily requires an expanding money supply to pay this interest. The expanding money supply is subsequently argued to result in a growth imperative as it forces society to generate an ever-increasing income flow [7]. This results in a need to accumulate "more and more debt to finance economic growth, and we need more future growth to repay the debt" [1]. As a consequence, different social actors degrade the environment through economic and industrial activities in an attempt to pay their growing monetary debt and finance economic growth.

In this paper we present a conceptual ABM using NetLogo [2] to test the hypothesis that debt-bearing socio-economic systems hinder sustainable development by decoupling economic and environmental systems. We model one SES which integrates a simple resource system within Steve Keen's [3] pure credit economic model, which we disaggregate through ABM. The aim is to examine the extent to which the latter impacts on different environmental natural resources indicators.

While there has been much attention to studying the actual nature of both economic and ecological systems independently, the attempts to do so for couple socio-ecological systems (SES) are scarce. As both ecology and economics are concerned with interactions among individuals, both have much to gain from computer modelling tools for complex systems, including agent-based modelling (ABM). ABM has been widely used in ecology, where they tend to be termed individual-based models [8]. In particular, they have contributed significantly to ecological theory, including population dynamics, group behaviour and speciation, forestry and fisheries management, conservation planning, and species re-introductions [9]. ABM has also been used in economics, although to a lesser extent than in ecology. For instance, the field of agent-based computational economics (ACE) has explored features of economies as complex systems by representing economic agents in computer models as autonomous and interacting decision makers [10]. This paper is aimed at contributing to the ABM literature in ecological economics which has space for further models in market dynamics [11], consumption and sustainable behavior [12], psychological aspects -such as subjective well-being [13], natural resource management and land-use change [14], common pool resource use [15], and dynamics of urban systems [16].

2. ODD Protocol: Overview, Design concepts and Details

We use Grimm et al.'s [4,5] ODD (Overview, Design concepts and Details) model description protocol to give an overview of our model, with a slight modification to introduce the scenarios used to test our hypothesis, as performed in Polhill et al. [17].

2.1. A coupled socio-economic and natural system model

Overview

Purpose. The purpose of the model is to test the hypothesis that debt-bearing socio-economic systems hinder sustainable development by decoupling natural resource extraction and use from land biocapacity.

Entities, state variables and scales. The key entities in the model are a *commercial bank,* which lends credits (loans) to *firms* and *households*, and the environment, consisting of a grid of 25 x 25 *land parcels* (patches), each with one *biomass stock*. Each firm harvests biomass from the land parcel at its current location using a *resource extracting* algorithm; harvested resources are stored in each firm's *biomass reserve*. Households *consume* goods based on a *price* and *demand* functions from the closest firm with lowest price.

These processes are computed under either a *credit-based* economy or *non-credit-based* economy. Under a credit-based economy, the commercial bank lends credits to both firms and households, whereas in a non-credit-based economy the credit market is non-existent. Under a credit-based economy, the commercial bank manages two different stocks of money: *bank reserve* and *withdrawable capital*, while under a non-credit based economy only the withdrawable capital stock is active. The bank reserve stock holds the monetary capital designated to lend credits to both firms and households, whereas the withdrawable capital retains household deposits available for direct withdrawal by households for good consumption. The proportion of the total household deposits allocated as withdrawable capital is given by the *cash reserve ratio* and the type of *banking system* selected (see 'Submodels' section). Under a credit-based economy, the commercial bank makes *profits* based on the difference between the gains from *credit interests* and losses from *deposit interests* (paid by the commercial bank to households based on their deposit accounts). In the fractional reserve banking system, the commercial bank *generates money* based on a *money multiplier*.

Credit crunches and two different *policy responses* (quantitative easing and fiscal stimulus) are simulated to examine their impact on different environmental and socio-economic indicators.

Process overview and scheduling

(i) The type of banking system is selected and the commercial bank manages its monetary capital.
(ii) Firms manage its monetary capital.
(iii) Firms compute resource extraction.
(iv) Biomass stock is updated.
(v) Households compute good consumption.
(vi) Firms set up prices based on aggregate demand of goods and their own biomass reserves.
(vii) Firms compute nominal-wages and move to a new location if labour is zero.
(viii) Under a credit-based economy, firms and households borrow and pay back credits (with interests) when going through economic downturns and to expand their business (only firms).
(ix) The commercial bank pays interests to households on their deposits.
(x) Firms compute business-expansion
(xi) Credit crunches take place when economic peaks are reached (exogenously set).
(xii) A policy response to the credit crunch is exogenously activated.

An example of the model and a UML class diagram of the features of the model are shown in Fig. 1

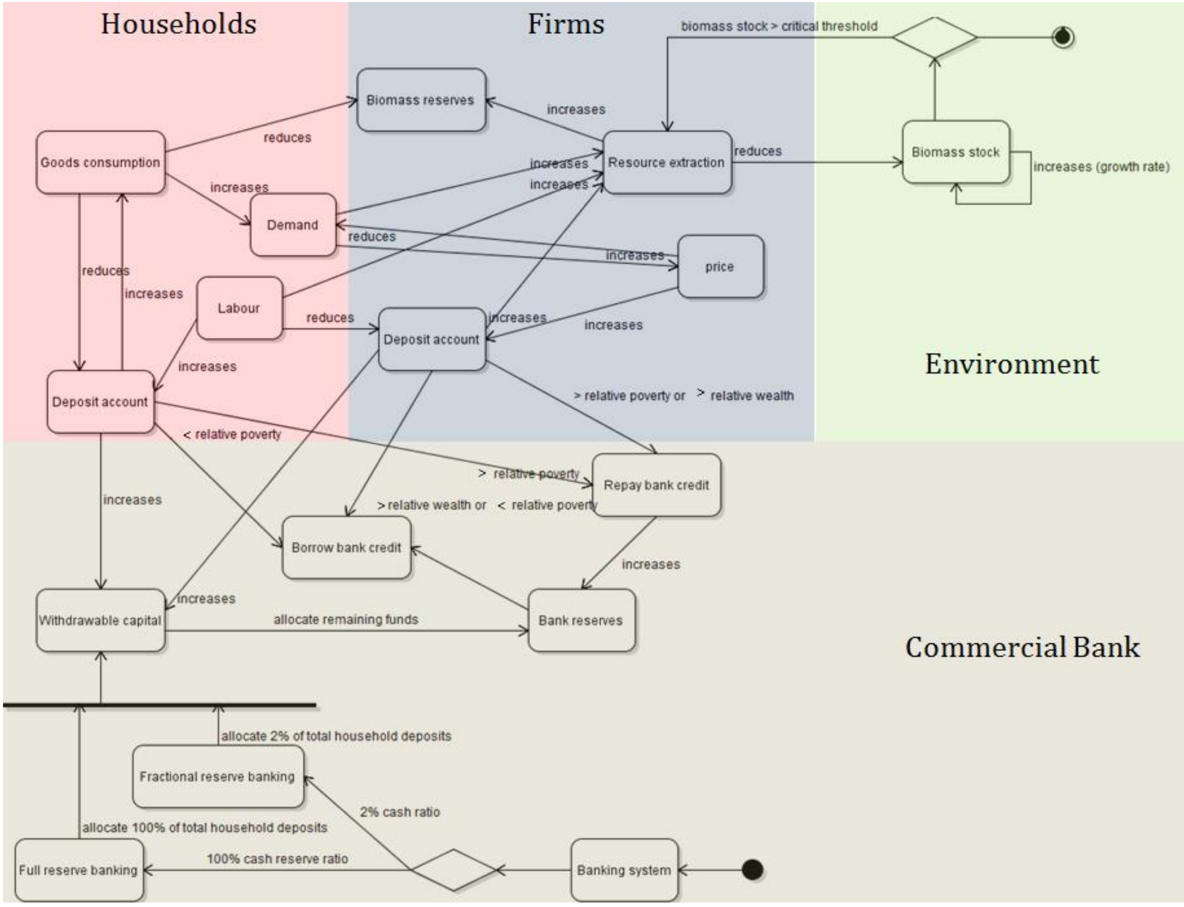

Fig 1. UML activity diagram showing the model structure. The different colours indicate the processes computed by each agent type (red = households; blue = firms; green = patches; and grey = bank)

Design concepts

Basic principles

The model is inspired by Steve Keen's [3] pure credit economic model, which is based on the Monetary Circuit Theory, an heterodox theory of monetary economics, particularly money creation, often associated with the post-Keynesian school. This economic framework holds that money is created endogenously by the banking sector, rather than exogenously by central bank lending. Moreover, it permits to examine the role of banks and debt through a simple monetary platform, elements that are usually ignored by mainstream economists [18].

The model also integrates two exogenously selected economic theories at the agent decision-making level; namely quantitative easing (monetarist response to credit crunches) and fiscal stimulus (Keynesian response). Keynesianism supports the role that fiscal policy can play in stabilising the economy, suggesting that higher government spending through expansionary fiscal policies can help the economy to recover quicker. Monetarism, on the other hand, criticises expansionary fiscal policies and rather advocates for controlling the money supply into the economy in order to control inflation, for instance by changing interest rates on loans and boosting bank reserves.

Emergence

The emergent outcomes from the model are grouped into environmental and socio-economic. The environmental outputs are: biomass stock (land parcels); ecological footprint (firms); biocapacity (land parcels); and potential to provide ecosystem services (ESPP) (land parcels). The socio-economic outputs are: debt (firms and households); monetary capital (firms, households and commercial bank); profits (commercial bank); generated money (commercial bank); policy responses to credit crunches.

Adaptation

Adaptation occurs through firms' labour and harvesting functions; when firms have no employees or when the biomass stock is below a critical threshold, firms move to the closest patch with highest biomass stock and higher number of households in neighbour patches. Furthermore, both firms and households adapt to negative financial situations by borrowing bank credits. The SES adapts to economic crunches by implementing policy responses.

Objectives

Objectives are implicit, but agents' decision-making algorithms are based on profit seeking behaviours.

Sensing

Firms are aware of the location of potential customers and those patches with high biomass stocks. Households are aware of the nominal wages and prices of firms. Policy responses are implemented with the necessary knowledge in order to overcome the economic crisis.

Interaction

Households directly interact with firms via labour and goods markets. Firms indirectly interact with each other via competition for resources and credits. Households interact with each other via competition for low good prices and high wages.

Observation

Environmental and socio-economic indicators are used to study the sustainability of the SES: biomass-stock (environmental indicator), biocapacity (environmental); ecological-footprint (environmental and socio-economic); ESPP (environmental); debt-stock (economic); households' and firms' deposit-account (economic); bank reserves (economic); and money generated (economic).

Details

Initialisation

The parameters and initial values are shown in Table 1.

Attributes	Description	Value	Attributes	Description	Value
banking-system	Type of banking system selected	FrR or FuR	growth-rate	Intrinsic growth rate of biomass	0.025; 0.05; 0.075; 0.1
cash-ratio	Proportion of money allocated as withdrawable-capital	0.2 or 1	interest-rate-deposits	Interest rate on household deposits	0.02
policy-response	Response to credit crunch	QE or FS	interest-rate-loans	Interest rate on loans	0.06
money-supply	Money used to boost bank reserves or firm & household deposit accounts	100$	biomass-stock	Number of resource units in each land parcel	0 - 2000
credit-lending-frequency	Frequency at which credits are lent our by the commercial bank to both households and firms	12	capital-technological-progress	Proportion of firms' capital allocated for new technologies	0.15
credit-repaying-frequency	Frequency at which credits repaid by firms and households to the bank	15	capital-wages	Proportion of firms' capital allocated for nominal wages	0.3
crit-biomass-stock	Minimum biomass threshold	200	capital-equipment-materials	Proportion of firms' capital allocated for equipment and materials	0.2
initial-deposit-accounts	Monetary capital of firms and households	$1 \cdot 10^5$ / $1 \cdot 10^2$ - $1 \cdot 10^4$	interest-rate-deposits	Interest rate on household deposits	0.02
nominal-wage	Minimum-maximum nominal wage	1000-5000	interest-rate-loans	Interest rate on loans	0.06
initial-price	Firms' initial sales price	50-200	initial-biomass-stock	Number of resource units (biomass) per patch	0 - 2000
initial-deposit-account	Monetary capital of firms	$1 \cdot 10^5$	nominal-wage	Minimum-maximum nominal wage	1000-5000

Table 1. Initial parameter values

Submodels

(i) Banking system selection and capital management of commercial banks

The type of economy is exogenously selected to be either credit-based or non-credit-based. Under a credit-based economy, the commercial bank lends credits to both firms and households, whereas in a non-credit-based economy the credit market is non-existent. Under a credit-based economy, the commercial bank manages two different stocks of money: bank reserve and withdrawable capital. The bank reserve stock saves the monetary capital designated to lend credits to both firms and households. The withdrawable capital stock retains household deposits, available for direct withdrawal by households for goods consumption. The proportion of the total household deposits allocated as withdrawable capital is given by the cash reserve ratio and the type of banking system selected (fractional reserve or full reserve). Under a fractional reserve banking system, only a proportion of the total household deposits is available for direct withdrawal by households, which is set by the cash ratio. The rest is allocated in the bank reserve. Most countries operate under a fractional reserve system, where the cash reserve ratio is set at 2%. Thus, 2% of the household deposits are available for withdrawal, while 98% is allocated in the bank reserve. On the contrary, in full reserve banking (i.e. 100% reserve), the commercial bank is required to keep the total amount of household deposits ready for immediate withdrawal on demand. The monetary capital allocated in the bank reserve is the surplus generated, which will be lower than in a fractional reserve banking system.

(ii) Capital management of firms.

Each firm computes capital-management to allocate the monetary capital from deposit-account in three different stocks, namely: capital-wages (CW), capital-technological-progress (CTP) and capital-equipment-materials (CEM).

(iii) Resource extraction.

Each firm computes resource extraction in their current patch following a harvesting function:

$$Re = (2AGD * W * \text{Dacc}) \tag{1}$$

Where AGD is the aggregate demand of goods by households regarding firm f, W is workforce of firm f (number of households working for each firm), and Dacc is the monetary capital of firm f. Note that AGD is multiplied by two based on the higher influence that goods demand has on extracting resources in comparison with W and Dacc.

Each firm allocates the extracted resources in its biomass reserve (BR), where such biomass is converted into goods through an exogenous biomass conversion ratio. Each firm moves to a new resource extraction point (patch) if the sum of the resource stock in their current land parcel and their biomass reserves is lower than those goods needed to meet the aggregate goods demand from households for one entire year.

Ecological-footprint indicates the extent to which firms (directly through resource extraction) and households (indirectly through good consumption) overshoot the available biocapacity of each patch (see 'Update biomass stock' section):

$$\mathrm{EF} = \left(\frac{DG}{YB}\right) * YF * EQF \tag{2}$$

Where YB is the biomass yield, YF is the yield factor and EQF the equivalent factor. YB is the number of tonnes per patch that is obtained from one country (to be selected) land type; YF is the difference in production of a given land type across different nations, measured in kg/ha; EQF translates a specific land type (e.g. cropland, pasture, forest, fishing ground) into a universal unit of biologically productive area (ha).

(iv) Update biomass stock.

Each land parcel (patch) has one resource stock. A growth rate parameter increases the stock of each patch and decreases with firms' resource extraction. If resource stocks drop below a critical resource threshold, growth rates is halved due the capacity of resources to regrow is affected. The simulation ends when all resource stocks are depleted.

The biological demand on each patch is determined by its biocapacity:

$$B = RS * YF * EQF \tag{3}$$

Where RS is the stock of resources in each patch. The original function uses hectares instead of resource units. However, since all patches have the same size (50 ha), we rather use the abundance of resources in each patch as a substitute. One other environmental indicator is based on ecosystem service provisioning potential:

$$ESPP = \left(\frac{B}{EF}\right) \tag{4}$$

Where B is the sum of all patches' biocapacity. ESPP is the capacity of the natural system as a whole to provide with other non-provisioning ES (i.e. regulating, supporting, cultural). This indicator is integrated based on studies suggesting that there is substantial value in conserving not only the quantity (area) of natural ecosystems, but also the quality (biodiversity) [19].

(v) Household consumption and good demands

Households consume goods from the closest firm with lowest price. The number of goods consumed at time t depends on each household's individual goods demand (IGD), which at the same time is calculated from individual monetary demand (IMD):

$$IGD = \frac{IMD}{P} \tag{5}$$

$$IMD = \text{Dacc} \tag{6}$$

Consumed goods are removed from firms' biomass reserves. Each household moves to the closest patch where the firm with the highest nominal wage and lowest price is located. Commuting and a shopping transport costs are charged to households.

(vi) Price set up.

Firms set a price for goods. The price, which links the monetary flow and the physical output produced by firms, is given by:

$$P = \frac{AMD}{BR} \tag{7}$$

Where AMD is the aggregate monetary demand, which is the sum of all IMD, and BR is the biomass reserve. Each household pays the price to the firm from which goods are bought.

(vii) Labour and wages.

Each firm sets a nominal wage value, given by the function:

$$\text{NW} = \frac{CW}{Wf} \tag{8}$$

Each household works for the closest firm with the highest wage. Each household receives a nominal wage in a monthly rate in its deposit account. Firms with no employees move to the empty patch with highest number of households in its neighbour patches, thus increasing its probabilities to sell goods. A transport cost is charged.

(viii) Firm economic downturn management.

Under a credit-based-economy, if each firm's mean deposit account from the previous year is higher than the current deposit account, one `credit` is borrowed from the commercial bank's reserves. The amount of the credit borrowed is based on the money needed to cover the expenses for one entire year, that is, the sum of CTP, CEM and CW. The credit is loaned in a monthly basis for one entire year (48 ticks). Those firms in debt start paying back the credit to the commercial bank when their current deposit account is equal or higher than the mean deposit account from the previous year. The full credit plus `interests` are repaid in a monthly basis to the commercial bank's reserves. Those firms with no monetary capital go bankrupt and are removed from the simulation if bank reserves are empty.

(ix) Business expansion.

When each firm's deposit account is higher than a `relative wealth` threshold, firms expand their business by creating one new firm in the closest patch with highest biomass stock. Business expansion is funded by a new credit borrowed from the commercial bank. In a non-credit based economic system, firms use their own deposit account to fund business expansion.

(x) Household economic downturn management.

Under a credit-based economy, households borrow one bank credit from the commercial bank's reserves if they cannot afford the average value between the minimum and maximum price regarding the firm from which they last bought goods- for one entire year. The amount of the credit borrowed is based on the money needed to cover these expenses. Those households in debt start repaying the borrowed credit (.plus interests) in a monthly basis when their current deposit account is equal or higher than the average value between the minimum and maximum price of the firm from which they last bought goods. Households die and are removed from the simulation if they are under an economic downturn and the bank reserves are empty. Under a non-credit based economy, households die if going through an economic downturn.

(xi) Deposit interests.

The commercial bank pays interests on households' deposit accounts in a monthly basis. The money is transferred from the bank's reserves to households deposit accounts based on an `interest rate`.

The commercial banks make profits due to the surplus obtained from the difference between the total amount of interests on deposits paid to households and the total amount of interests on credits received from both firms and households. Furthermore, the commercial bank `generates money` (MG) based on a `money multiplier` (MM), following the so-know 'Multiple Effect'. This effect is the expansion of a system's money supply that results from banks being able to lend. The multiplier effect size depends on the percentage of household deposits that the bank is required to hold as reserves (i.e. cash reserve ratio):

$$\text{MM} = \frac{1}{cash - reserve - ratio} \tag{9}$$

The MM measures the maximum amount of commercial bank money that can be created each time step. This parameter is used to calculate the MG in the system:

$$\text{MM} = \text{WC} * \text{MM} \tag{10}$$

Where WC is the withdrawable capital.

(xii) Policy responses to credit crunches

Credit crunches affect loan borrowing and repaying frequencies. In particular, credit borrowing frequency is halved during credit crunches, while credit repaying frequency is doubled. The economic crunch occurs at the peak of economic prosperity, which takes place at a different *time t* depending on each scenario (see 'Scenarios' section). One year after the economic crunch takes place, a policy response of either Monetarist (`quantitative easing`) or Keynesian (`fiscal stimulus`) nature is activated. The prior is based on boosting the bank reserve with a `money supply`, while the latter is based on boosting each household's deposit account with a quantity equal to the money supply divided by the total number of households.

2.2. Model experiments and scenarios

The three main goals of the scenario setting is based on testing the impact on the total biocapacity and ESPP of: (1) credit and non-credit-based economies; (2) two different banking systems (fractional and full reserve); and (3) two different policy responses to credit crunches (quantitative easing and fiscal stimulus).

Table 1 shows the different combination of parameters, from which 7 scenarios are selected: Yes/2%/Yes/Qe; Yes/2%/Yes/Fe; Yes/2%/No; Yes/100%/Yes/Qe; Yes/100%/Yes/Fe; Yes/100%/No; No. The last scenario simulates a non-credit based economy, where credit crunches and fractional reserve banking system cannot exist. All scenarios are simulated at a steady state population size, in order to avoid potential model biases based on the many different factors that currently affect population growth that are not included in our model.

Table 2 summarises the parameter explorations done. Each scenario (7) is runned for different biomass growth-rate parameter values (4), making 28 combination of parameters in total. Each combination of parameter will be repeated for 20 times, making 700 runs overall. Each run is for 100 time steps.

Parameter	**Values**	
credit-based-economy?	Yes	No
banking-system	Fractional Reserve banking 2% (FrR)	Full-reserve banking 100% (FuR)
Credit-crunch	Yes	No
Policy-responses	Quantitative-easing (QE)	Fiscal-stimulus-households (FE)

Table 2. Summary of parameter exploration

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