

MAIN ARTICLE

The dynamics of financial instability: simplifying Keen's Goodwin–Minsky model

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Abstract

Market capitalism typically goes through cycles of expansion and contraction. Every now and then, these common economic cycles go off the hinges. They become unstable and can lead to recessions, crises and depressions—phenomena that economists typically explain by looking to exogenous forces. Alternative explanations—mostly Marxian and Keynesian—for the instabilities have been sought within the structure of the economic system itself. One such explanation is provided by Steve Keen in his Goodwin–Minsky model. The model effectively mimics the dynamics of key indicators prior to, during and after the 2007/08 crisis. However, the model is also over-specified, highly sensitive to initial conditions and therefore more difficult to convey. In line with George Box's plea for parsimony, this paper presents a more straightforward version of Keen's model that remains consistent with its fundamental behaviour. The model also illustrates the potential for further dialogue between Marxian economics and system dynamics.

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Introduction

The world economy, measured as gross world product (GWP), has grown at a rate of ~7.4% from 1960 to 2016 (World Bank, 2017). Virtually all nations have contributed to this expansion through their individual gross national products. At the same time, economic instability has taken on global proportions (Bonaiuti, 2012; Cairó-i-Céspedes and Castells-Quintana, 2016). It has been argued that this instability is not accidental or exogenous, but structural and endogenous. Explanations must therefore be sought within the growth-based market capitalist economy (Minsky, 1992; Keen, 2013).

Neoclassical economics does not provide the tools for modelling instability. The discipline usually emphasizes the equilibrating interactions between supply and demand variables. However, real-world markets are almost never in equilibrium; supply rarely matches demand. In fact, disequilibrium is precisely why most firms keep stores of inventory (Beinhocker, 2006). Some

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economists might argue that this is of no consequence: disequilibrium is assumed to trigger a (usually stable) transition from one equilibrium to the next (Sterman, 1991).

While overemphasizing the balancing mechanisms of the market, the neo-classical school also tends to ignore or underestimate the reinforcing feedback loops responsible for disequilibrium (Mass, 1980; Sterman, 1991; Whelan and Msefer, 1996). By implication, complex combinations of balancing and reinforcing loops that sustain oscillations far from equilibrium are also disregarded (Meadows and Wright, 2008). In ecology, oscillations have long been elucidated by relatively simple models of predator–prey interactions (Lotka, 1925; Volterra, 1928). Such interactions are also believed to be at play within the economy. Based on Marxian thought, Richard Goodwin (1967, p. 8) famously applied predator–prey equations to show how economic cycles can be explained by “the inherent conflict and complementarity of workers and capitalists”.

When the amplitude of the oscillations becomes wider over time, the oscillating variables could begin to approach potential extremes. This is a source of economic instability and possible collapse. When observing real economic crises, the behaviour is even more complex. Empirical evidence shows “a period of economic volatility followed by a period of moderation, leading to a rise of instability once more and a serious economic crisis” (Keen, 2013, p. 221).

Building on insights from (among others) Karl Marx, John Maynard Keynes, Richard Goodwin, Hyman Minsky and Augusto Grazianni, Steve Keen presents us with a system dynamics model that succeeds in mimicking the dynamics of key indicators prior to, during and after the 2007/08 financial and economic crisis (Keen, 2012, 2013, 2014). As we shall see, “[t]he qualitative behaviour of this model reproduces the features of the last 30 years: a period of strong cycles in real output is followed by a period when the business cycle appears a thing of the past, but then suddenly a crisis breaks out with declining real output” (Keen, 2013, p. 233). The phenomenon of diminishing and rising cycles manifested in Keen’s model is known as the “Pomeau–Manneville intermittent route to chaos” (see Pomeau and Manneville, 1980, in Keen, 2013).

Keen’s model provides invaluable insights into the systemic causes of the crisis. At the same time, this can be achieved with fewer variables and connections. Keen incorporates more complexity with the intention to improve the model’s fit, but there is a downside. It becomes highly sensitive to initial conditions and more difficult to communicate to a wider audience. In line with George Box’s plea for parsimony (Box, 1976), this paper presents a simplified and adjusted model that remains consistent with the behaviour of Keen’s model (see Keen, 2013, 2014). In the process of building the present model, Keen’s original version was first replicated in STELLA. It was then stripped of many of its details without undermining its core dynamic. As

Levin (1992, p. 1944) pointed out: “the objective of a model should be to ask how much detail can be ignored without producing results that contradict specific sets of observations.”

The first part of the paper presents a STELLA version of Goodwin’s growth cycles model, which gives us a basic pattern of cyclical growth (Goodwin, 1967). As postulated by Marx, the dynamics emerge from a structure that constantly widens and narrows the distribution of value between wages (labour) and profits (capital) (Marx, 1976). Following Keen’s approach, Goodwin’s model is then extended to account for Minsky’s understanding of debt-fuelled boom-and-bust cycles (Minsky, 1992). In the final step, a price adjustment is incorporated to account for effective demand. The simulations match Keen’s results. At the same time, the proposed model relies on fewer variables and does not suffer from oversensitivity to initial conditions. The outcome is a faithful, yet simpler, translation of the structure of Keen’s model.

Simplification of Keen’s model also leads to less realistic parameter values. However, it should be noted that the aim in this paper is to uncover the logic behind the system’s behavioural tendencies only, not to test their accuracy against empirical data. For that reason, unless otherwise indicated, the graphs are deliberately devoid of numbers. A unit of time (month) has been specified to get a sense of the timing of different phases in the simulations, but this should also be taken with a grain of salt.

This paper’s supporting information Appendix S1 includes the models and equations used in STELLA, as well as a working version kindly reproduced by Professor Steve Keen in his open source system dynamics program called *Minsky* (see <https://sourceforge.net/projects/minsky/>).

Background

With notable exceptions, system dynamics has not yet paid much attention to the work of Marx (Goodwin, 1967; Stroh, 1992; Radzicki and Serman, 1994; Saeed, 2016). This is a missed opportunity. It has been suggested that Marx is one of the founders of the original systems approach (Levins, 1998). Marxian dialectical materialism and today’s systems science both grapple with the contradictory forces that arise from patterns of relationships within a system. In systems theory (notably in system dynamics), these contradictions occur when circular patterns of causality, or feedback loops, pull a system in different, even opposite, directions (Forrester, 1995; Meadows and Wright, 2008). For example, Stroh (1992) maps out Marx’s reasoning on monopolistic tendencies in capitalism that emerge from a combination of competing feedback loops.

While they are both concerned with studying processes of change over time, dialectics and system dynamics proceed to do so in distinctive ways.

Dialectical analysis remains qualitative, whereas the system dynamics method generally relies on mathematical models to simulate behaviour (cf. Forrester, 1995; Levins, 1998). Despite the differences, the extent to which present systems science can reveal Marxian thought is worth exploring.

In system dynamics, it has long been argued that while the human mind is capable of accurately representing parts of a complex structure, it becomes unreliable when it attempts to envision what behaviour will result from piecing all the parts together. This is where simulation models can help: they can interrelate many factors simultaneously that our minds cannot. Misrepresentations can be corrected as long as these models are openly discussed, which is typically challenging in the field of economics. Neoclassical economic models build on implicit theories and axioms privy to trained econometricians only. As a consequence, these models are rarely held to scrutiny by a wider audience. Similarly, Marxian economic thought suffers from its own disciplinary language barriers and complexity. As illustrated in this paper, however, many of Marx's insights into the workings of the capitalist system are well suited to further exploration using system dynamics.

Growth cycles model

Cycles of expansion and contraction are normal economic phenomena. Richard Goodwin's endogenous growth cycles model (GCM) is a Marxist interpretation of economic cycles in which downturns are caused by the increased bargaining power of workers—a result of high employment in upturn periods. High employment pushes up the wage share of national income, suppresses profits and leads to a reduction in capital accumulation. The fall in investment then lessens the disproportion between capital and labour power. The price of labour falls again to a level corresponding to the needs of capital (Goodwin, 1967). In Marx's own words:

accumulation slackens as a result of the rise in the price of labour because the stimulus of gain is blunted. The rate of accumulation lessens; but this means that the primary cause of that lessening itself vanishes, i.e., the disproportion between capital and exploitable labour-power. The mechanism of the capitalist production process removes the very obstacles that it temporarily creates. (Marx, 1976, p. 770).

Goodwin perceived a predator–prey structure in the arguments put forward by Marx. His GCM, represented in Figure 1, is biophysical (containing real quantities), except for wages and profits (which represent nominal quantities). Variables are connected through several feedback loops.

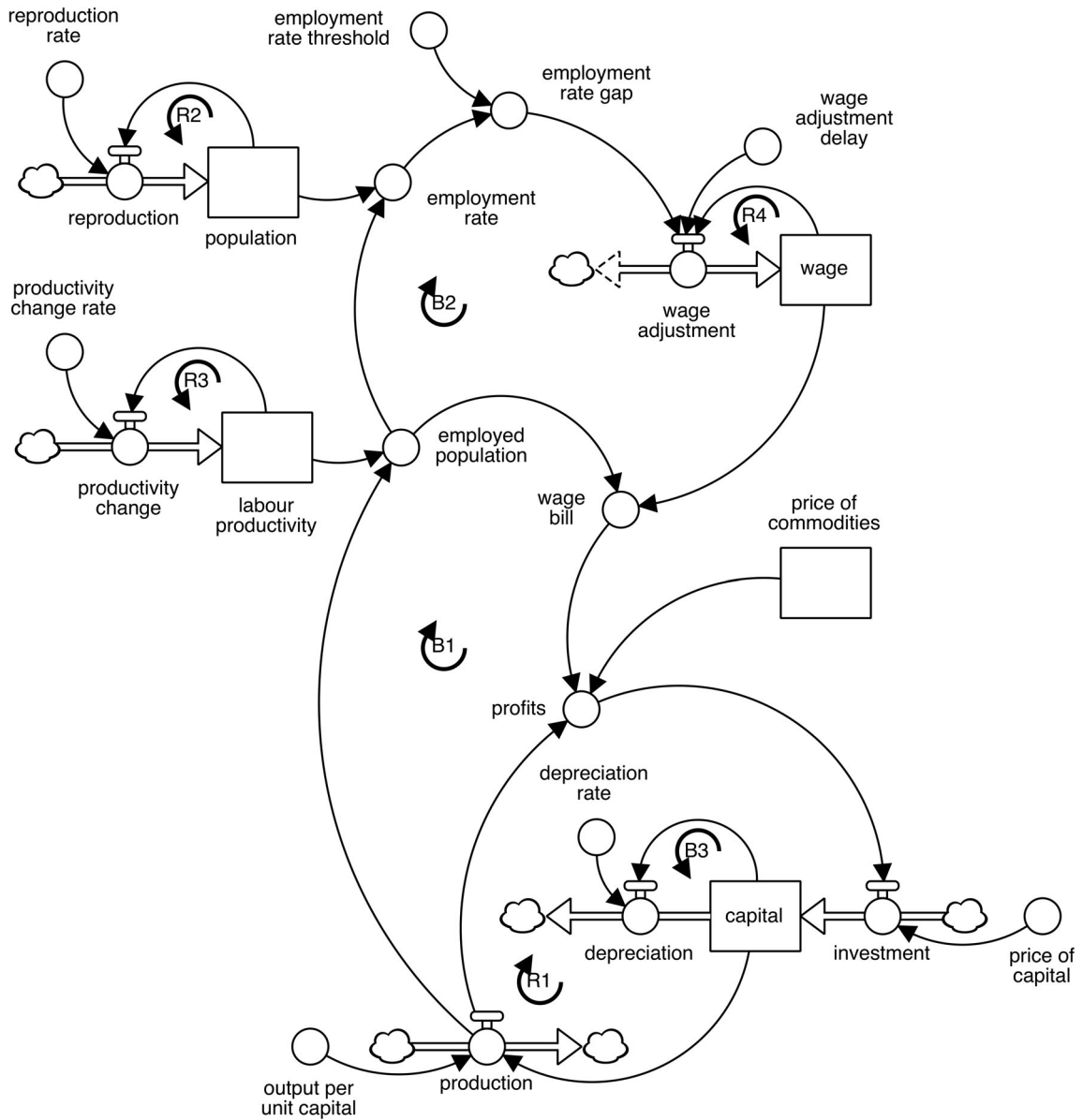


Fig. 1. Goodwin's growth cycles model

First, a rise in profits increases investment, capital and production, which brings about a further rise in profits (R1 in Figure 1). In this model, capitalists reinvest all their profits—no more, no less (Eq. (1)). Later, we will incorporate the possibility that investment exceeds profits through lending. It must also be noted that system dynamics has developed more robust alternative formulations to capital investment flows since Goodwin proposed his model (e.g., by accounting for desired capital and compensating for depreciation) (see Meadows and Wright, 2008). For now, the present model remains faithful to Goodwin's approach.

Production is equal to capital multiplied by the output per unit of capital (Eq. (2)). Profits are equal to revenue minus costs. For now, revenue is equated to production multiplied by the price of one item of output, i.e., the price of a commodity, which is held constant for now. Net costs to capitalists are limited to labour costs (Eq. (3)). While depreciation also represents a cost, it is disregarded because it represents a cost that is internal to the capitalist class.

Another essential feedback loop keeps the distribution of revenue between labour and capital from growing too far apart. The increase in profits is limited by the increasing costs of labour: rising production leads to rising employment and a rising wage bill, which leads to a fall in profits (B1 in Figure 1). The exact relationships are defined as follows. Labour productivity represents the number of commodities that a worker can produce in a given month. From the total flow of output produced and the level of labour productivity, we can derive the number of people employed at any given time (Eq. (4)). We multiply this number by the going wage and we get the total wage bill (Eq. (5)). As mentioned, the latter is deducted in the equation for profits (Eq. (3)).

$$\text{investment} = \text{profits} / \text{price_of_capital} \left[\frac{\text{productive_good}}{\text{month}} \right] \quad (1)$$

where $\text{price_of_capital} = 0.5$ [dollar/productive_good].

$$\text{production} = \text{capital} \times \text{output_per_unit_capital} [\text{commodity/month}] \quad (2)$$

where $\text{initial_capital} = 400$ [productive_good] and $\text{output_per_unit_capital} = 0.4$ [commodity/productive_good/month].

$$\text{profits} = \text{production} \times \text{price_of_commodities} - \text{wage_bill} [\text{dollar/month}] \quad (3)$$

where $\text{price_of_commodities} = 3$ [dollar/commodity].

$$\text{employed_population} = \text{production} \div \text{labour_productivity} [\text{worker}] \quad (4)$$

where initial labour_productivity = 1 [commodity/worker/month].

$$\text{wage_bill} = \text{wage} \times \text{employed_population} \text{ [dollar/month]} \quad (5)$$

where initial wage = 3 [dollar/worker/month].

The wage adjusts as a result of the bargaining position of labour. Under a certain threshold, say 80%, the employment rate (Eq. (6)) will have a depressing effect on the wage; above this threshold the wage will rise. In other words, as long as a growing demand for labour remains below 80% of the available labour force, the wage will continue to fall (see Eqs (7) and (8) and graph in Figure 2). The logic behind Eq. (8) is based on a wage gap adjusted by a wage adjustment delay. The wage gap is equal to an indicated wage minus the actual wage. The indicated wage is equal to one plus the employment rate gap multiplied by the wage. This feedback loop (B2 in Figure 1) has a balancing effect in the model; it contains a single opposing link from wage bill to profits.

$$\text{employment_rate} = \text{employed_population} \div \text{population} \text{ [dimensionless]} \quad (6)$$

with initial population = 200 [worker].

$$\text{employment_rate_gap} = \text{employment_rate} - \text{employment_rate_threshold} \text{ [dimensionless]} \quad (7)$$

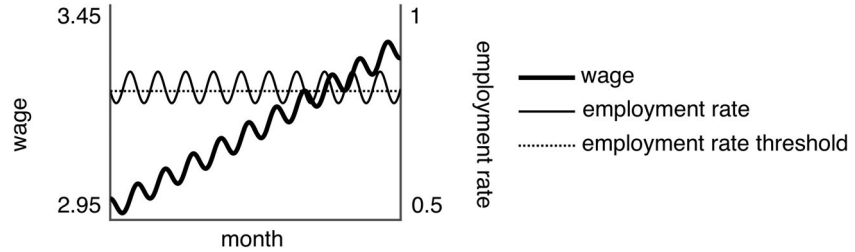
where employment_rate_threshold = 0.8 [dimensionless].

$$\text{wage_adjustment} = (((1 + \text{employment_rate_gap}) * \text{wage}) - \text{wage}) \div \text{wage_adjustment_delay} \text{ [dollar/worker/month/month]} \quad (8)$$

where wage_adjustment_delay = 10 [month].

In his model, Keen (2013, 2014) develops a more complex nonlinear wage adjustment function with several more adjustable parameters (the so-called Phillips curve). With a nonlinear relationship, wages can be modelled to rise more rapidly at high levels of employment and fall slowly at lower levels. This is more realistic, but is not necessary for generating the desired behaviour. The present model is therefore in line with Goodwin's use of a linear relationship (Eq. (9)). In Eq. (8), the slope of the linear Phillips "curve" (a in Eq. (9)) is controlled by a wage adjustment delay for a more intuitive understanding, but this does not affect Goodwin's logic.

Fig. 2. Effect of the employment rate on wages (duration: 150 months)



$$\text{wage_adjustment} = (a * \text{employment_rate} - b) * \text{wage} \quad (9)$$

where a and b are coefficients of the linear Phillips “curve”.

Four shorter feedback loops (B3, R2, R3 and R4 in Figure 1) connect stocks to their inflows or outflows (Eqs (10), (11), (12) and (8), respectively). Finally, two indicators are derived from the model’s variables. First, the economic growth rate is calculated as the difference between current production and production from the previous time step (i.e., month) divided by production from the previous time step (Eq. (13)). Second, the share of output that goes to labour, i.e., the wage share, is equal to the wage bill divided by total revenue (production multiplied by the price of commodities) (Eq. (14)).

$$\text{depreciation} = \text{capital} \times \text{depreciation_rate} \text{ [productive_good/month]} \quad (10)$$

where $\text{depreciation_rate} = 0.018$ [dimensionless/month]

$$\text{reproduction} = \text{population} \times \text{reproduction_rate} \text{ [worker/month]} \quad (11)$$

where $\text{reproduction_rate} = 0.0008$ [dimensionless/month]

$$\begin{aligned} \text{productivity_change} &= \text{labour_productivity} \times \text{productivity_change_rate} \\ &\text{ [commodity/worker/month/month]} \end{aligned} \quad (12)$$

where $\text{productivity_change_rate} = 0.0008$ [dimensionless/month].

$$\begin{aligned} \text{economic_growth_rate}(t) &= [\text{production}(t) - \text{production}(t-1)] \\ &\div \text{production}(t-1) \text{ [dimensionless]} \end{aligned} \quad (13)$$

$$\begin{aligned} \text{wage_share} &= \text{wage_bill} \\ &\div (\text{production} \times \text{price_of_commodities}) \text{ [dimensionless]} \end{aligned} \quad (14)$$

Simulation reveals cyclical growth of production, capital, wage bill and profits (Figure 3a,c). The rate of economic growth oscillates around a positive average (Figure 3b) and the employment rate oscillates around the threshold (Figure 3d). The share of total output that goes to wages never settles in equilibrium (Figure 3e,f). Keen summarizes the dynamics as follows:

a high level of investment causes high growth, so that unemployment falls—which leads to rising wages and a falling profit share; falling profit share then reduces investment and economic growth, leading to rising unemployment; this reduces wages and restoring profit share, leading the cycle to repeat (Keen, 2013, p. 224).

As seen in Figure 3e, the growth cycles are endless. The model shows no endogenous limits or propensity for crisis. To simulate this, several further adjustments are needed.

A simplified Goodwin–Minsky–Keen model

Goodwin's GCM is now expanded to account for debt and price adjustment, as indicated by the grey variables in Figure 4. This expansion is similar to, yet simpler than, Keen's own approach. Debt is incorporated first. The price adjustment will be incorporated after that.

Incorporating debt

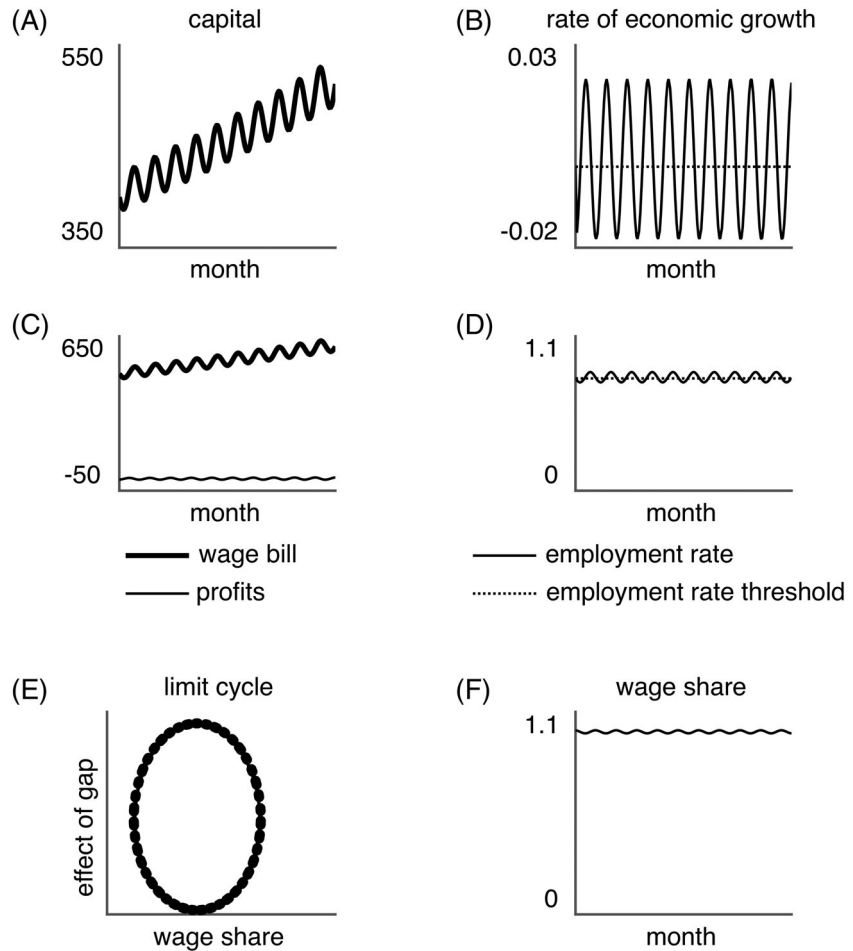
As seen, Goodwin's model generates permanent cyclical behaviour. Cycles, of course, can amplify and become unstable. Hyman Minsky recognized this and formulated his financial instability hypothesis, which posits that

from time to time, capitalist economies exhibit inflations and debt deflations which seem to have the potential to spin out of control. In such processes the economic system's reactions to a movement of the economy amplify the movement—inflation feeds upon inflation and debt-deflation feeds upon debt-deflation. (Minsky, 1992, p. 1).

Here, Minsky refers to Irving Fisher's theory of debt deflation, which describes how a combination of over-indebtedness, low inflation or even falling prices eventually leads to financial distress (Fisher, 1933). Minsky expands on Fisher's theory by incorporating the causes for over-indebtedness. Cycles are fuelled by typical 'bandwagon effects'—first during a period of debt-financed investments when asset prices are on the rise, and later in a period of distress sales when asset prices are falling.

Building on Fisher and Minsky's insights, Keen expands Goodwin's GCM to incorporate indebtedness. Goodwin's model reflected the assumption that

Fig. 3. Simulation results for Goodwin's growth cycles model (duration: 150 months)



investment is equivalent to profits at all times (the price of capital is taken as a constant). In reality, capitalists invest more during booms and less during slumps. If they wish to invest above what they earned in profits, capitalists borrow the desired loans from banks. In recent years, banks have no longer been constrained by reserve requirements and new loans can, in principle, always be accessed. “[I]f the banks are prepared to pay the required interest rate to borrow reserves [from central banks], then there is no limit on their credit creation” (Dow, 2005, p. 48, in Keen, 2014). The amount of currency in circulation is therefore not limited by how much banks are able to lend, but by how much firms are willing to borrow.

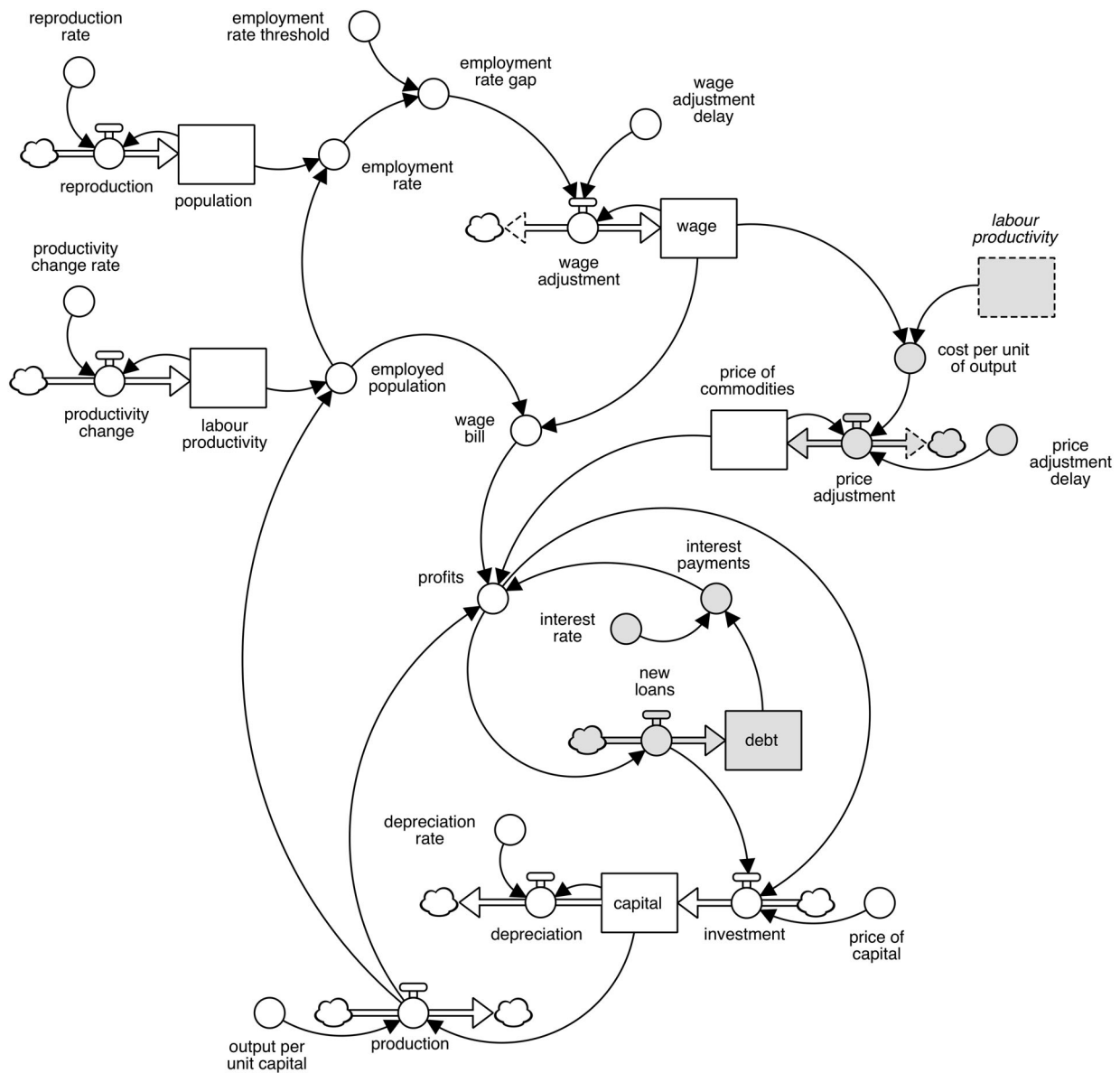
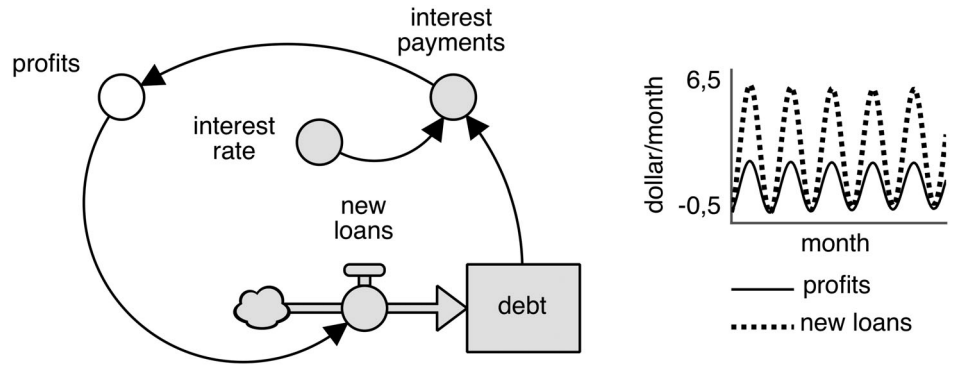


Fig. 4. Simplified Goodwin-Minsky-Keen (GMK) model

In the proposed simplified Goodwin-Minsky-Keen (GMK) model (Figure 4), the flow of new loans is equal to the flow of profits multiplied by a constant (Eq. (15)). Banks charge interest on outstanding debt (Eq. (16)),

Fig. 5. Profits and new loans (duration: 40 months)



which is taken out of profits (Eq. (17)). Actual investment is equal to profits plus new loans, divided by the price of capital (Eq. (18)).

$$\text{new_loans} = 2.5 \times \text{profits} \text{ [dollar/month]} \tag{15}$$

Note: new_loans is a unidirectional flow into the debt stock. When profits and desired loans are negative, new_loans equals zero.

$$\text{interest_payments} = \text{interest_rate} \times \text{debt} \text{ [dollar/month]} \tag{16}$$

where interest_rate = 0.007 [dimensionless/month] and initial debt = 0 [dollar].

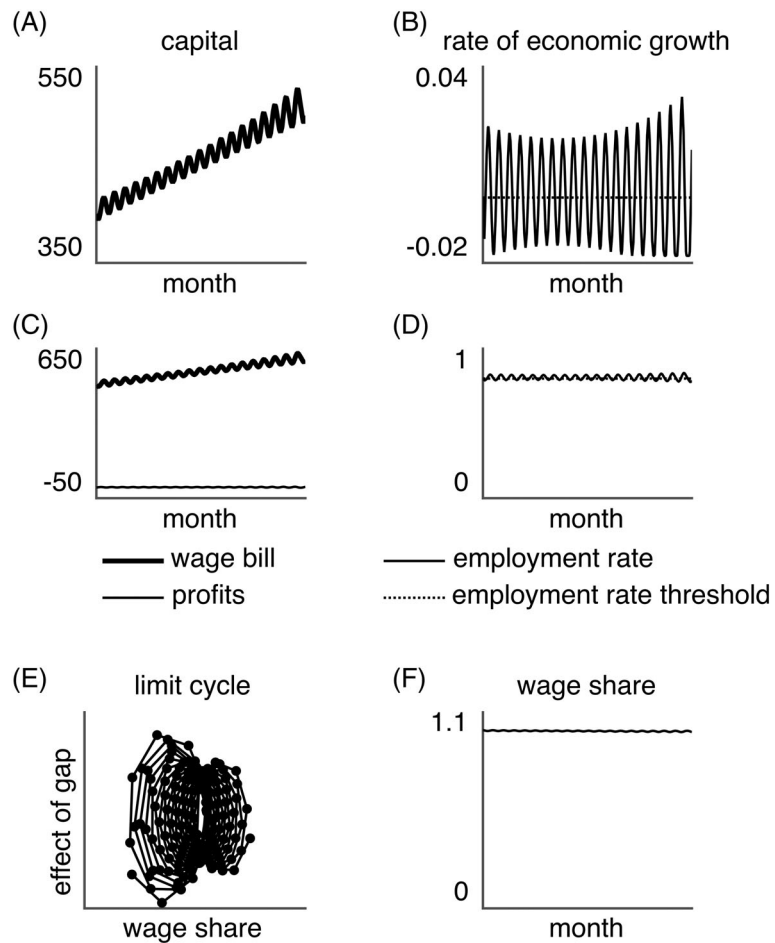
$$\text{profits} = \text{production} \times \text{price_of_commodities} - \text{wage_bill} - \text{interest_payments} \text{ [dollar/month]} \tag{17}$$

$$\text{investment} = (\text{profits} + \text{new_loans}) / \text{price_of_capital} \text{ [productive_good/month]} \tag{18}$$

This decision-making rule is incorporated into the simplified model in Figure 4. It replaces the direct causal link between profits and investment in Goodwin’s original GCM. The graph in Figure 5 shows the magnitude of new loans relative to profits.

Again, Keen’s approach for incorporating debt into his model is more elaborate. For example, he uses the rate of profit (profits divided by capital) as input to an investment function with adjustable parameters to fine-tune borrowers’ decisions. Keen also adds a sub-model for the financial sector, which incorporates money transfers, accounting operations, bankers’ consumption spending and new debt creation (for further details, see Keen, 2013, 2014). While these complexities are interesting and more adequately represent the real world, they are not required for explaining the basic

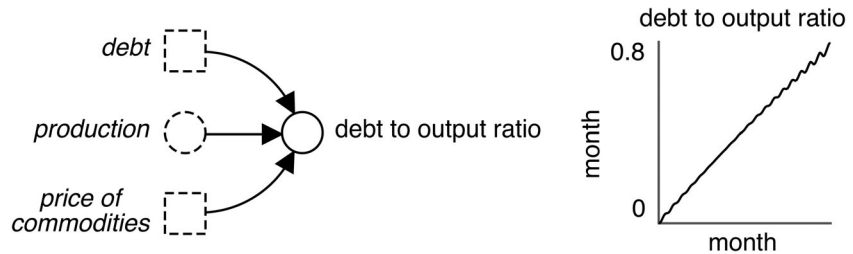
Fig. 6. Simulation results for the simplified GMK model (debt only) (duration: 150 months)



phenomenon of diminishing and rising cycles—“a lull before the storm” (Keen, 1995, p. 634).

Simulation results for the proposed simplified GMK model are shown in Figure 6. Note that only debt has been incorporated so far; price adjustment will be incorporated in the next section. Growth cycles for production, capital, wage bill and profits are similar to those in Goodwin’s GCM (Figure 6a, c). Additionally, we now see an initial phase of stabilization in the rates of

Fig. 7. Growing private-sector debt-to-output ratio (duration: 150 months)



economic growth and employment, preceded by widening fluctuations (Figure 6b,d). This matches Keen's discovery of the 'intermittent-route-to-chaos' dynamics in a Goodwin model with debt (Keen, 2017). We also see a shift to a lower wage share, again with widening fluctuations during the second half of the simulation (Figure 6e,f).

While the economy appears to be stabilizing during the first half of the simulation, firms borrow at a fast pace (see Figure 7 and Eq. (19)). Empirical data support the view that a growing private-sector debt to output ratio sets the scene for a crisis (Keen, 2013). However, this is not yet mimicked by the present simulation. To do so, we must still account for price dynamics.

$$\text{debt_to_output_ratio} = \text{debt} / (\text{production} \times \text{price_of_commodities}) \text{ [month]} \quad (19)$$

Incorporating price adjustment

So far, price has been held constant. We now introduce the price adjustment as shown in the simplified GMK model from Figure 4. Again, Keen's original model differs in how this is done (for details see Keen, 2014). His model incorporates an equilibrium price determined by monetary demand (the wage bill) and physical output. The difference between equilibrium and actual price determines the price adjustment and therefore the profit rate. In Keen's model, prices converge to a mark-up over the monetary cost of production.

While based on similar principles, in the version proposed here the price of a commodity simply fluctuates around the cost of production, which is limited to the costs of labour. Labour costs per unit of output depend on the wage level and on labour productivity; i.e., how many commodities a worker produces in a given period of time (Eq. 20). If the price of a commodity is high relative to its cost of production, then workers' households cannot afford to purchase the commodity and its price will tend to fall. Conversely, a relatively low price will tend to rise as a result of high effective demand. These tendencies do not occur instantaneously due to all sorts of frictions and delays in actual markets (Eq. 21). Price is multiplied by material

production to give us the revenue. As before, profits equal revenue minus the wage bill and minus the interest payments (Eq. 22).

$$\text{cost_per_unit_of_output} = \text{wage}/\text{labour_productivity} \text{ [dollar/commodity]} \quad (20)$$

$$\text{price_adjustment} = (\text{cost_per_unit_of_output} - \text{price_of_commodities}) / \text{price_adjustment_delay} \text{ [dollar/commodity/month]} \quad (21)$$

where $\text{price_adjustment_delay} = 12$ [month].

$$\text{profits} = \text{production} \times \text{price_of_commodities} - \text{wage_bill} - \text{interest_payments} \text{ [dollar/month]} \quad (22)$$

We raise the initial debt to 200 dollars and the simulation stop time to 800 months. The results of the simulation in Figure 8 show a period of moderation, followed by a period of increasing instability, followed by a financial and economic collapse. This coincides with Minsky's verbal description and with the behaviour of Keen's formal model.

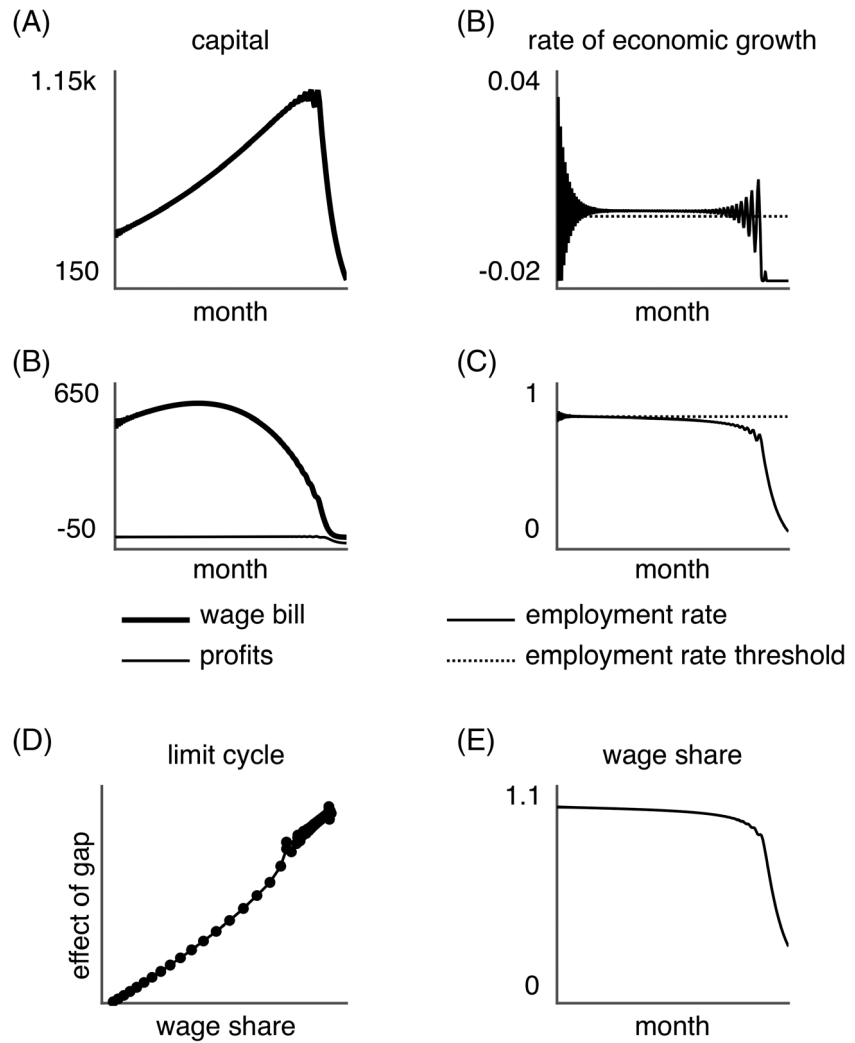
Conclusion, limitations and further research

Keen's incorporation of debt into Goodwin's model replaces stable cyclical behaviour with dampening cycles in the short run and widening cycles in the long run—followed by collapse (Keen, 1995). In the short run, the interest payments on rising debt reduce profits and investment. The next peak is lessened and the oscillations gradually dampen. In the long run, however, debt has continued to accumulate. Higher and growing interest payments reduce investment and employment, which leads to a more rapidly falling wage bill. This causes a surge in profits, loans and investment. This again boosts employment, raises the wage bill, and so on. Rather than dampened, the cycles now become more intense. Eventually, the peak is so extreme that the incurred debt brings profit down below zero and keeps it there. The system collapses (Keen, 1995).

Containing fewer variables and parameters, the behaviour of the present model matches that of Keen's (and in part Minsky's verbal model). However, it does not mean that one is superior to the other; the models merely serve different purposes. Keen aims to validate his model with empirical data (Keen, 2014), but its complexity is more difficult to communicate to a wider audience. The aim of this paper is closer to Goodwin's intention to propose "a starkly schematized" model (Goodwin, 1967, p. 1).

Not only is the proposed model easier to convey, but it is also less sensitive to initial conditions. Relative to Keen's original model, the simplified version

Fig. 8. Simulation results for the simplified GMK model (debt and price adjustment) (duration: 800 months; initial debt: \$200)



is more stable as parameter values are adjusted. This facilitates real-time exploration of scenarios. For example, depending on different parameter settings, the following possible dynamics occur: a lengthening or shortening of the time it takes for the system to collapse; collapse is sometimes preceded by rising cycles and sometimes not (i.e., it collapses “steadily”).

On a more general note, even if a model’s behaviour eventually conforms to some expected or observed phenomenon, it is still only a mere abstraction

of a specific part of reality, with strictly defined temporal and spatial boundaries. And this is a good thing. The mistake is not to simplify (we do that anyway, with or without simulation models); the mistake is to over-complicate. Of course, “[t]he art of modelling requires the sensitivity to decide when in the development of a science a previously necessary simplification has become a gross oversimplification and a brake to further progress” (Levins, 1998, p. 398). Keep things as simple as possible, but not simpler, said Albert Einstein.

The present model also suffers from several limitations. First, simplification came at a cost: the model may be more accessible, but some of its parameters and ranges are less realistic when compared to Keen’s version. There is undoubtedly potential for improvement, e.g., by adopting more robust system dynamics formulations for capital investment or other adjustment flows, as suggested in the paper.

A second limitation to the present model is that it cannot be initialized in equilibrium without further adjustments, e.g., by accounting for depreciation in the investment equation or by incorporating a mark-up (as a percentage of cost per unit of output). The latter would be in line with Keen’s model. It will need to be developed in future iterations of the present model.

A third limitation concerns policy analysis. “Can ‘It’—a Great Depression—happen again?” Minsky famously asked (Minsky, 1982, p. xii). His own conclusion was that crises in pure free-market capitalism were inevitable. In a recent review of policy proposals, Keen (2017, p. 48) further argues that “neither market nor indirect government action is likely to reduce private debt sufficiently”. Keen’s “debt jubilee” proposal is a direct cash injection into all private bank accounts, but with the requirement that it is first used to pay down any outstanding debts (Keen, 2017). Debtors whose debt exceeded their injection would have their debt reduced but not eliminated. Recipients with no debt would simply have more money in their accounts. A further step in the development of the present model would be to explore the effects of such a leverage point. Doing so would involve reintroducing other parts of Keen’s original model, which contains a banking module with deposit accounts.

The aim was to provide a starting point and introduction to Keen’s more elaborate insights building on Marx, Goodwin and Minsky. Several directions for further exploration have already been suggested. Others could involve incorporating counter-cyclical government policies or bailouts after collapse; the effects of globalization and outsourcing; the rise of oligopolies (which would influence mark-up pricing); impacts on different social groups in the aftermath of a crash; or shifts towards more flexible, freelance and temp employment. The present model provides a basic foundation upon which these various extensions could be built (provided some of the aforementioned limitations were addressed). To stimulate further exploration of this work, STELLA and *Minsky* versions, as well as the separate simulation

code, are available for download in the supporting information Appendix S1.

The model proposed in this paper is also intended to bring system dynamics and Marxian thought closer together. For the followers of Marx's dialectics, the model is likely to be too mechanistic. However, it is important to note here that stock and flow concepts are, in fact, dialectical: the boundaries between them overlap. That being said, no dialectical concept overlaps with its opposite all the way: "[t]hough they are not discretely distinct, dialectical concepts are nevertheless distinct" (Georgescu-Roegen, 1971, p. 47). Establishing such boundaries is necessary for logic, "[p]recisely because the whole has no seams" (Georgescu-Roegen, 1971, p. 213). For dialecticians, the separation of intellectual constructs is a necessary—yet insufficient—analytical step in understanding the world: "[a]fter separating, we have to join them again, show their interpenetration, their mutual determination, their entwined evolution and yet also their distinctness" (Levins, 1998, p. 381). In other words, once their distinctiveness has been established in a model, dialectical concepts must be re-entwined. This seems like a worthwhile discussion starter.

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References

- Beinhocker ED. 2006. *The origin of wealth: evolution, complexity, and the radical remaking of economics*. Harvard Business Press: Boston, MA.
- Bonaiuti M. 2012. Degrowth: Tools for a complex analysis of the multidimensional crisis. *Capitalism Nature Socialism* **23**(1): 30–50.

- Box GE. 1976. Science and statistics. *Journal of the American Statistical Association* **71**(356): 791–799.
- Cairó-i-Céspedes G, Castells-Quintana D. 2016. Dimensions of the current systemic crisis: Capitalism in short circuit. *Progress in Development Studies* **16**(1): 1–23.
- Dow S. 2005. Endogenous money. In *The general theory: Vol. 2. Overview, extensions, method and new developments*, Harcourt GC, Riach PA (eds). Routledge: Abingdon; 43–54.
- Fisher I. 1933. The debt-deflation theory of great depressions. *Econometrica* **1**(4): 337–357.
- Forrester JW. 1995. *Counterintuitive behaviour of social systems*. Massachusetts Institute of Technology: Cambridge, MA.
- Georgescu-Roegen N. 1971. *The entropy law and the economic process*. Harvard University Press: Cambridge, MA.
- Goodwin RM. 1967. A growth cycle. In *Socialism, Capitalism and Economic Growth*, Feinstein CH (ed). Cambridge University Press: Cambridge; 54–58.
- Keen S. 1995. Finance and economic breakdown: modeling Minsky’s “financial instability hypothesis”. *Journal of Post Keynesian Economics* **17**(4): 607–635.
- Keen S. 2012. The crisis in 1000 words—or less. Steve Keen’s Debtwatch, July. Available: www.debtdeflation.com/blogs/2012/07/22/the-crisis-in-1000-words-or-less/ [31 March 2019].
- Keen S. 2013. A monetary Minsky model of the great moderation and the great recession. *Economic Behavior and Organization* **86**(2): 221–235.
- Keen S. 2014. Behavioural finance lectures. Available: <https://youtu.be/KWUG1n1jEJI> [31 March 2019].
- Keen S. 2017. *Can we avoid another financial crisis? (The future of capitalism)*. Polity Press: London.
- Levin SA. 1992. The problem of pattern and scale in ecology: the Robert H. MacArthur award lecture. *Ecology* **73**(6): 1943–1967.
- Levins R. 1998. Dialectics and systems theory. *Science and Society* **62**(3): 375–399.
- Lotka AJ. 1925. *Elements of physical biology*. Williams & Wilkins: Philadelphia, PA.
- Marx K. 1976. *Capital: a critique of political economy*, Vol. 1. Penguin: Harmondsworth.
- Mass NJ. 1980. Stock and flow variables and the dynamics of supply and demand. In *Elements of the system dynamics method*, Randers J (ed). MIT Press: Cambridge, MA; 95–112.
- Meadows DH, Wright D. 2008. *Thinking in systems: a primer*. Chelsea Green: White River Junction, VT.
- Minsky HP. 1982. *Can “it” happen again? Essays on instability and finance*. ME Sharpe: Armonk, NY.
- Minsky HP. 1992. *The financial instability hypothesis*. The Jerome Levy Economics Institute of Bard College: Annandale-on-Hudson, NY.
- Pomeau Y, Manneville P. 1980. Intermittent transition to turbulence in dissipative dynamical systems. *Communications in Mathematical Physics* **74**(2): 189–197.
- Radzicki MJ, Sterman JD. 1994. Evolutionary economics and system dynamics. In *Evolutionary concepts in contemporary economics*, England RW (ed). University of Michigan Press: Ann Arbor, MI; 61–92.
- Saeed K. 2016. *Development planning and policy design: a system dynamics approach*. Worcester Polytechnic Institute: Worcester.

-
- Sterman JD. 1991. A skeptics guide to computer models. In *Managing a nation: the microcomputer software catalog*, Barney GO (ed). Westview Press: Boulder, CO; 209–229.
- Stroh P. 1992. The rich get richer and the poor. *The System Thinker* 3(2): 8–9.
- Volterra V. 1928. Variations and fluctuations of the number of individuals in animal species living together. *ICES Journal of Marine Science* 3(1): 3–51.
- Whelan JG, Msefer K. 1996. Economic supply and demand. D-4388, MIT System Dynamics Group Literature Collection. Available: <https://ocw.mit.edu/courses/sloan-school-of-management/15-988-system-dynamics-self-study-fall-1998-spring-1999/readings/economics.pdf> [31 March 2019].
- World Bank. 2017. GDP per capita growth (annual %). Available: <http://data.worldbank.org/indicator/NY.GDP.PCAP.KD.ZG> [20 January 2018].

Supporting information

Additional supporting information may be found in the online version of this article at the publisher's website.

Appendix S1. System models and equations.