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Intermediation, Money Creation, and Keynesian Macrodynamics in Multi-agent Systems

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ABSTRACT

This paper offers a simple computational model of monetary creation, derived from individual agent behavior, that provides additional support for the well-known and more or less universally accepted idea that money creation is inevitable in demand-driven Keynesian economies. The endogeneity of money is linked to *asynchronous* production, in which investment is set autonomously by a combination of animal spirits and capacity utilization, while savings adjusts to bring about macroeconomic equilibrium. It is seen that once these Keynesian motifs are translated into the agent-based framework, endogenous money arises as a natural consequence of the model. The contribution of the paper is twofold. First, it links endogenous money creation to decision making in real historical time—two shibboleths of post-Keynesian macroeconomics. Second, it suggests a fruitful cross-fertilization between post-Keynesian economics and the methods of agent-based modeling.

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1. Introduction

The notion that investment-led growth is accompanied by endogenous money creation is central to post-Keynesian macroeconomics and has been discussed in great detail in the literature.[1] This paper shows that when Keynesian mechanisms are introduced into an agent-based model (ABM), money is endogenous. The result is derived in the process of extending a standard post-Keynesian model, first to two sectors and then to an ABM. It is well known that in a one-sector model, the equality of savings and investment requires a smooth and efficient transfer from savers to investors that goes on in the background. A two-sector model highlights potential problems that might arise when one firm wishes to invest more than it has saved and must therefore borrow from the other. The multi-agent extension reveals that this 'smooth and efficient transfer' cannot take place without endogenous money creation.[2] Endogenous money emerges as a rigorous, well-defined and irreducible concept. More realistic multi-agent systems will always generate

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[1]See, for example, Lavoie (2014) and the various references therein.

[2]The quantity of endogenous money created can be zero in a limiting case in which the investment plans of *all* lenders just happened to be executed *before* any lending took place. As the number of agents grows large, the probability that this might occur is asymptotically zero. Apart from this case, the quantity of endogenous money created is alway greater than zero. See below, Section 4.

endogenous money, irrespective of any desire on the part of the monetary authority to limit credit creation. At the same time, not all credit-worthy demand for bank loans results in money creation at the microeconomic level, and this has important implications for the theory of crisis. The conclusions are hardly new; the goal of this paper is rather to examine some extremely well-established results in the context of the agent-based methodology.

The paper is organized as follows. The next section discusses the contribution that ABMs can make to the post-Keynesian research program, making the case that ABMs and the post-Keynesian approach are methodologically compatible. Section 3 presents a small two-firm prototype analytical model, that when stripped down to its essentials conveys the basic mechanisms on which the larger multi-agent model is built. Section 4 outlines the generalization of the analytical model to a full multi-layered, multi-agent system, and identifies asynchronicity as essential to an agent-based conception of endogenous money. Section 5 concludes.

2. Agent-based and post-Keynesian models

The agent-based approach of this paper shares a number of broad affinities with the post-Keynesian research program *writ large*.[3] First, realism about what agents can and do know is uppermost in all agent-based models. Agents are rational, but boundedly so: they rarely, for example, engage in inter-temporal optimization. This resonates with the post-Keynesian theme that decision making is subject to fundamental uncertainty. Second, agent-based modeling methodology is *constructive*, with careful attention to how one starts from some initial conditions to arrive at the emergent properties of the model. This echoes long-standing themes in post-Keynesian economics. Keynes's paradox of thrift, for example, illustrates how seemingly 'perverse' macro results emerge from individual agents' savings decisions.

As in virtually all post-Keynesian theory, *time* is essential to agent-based modeling. Mainstream macro theory has concocted various ingenious means to extricate economic logic from the messiness of time, treating all events as consistent with equilibrium (however defined). ABMs, on the other hand, are solved sequentially: the computer plays a central role, and its compiler can only process commands *asynchronously*, so that different decisions and actions of agents are necessarily undertaken non-contemporaneously. The methods of ABMs demand from the outset that time be taken seriously, a methodological perspective clearly shared with post-Keynesians in virtually every aspect of that approach. Joan Robinson's emphasis on history versus equilibrium is an early and obvious example of this shared outlook.

Both ABM and post-Keynesian approaches soundly reject the synchronicity of the orthodox school as well as the representative agent assumption, which authorizes a common inter-temporal optimization model. This aspect of the standard program has always been set aside by post-Keynesians as irritating and unrealistic. ABMs, on the other hand, begin with heterogeneous agents, heterogeneous not only in their behavior,

[3]There is here a clear link between the disaggregated version of the standard post-Keynesian model of this paper and the rich history of multi-sectoral analysis in Keynesian macroeconomics (Pasinetti 1981). For the methodological claim that ABM modeling is consistent with the pre-analytic vision of Keynesian theory see Bucciarelli and Silvestri (2013). For numerical simulations of the exact model discussed in this paper, see Gibson and Setterfield (2018).

but also in their access to information, their ability to process data, and to form expectations. The latter approach is not only fully consistent with post-Keynesian priors, but also adds depth and realism to the emergent macroeconomic model. In what follows, the interaction of non-bank spending units with banks, each modeled as a cohort of individual agents, together with the asynchronous nature of their behavior is shown to be the well-spring of endogenous money creation.

The model builds on an existing ABM due to Setterfield and Budd (2011) as modified by Gibson and Setterfield (2018), which has roots in the post-Keynesian tradition (Pasinetti 1981; Taylor 1983, 1991) but lacks a financial side. Many multi-agent systems model the financial system in isolation from the real-side of the economy, while some integrate the real and financial sides. None of the latter models employ the assumptions of the standard neoclassical general equilibrium model for the real side, but drift away to varying degrees with a range of ad hoc assumptions. To our knowledge, the ABM of this paper is unique in its use of a thorough-going post-Keynesian model for the real side in combination with the financial.

The resulting model offers a simple account of real-financial interactions in which multiple, heterogeneous firms and financial agents, which together form the banking system, are interconnected in a two-layer network. Financial nodes are connected by edges that represent borrowing on one level of the network, while firms on a second level are connected by edges that represent sales and purchases of goods and services. The demand side is not explicitly modeled in detail, other than that households either save or consume. The model focuses instead on the behavior of firms and their decision to invest, either by way of retained earnings or by borrowing from other firms through financial intermediaries. The financial subnetwork is sparsely connected to the real subnetwork as described in detail below.[4]

The intent of the model discussed here is not a realistic representation of a financial system of an actual economy. There is, for example, no central bank and the interaction of financial agents is limited. Moreover, no effort is made to trace the initial creation of bank credit through to the creation of money in a fully developed monetary circuit. The analysis, moreover, does not explicitly keep track of assets and liabilities that accumulate on bank balance sheets in the course of economic expansion. Consequently the model does not reprise the first principle of endogenous money theory, that loans create deposits, which themselves constitute money by any sufficiently broad definition of the category. This is not to deny that credit creates money, but rather to shift the focus of the model to the need for, and process of, credit creation in an expanding economy.[5] The purpose here is to establish the asynchronous interaction of firms and banks as the basic causal mechanism that *initiates* the process of endogenous money creation. The process begins with the highly abstract reduction of credit creation to an atomistic bilateral exchange between two producers, a surplus and a deficit firm, that is brought about by a third financial agent who belongs to the banking system.

The core of the argument thus joins two streams of thought: from post-Keynesian theory, investment is driven by animal spirits and generates in its wake the savings

[4]The precise structure of the financial network is seen to be crucial to the propensity of the model to experience a financial crash. See Gibson and Setterfield (2018).

[5]It is perhaps more accurate, therefore, to say that this is a model of endogenous *credit*, rather than endogenous money. Hopefully, our use of the term endogenous money will not be a source of confusion in the remainder of the paper.

necessary to finance the investment. The multi-agent framework provides a step-by-step analysis of precisely how and in what order this process unfolds. It turns out that along the way there are many hidden assumptions about how investment can drive the system when some firms save less than they invest. It shall be seen that credit and thus money creation is inevitable if savings and investment decisions are made in the asynchronous ecology of agent-based models. Even if time intervals are short, the non-contemporaneous nature of savings and investment decisions leads to endogenous money creation when firms behave as specified in post-Keynesian theory. At some point in the evolution of the system, conflicting claims on deposits arise that can only be resolved by way of money creation. The results of the ABM studied here thus support the broadly accepted notion that animal spirits and endogenous money are two sides of the same analytical coin.

3. Money and Production in One- and Two-sector Models

In Keynesian macroeconomics, endogenous money creation within the private sector is well understood to accompany the income-generating process. Indeed, it has been known for decades that when economic activity is demand-led, endogenous money creation is logically necessary for real expansion to be feasible (Chick 1983). As will become clear, the argument here centers on the financing of fixed capital formation and the fact that economic activity takes time, specifically that adjustment to equilibrium is not instantaneous.[6] This is self-evident to most post-Keynesians and goes back at least to Robertson's discussion of the multiplier concept (Robertson 1940).[7]

3.1. A one-sector model

In one-sector Keynesian models, saving depends on income while investment spending does not. Unlike some neoclassical models, Solow's among them, saving cannot *initiate* a change in income. In Keynesian models, an autonomous increase in investment increases income and a concomitant rise in savings follows in the wake of this change. As is commonplace, macroeconomic equilibrium is established when income rises to the point that total savings balances investment.

In a one-sector, one-period model, the purchasing power to back up the desire to invest must come from somewhere. Traditionally, it is assumed to come from the savings that agents—some of whom who are hired as a result of the new investment—will generate. In the storied equilibrium of the Keynesian model, this all comes out 'in the wash'. It was clear to the early Keynesian theorists, however, that something more complex and potentially problematic was going on in the unexamined background. In particular, it became self-evident that investment spending can *increase* above its current level of savings in the previous period, if and only if additional credit is created.[8] As Chick writes

> …[i]f the investment is not financed it will not take place … one needs to back demand with purchasing power. The solution to the problem lies in the capacity of banks to create credit in

[6]See Arestis (1987, pp. 10–11) for similar arguments regarding the importance of endogenous money creation for the expansion of *working* capital by firms, when production takes time so that the costs of production must be incurred before revenues accrue from the sale of output.
[7]See Chick (1983, pp. 257–263) for a discussion and reconfiguration of Robertson's model.
[8]Note that there is no parallel constraint on saving-constrained investment falling *below* its current level.

> excess of current saving, and so finance investment in excess of current saving. (Chick 1983, p. 189)

Chick (1983) notes that there is an historical as well as logical dimension to this process: the independence of investment from prior savings requires that commercial banks have the capacity to create credit in excess of saving. Banks act as more than mere conduits or intermediaries for existing saving and hence effectively relax the constraint that would otherwise be imposed by prior savings on investment spending. Once disequilibrium adjustment is complete so that savings is once again equal to investment, current savings is sufficient to fully fund current investment spending. The bank credit originally created is now either 'destroyed' by repayment of the loans, as firms refinance by issuing bonds, or held by households in the form of higher transactions, precautionary, and/or speculative balances.[9] For most post-Keynesians this is received wisdom, based on a one-sector, aggregate analysis, an analysis not always accompanied by an explicit account of the timing of flows of deposits and withdrawals from individual banks.

A sufficient condition for real expansion in Keynesian systems is provided by the perfectly interest-elastic credit supply conditions originally associated with *horizontalism* (Moore 1988; Lavoie 2007), but the necessary condition for endogenous money is only that the elasticity of the supply of credit be non-zero, a position originally claimed by *structuralists* (Pollin 1991; Dow 2007). Under these conditions, the monetary authority cannot prevent banks from responding to the incentive of higher interest rates by creating more credit. The result is an upward-sloping credit supply curve in quantity of credit-interest rate space. Whether banks require an incentive in the form of some increment in the interest rate is not central to the argument advanced in this paper. From this perspective an upward-sloping credit supply curve is just a variation on the theme of horizontalism.[10] Suffice it to say that until now, the debate has proceeded at the level of *aggregates*: banks, households, firms and the like rather than their constitutive agents. More detailed agent-based analysis shows that endogenous credit/money is the normal state of the macroeconomic system, whatever the slope of the credit-supply schedule.

Verticalists, by contrast, describe a world in which this endogenous creation of money goes to zero. In this case, the supply of money is infinitely inelastic. Here again, however, the onus of the argument is on the behavior of banks in a homogeneous banking system. A vertical credit supply function is simply a limiting case as the responsiveness of banks to the incentive of higher interest rates diminishes. It is the limit as the desire to create endogenous money goes to zero. Only at this limiting case in which the elasticity of the credit supply curve goes to zero, do central banks wrest control of the money supply from the banks. In any other state, money is endogenous.

Returning to the real side, a one-sector Keynesian model can be specified as follows: let x be the level of output in the economy and K is the given aggregate capital stock in a

[9]See, for example, Graziani (1989). For a balance sheet presentation of how these adjustments take place, see Chick (1983, pp. 261–262).

[10]The debate between horizontalists and structuralists has, at times, been vexing. It is beyond the scope of this paper to contribute to—much less resolve—ongoing debates between schools of thought in endogenous money theory, although we note in passing that recent contributions are marked by a greater degree of *rapprochement* between previously competing perspectives (Rochon and Rossi 2017).

particular year. Define the current level of capacity utilization, u as

$$u = x/K \tag{1}$$

Assuming for convenience that household savings is only out of profits at rate $0 < s \leq 1$, the savings-investment balance, normalized by the capital stock, can be expressed as

$$I/K = s\pi u \tag{2}$$

where π is profit (retained earnings) per unit of output, x. Investment in this variety of models is usually written as a function of capacity utilization in the previous period, $I/K = g(u_{t-1})$, where the shape of the function g depends on exogenous animal spirits and is independent of savings in the economy. Equilibrium output can be expressed in terms of u by combining this expression with Equation (2) to write

$$u = \frac{g}{s\pi}$$

Aggregate savings per unit of capital, $s\pi u$, is then determined by g, which is, in turn, given by expectations of the ability of the firm to meet demand as a function of last-period's capacity utilization, buoyed by animal spirits. This period's savings is equal to investment but plays no role in its determination. Indeed, if last period's saving *rate* were higher, last period's capacity utilization would be lower and thus investment this period would be *lower*, for the same level of animal spirits. Last period's savings is not even available to finance current investment, since its material form is nothing but a claim on the capital stock of firms that is now enlarged by last period's investment.

The one-sector, one-period Keynesian model holds that savings will adjust to investment without bothering to explain how consumers make their savings available to firms for investment. One way to finesse this point is to say that consumers own the firms and use them as a vehicle to store their accumulated savings in the form of the capital stock and retained earnings. No banking system is then necessary since the aggregate firm controls all the savings in the system on behalf of the households. The firm simply directs investment in the way it sees fit and in the process of expanding output and employment, generates the savings.

3.2. A Two-sector Model

Now let there be two sectors. Unless each firm invests precisely as much as the savings it generates, there is an unavoidable problem: how is the surplus savings of firms that do not invest as much as they save, transferred to firms who have a deficit of savings to finance their investment? It is evidently done by middlemen, the banks, based on the collateral and credit-worthiness of the borrower as assessed by the financial agents of the system.

Again assume that some fraction of households owns, but does not control, the retained earnings of firms. One need only consider then the borrowing of the deficit firm and the availability of loanable funds from the surplus firm.[11] Deficit firms cannot retain sufficient earnings for their investment plans, but must borrow from surplus firms that have more than enough retained earnings relative to their own investment plans. In effect, the

[11]This account ignores the rate of interest and inter-firm interest payments in order to simplify matters.

households that own shares in the surplus firm now diversify, owning shares of the deficit firm as well.

Consider the equilibrium solution to a demand-determined real-side model in which the number of firms is n=2. There is only one good, the price of which is fixed at unity. Output, x_i for i=1,2, is a share, θ (for firm 1) and $1-\theta$ (for firm 2) of aggregate demand, which is the sum of consumption and investment. Workers consume all their income while consumption of capitalists is income less savings. Equilibrium is defined by the balance of supply and demand for each of the two firms

$$x_1 = \theta[(1 - s_1\pi_1)x_1 + (1 - s_2\pi_2)x_2 + g_1K_1 + g_2K_2]$$
$$x_2 = (1 - \theta)[(1 - s_1\pi_1)x_1 + (1 - s_2\pi_2)x_2 + g_1K_1 + g_2K_2]$$

Here capitalists save a fraction s_i of their profits $\pi_i x_i$, where again π_i is the profit share of output. Investment is given by $\sum_{i=1}^{2} g_i K_i$, where g_i is the accumulation function that depends on last period's capacity utilization rate. Normalizing by K_1, the capital stock of firm 1, so that $k = K_2/K_1$, the model can be expressed as

$$u_1 = \theta\{(1 - s_1\pi_1)u_1 + g_1 + [(1 - s_2\pi_2)u_2 + g_2]k\} \tag{3a}$$

$$s_1\pi_1u_1 + s_2\pi_2u_2k = g_1 + g_2k \tag{3b}$$

where the rate of capacity utilization of the ith firm is given by Equation (1) above for each sector. Equation (3b) is simply the savings-investment balance for the economy as a whole. The firm's financial surplus f_i per unit of capital in each firm is given by

$$f_i = s_i\pi_iu_i - g_i.$$

The macroeconomic equilibrium condition is

$$\sum_i f_i = 0 \tag{4}$$

that is, the sum of the financial surpluses is equal to zero.

Figures 1 and 2 illustrate a solution to the two-sector model when the savings rates are given. In both diagrams lagged capacity utilization, u_{t-1}, is given. Total savings is the same in both diagrams, shown as s on the positive ordinate. The total savings schedule is shown as the solid line in the non-negative orthant and is the right-hand side of Equation (3b). Its slope in Figure 1 is $s_1\pi_1$ and its intercept is $s_2\pi_2k$. Total investment, g, is then also the same in both diagrams and is shown by the solid line in the 3rd quadrant. The intercept in Figure 1 is g_2k and the slope is the response of firm 1's accumulation function with respect to lagged capacity utilization.[12] The 45-degree line in quadrant 2 of both figures reflects g onto the positive ordinate. The equilibrium of the model is shown as the point at which total investment determines total savings and is the same in both diagrams.

Causality runs in a clockwise direction starting with last period's capacity utilization rate, u_{it-1}, measured in the negative direction on the ordinate. With total investment determined, the intercept of the savings function in the first quadrant adjusts to determine the current period capacity utilization for both firms. This establishes the general

[12]Both s and g are normalized by firm 1's capital stock, K_1, as in the model above. The accumulation functions are shown in the diagram as linear and homogeneous for simplification only.

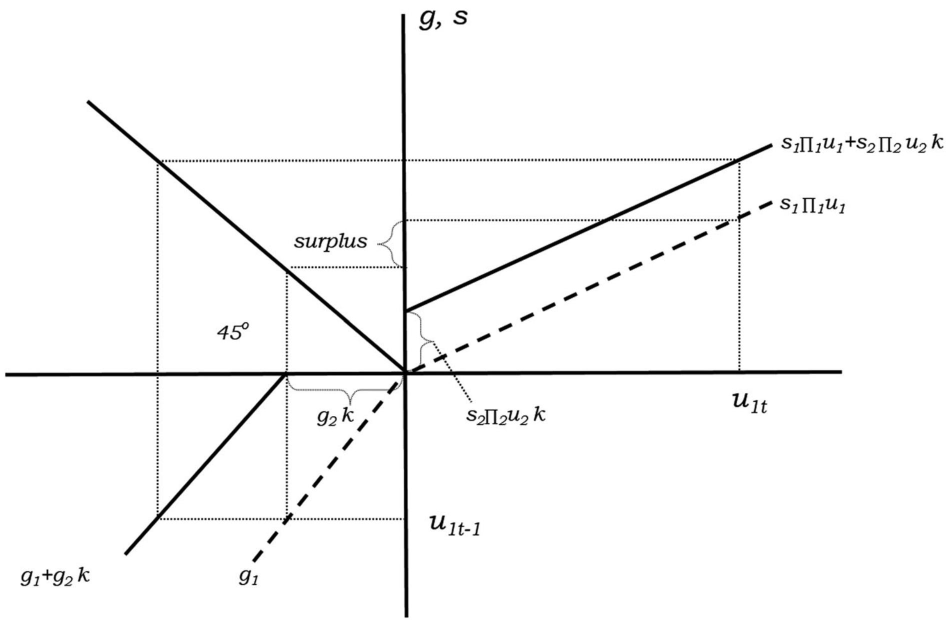

Figure 1. Saving and investment of the surplus firm. Lagged capacity utilization is given and together with investment from Figure 2 total investment, g, determines total savings. This firm is in surplus since its investment, g_1, is less than its savings, $s_1\pi_1 u_1$.

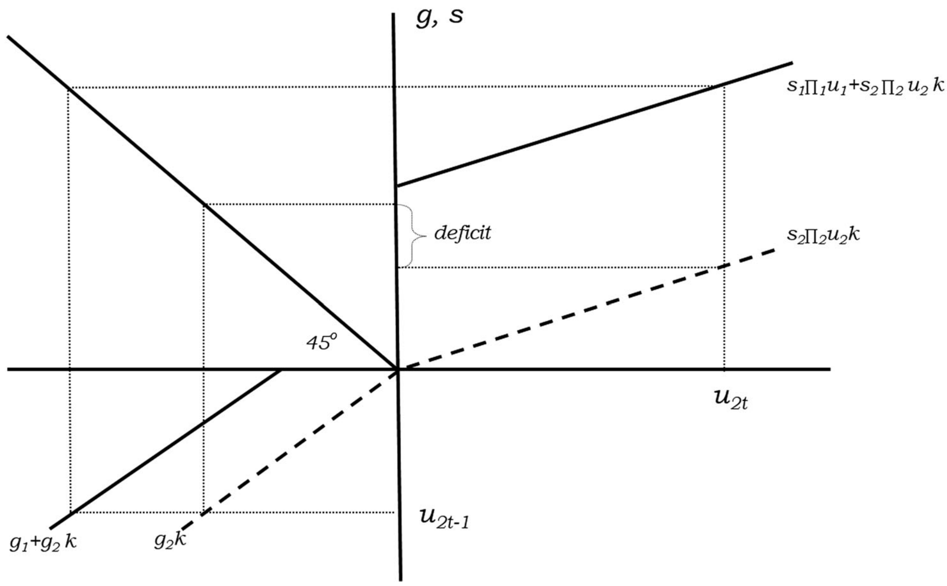

Figure 2. Saving and investment of the deficit firm. Lagged capacity utilization is given and together with investment from Figure 1 total investment, g, determines total savings. This firm is in deficit since its investment, g_2, is greater than its savings, $s_2\pi_2 u_2 k$.

equilibrium of the system, but does not tell us which of the two firms is in deficit and which is in surplus.

To see which is which, note that with u_{1t} determined, it is also known how much savings firm 1 has done, as shown on the dotted line in the first quadrant of Figure 1. Firm 1's investment is determined in the third quadrant by the dotted line. Reflecting this into the first quadrant using the 45-degree line, it can be compared with firm 1's level of savings. The difference is the financial surplus of firm 1. In Figure 1, investment falls short of savings. This confirms a financial surplus for firm 1 in the current period. In Figure 2, firm 2's investment exceeds its savings so it is in deficit in the current period.

The comparative statics of a change in the structure of demand, θ, can easily be shown using these diagrams. A reduction in θ would shift demand from the first firm to the second, raising u_2 and simultaneously reducing u_1. In Figure 1, the savings of firm 1 falls, while in Figure 2, the savings of firm 2 rises. Since g_1 in the third quadrant of Figure 1 remains unchanged, the reduction in u_1 can easily cause the formerly surplus firm 1 to become a deficit firm. The logic of the model implies that in this case, firm 2 would switch to a surplus.

As noted, in the two-firm example of Figures 1 and 2 there must be an implicit financial sector channeling funds between the two real-side firms. Could this flow of funds be disrupted? Clearly yes if the deficit firm in Figure 2 cannot borrow from the surplus firm in Figure 1. Only if loans are available and meet or exceed the firm's deficit can the latter invest at its desired level. A second problem lies in the intermediation itself. Despite the existence of a surplus of loanable funds *and* a potential intermediary, there is no guarantee that a financial agent might not block the flow of funds, effectively preventing financing from finding its way to the deficit firm. Since banks' profits depend on facilitating the flow, it may seem natural to assume that they will find an efficient way to channel resources from lender to borrower. If, however, the firm is not deemed to be creditworthy or the financial agent perceives some threat to the ability of the firm to repay the loan, the agent may well defer, effectively preventing the investment that would otherwise have taken place.

Observe that were a financial agent to block the flow of funds from firm 1 to firm 2, the level of activity at which savings comes into balance with investment depends only on the level of investment by the first firm and what can be financed by the second firm so that its financial surplus is zero. The new equilibrium condition replaces Equation (4) with

$$f_i = 0, \quad \forall i$$

To the extent that intermediation fails, part of the *ex ante* surplus of the lending firm simply evaporates. Investment becomes financially constrained, and the system cycles down to an equilibrium in which aggregate savings is equal to aggregate investment at a *lower* overall level of economic activity. All this is brought about by the unwillingness of the bank to serve as a conduit of loanable funds. On the other hand, if credit is fully accommodating (the credit supply schedule is perfectly elastic and there are no credit worthiness checks), there is no limit to the rate at which the economy can expand.

4. A multi-layered network model

The model with just two firms initiates the transition to a full multi-agent system that depends on the microeconomic details of inter-agent communication and negotiation (Gibson and Setterfield 2018). Multi-agent systems do not just allow for a more careful examination of agent interaction but actually require it, since the rules agents follow are together responsible for the emergent macroeconomic properties of the system. As noted above, such an examination uncovers some important properties that are concealed in models lacking detail about the activities of individual agents.

Consider an economy consisting of two breeds of agents: firms and financial entities, or banks. The model structure is summarized by a multi-level network, as shown in Figure 3. The top plane represents the financial sector, and is populated by nodes that are linked by borrowing relationships that are non-directional in the sense that funds can flow in either direction between financial entities. It is assumed that these agents are not randomly connected, but are preferentially attached in that the probability that any new node would connect to an existing node is proportional to its *degree*, or number of existing links to other entities (Gibson and Setterfield 2018). The lower level represents the real sector in which firms are linked by flows of final aggregate demand, purchases and sales of commodities, that in principle change with technology and demand preferences.

Were there just one unconnected financial agent per firm, the agent could only accumulate loanable funds when its associated firm was in surplus. These funds would then be available to the same firm to use in the following period. In effect the network would then break up into a set of separate autonomous economies as in the one-good model above.[13] Meanwhile, multiple financial agents are required to break up the centralized coordination of information within the financial sector that might otherwise thwart the consequences (discussed below) of asynchronous firm behavior. A single bank that faces no competition for its financial services could identify deficit and surplus firms. It could then decline to provide credit to deficit firms until it knows the total supply of loanable funds. In this way, it would ensure that the total demand for loans never exceeds supply. Here, however, the bank would be acting as a Walrasian auctioneer, extricating an economic process from the flow of real time in precisely the manner to which post-Keynesians typically object. The basic principle of endogenous money theory, that loans create deposits, would break down, as would the capacity of the real economy for demand-led expansion.

Centralized information flows would also prevent financial agents from learning from each other and their associated clients at different rates. With more than one financial agent on the grid, each can learn differentially about the profitability of its clients, a private signal, as well as the clients of their neighbors, a public signal. Gibson and Setterfield (2018) show how Bayesian updating can be employed in a model of reinforcement learning that can lead to a financial crisis.

Figure 3 shows financial agents connected to each other, with just one agent per firm. Note that the lightly shaded deficit firm on the far left cannot fulfill its investment plans since its financial agent, shown as number 1, is only connected to another deficit firm through financial agent 2. To arrange for funding, the firm would have to persuade

[13]See also Setterfield and Budd (2011).

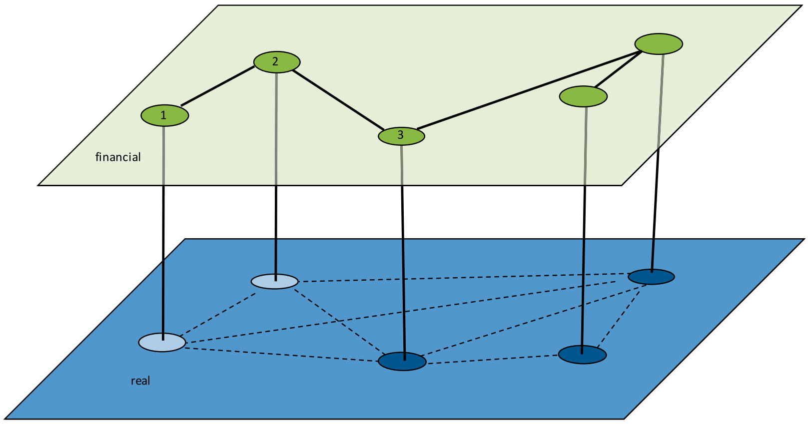

Figure 3. Multi-level network structure with firms on the lower level and financial agents on the upper level. Light disks are *deficit firms* that wish to invest more than they save, while dark disks are *surplus firms* that save more than they invest.

financial agent 2 to ask financial agent 3 for funds from its associated firm, which is indeed in surplus.

4.1. Two critical assumptions

Despite its simplicity, Figure 3 affords some insight into the necessary structure of financial networks. Observe that if the upper network is *connected*—there are no isolated communities of financial agents—any firm would have access to the surpluses of the *entire grid*. The agent-based framework would then add nothing of value to the two-sector model studied in Section 3. In reality, firms have limited access to the financial surpluses of other firms and for the model to reflect this more realistically, a 1-ply assumption is invoked: financial agents can borrow from their linked neighbors only 1-ply deep.[14] In Figure 3, the assumption prevents financial agent 1 from borrowing, using financial agent 2 as an intermediary to 3. As a result, only the second deficit firm (in the northwest corner, associated with financial agent 2) can borrow from the surplus firm served by financial agent 3.

The 1-ply assumption enhances the realism of the model, but it also implies that any given firm will only be able to borrow from firms served by associates of its own financial agent. This assumption is restrictive. It causes the network of firms to experience large deficits of aggregate demand since so many deficit firms are unable to find financing for their projects. A less restrictive assumption is simply that the number of financial agents, m, is greater than the number of firms, n. This assumption produces more robust growth and prevents subsets of firms from experiencing very low levels of effective demand and capacity utilization when the rest of the grid is booming. The two critical assumptions of the model are, then, 1-ply borrowing and $m>n$, and it should now be clear how the model would behave if either of these assumptions were relaxed.

[14]A 2-ply assumption, or indeed an n-ply assumption, would serve the same purpose of limiting borrowing access, although by much less. The 1-ply assumption is invoked for simplicity.

4.2. Endogenous money in asynchronous agent-based models

If, at any point in time, the client of the *i*th financial agent is a *surplus firm*, the change in loanable funds, $\Delta\ell$, of bank i is

$$\Delta\ell_i = F_i/m_i$$

where $F_i = S_i - g_iK_i$ is the current savings, S_i, less investment planned for the next period, g_iK_i, and where the number of financial agents directly linked to firm i is m_i. As noted above, if the banking system is unwilling to allow any credit expansion, then investment by deficit firms is limited by the availability of loanable funds. In the standard account, the central bank can prevent money creation by simply limiting loans to $\sum_{f^+} F_i$, where f^+ is the set of surplus firms.

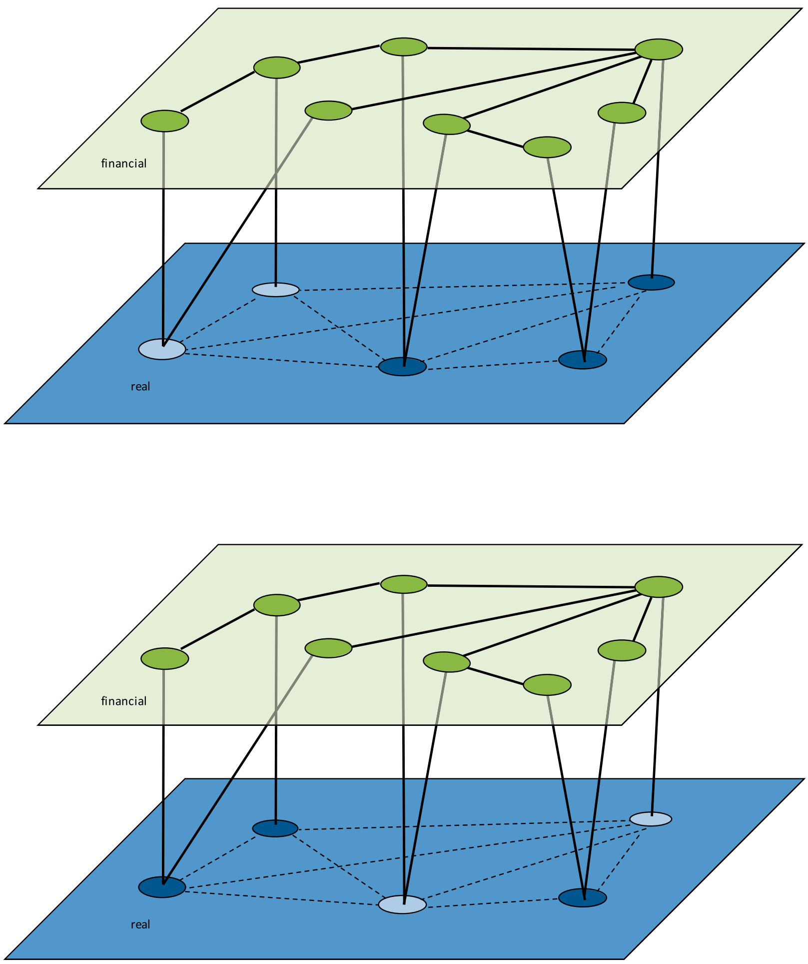

Figure 4. Multi-level network structure with more than one financial agents per firm. Notice that the pattern of surplus and deficit firms changes in the bottom frame, one period later.

Figure 4 shows the final model for $m>n$, so that some firms are served by more than one financial agent. Notice the pattern of preferentially attached network structure for financial agents, while firms are connected in a more random network. This structure is intuitively appealing and conforms to the assumptions commonly made in networked financial systems (Gibson and Setterfield 2018). The performance of this system is prone neither to explosive growth nor collapse due to lack of effective demand. The two panels of Figure 4 represent two periods in time for the same model; in the first, the pattern of surplus and deficit firms is the same as in Figure 3, but just one sweep of the model later, the two deficit firms on the left are now in surplus.

This is stereotypical of the model's behavior and easy to interpret. If a firm cannot invest as much as it wants because it cannot find funds, it cannot increase its installed capacity. If demand continues apace in the next period, it remains a deficit firm. Any of its linked neighbors that did invest, however, and are now operating with higher capacity levels, are likely to become surplus firms. The latter could then provide funds to allow their frustrated associate to proceed with its planned investment.

Figure 5 summarizes the normal functioning of the model. The deficit firm in the foreground has two financing options. The first is with financial agent 1 who is linked to agent 2. The problem here is that the client of agent 2 has no surplus to lend. The deficit firm must then ask financial agent 3 to obtain funds from its linked neighbor, financial agent 4, and then channel them along to the deficit firm as shown by the arrows. This assumes that neither of the agents blocks the flow because of negative expectations. It is easy to see how a blocked flow could set off a crisis that then spreads through the grid.

How, then, does endogenous money come about? Consider Figure 6, which is an enlargement of an aspect of the multi-layer grid. At time period t the surplus firm on the right-hand side of the diagram holds funds with financial agent 1. However, in period $t + \delta t$ those very funds are borrowed by the deficit firm, via financial agent 2, depriving the surplus firm of access to its own funds.

This raises the key question: could a financial agent block a surplus firm from accessing its deposits on the grounds that those funds had already been loaned to a deficit firm? In

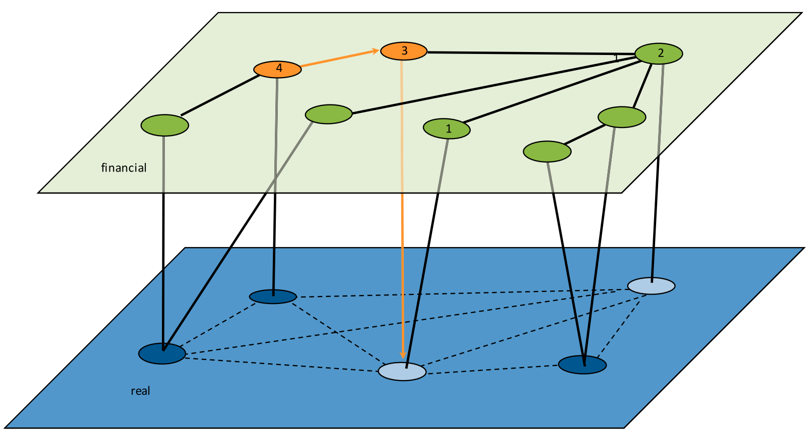

Figure 5. The deficit firm associated with financial agent 1 obtains financing from the firm associated with financial agent 4 via agent 3.

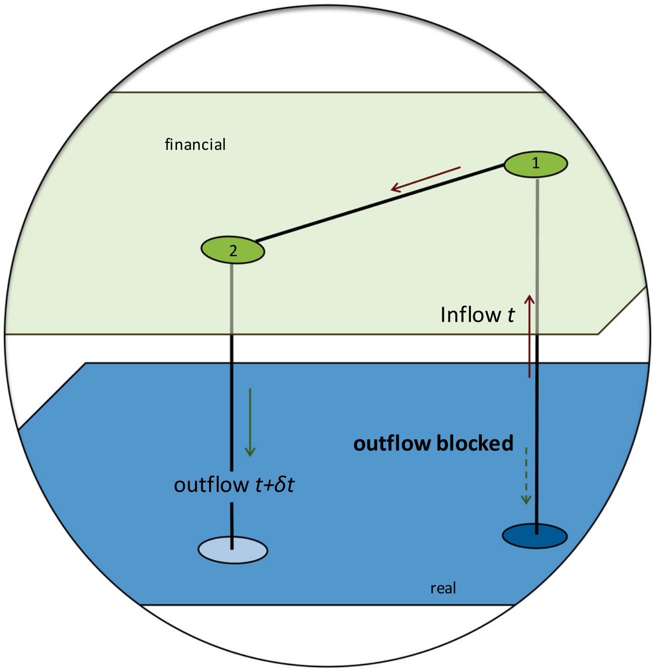

Figure 6. The deficit firm associated with financial agent 2 obtains financing from the firm associated with financial agent 1, thereby blocking the return of those funds to the surplus firm when it is ready to invest.

reality, of course, the answer is no: surplus firms are legally entitled to their deposits and so it is only under the extraordinary circumstances of a credit freeze that a surplus firm would be barred from using its deposits for investment.[15] In practice, the financial agent or bank simply creates credit to reinstate the funds of the surplus firm. In this way there is a *forced* increase in credit, whether planned or not by the monetary authority. This increase causes money to become *endogenous* in the sense that the central bank is powerless to stop the credit expansion.

As noted above, in agent-based modeling, agents interact sequentially during each period of time. This interaction is typically random. In the first sweep, agent *i* might interact with agent *j before k* interacts with *l*, but in the following sweep, this temporal sequence can change. Contrary to models of general economic equilibrium, in which all agents come into balance at one instant, synchronously, multi-agent systems are typically *asynchronous*, and randomly so. In some runs, therefore, the surplus firm will be able to invest without any additional money creation; in others the deficit firm will deplete the funds the surplus firm has on deposit with financial agent 1. The surplus firm still invests, but this time with funds created by the monetary system. Which outcome occurs is determined by the order in the queue of the two firms.

The asynchronicity of the multi-agent system implies that the central bank becomes powerless to stop the endogenous creation of money. This gives rise to the possibility

[15]To deny surplus firms the use of their own savings is to announce catastrophic financial failure. In this worst-case scenario, a system-wide run on deposits could well occur.

that investment in the current period may exceed the sum of savings in the last. The root cause of the increase in the money supply is that there is a time interval Δt in the model *between* the instant that firms make deposits and the spending down of those deposits for investment purposes. Financial agents in the model, however, are under no obligation to deny a request for a loan from a deficit firm on the grounds that some of its deposits might soon be withdrawn by surplus firms for their own planned investment. All the financial agent perceives is that it is flush with deposits at that moment. Indeed, there is no mechanism in the model to communicate to the financial agent that some of its recent inflow of deposits should be held in reserve to enable their owners to purchase capital goods as planned when their time comes in the queue.

The model thus makes explicit how endogenous money might come about, since if deficit firms have already contracted to borrow in excess of what would be the available financial surplus, financial agents have no choice but to create the liquidity when surplus firms are themselves ready to invest. Although deficit firms can and do crowd out other deficit firms, they cannot legally crowd out surplus firms. The larger conclusion is that the realism imparted by the agent-based approach breaks the dependence of current investment on previous savings. In this way the model retains its Keynesian flavor, since animal spirits, in the function g above, ultimately allow aggregate investment in period $t+1$ to exceed savings in period t.

4.3. Money and Keynesian macrodynamics

It may seem that relying on a computer program to determine the order in which firms invest, and therefore total investment, is somewhat arbitrary. After all, in a standard Walrasian account no trades would be made until the auctioneer balances offers to sell with offers to buy. Epstein and Axtell (1996) have argued, however, that computer driven bilateral trades between two discrete agents offer a more realistic account of how markets actually function. The multi-market equilibria in bilateral systems produces a *statistical equilibrium* rather than a unique price vector, provided additional necessary but reasonable assumptions hold.

It follows that if all savings and investment decisions were made at the same instant in time, synchronically, the monetary authority could drive endogenous money to zero. In asynchronous models, however, this is generally not possible. Endogenous money will necessarily arise in asynchronous models.[16]

The synchronous model is logically coherent but has some important and highly unrealistic implications that may not be immediately self-evident. One is that without endogenous money, aggregate savings in the previous period determines investment. Even if the excess savings of one firm is channeled to another, at no point can aggregate investment in period t exceed the savings available from the previous period. Since savings also equals investment in the previous period, it follows that investment is at best *constant over time*. This is a serious defect in the simple prior savings model and obviously rules out any important expansionary effects of animal spirits.

[16]As noted in footnote 2 above, the lower bound of the quantity of endogenous money can be zero if the investment plans of *all* lenders just happened to be executed *before* any lending took place. As the number of agents grows large, the probability that this might occur is asymptotically zero.

Moreover, were this constant level of investment to exceed depreciation, capital stock would then accumulate with each round of investment. With a fixed distribution of capital-output ratios, capacity utilization, u_t in Equation (1), will therefore have to fall. Since in the standard post-Keynesian model investment itself depends on capacity utilization, investment will not remain constant but will instead fall below its savings-constrained value. Savings will immediately adjust to this lower level of investment, and therefore savings available for investment in the following period will be even less. Since investment cannot escape the constraint of prior savings, the model becomes unstable, cycling down to zero output and employment. The prior savings model, evidently, cannot serve as the foundation for any coherent model of systems with both real and financial components.

Observe that if there were no constraint on credit, there would be no reason to distinguish surplus and deficit firms. Firms that lacked sufficient savings from the previous period would simply borrow for investment from bankers who are freely able and willing to create credit. Monetary policy is then fully accommodating. While this may be one definition of endogenous money, equating endogenous money to the absence of any imposed financial constraint does not reflect the centrality of the institutions that define the monetary system (Palley 2013, pp. 417–419). In this simple but arguably more realistic account of the financial system, time matters and time intervals in which conflicting claims on financial resources can arise imply that money must be inherently endogenous.

As noted, if monetary policy were fully accommodating, so that all planned investment became realized investment spending, nothing prevents the system from expanding without limit. Figure 7 shows this scenario as one of two possible limiting cases, derived from the empirical model in Gibson and Setterfield (2018). The upper trajectory

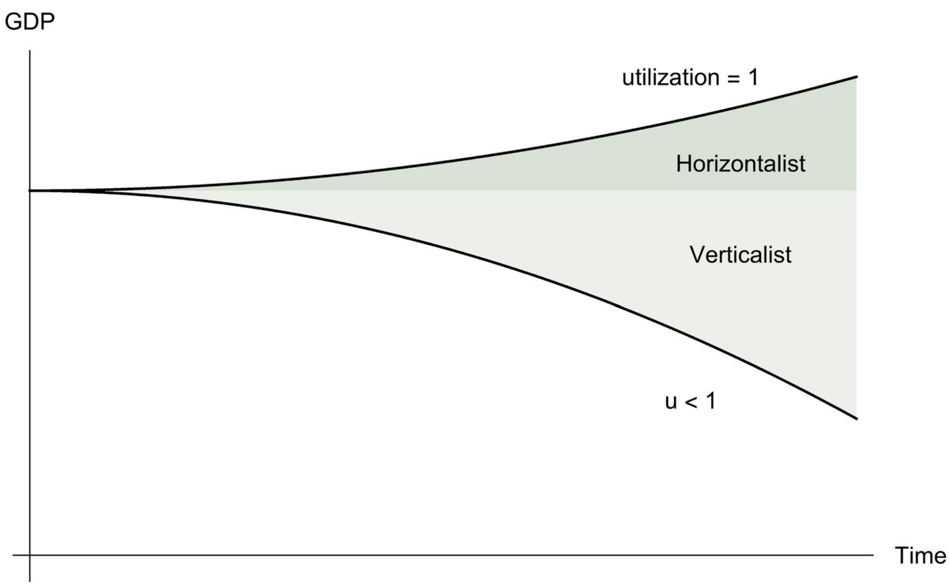

Figure 7. The upper bound of the shaded area describes the model with no financial constraint. The lower bound shows the path when investment in the period is determined by savings in the previous period.

in Figure 7 corresponds to full capacity utilization, with fully accommodating endogenous money and nothing but pure animal spirits guiding economic expansion. Along the lower trajectory, meanwhile, the economy is limited by previous savings.[17] This is the synchronous model, described above, and Figure 7 clearly shows a negative trend to GDP as expected.

The horizontal line dividing the two shaded regions in Figure 7 is the upper bound of the prior savings model. Any real economy, on the other hand, would have some degree of endogenous money, and therefore operate above the boundary. How far above the boundary depends on the elasticity of credit supply.

Even with endogenous money, there are important financial impediments to smooth growth that are easily captured by the multi-agent model. Intermediation failures can arise, for example, in which either a deficit firm is rejected by the financial agent or the deficit firm cannot locate an agent willing and able to lend in the local region. As mentioned above, the degree to which this problem arises depends upon the number of financial agents, m, and the density of the network connections between financial agents. The *character* of the financial network that exists—whether random or preferentially attached—also has a role to play (Gibson and Setterfield 2018). If investment by a deficit firm is blocked for any reason, then total investment falls and with it available savings for the next period. Firms that would otherwise have been in surplus are now in deficit if their investment plans are not scaled back to match their savings. With a sufficient contraction of demand, all firms can fall into deficit simultaneously and the result will be a sharp contraction in investment in the following period. A full-blown crisis ensues.

5. Conclusions

Keynesian economies are more intrinsically monetary than is often recognized. On one hand, an economy is unable to enjoy continuous net expansion without *some* money creation. In its absence, an economy is unlikely to maintain even a constant level of investment. On the other hand, the view that money creation is always and everywhere fully accommodating masks the still-important role of intermediation as a cause of significant macroeconomic imbalances. It neglects the power of the financial sector to affect real performance by blocking the flow of finance from surplus to deficit firms. In the worst case, models of social learning show that learning can break down, leading to a financial crisis, when agents place time-dependent weights on social and private signals. This is all beyond the scope of this paper, but has been thoroughly addressed elsewhere (Gibson and Setterfield 2018).

This paper shows only that 'endogenous money' need not be associated with the view that banks are passive players in a world of fully-accommodating credit creation. Financial agents in multi-tiered network structures retain significant power due essentially to the institutional framework in which they operate. Not only can they lay the groundwork for financial catastrophe and collapse but they necessarily wrest away power from the central monetary authority, power that is essentially bottom-up in its nature and resistant to monetary restriction. The key element of this paper's model is asynchronicity: if time is built into a model in a careful and realistic way, the non-contemporaneous nature of real-financial interactions virtually guarantees endogenous money creation.

[17]This, of course, corresponds to the verticalist case of perfect interest inelasticity of the credit supply discussed above.

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