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Axe: Dynamiques du Capitalisme et Analyses Post-Keynésiennes

# Stabilizing an Unstable Complex Economy
# On the limitations of simple rules

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Abstract : This paper analyzes a range of alternative specifications of the interest rate policy rule within a macroeconomic, stock-flow consistent, agent-based model. In this model, firms' leverage strategies evolve under the selection pressure of market competition. The resulting process of collective adaptation generates endogenous booms and busts along credit cycles. As feedback loops on aggregate demand affect the goods and the labor markets, the real and the financial sides of the economy are closely interconnected. The baseline scenario is able to qualitatively reproduce a wide range of stylized facts, and to match quantitative orders of magnitude of the main economic indicators. We find that, despite the implementation of credit and balance sheet related prudential policies, the emerging dynamics feature strong instability. Targeting movements in the net worth of firms help dampen the credit cycles, and simultaneously reduce financial and macroeconomic volatility, but does not eliminate the occurrence of financial crises along with high costs in terms of unemployment.

Keywords: Agent-based modeling, Credit cycles, Monetary and Macroprudential policies, Leaning against the wind

JEL Codes: C63, E03, E52

# 1 Introduction

The 2007-08 financial crisis, the ensuing Great recession and "not so great" recovery have revived the idea that credit-driven expansions, when accompanied by growing financial imbalances, may result in debt deflation dynamics and deep recessions that have persistent effects on the real economy. This idea has challenged the so far prevailing view that the central banks should only care about credit growth insofar as it affects inflation (and growth) outlooks (see the extensive literature in the wake of the seminal contribution of Bernanke & Gertler (1999)). Whether monetary policy should integrate an additional objective of financial stability within the inflation targeting frameworks, whether such an objective could be achieved through the use of interest rate policies only, or whether it should be left to prudential policies and banking supervision institutions are still debating questions. Smets (2014) provides a survey of the terms of the debate, and highlights the non-trivial trade-offs that are implied.

If central banks would worry about the level of private debt in the economy, as advocated for instance by Christiano et al. (2007), they would follow a so-called "leaning-against-the wind" policy: they would cautiously increase interest rates in face of growing indebtedness, which would discourage excessive leverage and risk-taking and hence reduce over-investment, so that the bust would eventually involve less severe economic consequences. Such a policy is a reaction to the pro-cyclical nature of credit, private debt and leverage that tend to grow in good times, and contract along busts. However, at least two risks have raised concerns. The implied monetary tightening may come at the expense of output (Svensson 2016), and measuring ex ante the risk of financial crisis is a particularly uneasy task (Woodford 2012). This raises the additional question of which indicators the central bank should monitor. The effectiveness of such a monetary policy may also depend on the availability and effectiveness of macroprudential tools, which broadly speaking refer to any policy tool directed towards the decrease in systemic risk, rapid credit growth and excess leverage. Some voices advocate the primary use of those tools to contain financial risk (see Dudley (2015) for a detailed argumentation).

In that respect, empirical studies provide tentative evidence that those tools help limit credit-driven expansions, but the results seem sensitive to the rest of the monetary policy framework (Lim et al. 2011, IMF 2015). In other words, the debate whether monetary policy should "lean against the wind" is far from being settled.

A related but more radical view is that the recent financial crisis has been caused by policy making walking away from rules-based policies (Taylor 2010). Such a view makes the case for the systematic implementation of monetary policy rules to prevent the buildup of massive financial imbalances, excessive risk-taking, and outburst of prolonged recessions. Leaning against the wind policies would be therefore at least redundant, if not detrimental.

In this paper, we aim to contribute to this ongoing debate on monetary policy reformulation in the wake of the financial crisis. We do so by using an agent-based model (hereafter ABM), namely the `Jamel` model (Seppecher 2012, Seppecher & Salle 2015, Seppecher et al. 2016, 2017). A number of original features makes this framework particularly well-suited for tackling those questions. Following the AB tradition, the model builds upon a collection of heterogeneous agents conceived as individual units (firms, households) that interact with each other on decentralized markets (see for instance Delli Gatti et al. (2011) for an introduction, Fagiolo & Roventini (2017) for a recent survey). From those local interactions emerge macroeconomic patterns. Once the main emergent properties of a baseline simulation have been validated against a set of stylized facts from real world economies, the model becomes a sort of artificial economy that can be used as a laboratory to experiment alternative policy designs. We can therefore easily implement different prudential regulations without bearing the constraint of analytical tractability, which is a major obstacle to their analysis in DSGE models.

The `Jamel` model features a leverage engine that produces a strong investment accelerator and endogenously create credit cycles à la Minsky (1986). The model additionally incorporates an aggregate demand feedback that interconnects the labor and the goods markets in a Keynesian fashion (see Chiarella et al. (2005) for a comprehensive account of this literature). Our model therefore provides an example of a microfounded Keynesian and Minskyan framework.[1] Furthermore, in line with the growing interest in incorporating stock-flow consistency from the post-Keynesian school of thought into ABMs, our model is fully stock-flow consistent (Caverzasi & Godin 2015, Caiani et al. 2016). The balance sheets of all agents are interconnected and interdependent, which is a particularly appealing feature to keep track of financial imbalances in the model and account for the booms and busts along credit cycles and their consequences in terms of bankruptcies and unemployment. Put together, those three features – a Minskyan leverage engine, a Keynesian aggregate demand loop and an SFC framework – ensure the existence of strong feedback mechanisms between the financial and the real sides of the simulated economies. Monetary policy operates through the credit channel, as typical in macroeconomic ABMs: interest rates enter the investment decisions of firms and, hence, influence both their risk taking behavior and the service on their debt. It is worth noting that money is endogenous in the model, so that credit is not independent from monetary policy, by contrast to most DSGE models which feature the long-run neutrality of money. This characteristic of our model is likely to magnify the strength of the transmission channel of monetary policy to credit variables. Overall, the model is a virtual laboratory that mimics a complex world, where to confront different simple policy rules that have been suggested in the related literature or empirically tried out.

This paper is not the first attempt to investigate leaning-against-the -wind monetary policy and macroprudential policies in an ABM.[2] Most contributions have focused on the analysis of prudential tools. Ashraf et al. (2017) show how micro-prudential rules (namely limitation of the loan-to-value ratios) can conflict with economic performances in the wake of a downturn. Cincotti et al. (2012) analyze the stabilizing power of countercyclical capital buffers. Van der Hoog & Dawid (forthcoming) use the Eurace@Unibi model to analyze alternative macroprudential policies, and conclude that reserve requirements succeed in dampening fluctuations, while capital adequacy ratios, due to their

[1] ABMs have proven to be successful in that direction, see inter alia, Cincotti et al. (2010), Chiarella & Di Guilmi (2011, 2017), Dosi et al. (2013).

[2] We refer the reader to the survey of Fagiolo & Roventini (2017) for a more comprehensive treatment of macro policy analysis in general withing ABMs.

pro-cyclical nature, do not. The closest contribution to ours is Chiarella & Di Guilmi (2017), who present an ABM that accounts for the risk-taking channel and the coincidence of low inflation and growing financial imbalances along booms. The authors show that a leaning-against-the-wind policy that reacts to excess leverage of private units may turn counterproductive. Few papers have explored the combination of macroprudential and monetary policies. Da Silva & Lima (2015) show how countercyclical capital buffers can conflict with monetary policy rules. Popoyan et al. (2015) explore the joint effects of the different requirements of Basel III together with alternative interest rate rules, and highlight significant interactions between the two types of policies.

In this paper, we find that adding an objective of financial stability to the monetary policy rule may help dampen the Minskyan type of boom and bust dynamics in the real side of the economy (both on the goods and the labor market) and in the financial variables (debt and interest rates). This result is obtained even in the presence of macro and microprudential regulations, namely a risk-weighted capital ratio requirement at the bank's level, and a cap on the debt service ratio on the firms' side. However, such a stabilizing effect is sensitive to the exact design of the interest rate rule, namely the central bank has to react to the leverage or, equivalently, to movements in the firms' net worth. Other indicators that we have tried out, including the interest spreads, turn out to be too procyclical to convey enough ex ante information about financial risk. Furthermore, the inherent instability of our economy remains a robust feature, even in the presence of systematic hawkish leaning-against-the-wind policies and prudential rules.

The rest of the paper is organized as follows. Section 2 presents the general architecture of the model and the alternative policy scenarios that we consider. A comprehensive exposition of the behavioral rules of the agents, as well as the timing of events and the parameter values are left to the Appendices. Section 3 explains the simulation protocol and presents an extensive analysis and empirical validation procedure of the baseline scenario. Section 4 provides the alternative policy scenarios under study and the results of their comparison with respect to the baseline scenario, and Section 5 concludes.

# 2 The model

We provide an overview of the architecture of the model and detail the main and new features that are introduced for the purpose of this paper, especially the functioning of the banking sector and the interest rate dynamics. We invite the reader to refer to Seppecher & Salle (2015) for a comprehensive introduction to all the assumptions in the model. Appendix B details the exact timing of events together with an explicit description of every behavioral rule through a pseudo-code. Appendix C reports the stock-flow consistency of the model. The open source code (in java) as well as an executable demo are available on the author's website at `http://p.seppecher.free.fr/jamel/`.

## 2.1 Architecture of the model

We elaborate on the `Jamel` model that we develop in previous contributions (Seppecher & Salle 2015, Seppecher et al. 2016, 2017). Figure 1 summarizes the structure of the model, red lines stand for financial flows, and blue ones for real transactions. The model encompasses a collection of heterogeneous firms, who produce a generic good by combining capital (machines) and labor inputs with complementary production factors. The model features a capital accumulation dynamics through firms' investment and depreciation of the machines. Capital depreciates as each machine lasts for an exogenous and stochastic number of periods, after what it breaks down and becomes irreversibly unproductive. There is no technical progress, as each machine has the same, exogeneously fixed productivity, that is common to all firms. Firms willing to invest have to purchase generic goods from other firms. A fixed quantity of the goods can then be transformed into a machine, immediately and at no cost.[3] A collection of heterogeneous households interact with the firms on the labor market, by providing labor supply against wages, and on the goods market, by purchasing the goods for consumption purposes with their available cash-on-hand. Additionally, some households are randomly drawn to own shares of the

[3] See Seppecher et al. (2017) for a version of `Jamel` with a capital good sector. Debt deflation dynamics are quite similar to the model presented here, so that this additional complexification is voluntarily overlooked for the purpose of the present analysis.

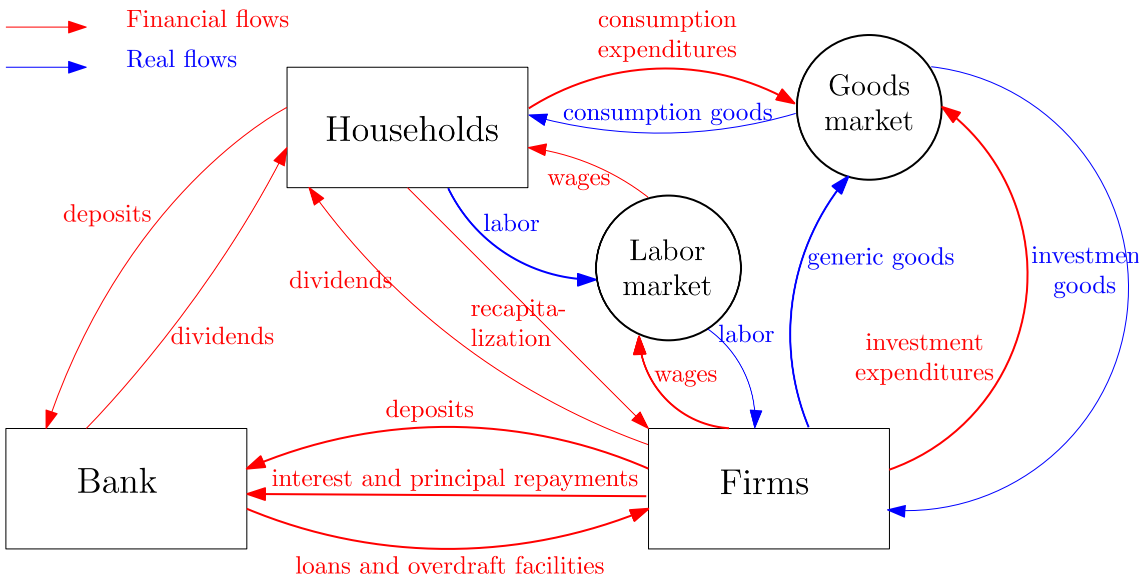


Figure 1: General architecture of the model

firms and the bank, and receive dividends accordingly.

The total number of firms is fixed, but their size endogenously evolves as a result of their investment decisions. Firms' investment decisions are guided by a twofold objective, that encompasses both an effective demand component that relates to future sale prospects, and a financial strategic component, where the decision variable is a leverage target. The leverage target of the firms endogenously evolve as a result of an evolutionary mechanism rooted into the market selection pressure.

The total number of households remains fixed, and there is one single bank, standing for the whole banking sector, which hosts deposits of households and firms, grants loans to the firms to finance their production (through short-term loans) and their investment (through long-term loans). The prevailing interest rates depend on a common component, that is the level of the risk-free interest rate (set by a Taylor rule), and an individual component (depending on the firm's creditworthiness). How those interest rates are set and to what conditions those loans can be granted are the core instruments of monetary and macroprudential policies in the model. Additionally, bankruptcy occurs by insolvency. In that case, the bank launches a foreclosure procedure and recovers (at least) part of the value of the failed firm by finding new household-shareholders. The remaining losses are absorbed by the bank's capital, unless it is not enough. In this (exceptional) case, a banking crisis occurs and the simulation stops. One time step may be understood as a month.

## 2.2 The firms

### 2.2.1 Production process

Each firm possesses a given number of machines. Production takes time: in every period, each machine, if combined with one unit of labor (one worker), increments the production process of the generic good, that is completed after several periods and then delivers a number of units of goods (given by the productivity in the economy) to be added to the firm's inventories level. The number of employees in each firm can then never exceed its number of machines.

Firms have to decide upon the quantity of goods to produce, the corresponding labor demand and wage offers, the price and how much to invest in new machines.

### 2.2.2 Price and quantity decisions

Each firm maintains a fraction of its inventories as a buffer to smooth out its sales in face of variations in its demand. The remaining fraction of inventories is put in the goods market. The firms also use the changes in their inventories to proxy the variations in their demand, and decide upon the corresponding price *and* quantity adjustments. Lower-than-targeted (resp. higher-than-targeted) inventories signal excess demand (resp. lack of demand), and firms are likely to increase (resp. decrease) their price and their production, and hence their labor demand. The firms then proceed by small, stochastic adjustments in the corresponding direction. Additionally, for the pricing decisions, each firm also keeps track of a floor price and a ceiling price, that is dynamically updated so as to materialize the firms' *tâtonnement* process to discover the market clearing price in a decentralized and ever-changing economy. Prices (and wages) therefore exhibit a certain degree of stickiness, as they are not necessary updated in every period if market conditions have changed, or certainly not in a way as to equalize the supply and the demand at the aggregate level. However, our state-dependent price-setting rule allows firms to adjust their prices in a stronger and quicker way, the more unstable the aggregate price dynamics, so as to guarantee more flexible prices in such a context. This mechanism is well in tune with the extensive empirical evidence documenting more frequent price adjustments in hyperinflation or deflation periods, and the self-reinforcing nature of the price dynamics in such circumstances.

#### 2.2.3 Wage setting

Firms adjust their wages as a reaction to the labor market tightness that they individually experience or by copying the wage offers prevailing in other firms. Large firms tend to be wage makers, and adjust their wage offer according to their observed level of vacancies. However, the vacancy level provides little information about the labor market conditions for a small firm (i.e. a firm with few machines, and therefore few employees), because a firm only goes to the labor market in periods when a contract has to be renewed or the workforce has to be increased, so that the information collected from the interactions with the unemployed households may be too fragmented to provide an accurate picture of the labor market conditions. Therefore, we model small firms as wage takers, and they simply copy the wage levels offered by larger firms, which is consistent as every machine, and hence every worker, has exactly the same productivity. This imitation process stands for an "institutional" component, that undoubtedly plays an essential role in the determination of wage levels in developed economies. The duration of a contract is randomly drawn on a uniform support, the wage remains fixed for the whole period, but the contract may be broken before its termination period if the firm adjusts downward its labor demand. We note that such a design implies some degree of nominal wage stickiness.

#### 2.2.4 Determinants of investment decisions

We assume that the amount of entrepreneurial equity is the first limitation to the expansion of the firms (see e.g. Kalecki (2010)). In the model, each firm has a targeted level of equity (denoted by $\ell^T_{j,t}$) and decides to invest if, and *only if*, its actual amount of equities is above that target. In this case, the firm computes the size of its desired expansion by applying a "greediness" factor to its average past sales (in quantities). Note that we do not distinguish between renewing and expansionary investments, as this simple computation includes both.

Firms then integrate expected demand, real interest rates and profitability considerations into the determination of the size of their investment. In order to so, we assume that firms use the net present value (NPV) analysis. The discount factor is taken to be equal to the risk-free interest rate set by the central bank discounted by average past inflation, the expected cash-flow is computed using the firm's current price and wage level. Each firm also faces a *limitation on its debt service to profit ratio* that determines the maximum amount of its investment expenditures, given its leverage target, as detailed hereafter. The firm then randomly samples other firms in the goods market to estimate the price of the generic goods to purchase and transform into the desired number of machines. The firm eventually chooses the investment size (i.e. the number of machines) that return the highest expected NPV.

#### 2.2.5 Financing of investment

Once the size of the investment and its price are established, the firm finances a share $\ell^T_{j,t}$ of the investment using a long-run amortized loan and the remaining share using its own cash-on-hand. If its cash-on-hand is insufficient, the firm supplements with an amortized short-run loan so as to *only temporary* exceed its leverage target. This procedure simply ensures that the cash-on-hand of the firm can never constraint its investment decisions. A fixed capital depreciation on the asset side of the balance sheet is introduced at a linear pace to match the long run loan amortization on the liability side, so as to allow the firms to roughly stay in line with their leverage target throughout the lifetime of the machines.

This leverage target $\ell^T_{j,t}$, together with the maximum credit allowance, dictates the investment decision and the amount of the firms' indebtedness, and therefore the behavior of the firms towards their "growth-safety trade-off". This is the reason why the leverage target is the driving variable of the leverage engine, and the resulting credit-driven expansions and ensuing debt-deflation patterns that we observe in the model (see Seppecher et al. (2016) for detailed analysis of the "growth-safety trade-off" within the population of firms in the model). As in Seppecher et al. (2016, 2017), we assume that the leverage targets of the firms evolve through an evolutionary algorithm, whose selection pressure is directly rooted into market competition. If a firm becomes insolvent (i.e. when negative profits exhaust its equity), it goes bankrupt and its leverage target $\ell^T_{j,t}$ is copied on a *randomly chosen* surviving firm, independently from its relative market performances. This imitation occurs once the bank launches the foreclosure procedure (see below), and could stand for a change in the management team or financial strategy. Such an imitation also occurs if a firm runs out of business because it did not succeed in investing enough to renew its capital and all its machines are depreciated. Additionally, in every period, the leverage targets of all firms are subject to (small) idiosyncratic shocks with mean zero. Those shocks constantly introduce novelty in the pool of firms' potential strategies, and can be interpreted as control error or trial-and-error processes.

## 2.3 The banking sector

### 2.3.1 Credit and interest rates

The banking system is designed to capture the main mechanisms at play along credit-driven expansions and debt-deflation dynamics. The bank hosts firms and households' cash-on-hand as deposits at a zero-interest rate, and provides loans to the firms. There are three types of loans. Short-run (non-amortized) loans are only used to finance firms' production, in the case where their available cash-on-hand is insufficient to entirely cover their wage bill. Short-run (amortized) loans partly finance their investment as explained above. Most importantly, investment is primary financed with (amortized) long-run loans.

What is key in our present study is at which conditions those loans are granted, and how those conditions may influence economic developments along business cycles. In line with commonly discussed microprudential regulations (see, for instance, Lim et al.

(2011)), we first assume that the firm's ability to obtain a loan is subject to a cap on its debt service to income ratio. A firm always obtains new long-run loans from the bank to finance its investment within the limit of its debt service to profits ratio: the debt service (including interest rate payments and principal repayments on ongoing short-and long-run loans of the firm) cannot exceed a share $\bar{b}$ of its average past gross profits. For simplification, we further assume that interest rates are the same on all types of loans, and depend only on the firms' creditworthiness, that the bank proxies by categorizing the firm in one of the three Minskyan firm categories: *hedge*, when cash-flow are sufficient to cover interest payments and part of the principal, *speculative*, if those cash-flow only cover the interest payments, and *Ponzi* if new loans are necessary to even cover the due interest payments. Hedge firms receive loans at the risk-free interest rate $i_t$ that is set by the central bank. Speculative firms have to pay a risk premium over the risk-free interest rate, and receive loans with an interest rate corresponding to $i_{j,t} = i_t(1 + \Delta)$, while Ponzi firms receive $i_{j,t} = i_t(1 + 2\Delta)$ (see, e.g., Dosi et al. (2015) for a similar mechanism). Despite its simplicity, this assumption introduces endogenous risk-premia into the model, as the classification of the firms into one of those categories endogenously evolves as the result of the variation in their leverage target, their market strategies and the market competition.

Furthermore, if a firm has insufficient cash-flow to pay off a loan in due terms, it receives an overdraft facility at a higher interest rate $i_{j,t} + rp$, $rp$ assumed to be the same for all firms. In case of insolvency, the firm goes bankrupt and the bank starts a foreclosure procedure, by first erasing the amount of debt so as to make assets and liabilities coincide, and recapitalizing at least partially the firm with the available cash-on-hand of households, who then become the new owners of the firm (see Seppecher et al. (2017) for more details). If the capital of the bank is not enough to absorb the debt cancellation of the bankrupted firm, the bank itself goes bankrupt, this is defined as a banking crisis and the simulation has to stop. As documented below, this is fortunately a rare event in the simulations, while the benefits from this procedure are clear in terms of simplification of market dynamics. As failed firms do not disappear, the total number of firms remains always constant, and we do not have to complicate the model with an entry process of new firms.

### 2.3.2 Macro prudential regulation

Following the recent developments in the macroprudential framework induced by Basel III, the bank in our model has reserve requirements, and must maintain a given objective of equity to risk-weighted assets ratio. We assume that the bank targets this ratio (or equivalently, has a net worth objective) and distributes as dividends its excess net worth, if any, compared to its targeted one. The risk-weighted assets of the bank are evaluated by attributing a weight of 50% to hedge firms, 100% to speculative firms and 150% to Ponzi firms. Those weights are broadly in line with how risks are weighted in the assessment of risk exposure.[4] Hence, our baseline scenario includes a liquidity-related macroprudential tool that constraints the capital of the bank, as well as a credit-related microprudential tool that restricts the access to credit of leveraged firms.

## 2.4 Monetary policy

Monetary policy sets the risk-free interest rate by following a Taylor rule with a double objective of inflation and output growth, taking into account the zero-lower bound and possibly an additional objective of financial stability:

$$i_t = \min\left(0, \phi_\pi(\pi_t - \pi^T) + \phi_y \frac{\Delta GDP_t}{GDP_t} + \phi_f \mathcal{F}_t\right) \tag{1}$$

with $\phi_\pi, \phi_y, \phi_f$ the reaction coefficients to, respectively, inflation $\pi_t$, output growth $\frac{\Delta GDP_t}{GDP_t}$ and an indicator of financial instability $\mathcal{F}_t$ (or, equivalently, of the amount of private debt in the economy), and $\pi^T$ the inflation target. In the baseline scenario, we consider a standard Taylor rule, and set $\phi_f = 0$. In Section 4, we consider a wide range of alternative indicators $\mathcal{F}_t$ and assess the efficiency of the augmented Taylor rule at stabilizing the economy. Due to the design of monetary policy and the determination of interest rates on

[4]For instance, in the framework of Basel III, the risk weights associated to assets range from 0% for a credit assessment of AAA to 150% below B-.

firms' loans, our model captures both the increase in nominal interest rates and in the risk premium corresponding to an increase in borrowers' financial fragility along credit-driven booms (Stockhammer & Michell 2014).

## 2.5 The households

In the labor market, each household supplies a one unit of labor, subject to his reservation wage. His reservation wage remains equal to his current wage if the household is employed, and is adjusted downward if unemployed. As for the goods market, we assume that households follow a buffer-stock rule to smooth their consumption level in face of unanticipated changes in their income, and build precautionary savings as deposits at the bank. Households cannot borrow and consumption expenditures are always budget-constrained.

## 2.6 Matching and aggregation

The matching process between demand and supply on the markets is entirely decentralized and follows a tournament selection procedure. On the labor market, each firm posts its job offers, each unemployed household samples a given number of those and selects the one with the highest wage, provided that this wage is not lower than his reservation wage. Otherwise, he stays unemployed. As for the goods market, each firm puts a proportion of its inventories in the market at its chosen price. Each household enters with his desired level of consumption expenditures, and each investing firm enters with an investment budget. We assume that the biggest purchasers interact first with the suppliers, i.e. the firms first meet the investor-firms, and then interact with households.[5] Each demander samples a given number of firms and buys from the cheapest one first. Those processes are repeated until one side of the markets is exhausted. Aggregate variables are simply the sum of individual ones.

[5]This matching order has no influence on the pace of the simulations, as rationing in the goods market remains a rare and negligible event in our model, which would not be realistic otherwise.

# 3 Numerical results from the baseline scenario

## 3.1 Parameter values

All the parameters of the model are listed in Appendix A, and Appendix B gives how they intervene into the agents' behavioral rules. Most parameter values are taken from Seppecher et al. (2016, 2017), where empirical values or reasonable orders of magnitude are used whenever they are available. If not, we have performed unilateral sensitivity analysis of the model to the parameter values, whose results we briefly discuss hereafter, and then proceeded in Section 3.2 to an empirical validation of the baseline scenario.

The lifetime $d^k$ of the machines is a random draw in $\mathcal{N}(120, 15)$ to match empirical order of magnitude on capital depreciation. The length of the long-run loans is then also set to 120 periods (and 12 periods for the short-run ones). We set $v^k = 600$, where $v^k$ represents the real cost of an investment (i.e. the number of units of the generic goods that are necessary to produce one machine), while a machine delivers $pr^k = 100$ units of the generic good every $d^p = 4$ period. Those parameters tune the profit share and the share of investment in GDP in the model. The targeted level of inventories of a firm is set to $d^m = 2$ periods of production at full capacity. The expansion parameter $\beta$ has to be high enough to counteract the depreciation of capital and allow for expansion investment. We use $\beta = 1.2$, which translates into an intended 20% increase in productive capacities when envisioning an investment. Highest values only slightly accentuate the cycles, which is quite expected given the importance of the investment multiplier in our model. The standard deviation of the idiosyncratic shocks on the leverage targets is set to 0.01, in line with the interpretation of small control errors in the implementation of the leverage strategies by the firms.

In accordance with empirical evidence, we assume that wages are less flexible than prices (Daly & Hobijn 2015) and set $\delta^P = 0.04$ and $\delta^W = 0.02$. Households may revise downward their reservation wage by 5% in each period (parameter $\eta_H$) after more than 12 months of unemployment (parameter $d^r$). In our model, relative wage rigidity acts as a buffer along bust dynamics by interrupting deflationary spirals and hence avoiding the bankruptcy of the single bank (see Seppecher & Salle (2015) for more detail). This mechanism corresponds to the well-documented aggregate demand effect of real wages on the economic activity (see, for example, Asada et al. (2010) in the Keynesian literature).[6] The length of the work contracts (randomly drawn between 3 and 60 periods), over which the wage remains fixed, induces an additional element of wage rigidity in the model. The model includes additional elements of stickiness in the production process: the maximum adjustment of the labor demand reaches 10% in each period (parameter $\nu_F$). We further consider adaptive expectations with a memory of 12 periods.

The households have a rather conservative consumption rule, where their targeted level of precautionary savings is 20% of their income and they consume up to half of their excess savings in each period. This conservative behavior is intuitive given the absence of insurance scheme such as unemployment benefits in the model. We set the size of the market exploration $g = 10$ for both markets, which corresponds to radically decentralized interactions given the number of firms (400) and households (6000). The risk premium parameter $\Delta$ is set to 0.1, which means that speculative firms pay a 10% higher interest rate, and the Ponzi firms a 20% higher rate than the hedge firms. The additional penalty on doubtful debt is set to 4% (monthly). The qualitative dynamics of the simulations does not seem sensitive to these specific values, as long as they remain of reasonable orders of magnitude. We set the parameters of the Taylor rule to standard values ($\phi_\pi = 1.5$, $\phi_y = 0.5$ and $\pi^T = 2\%$). The equities to risk-weighted assets ratio is set to 0.15 which, together with the weights assigned to each category of loans in the bank's equities, is broadly in line with the strictest requirements of the Basel III framework. The debt service cap is set to 120%, so that not only hedge firms have access to credit (which would be the case with a ratio of 100%), but Ponzi firms are systematically excluded.

We run the simulations for $3,000$ periods, ans systematically discard a 1000 period burn-in phase.

[6] This is also a consequence of the absence of government intervention, besides the Taylor rule, that is constrained by the ZLB, and the prudential rules that we have introduced but only act *ex ante* on the behaviors of the agents.

## 3.2 Validation

By construction, our model already provides a realistic account of real world economies in the following important dimensions: it is a complex, monetary and stock-flow consistent market economy. In order to validate a baseline scenario, the state-of-the-art practice in macro ABM is to proceed through an empirical validation exercise, and check that the simulated time series, both at the macro and at the micro level are broadly consistent with major observed stylized facts (see, among others, Dosi et al. (2010) and the follow-up contributions on their K+S model, Assenza et al. (2015) or Caiani et al. (2016)). As in Seppecher & Salle (2015), Seppecher et al. (2017), we perform such an exercise and show that the baseline scenario of our ABM is able to account for various macro- and microeconomic empirical regularities.

Table 1 reports statistics of the main macroeconomic variables over 30 replications of the baseline scenario with different seeds of the RNG. First, the low values of the standard-deviations across the 30 runs indicate that replications are quite similar, and the stochastic draws involved in the behaviors of the agents and the markets are not responsible for the emerging patterns. Second, the order of magnitude of the reported variables appears reasonable. For instance, the emerging distribution gives a one third profit share and a two third wage share. Our model being stationary in the long run, in the absence of technological progress or population growth, the average GDP growth rate is zero. The share of net investment is rather low, but not unrealistic given the absence of real estate investment in the model.

A closer look at the macroeconomic simulated data uncovers the main emergent property of the model, that is pronounced business cycles, with episodes of occasionally moderate volatility followed by severe crises with deflation, near zero interest rates, spikes in unemployment and epidemic of bankruptcies. Hence, our model is able to reproduce i) persistent fluctuations in real variables, including GDP (Figure 2a) or the rate of capacity utilization (Figure 2b); ii) a downward-sloping Phillips curve (Figure 2c); and iii) a downward-sloping Beveridge curve (Figure 2d). As also striking from Figure 2a, iv) GDP

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|---|---|---|---|
| GDP growth rate | 0.0005<br>(0.0014) | Unemployment rate | 0.1046<br>(0.0127) |
| Utilization rate | 0.8532<br>(0.003) | Bankruptcy rate | 0.056<br>(0.0007) |
| Financial fragility | 2.471<br>(0.3804) | Velocity of money | 3.642<br>(0.0086) |
| Wage share | 0.6865<br>(0.0042) | Average firms' leverage | 0.5664<br>(0.0048) |
| Unemployment duration (periods/months) | 4.712<br>(0.2726) | Ratio firms' to households' deposits | 0.664<br>(0.0053) |
| Capital to capacity ratio | 4.5948<br>(0.0047) | Share of net investment | 0.0726<br>(0.0014) |

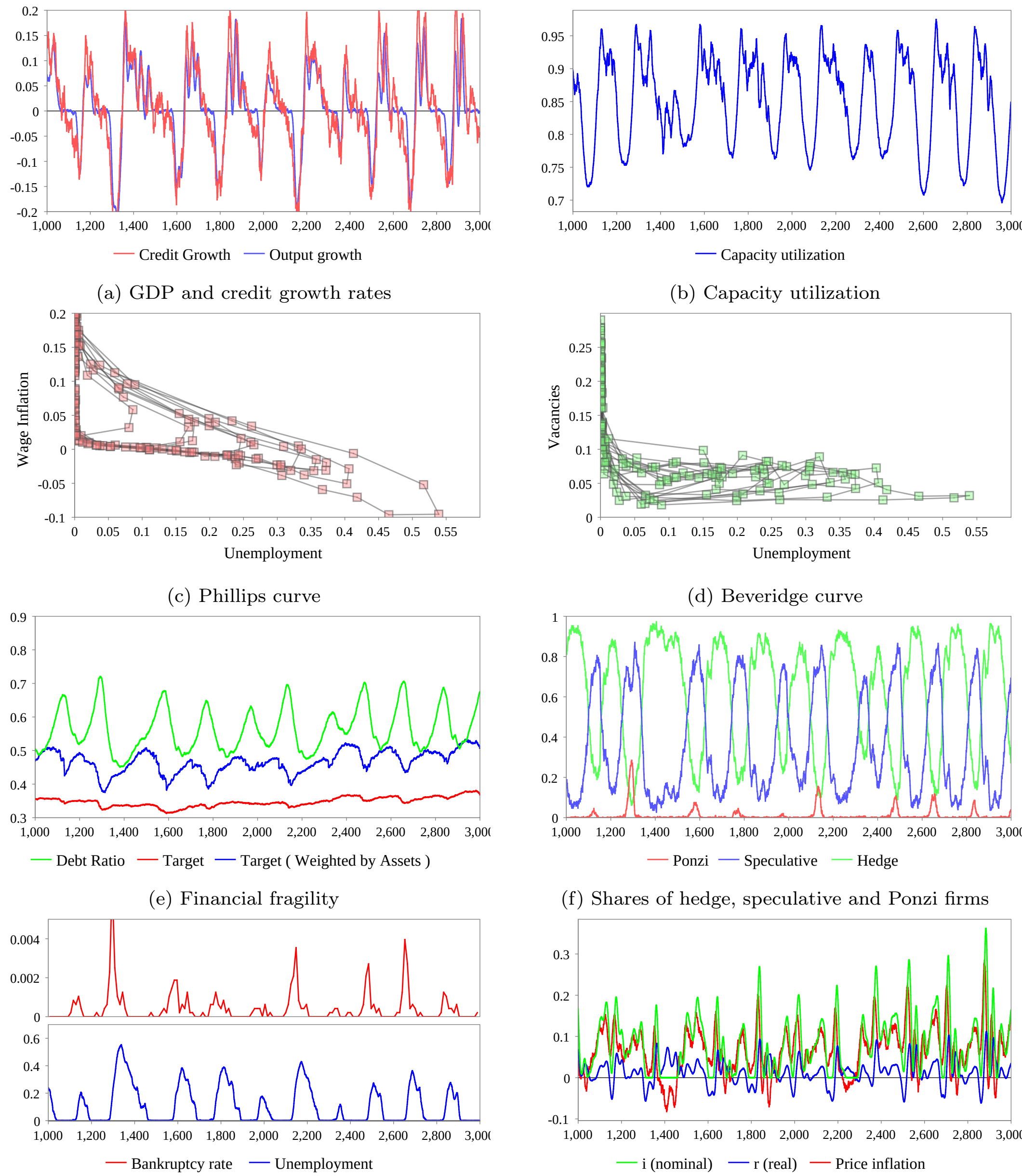
Table 1: Baseline scenario (average over 30 replications, standard deviations between brackets)

growth rates are highly correlated with credit growth (or equivalently with firms' debt), which also corresponds to swings in the leverage behaviors of firms (Figure 2e) and the resulting financial position of the firms (as described by the evolution of the shares of the three Minskian categories of firms in Figure 2f). Figure 4 reports the correlation patterns between the main macroeconomic variables of the simulated data.[7] Time series display v) considerable persistence, both in GDP (Figure 4a) and in inflation (Figure 4b). A Dick-and-Fuller test cannot reject the hypothesis of unit root in the simulated GDP time series (the value of the statistics is 0.41), or in aggregate consumption for example (the same statistic is 0.38). Additionally, vi) normality tests lead to the rejection of the null hypothesis of normal distributions of the inflation and the GDP growth rates.[8]

Moreover, the Keynesian aggregate demand engine in our model translates into vii) a strongly procyclical consumption (Figure 4c), and viii) inflation (Figure 4e), as price changes are demand-driven in the absence of cost-push shock in the model. The same goes for ix) investment, as it is part of aggregate demand. It should be noted that investment is x) much more volatile than GDP, and xi) consumption falls with a lag in the wake of a recession even in the absence of automatic fiscal stabilizers in the model (see Figure 3).

[7] All time series are filtered using a Baxton-King filter recommended for monthly data.

[8] The associated p-values of the Shapiro-Wilk tests are below 1e-10 in both cases, and the time series display excess kurtosis (3.34 for inflation and 3.89 for GDP growth in the baseline simulation), indicating the presence of fatter tails than the normal distribution.




(a) GDP and credit growth rates

(b) Capacity utilization

(c) Phillips curve

(d) Beveridge curve

(e) Financial fragility

(f) Shares of hedge, speculative and Ponzi firms

(g) Firms' debt ratios

(h) Inflation and interest rates

Figure 2: Baseline scenario, simulated data, $t = 1000, ...., 3000$.

This feature is explained by the buffer-stock consumption rule followed by the households, who build precautionary savings in periods of employment. Conversely, unemployment is strongly counter-cyclical, which indicates that xii) the model replicates the Okun law (Figure 4d). The coincident nature of the comovement between GDP and unemployment is a consequence of our relatively flexible labor market, especially with work contracts of limited duration.

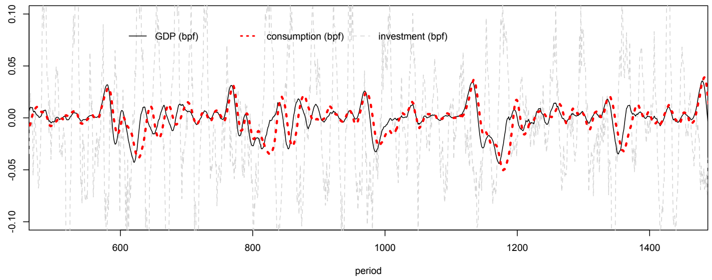
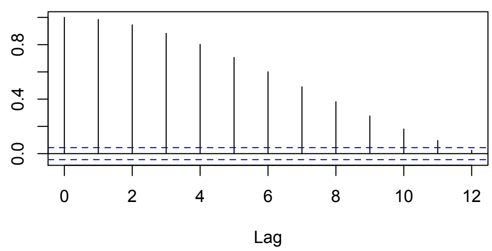


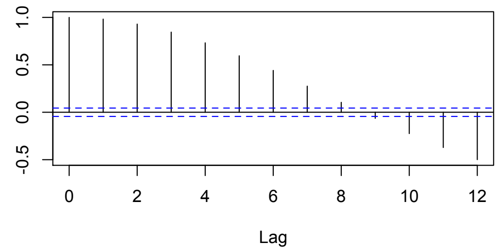

Figure 3: Cyclical co-movements of GDP, consumption and investment, baseline scenario, $t = 1000, ...., 3000$

Focusing on the financial dynamics, xiii) credit is highly and positively correlated with GDP, and the correlation structure revealed by Figure 4f shows that the risk-taking channel is strongly active in our model: a rise in credit predicts a future rise in output, but the strongest effect is lagging, so that, in turn, firms build-up debt in periods of output expansion. This is confirmed by xiv) the pro-cyclical and lagging nature of the doubtful debt in the economy, that is a proxy for financial fragility (Figure 4h). The same can be said xv) about the bankruptcies (Figure 4g). This positive feedback mechanism is typical of *credit cycles* induced by pro-cyclical leverage of the firms in our model (Minsky 1986, 1992). xvi) The share of non-hedge firms also appears to rise in upturns (see below Figure 5c), which is in line with this interpretation (Chiarella & Di Guilmi 2011). We further discuss this engine below (see in particular Figure 6d).

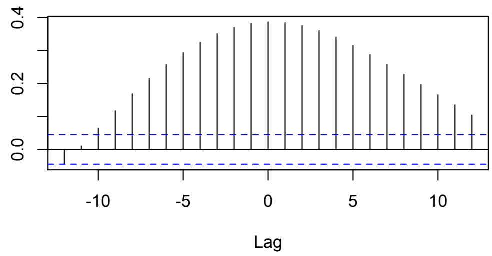
At the industry level, in the absence of technical progress (recall that, in our model, productivity is time-invariant), the number of stylized facts that we can seek to replicate with our model is limited. Yet, we can take a look at the cross-sectional distributions of some firms' characteristics at a given period of the baseline simulation ($t = 1000$). Normality tests lead to reject the null hypothesis of xvii) normality of firms' sizes and growth rates (the associated p-values are below 1e-16 in every case). Figure 5a indicates that the cross-sectional distribution of firms' sizes (measured either by sales, assets, or as displayed by the production capacity) exhibits instead skewness and fat-tails. We shall recall that all firms are initially endowed with the same number of machines, so that heterogeneity in their sizes is an emerging property of the model resulting from their individual



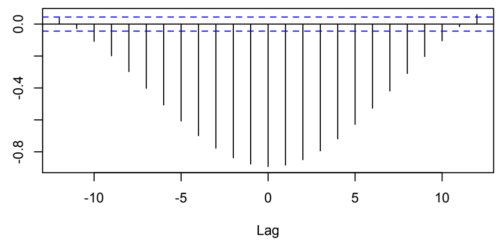

(a) Auto-correlation of GDP



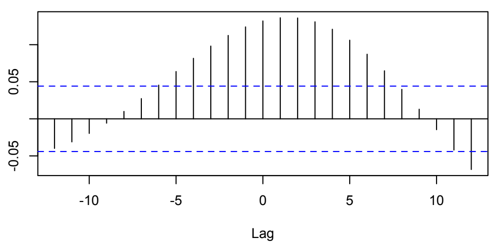

(b) Auto-correlation of inflation



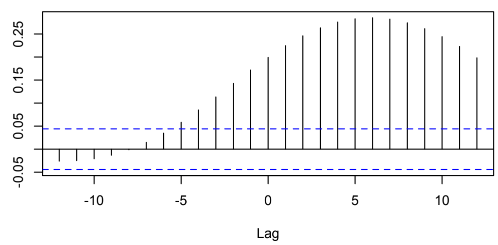

(c) Cross-correlation between consumption and GDP.



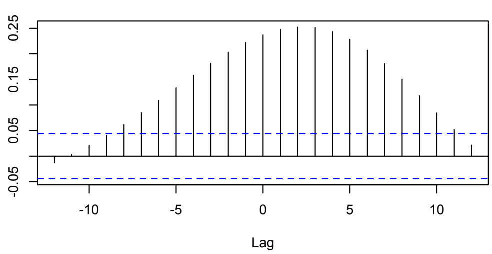

(d) Cross-correlation between unemployment and GDP.



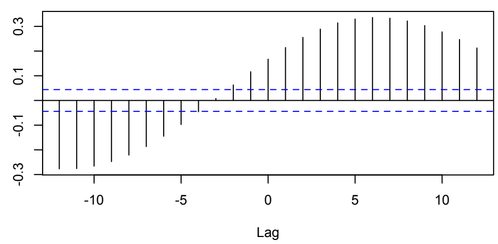

(e) Cross-correlation between inflation and GDP.




(f) Cross-correlation between credit and GDP.



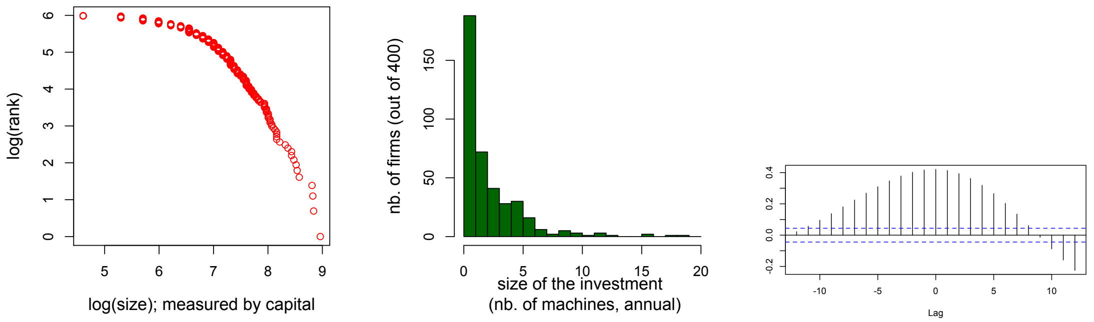

(g) Cross-correlation between bankruptcies and GDP.




(h) Cross-correlation between the share of doubtful debt of firms and GDP.

Figure 4: Macro cross-correlation patterns (detrended series) in the baseline scenario, $t = 1000, ...., 3000$, all series depict the correlation between any variable in $t + k$, $k = -12, ..., 0, ...12$ and GDP in $t$.

leverage and investment behaviors and the market competition. Furthermore, Figure 5b reports the distribution of investment decisions at $t = 1000$ of the baseline simulation: while almost half of the firms are not considering any investment, some simultaneously are purchasing few machines, and only a handful of them are massively investing. This fact, known as xviii) investment lumpiness constitutes also an emergent property of our




(a) Firms' rank-size distribution ($t = 1000$)

(b) Firms' investment distribution ($t = 1000$)

(c) Cross-correlation of speculative and Ponzi firms and GDP

Figure 5: Baseline scenario, – microeconomic distributions

model (see the discussion and references in Dosi et al. (2010)).

## 3.3 A closer look at the dynamics

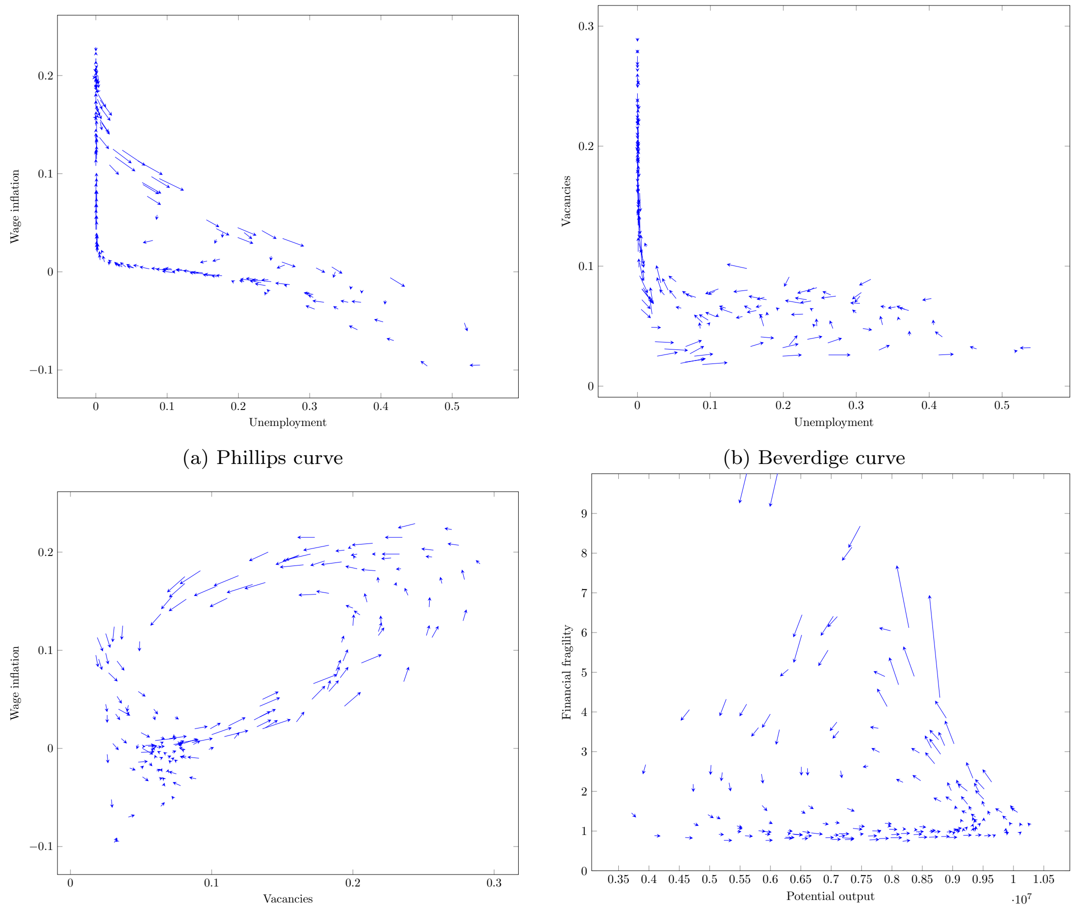
The credit cycles remain the main emerging property of our model as discussed in Seppecher et al. (2016) despite the macroprudential tools that we have introduced into the model, namely the risk-weighted capital requirement imposed to the bank, and the cap on the debt service imposed to the firms, next to the state-dependent individual risk premia. This is as such an important message: simple restrictions are not sufficient to eliminate those credit cycles, and the abrupt recessive episodes that accompany the ensuing sudden deleveraging phases.

To shed some additional light on those cycles, Figure 6 uncovers the cyclical relationships between real and financial variables by the use of vector fields of the model's dynamics. Those tools, borrowed from dynamical systems, provide an intuitive picture of the evolution of the economy along the business cycles. One loop corresponds to one cycle, and the recurrent dynamics clearly shows the similarity among all successive cycles in a simulation. Figures 6a and 6b give the dynamics along the Phillips and the Beveridge curves. Interestingly, the directions of rotation are the same as found in empirical data. xix) The Beverdige curve rotates in an anti-clockwise manner, and wages rise slower when approaching full-employment than they fall along a bust (to be compared to Figures 1 and 3 in Daly & Hobijn (2015) over the recent period covering the Great Recession in the

USA). In our model, as there is no frictional unemployment, full employment is reached on the top of the boom, and wages then expand quickly.[9] By contrast, xx) the Phillips curve follows a clockwise motion, which is consistent with our assumption of backward-looking expectations in the firms' behavior and the nominal wage rigidity implied by the fixed term contracts along upturns (see Tobin (1980) and the discussion and the figures presented in Krugman (2015)).

Figure 6c provides an additional particularly interesting insight into the business cycles arising from the simulations. It plots the wage inflation rate against the vacancy rate. The two variable co-evolve in an anti-clockwise motion. Most of the points are concentrated around a relatively low level of vacancies together with steady or slightly rising nominal wages. Those points form loops that depict regular cycles. Occasionally, the points exit the loops and accumulate in the bottom left corner of the figure, where nominal wages decrease and open vacancies are rare, which corresponds to a very tight labor market associated to a deep recession with zero nominal interest rates and positive real interest rates due to deflationary pressures. Those temporary deviations from an otherwise repetitive pattern recalls the "dark corners" introduced by Blanchard (2014) as a reference to the economic developments in the wake of the recent deleveraging crisis and the ensuing Great Recession. Another, related, way to look at the figure is to see those deviations as exit dynamics from a "corridor of stability" (Leijonhufvud 1973). Within the corridor, the economy is self-regulated, the labor market dynamics give rise to an average positive wage dynamics, but debt and financial imbalances can accumulate in the background of that corridor, sometimes beyond a level that corresponds to a "tipping" point (in the language of dynamical systems). Once that tipping point is passed, the economy exits the corridor of stability, which gives rise to a potentially systemic crisis where economic logic reverts, prices and wages decrease and rolling upwards back into the corridor is particularly challenging (see also the discussion in Eggertsson & Krugman (2012) on that matter, and Ashraf et al. (2017) in an ABM).

[9] A more elaborate version of the labor market and the reservation wage updating process allows to circumvent this feature, but without changing any of our qualitative conclusions. We therefore decided to keep this simpler version of the ABM.




(a) Phillips curve

(b) Beverdige curve

(c) Wage curve

(d) 6d curve

Figure 6: Cyclical patterns in the baseline scenario, $t = 1000, ...., 3000$.

Finally, Figure 6d reports the curve used in 6d which represents the cyclical dynamics between financial fragility, measured as the ratio between the firms' debt level and the net profits (i.e. net of interests and capital depreciation), and real output. Intuitively, the financial fragility indicator measures the number of years of net profits that would be necessary to repay the whole debt of the firms. This is one of the main indicators that we use in the sequel to compare policy scenarios. Most of the points in Figure 6d are scattered around relatively high levels of GDP and low levels of financial fragility, but the curve occasionally spikes following an anti-clockwise motion, which indicates that GDP expansion precedes the build-up of financial imbalances and the resulting financial stress. Along the bust, financial fragility decreases back to low levels as a cascade of bankruptcies drive the most fragile units to bankruptcy (see Stockhammer & Michell

(2014) and Seppecher et al. (2016) for a more detailed discussion). In few words, the business cycles in our model are credit cycles, that are the result of a sustained increase in firms' indebtedness along with an increase in GDP, followed by a brutal market correction through numerous bankruptcies. Those Minskyan forces of financial instability feed into aggregate demand through an "investment accelerator" effect: the rise in credit allows for more investment, that in turn inflates the demand for the goods and opens up favorable economic outlook for investing firms. However, this positive feedback comes at the cost of an increasing deterioration of the balance-sheets of the firms. Financial imbalances progressively fuel a negative feedback from the lending interest rates – operating both through the counter-cyclical monetary policy and the inflating risk premium applied to increasingly risky firms, to aggregate demand. Once this negative feedback becomes stronger than the positive one, the boom dynamics revert into a fall in investment and profits, starting from the most fragile firms in the system, which are driven out of business. An epidemic of bankruptcies along with a strong rise in unemployment accompanied by deflationary forces follow, and a Fischerian debt-deflation sets in: firms attempt to deleverage but the burden of their debt increase as prices fall. In our model, as mentioned in Section 3.1, the relative wage flexibility in comparison to prices interrupt the downturn (see also Seppecher & Salle (2015)), and the cycles start all over again.

# 4 Comparative study of alternative monetary policy rules with a private debt objective

## 4.1 Definition of the policy scenarios

Beyond the mere question of what is observable or accurately measurable to the central bank, the identification of an indicator of the level of private debt, or equivalently of the extent of financial fragility in the economic system, is not an easy task. An additional difficulty refers to the exact specification of the augmented Taylor rule: shall the central bank react to the level of that indicator? with which target in this case? or to the changes in that indicator? and how strong should that reaction be? For instance, Lambertini et al. (2013) or Popoyan et al. (2015) use credit growth, Da Silva & Lima (2015) the credit to GDP ratio. Borio & Drehmann (2011) advocate the use of credit or asset price "gaps" (i.e. in deviation from a trend) to extract predictive power of growing financial imbalances. Chiarella & Di Guilmi (2017) consider the share of Ponzi firms in the economy. Cúrdia & Woodford (2016) integrate a moving average of short-term interest spreads to the Taylor rule. Using a regime-switching model, Woodford (2012) introduces a reaction of the interest rate to a “crisis" state whose associated transition probability increases with the firms' leverage. In line with those various suggestions, we use our model as a policy simulator, and successively consider a range of possible indicators of financial fragility (variable $\mathcal{F}_t$), and the corresponding design of the monetary policy rule (reaction coefficient $\phi_f$). All the scenarios are summarized in Table 2. The values of $\phi_f$ for which we perform a systematic analysis come from prior trial-and-error analysis on the simulations. All the scenarios that we design correspond to some form of leaning-against-the-wind policies, where the central bank is supposed to increase the nominal interest rate whenever financial imbalances grow (by also taking into account its primary objective of price stability and output considerations).

The first scenario, named *fragility*, targets the index of financial fragility measured as the ratio between firms' total debt and their net profits (i.e. the $y$-axis in Figure 2g). The bottom of Figure 2g indicates that the value of this indicator in stable times corresponds to the bottom of the curve, which is roughly 2 (see also Table 1). The central bank then targets the deviations of that curve from its "corridor", normal time value.

In the second scenario, denoted by *netWorth*, the central bank targets the firms' level of net worth (i.e. the blue curve in Figure 2e), where the 0.5 target is roughly in line with the average value observed in the baseline scenario (see Table 1). In a third scenario *changeNetWorth*, the central bank reacts to the changes in that net worth. It should be underlined that the central bank uses the weighted average (by assets) to compute firms' net worth, as the arithmetic mean would be misleading by underestimating the risk associated to highly leveraged big institutions (see Woodford (2012) for a related

| Scenario | $\mathcal{F}_t$ | $\phi_f$ |
|---|---|---|
| *fragility* | $\left(\frac{D_t}{\Pi_t} - 2\right)$ | 0.01 |
| *netWorth* | $\left(\frac{A_t}{L_t} - 0.5\right)$ | 1.5 |
| | (average, weighted by assets) | 2.5 |
| *changeNetWorth* | $\Delta \frac{A_t}{L_t}$ | 1.5 |
| | (average, weighted by assets) | 2.5 |
| *spreads* | $\tilde{i}_t - i_t$ | 1 |
| | (weighted by firms' categories) | 2 |
| *changeSpreads* | $\Delta(\tilde{i}_t - i_t)$ | 1 |
| | (weighted by firms' categories) | 2 |

Table 2: Monetary policy scenarios with a Taylor rule augmented by an objective of financial stability

discussion).

In a fourth scenario, referred to as *spread*, the Taylor rule includes a reaction to the level of the spreads between the different categories of firms. This spread is computed as the difference between the average interest rate paid by the firms and the risk-free interest rate as follows:

$$\tilde{i}_t - i_t \equiv \kappa_H i_t + \kappa_S i_t(1 + \Delta) + \kappa_P i_t(1 + 2\Delta) - i_t \tag{2}$$

with $\kappa_H, \kappa_S$ and $\kappa_P$ the share of (respectively) hedge, speculative and Ponzi firms, as displayed in Figure 2f and $i_t$ the risk-free interest rate. This scenario boils down to react to the increase in the number of speculative and Ponzi firms in the system, as the spread would equal zero if all firms were hedge. The last scenario *changeSpreads* studies a reaction of the central bank to the changes in the spread.

## 4.2 Indicators for the result analysis

We compare the effects of the different monetary policy rules on the dynamics of the model along a set of indicators that summarize the financial and economic situation in a given simulation (see Van der Hoog & Dawid (forthcoming) for a similar effort to quantify recessions). The first indicator is the *number of crisis*, defined as an episode in which unemployment rate exceeds 5%. Given that unemployment rate is close to zero in expansionary periods in our baseline model, which indicates the absence of fictional unemployment, that 5% threshold seems appropriate to capture recessive episodes (see also Figure 2c). Alternative indicators, such as negative output growth, lead to the identification of similar patterns, because the Okun law holds in our model, but we shall focus our analysis on the welfare costs of recession, and unemployment seems a natural barometer of those costs. For a similar reason, the second indicator is the *recession duration*, defined as the number of periods for which unemployment has been constantly above 5%. The third indicator is the *depth* of the crisis, that we measure as the peak of the unemployment rate along a given crisis. The next indicator is the *breadth* of the crisis that we compute with the number of unemployed households throughout the crisis (in intuitive terms, it corresponds to the area under the unemployment curve during a crisis episode) divided by the number of households in the economy. This gives the average number of months of unemployment per household along the recession. Providing such a systematic and detailed account of the economic costs of financial crises is also a contribution of this paper. So is the ability of our model to endogenously produce crises of various lengths and amplitudes. Additionally, we look at the *number of firms' bankruptcies* over a given crisis, and the *maximum of the financial fragility index* as displayed in Figure 6d, because the latter appears to us as a good indicator of the severity of a crisis episode. Finally, as an indicator of the volatility in the model, we use the *standard deviation of output growth, inflation and the nominal interest rate.*

## 4.3 Comparative performances of augmented Taylor rules

### 4.3.1 Overview of the indicators

Figure 7 gives an overview of the correlation between the aforementioned indicators in the baseline scenario (with $\phi_f = 0$, i.e. without any reaction to private debt in the Taylor rule) and in the main monetary policy scenarios considered. Data are reported for all crises pooled together from all scenarios, identified as explained in Section 4.2. The strong and significant positive correlation[10] between the maximum of financial fragility that is attained during a given episode of financial turmoils and every unemployment measurement of the real costs of the ensuing recession provides a striking picture of the interconnection between the financial and the real sides of the economic system. The longer and deeper recessions invariably coincide with the most fragile balance sheets of the firms, no matter the scenario under consideration. This first observation suggests that none of the alternative augmented Taylor rules succeeds in breaking this correlation, and cancel out the employment costs of financial crises once they break out.

A closer look at Figure 7 reveals that our economy is certainly not linear: the economic costs of financial crises is admittedly increasing with respect to the financial fragility index, but this relation is not linear, it is concave: a rather modest increase in financial fragility causes a strong aggravation of the recessions, but there seems to be a threshold effect, beyond which further deterioration of firms' balance sheets does not really create additional economic costs along the recession. We shall point out that for the highest levels of financial fragility observed (see the top right corners of Figure 7), those economic costs are already considerable.

#### 4.3.2 Statistical comparison of the scenarios

In order to assess the statistical significance of the effects of monetary policy, Table 3 reports the indicators in 30 replications of the baseline scenario and each leaning-against-the-wind policy scenario. The last column reports the number of systemic crises over the 30 replications – recall that the single bank feature of our model causes the simulations to stop in case of insolvency of the bank. Those simulations have stopped prematurely and are dropped out for the computation of the other statistics presented in the table.

First of all, in no scenario we observe a significantly higher macroeconomic volatility than in the baseline scenario, neither in GDP growth, inflation or interest rate. On

[10] The p-value of the Pearson's correlation test is below 1e-10 in every policy scenario, and for every indicator. Figure 7 only reports the maximum financial fragility along a given recession against the recession duration, but an almost identical pattern holds for all the other crisis indicators, that we do not show here to avoid redundancy.

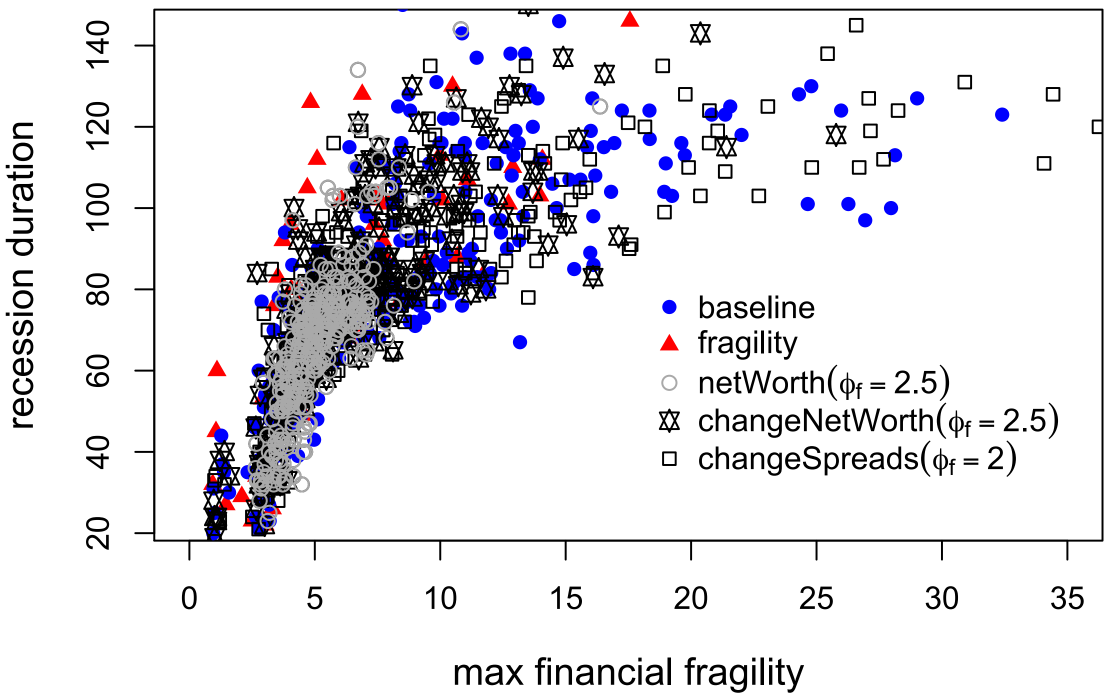



Figure 7: Recession duration against the maximum recorded financial fragility

the contrary, volatility is significantly decreased in several scenarios (more below). This counteracts the fear that reacting to private debt or financial risk may come at the expense of the other objectives of monetary policy (Svensson 2016).

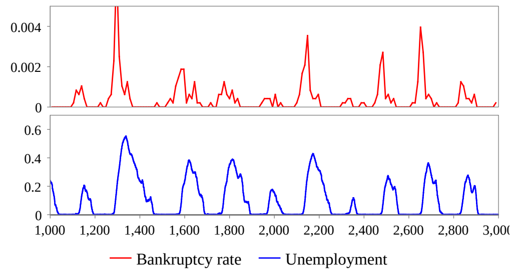
The first scenario, namely *fragility*, clearly delivers the worse performances: more than half of the simulations experience a systemic crisis, while none is reported in the baseline scenario. In the remaining simulations, recessions are significantly deeper, longer and more costly in terms of bankruptcies and unemployment than in any other scenario, and the financial fragility levels recorded are significantly higher. Note that the high standard deviation of that indicator denotes the occurrence of very deep recessions. Such a bad outcome results from the nature of the indicator used in the Taylor rule: financial fragility is lagging, stays at low levels throughout the boom, and peaks along the bust (see Figure 6d). When used as an the indicator of financial imbalances by the central bank, it is not forward looking enough, and does not contain any leading signal of the presence of imbalances and upcoming financial turmoils.

| Scenario | Nb. of recessions | Duration | Depth | Breadth | Max. Financial fragility | Nb. of bankrupcies | sd. GDP growth | sd. inflation | sd. nom. interest rate | Nb. systemic crises |
|---|---|---|---|---|---|---|---|---|---|---|
| Baseline ($\phi_f = 0$) | 10 (0.76) | 85.5 (8.35) | 0.32 (0.02) | 19.6 (3.06) | 14.3 (14.8) | 12.4 (3.3) | 0.012 (0.000) | 0.053 (0.003) | 0.006 (0.000) | 0 |
| *fragility* | 8.3* (0.89) | 129*** (20.2) | 0.39*** (0.04) | 37*** (7.9) | 82.5*** (53.9) | 43** (14.3) | 0.013** (0.000) | 0.061* (0.006) | 0.012** (0.004) | 18 |
| *netWorth* ($\phi_f = 1.5$) | 11.3*** (0.55) | 70*** (3.7) | 0.28*** (0.01) | 13.8*** (1.24) | 5.67*** (0.27) | 3.8*** (1.18) | 0.011** (0.000) | 0.058 (0.002) | 0.007* (0.000) | 0 |
| *netWorth* ($\phi_f = 2.5$) | 11.5** (0.73) | 67*** (4.9) | 0.27*** (0.018) | 13*** (1.9) | 5.14*** (0.31) | 2.96*** (1.05) | 0.011** (0.000) | 0.061 (0.002) | 0.007** (0.001) | 0 |
| *changeNetWorth* ($\phi_f = 1.5$) | 10.6 (0.82) | 77.5** (6.6) | 0.31** (0.02) | 16.7*** (2.5) | 7.7*** (2.6) | 7.8*** (2.8) | 0.011** (0.000) | 0.054 (0.002) | 0.007* (0.000) | 1 |
| *changeNetWorth* ($\phi_f = 2.5$) | 10.5 (0.8) | 76.6** (6.6) | 0.3*** (0.02) | 16.5** (3.3) | 6.8*** (2.3) | 7*** (4.3) | 0.012 (0.001) | 0.055 (0.006) | 0.007** (0.000) | 0 |
| *spreads* ($\phi_f = 1$) | 9.9 (0.8) | 88.1 (10.5) | 0.33 (0.02) | 21 (4.7) | 50 (97.9) | 13.9 (5) | 0.012 (0.001) | 0.056 (0.005) | 0.006 (0.000) | 3 |
| *spreads* ($\phi_f = 2$) | 10 (0.76) | 87.3 (10.9) | 0.33 (0.02) | 20.7 (4.65) | 37.6 (74) | 13.4 (4.95) | 0.012 (0.000) | 0.054 (0.004) | 0.006 (0.000) | 0 |
| *changeSpreads* ($\phi_f = 1$ ) | 9.9 (0.95) | 89 (10.3) | 0.33 (0.02) | 21.45 (4.48) | 90.8 (206.9) | 13.7 (4.4) | 0.012 (0.001) | 0.056 (0.005) | 0.007 (0.000) | 2 |
| *changeSpreads* ($\phi_f = 2$ ) | 9.9 (1) | 88.5 (12.3) | 0.33 (0.03) | 20.7 (4.46) | 70.8 (224) | 13.7 (3.65) | 0.012 (0.000) | 0.053 (0.003) | 0.006 (0.000) | 2 |

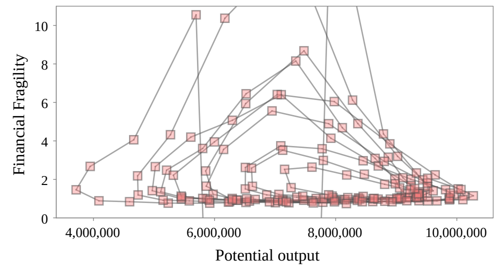
Table 3: Comparative statistics over the monetary policy scenarios, average over 30 replications (standard deviation between brackets) N.B.: Significant difference in the means between a scenario and the baseline is established using two-sided K-S tests and confirmed by a Mann-Whitney median test, as outliers can drive standard deviations to very high values (especially for the financial fragility index) and normality tests lead us to reject the null hypothesis of normal data series (*: p-value $< 0.01$, **: $< 0.001$, ***: $< 0.0001$).

The outcomes under the two scenarios involving a reaction to the spreads (*spreads* and *changeSpreads*) appear indistinguishable from the baseline outcomes, no matter the strength of the interest rate adjustments (i.e. coefficients $\phi_f$), except that fewer banking failures occur. Recall first that the spreads are computed as an increasing function of the share of speculative and Ponzi firms. Looking back at the results in Section 3.2, and especially Figure 5c, we can see that those shares are pro-cyclical and mainly coincident,. Their ex-ante information content is therefore limited, GDP, inflation and spreads co-move, so that monetary policy is equally constraint by the zero-lower bound when reacting to the spreads and when not including them into the reaction function. As a consequence, the outcomes of scenarios *spreads* and *changeSpreads* are not significantly different from those obtained in the baseline scenario. This result echoes the finding of Chiarella & Di Guilmi (2017): adjusting interest rates to the share of Ponzi firms does not break down the pro-cyclicity of the credit bubble, and the ensuing develerage crisis and debt deflation.

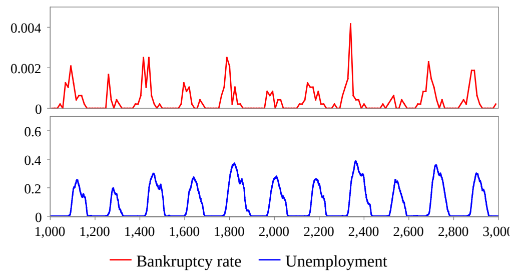
Significant improvements are observed when the central bank reacts to the movements in the firms' net worth (scenarios *netWorth* and *changeNetWorth*). Those improvements concern almost every indicator considered: the measurements of the unemployment costs of recession, financial fragility and the resulting bankruptcy costs of recessions, as well as macroeconomic volatility measured by GDP growth and interest rate volatility – note that the volatility of inflation is not significantly impacted, in any of the scenario under study. Moreover, in scenarios *netWorth* and *changeNetWorth*, like in the baseline, no systemic crisis is observed over any of the 30 replications. However, if recessions are shorter and involve fewer unemployed households in those scenarios, the number of crisis episodes appear slightly but significantly higher in scenario *netWorth* compared to the baseline. This is not the case under scenario *changeNetWorth*. The benefits from reacting to the net worth developments are the clearest regarding financial fragility, where the pikes in financial fragility are eliminated (compare Figures 8b, 8f and 8d for the purpose of illustration, and notice the particularly low standard deviations reported for this indicator in Table 3 compared to the baseline). The level of unemployment recorded along recessions



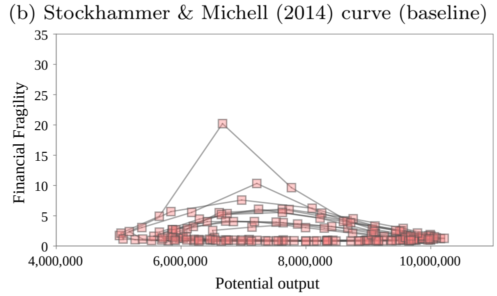

(a) Unemployment rate and bankruptcies (baseline)



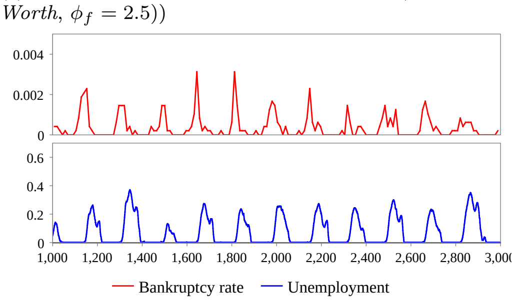

(b) Stockhammer & Michell (2014) curve (baseline)



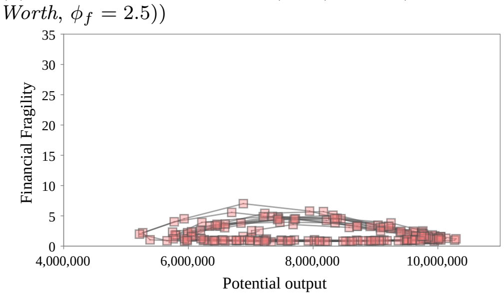

(c) Unemployment rate and bankruptcies (*changeNetWorth*, $\phi_f = 2.5$))



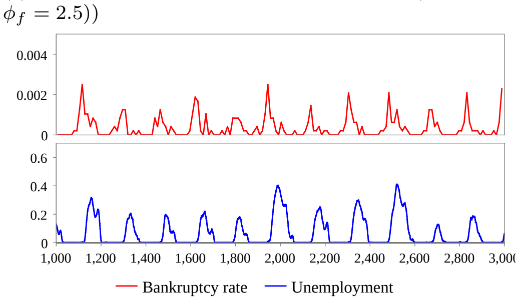

(d) Stockhammer & Michell (2014) curve (*changeNetWorth*, $\phi_f = 2.5$))



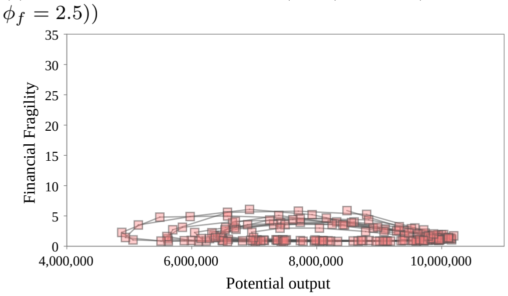

(e) Unemployment rate and bankruptcies (*netWorth*, $\phi_f = 2.5$))




(f) Stockhammer & Michell (2014) curve (*netWorth*, $\phi_f = 2.5$))




(g) Unemployment rate and bankruptcies (*netWorth*, $\phi_f = 3$))




(h) Stockhammer & Michell (2014) curve (*netWorth*, $\phi_f = 3$)

Figure 8: Illustration of the comparison between policy simulations, $t = 1000, ...., 3000$.

remains quite high though, even in those scenarios. Eliminating extreme values of financial fragility does help reduce bankruptcies but does not smooth out drastically the costs of financial crises (intuitively, the economy remains on the steep part of the curve on Figure 7, in the bottom left corner of the scatterplot; see also Figures 8a, 8c and 8e). Finally, further increases in the reaction coefficient $\phi_f$ do not seem to improve stabilization performances (see 8g-8h).

In order to explain the relatively good performances of the scenarios *netWorth* and *changeNetWorth*, recall that they involve a monitoring of private sector balance sheets and their growing fragility during favorable economic conditions. Those indicators directly measure the financial imbalances that build up among leveraged agents during a boom, as typical along credit cycles, and do include predictive power as discussed in, among others, Borio & Drehmann (2011). Hence, the interest rate rule directly influences the incentives of firms to seek higher leverage, which acts directly upon risk exposure (Woodford 2012).

In a nutshell, only two designs of the Taylor rule – *netWorth* in which the central bank reacts to the average level of the leverage ratio of firms, and in a quite stronger way ($\phi_f > 2$), and to a lesser extent the scenario *changeNetWorth* – significantly reduce the unemployment costs of recessions, increase financial stability, reduce the number of bankruptcies and slightly limit GDP volatility. However, the frequency and the costs of those crisis episodes remain high in any scenario considered.

## 5 Elements for conclusion

This paper conducts a comparison of the stabilizing power of a wide range of monetary policy rules in a complex economy, featuring a Minskyan leverage engine and a Keynesian aggregate demand loop, which give rise to an investment accelerator and credit cycles on the goods and the labor markets, followed by debt-deflation type of recessions. Those dynamics are present despite prudential regulations that constrain firms' access to credit and ensure a minimum of risk-weighted capital buffer in the banking system. This observation already stresses the limitations of micro- or macroprudential policies that have been advocated as a better tool than monetary policy to prevent financial crises.

The central bank can achieve significant stabilizing benefits if the Taylor rule is augmented by a reaction to the developments in private debt in the economy, in our case measured through the net worth of firms. This is the only indicator that we have identified that contains enough leading information regarding growing financial imbalances and upcoming economic risks to allow the central bank not to react ex post. This conclusion should be qualified along three lines. Firstly, from a practical point of view, if reacting to the leverage of the non-financial sector may be a good idea, our analysis has left open the question of how the central bank may be able to observe, accurately and timely estimate, or aggregate firms' financial strategies, that is essentially private and decentralized information. This points out to the inherent difficulty associated to so-called leaning-against-the-wind policies in finding early detection signals. A more comprehensive treatment of expectations in our model could shed some further light into that direction, but is beyond the scope of this study. Secondly, the specific design of the policy rule seems to matter so that rules-based policy making inevitably involves some fine tuning, which raises the question of the robustness of such policies to model misspecifications. Thirdly, the frequency as well as the employment costs of recessions remain high, no matter the design of the monetary policy rule under study. This result suggests that rules-based policies are not a panacea, even if augmented with reactions to financial instability or accompanied by prudential regulations. Simple rules are certainly not able to stabilize a complex economy, with interdependent balance-sheets, non-linear, "corridor"-type of dynamics, and numerous feedback loops between market and agents. The instability of the economy seems somehow inherent to the functioning of the complex economy. This suggests that policy making should be conceived as piloting the economy to keep the system away from those "dark corners". Simple systematic rules do not appear to be sufficient to the task, at least in the somehow rudimentary model that we have presented in this paper, especially regarding the very stylized design of the banking sector. This observation casts some doubts on how simple rules-based policies could do a better job in the admittedly much more complex real world economy.

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# A Parameter values

| Parameter | Description | Baseline value |
|---|---|---|
| **Households** | | |
| $h$ | number | 6,000 |
| $d^r$ | wage resistance | 12 (months) |
| $\eta_H$ | wage adjustment parameter | 0.05 |
| $g$ | size of the market selection (same for firms) | 10 |
| $window$ | memory (same for firms) | 12 (months) |
| $\kappa_S$ | targeted savings rate | 0.2 (share) |
| $\mu_H$ | rate of consumption of excess savings | 0.5 |
| **Firms** | | |
| $f$ | number | 400 |
| $d^k$ | lifetime of the machines | $\mathcal{N}(120, 15)$ (months) |
| $d^l$ | short-run credit length | 12 (months) |
| $d^L$ | long-run credit length (= average machine lifetime) | 120 (months) |
| $d^p$ | length of the production process | 4 (months) |
| $d^w$ | length of employment contracts | $\mathcal{U}[3, 60]$ (months) |
| $g'$ | number of wage observations | 3 |
| $pr^k$ | productivity of the machines | 100 (units) |
| $v^k$ | value of a new machine in real terms (number of goods to produce a machine) | 600 (units) |
| $\beta$ | greediness in investment | 1.2 |
| $\delta^P$ | price flexibility parameter | 0.04 |
| $\delta^W$ | wage flexibility parameter | 0.02 |
| $\nu_F$ | production flexibility parameter | 0.1 |
| $\mu_F$ | proportion of goods to be sold | 0.5 |
| $\kappa_d$ | maximum share of equity to be distribute as dividends | 0.2 |
| $\sigma_\ell$ | size of individual leverage innovations | 0.01 |
| **Bank** | | |
| $\kappa_b^T$ | capital adequacy ratio | 0.15 |
| $b$ | cap on the debt service ratio | 120% |
| $\Delta$ | risk premium parameter | 0.1 |
| $rp$ | additional penalty on doubtful debt | 0.04 (monthly rate) |
| $\omega_H$ | asset risk weight for hedge debtors | 50% |
| $\omega_S$ | asset risk weight for speculative debtors | 100% |
| $\omega_P$ | asset risk weight for ponzi debtors | 150% |
| $\phi_\pi$ | reaction to inflation (Taylor rule) | 1.5 |
| $\phi_y$ | reaction to output growth (Taylor rule) | 0.5 |
| $\pi^T$ | inflation target | 0.02/12 (monthly) |
| **Model** | | |
| $d^S$ | length of the simulations | 3,000 (months) |

Table 4: `Baseline` scenario. Random draws are performed at each period and for each agent.

# B Pseudo-code of Jamel

**Initialization** (all scenarios):

| Variable | Description | Initial value |
|---|---|---|
| $k_{j,0}$ | capital (i.e., the number of machines per firm, which is also the initial maximum number of jobs per firm) | 15 |
| $W_{j,0}$ | wage offer (monetary units) | 50 |
| $\ell^T_{j,0}$ | leverage ratio target (Random draws are performed for each firm) | $\hookrightarrow \mathcal{U}[0, 0.9]$ |
| Initial shareholding | $E_{j,0}$ of each firm and of the bank are divided in *ten equal shares*, and distributed to randomly drawn households. | |
| All other individual and macroeconomic variables incl. the initial money balances of households and the total assets and liabilities of the firms and the bank | | 0 |

**Execution** In each period $t$, $t = 1, ..., d^S$:

1. **Interest rate adjustment:**

$$i_t = \min\left(0, \phi_\pi(\pi_t - \pi^T) + \phi_y \frac{\Delta GDP_t}{GDP_t} + \phi_f \mathcal{F}_t\right) \tag{3}$$

   where $\pi_t$ is the price inflation computed over the past *window* periods.

2. **Fixed capital stock depreciation:** Each machine $m$ of each firm $j$ is depreciated by $\frac{I_{j,m}}{d^k}$ where $I_{j,m,}$ is the initial value of the machine paid by $j$ and $d^k$ the expected life time of the machine (in months, straight-line depreciation method).

   If $k_{j,t} = 0$ (i.e. after capital depreciation, firm $j$ is left without any productive capital), **new management team**: firm $j$ copies a leverage target ratio $\ell_{k,t}$ on a randomly drawn firm $k$, among all the operating firms, independently of their relative profit levels.

3. **Payment of dividends (firms):**

   Each firm $j$:

   (a) computes its targeted level of equities given its targeted leverage ratio $\ell^T_{j,t}$;

   (b) computes $\tilde{F}_{j,t}$, its average past net profits $F_j$ over *window* periods;

   (c) computes the share of its equities to be distributed as $\frac{E_{j,t}}{E^T_{j,t}}$;

   (d) distributes to its owners the amount $FD_{j,t} = \min\left(\frac{E_{j,t}}{E^T_{j,t}}\tilde{F}_{j,t}, \kappa_d E_{j,t}\right)$, in proportion to their relative share holding.

4. **Payment of dividends (the bank):**

   The bank:

   (a) computes its risk-weighted assets $\text{RWA}_t$ as a weighted average of all debts of the firms, where each hedge firm receives a weight $\omega_H$, each speculative firm a weight $\omega_S$, and each Ponzi firm a weight $\omega_P$;

(b) computes its mandatory capital buffer (or conversely its amount of equities $E^T_{B,t}$) as $E^T_{B,t} = \kappa^T_b * \text{RWA}_t$;

(c) distributes $FD_{B,t} = \max(E_{B,t} - E^T_{B,t}, 0)$.

5. **Price:**

$$
\begin{aligned}
&\text{if } (s_{j,t-1} = s^T_{j,t-1} \text{ and } in_{j,t} < in^T_{j,t}) &&\begin{cases} \overline{P}_{j,t} = \overline{P}_{j,t-1}(1+\delta^P) \\ \underline{P}_{j,t} = P_{j,t-1} \\ P_{j,t} \hookrightarrow \mathcal{U}(\underline{P}_{j,t}, \overline{P}_{j,t}) \end{cases} \\
&\text{else if } (s_{j,t-1} < s^T_{j,t-1} \text{ and } in_{j,t} > in^T_{j,t}) &&\begin{cases} \overline{P}_{j,t} = P_{j,t-1} \\ \underline{P}_{j,t} = \underline{P}_{j,t-1}(1-\delta^P) \\ P_{j,t} \hookrightarrow \mathcal{U}(\underline{P}_{j,t}, \overline{P}_{j,t}) \end{cases} \\
&\text{else} &&\begin{cases} \overline{P}_{j,t} = \overline{P}_{j,t-1}(1+\delta^P) \\ \underline{P}_{j,t} = \underline{P}_{j,t-1}(1-\delta^P) \\ P_{t,j} = P_{j,t-1} \end{cases}
\end{aligned} \tag{4}
$$

with :

- $s_{j,t-1}$ and $s^T_{j,t-1}$, respectively, the sales (in quantities) and the total good supply in the last period.
- $\overline{P}_{j,t}$, the ceiling price,
- $\underline{P}_{j,t}$, the floor price.

6. **Wage offer:** Each firm $j$ observes a random sample of $g'$ other firms. If the observed sample contains a firm $k$ such that $k_{k,t} > k_{j,t}$, then:

$$
\begin{cases} W_{j,t} = W_{k,t} \\ \overline{W}_{j,t} = W_{j,t}(1+\delta^W) \\ \underline{W}_{j,t} = W_{j,t}(1-\delta^W) \end{cases} \tag{5}
$$

else:

$$
\begin{aligned}
&\text{if } (\rho_{j,t-1} > 0) &&\begin{cases} \overline{W}_{j,t} = \overline{W}_{j,t-1}(1+\delta^W) \\ \underline{W}_{j,t} = W_{j,t-1} \end{cases} \\
&\text{else} &&\begin{cases} \overline{W}_{j,t} = W_{j,t-1} \\ \underline{W}_{j,t} = \underline{W}_{j,t-1}(1-\delta^W) \end{cases} \\
&\text{and then} && W_{j,t} \hookrightarrow \mathcal{U}(\underline{W}_{j,t}, \overline{W}_{j,t})
\end{aligned} \tag{6}
$$

with:

- $\rho_{j,t-1} = \frac{n^T_{j,t-1} - n_{i,t-1}}{n^T_{j,t-1}}$, the vacancy rate previously observed by the firm,
- $\overline{W}_{j,t}$, the ceiling wage,
- $\underline{W}_{j,t}$, the floor wage.

7. **Labor demand:** $n^T_{j,t}$ (within the lower bound 0 and the upper bound $k_{j,t}$):

$$
n^T_{j,t} = (1 + \delta^h_{j,t}) n^T_{j,t-1} \tag{7}
$$

where $n^T_{j,t-1}$ is the labor demand of the firm in period $t-1$, and $\delta_{j,t}$ is the size of the adjustment, computed as:

$$\delta^h_{j,t} = \begin{cases} \alpha_{j,t}\nu_F & \text{if } 0 \le \alpha_{j,t}\beta_{j,t} < \frac{in^T_{j,t} - in_{j,t}}{in^T_{j,t}}, \\ -\alpha_{j,t}\nu_F & \text{if } 0 \le \alpha_{j,t}\beta_{j,t} < \frac{in_{j,t} - in^T_{j,t}}{in^T_{j,t}}, \\ 0 & \text{else.} \end{cases} \quad (8)$$

with $\alpha_{j,t}$, $\beta_{j,t} \hookrightarrow \mathcal{U}(0,1)$ and $\nu_F > 0$.

**Job posting:**

$$\begin{cases} \text{if } n_{j,t} > n^T_{j,t} & \text{fires } n_{j,t} - n^T_{j,t} \text{ (on a last-hired-first-fired basis)} \\ \text{else} & \text{posts } n^T_{j,t} - n_{j,t} \text{ job offers.} \end{cases} \quad (9)$$

8. **Financing of current assets:** according to the existing job contracts, the workforce target $n^T_{j,t}$, and the wage rate offered on the labor market $W_{j,t}$:
   (a) computes the anticipated wage bill $WB^T_{j,t}$;
   (b) borrows $\max(WB^T_{j,t} - M_{j,t}, 0)$ (non-amortized short-term loan).

9. **Reservation wages:**
   Each household $i$ updates his reservation wage $W^r_{i,t}$.
   - If $i$ is unemployed :
     - if $(unemploymentDuration_{i,t} < d^r)$ :
       $$W^r_{i,t} = W^r_{i,t-1} \quad (10)$$
     - else :
       $$W^r_{i,t} = W^r_{i,t-1}(1 - \eta_H \cdot \alpha_{i,t}) \quad (11)$$

     where $\alpha_{i,t}$ is $\mathcal{U}(0,1)$, and $\eta_H > 0$ and $d^r \ge 0$ are parameters.
   - Else:
     $$W^r_{i,t} = W_{i,t-1} \quad (12)$$
     where $W_{i,t-1}$ is the wage earned by household $i$ in the previous period $t-1$.

10. **Labor market :**
    Each unemployed household:
    (a) consults a random sample of $g$ job offers;
    (b) selects the job offer with the highest offered wage, denoted by $W_{j,t}$;
    (c) if $W_{j,t} \ge W^r_{i,t}$, accepts the job for a duration of $d^w$ months; else, remains unemployed for the period $t$.

11. **Production:** Each firm distributes randomly the hired workers on its machines (one per machine). Once a production process of a machine is completed (after $d^p$ iterations by a worker), it adds $pr^k$ goods to the firm's inventories $in_{j,t}$, whose value is then incremented by the production costs.

12. **Goods supply:** Each firm $j$ puts $s_{j,t}^T$ goods in the goods market:

$$s_{j,t}^T = \mu_F \cdot in_{j,t} \tag{13}$$

13. **Individual experimentation :** For each firm $j$, $\ell_{j,t+1}^T \hookrightarrow \mathcal{N}(\ell_{j,t}^T, \sigma_\ell)$ (the normal distribution is truncated at zero).

14. **Investment decision:**

    Each firm $j$ considers whether to invest or not:

    (a) selects a random sample of $g$ suppliers (other firms) to estimate the average price of the goods (costs of the investment);

    (b) if $k_{j,t} = 0$, buys $m_{j,t} = 1$ new machine, for a value $I_{j,t}$;

    (c) else, if and only if ($E_{j,t}^T > E_{j,t}$ and $grossProfits_{j,t} > 0$), the firm considers investing and computes its maximum credit capacity:

    i. Computes its current total debt service $debtService_{j,t}$ by summing up all its due monthly repayments on all its short- and long-run ongoing bank loans;

    ii. computes its maximum credit capacity as $\max\left(0, \frac{debtService_{j,t}}{grossProfits_{j,t}} - \bar{b}\right)$.

    (d) Only if its maximum credit capacity $> 0$, the firm will invest and:

    i. computes its maximum monthly additional repayments that the firm can afford:
    $maxInstalment_{j,t} = \left(\bar{b} - \frac{debtService_{j,t}}{grossProfits_{j,t}}\right) * grossProfits_{j,t}$

    ii. and its corresponding maximum investment expenditures $I_{\bar{m_{j,t}}}$ taking into account its interest rate level $i_{j,t}$, its current cash-on-hand $M_{j,t}$, the length of the short and the long-run credits $d^l$and $d^L$, and its leverage target $\ell_{j,t}$ as:

$$I_{\bar{m_{j,t}}} = \left(i_{j,t} + \frac{\ell_{j,t}}{d^L} + \frac{1-\ell_{j,t}}{d^l}\right)^{-1} \left(maxInstalment_{j,t} + M_{j,t} \cdot \left(\frac{1}{d^l} + i_{j,t}\right)\right)$$

    iii. computes the maximum number of machines $\bar{m}_{j,t}$ that the firm can afford for $I_{\bar{m}}$.

    iv. computes $\tilde{s}_{j,t}$, average of the sales $s_j$ over the past *window* periods;

    v. computes $s_{j,t}^e = \beta \cdot \tilde{s}_{j,t}$, its sales expansion objective;

    vi. given its sales expansion objective $s_{j,t}^e$, the expected life time of a machine $d^k$, the current price $P_{j,t}$, the current wage $W_{j,t}$, the discount factor $r_t = i_t - \tilde{\pi}_t$ ($\tilde{\pi}_t$ is the average past inflation computed over the *window* last periods), and the price $I_{m_{j,t}}$ of each investment project $m_{j,t}$, computes the net present value $NPV_{m_{j,t}}$ of each investment project $m_{j,t}$ for $m_{j,t} = 1, .., \bar{m_{j,t}}$:

$$NPV_{m_{j,t}} \equiv \frac{CF_{m_{j,t}}}{r_t}\left(1 - \frac{1}{r_t(1+r_t)^{d^k}}\right) - I_{m_{j,t}}$$

where $CF_{m_{j,t}}$ is the expected cash-flow of the project:

$$CF_{m_{j,t}} = \min(s^e_{j,t}, m_{j,t} \cdot pr^k) \cdot P_{j,t} - m_{j,t} \cdot W_{j,t}$$

where the min term ensures that the future sales cannot exceed the production capacity of the firms.

vii. chooses the project $m_{j,t}$ with the highest NPV.

viii. adds $\frac{I_{m_{j,t}}}{m_{j,t}}$ per new machine to its assets.

15. **Financing of fixed assets:**

    (a) borrows (amortized long-run loan) the amount: $\ell^T_{j,t} I_{m_{j,t}}$;

    (b) borrows (amortized short-run loan) the amount: $\max((1 - \ell^T_{j,t}) I_{m_{j,t}} - M_{j,t}, 0)$;

16. **Saving/consumption plan:** Each household computes

    (a) his average monthly income flow over the last *window* periods, denoted by $\tilde{Y}_{i,t}$;

    (b) his cash-on-hand target $M^T_{i,t} = \kappa_S \cdot \tilde{Y}_{i,t}$;

    (c) his targeted consumption expenditures as:

$$C^T_{i,t} = \begin{cases} (1 - \kappa_S)\tilde{Y}_{i,t} & \text{if } M_{i,t} \leq M^T_{i,t} \\ \tilde{Y}_{i,t} + \mu_H (M_{i,t} - M^T_{i,t}) & \text{else.} \end{cases} \tag{14}$$

    The budget constraint always gives $C_{i,t} \leq \min(C^T_{i,t}, M_{i,t})$.

17. **Goods market ::**

    (a) matches first the investor-firms' demand, then the households' demand with the firms' supply;

    (b) goods bought by investor-firms are transformed into new machines, while goods bought by households are consumed;

18. **Loans :** The firms pay back part of their loans and the interests to the bank. Interest is due in each period. The interest $i_{j,t}$ depends on the firm being hedge ($i_{j,t} = i_t$), speculative ($i_{j,t} = i_t(1 + \Delta)$) or Ponzi ($i_{j,t} = i_t(1 + 2 \cdot \Delta)$) at the time of borrowing. For an amortized loan, principal is repaid by equal fractions in each period, while for a non-amortized loan, the total principal is due at the term. If the cash-on-hand $M_{j,t}$ of a firm $j$ cannot fully cover the debt repayments, it benefits of an overdraft facility, i.e. a new short term loan at an higher rate including the risk premium of the bank ($i_{j,t} + rp$).

19. **Foreclosure :** If, and only if, a firm $j$ has become insolvent ($A_{j,t} < L_{j,t}$), the bank starts the foreclosure procedure:

    (a) The amount of debt $L_{j,t} - A_{j,t}$ is erased, and deducted from the bank's capital, the failed firm's new book value is set to zero and its shareholders lose their shares;

(b) **New management team**: the failed firm $j$ copies a leverage target ratio $targetDebtRatioj, t+1 = \ell^T_{k,t}$ on a randomly drawn firm $k$, among all the operating firms in the same sector, independently of their relative profit levels.

(c) The firm $j$ updates $E^T_{j,t}$ on the base of its new $\ell_{j,t+1}$. As $E_{j,t} = 0$, the new financial needs of the firm are equal to $E^T_{j,t}$.

(d) The bank randomly draws $g$ potential shareholders among the households.

(e) The firm is sold to those shareholders for a maximum amount of $E^T_{j,t}$ within the limit of their available cash-on-hand. Households hold shares in proportion to their contribution (i.e. their excess savings in the limit of $E^T_{j,t}$). The funds from the households allow the bank to at least partially restore the firm's equities (recapitalization).

20. **Next period**. Unless the bank has become insolvent (i.e., bank failure and systemic crisis), this process starts all over again for $d^S$ periods.

# C Stock- flow consistency

| | |
|---|---|
| $E$ | Value of equities held by households |
| $E_b$ | Value of equities issued by banks |
| $E_f$ | Value of equities issued by firms |
| $IN$ | Inventories of finished goods, at production cost |
| $K$ | Value of fixed capital stock |
| $L$ | Loans supplied by banks |
| $L_f$ | Loans to firms |
| $M$ | Money deposits supplied by banks |
| $M_f$ | Money deposits held by firms |
| $M_h$ | Money deposits held by households |
| $NW$ | Net worth of households |
| $WIP$ | Work in process, at production cost |

Table 5: Stocks

| | **Households** | **Firms** | **Banks** | **Σ** |
|---|---|---|---|---|
| Work In Process | | $WIP$ | | $WIP$ |
| Inventories | | $IN$ | | $IN$ |
| Fixed Capital | | $K$ | | $K$ |
| Deposits | $M_h$ | $M_f$ | $-M$ | 0 |
| Loans | | $-L_f$ | $L$ | 0 |
| Equities | $E$ | $-E_f$ | $-E_b$ | 0 |
| Balance | $-NW$ | 0 | 0 | $-NW$ |
| Σ | 0 | 0 | 0 | 0 |

Table 6: Balance sheet matrix

| | |
|---|---|
| $AF$ | Amortization funds |
| $C$ | Consumption goods sold by firms to households |
| $CAP$ | Recapitalizations |
| $F_b$ | Bank profits |
| $F_f$ | Entrepreneurial profits |
| $FD_b$ | Dividends of banks |
| $FD_f$ | Dividends of firms |
| $I$ | New fixed capital goods |
| $INT$ | Interest payments paid by firms |
| $L^{back}$ | Repaid loans |
| $L^{new}$ | New loans |
| $L^{np}$ | Non performing loans |
| $PROD$ | New finished goods valued at cost |
| $S$ | Value of sales, at historic costs |
| $WB$ | Wages paid to households |

Table 7: Flows

| *Change in the stock of* | **Households** | **Firms** | **Banks** | $\mathbf{\Sigma}$ |
|---|---|---|---|---|
| Work In Process | | $+WB - PROD$ | | $+WB - PROD$ |
| Inventories | | $+PROD - S$ | | $+PROD - S$ |
| Fixed Capital | | $+I - AF$ | | $+I - AF$ |
| Deposits | $+WB - C + FD_f + FD_b - CAP$ | $+L^{new} - L^{back} - WB + C - INT - FD_f + CAP$ | $-L^{new} + L^{back} + INT - FD_b$ | 0 |
| Loans | | $-L^{new} + L^{back} + L^{np}$ | $+L^{new} - L^{back} - L^{np}$ | 0 |
| Equities | $-S + CAP + I - AF + C - FD_f - FD_b$ | $+S + INT - L^{np} - I + AF - CAP - C + FD_f$ | $-INT + L^{np} + FD_b$ | 0 |
| $\Sigma$ ($\Delta$ Net worth) | $+WB - S + I - AF$ | 0 | 0 | $+WB - S + I - AF$ |

Table 8: Full-integration matrix