Stabilizing an Unstable Complex Economy
On the limitations of simple rules

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Abstract

This paper offers a systematic comparison of a wide range of leaning-against-the-wind interest-rate policy rules within a macroeconomic, stock-flow consistent, agent-based model. The model 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. We show that a monetary policy rule that targets the movements in the net worth of firms significantly dampens the credit cycles and reduces the employment costs of financial crises, because this indicator incorporates early signals of financial imbalances. Performances of this three-mandate Taylor rule are also more robust to the specific parameter values and regulatory framework than the standard dual-mandate Taylor rules. Nonetheless, none of the policy rules under study completely eliminates the high employment costs of financial crises.

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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 and 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, 2017), and measuring *ex ante* the risk of a 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. Under this view, leaning-against-the-wind policies would be 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 by the use of an agent-based model (hereafter ABM). We add to the existing literature by offering a systematic comparative study of alternative designs of interest-rate policies to lean against the wind, possibly in combination with prudential regulations, within a simple but yet fully-fledged macroeconomic ABM. In particular, we seek to identify an indicator that contains early signals about upcoming financial imbalances. To the best of our knowledge, such a systematic search is new in the literature, but it is highly needed given the lack of consensus about which indicators of financial imbalances the central bank should react to, if it should at all. The technical and conceptual challenges to such a exercise certainly explain the scarcity of this type of policy analysis within DSGE frameworks.[1]

Some very recent contributions address the challenging issue of financial stability through monetary policy and prudential regulation within macro ABMs. However, most of those contributions have largely focused on the analysis of prudential tools, while leaving monetary policy through interest-rate setting rules out of the picture.[2] There also

[1]Those challenges concern in particular the restrictions on heterogeneity and disaggregation, the equilibrium focus of the model resolution, the fully rational and infinite-horizon expectations as the main transmission channel of policies, as well as the difficulty to model non-linear feedback loops between the financial and the real sides of the economy. Woodford (2012) is an example but the proposed framework remains heavily stylized, and does not analyze various indicators.

[2]We refer the interested reader to the survey of Fagiolo and Roventini (2017) for a comprehensive

exist few ABMs that incorporate a traditional, dual-mandate Taylor rule and analyze prudential policies, see e.g. Ashraf et al. (2017) or Assenza et al. (2017), but studies aimed to explicitly model leaning-against-the-wind monetary policy within ABMs do remain scarce.

Da Silva and Lima (2016) show how countercyclical capital buffers can conflict with leaning-against-the wind monetary policy that react to a credit gap. However, the authors do so in a simplified framework where the labor market and unemployment are absent, which limits the analysis of the real costs of recessions. Popoyan et al. (2017) study in a systematic way the prudential rules involved in Basel II and III, and their interactions between each other and monetary policy within a rather sophisticated macroeconomic ABM. The paper does not achieve crystal-clear results regarding the role of monetary policy for a given macroprudential framework: while dampening credit cycles is best achieved through leaning-against-the-wind rule that targets credit growth, the authors reveal the existence of conflicting objectives between financial stability, unemployment rate and inflation. The closest contribution to ours is Chiarella and Di Guilmi (2017), who present a stylized ABM that accounts for the risk-taking channel. The authors show that a leaning-against-the-wind policy that reacts to excess leverage of private units may turn counterproductive. A major difference with our study though is that none of those papers compare different designs of the policy rules, neither regarding the policy parameters nor the incorporated indicators. The main contribution of our paper is to fill this gap by offering such a systematic comparative study of a large range of potential interest rate policies to lean against the wind, in interaction with simple prudential rules, within a fully-fledged macroeconomic ABM.

ABMs offer indeed a number of interesting features that make them particularly suited to tackle those issues. An ABM builds upon a collection of heterogeneous agents con-

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treatment of macroeconomic policy analysis in general within ABMs. Cincotti et al. (2012) and Teglio et al. (2012) analyze the stabilizing power of counter-cyclical capital buffers. Van der Hoog and 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 pro-cyclical nature, do not. Krug et al. (2015) perform pairwise analyses of micro and macroprudential components implied by Basel II and III in a model featuring a detailed interbank market.

ceived as individual units (firms, households) that interact with each other on decentralized markets.[3] 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 implement different monetary policy rules, in which indicators of financial stress are directly observable, without bearing the constraint of analytical tractability or aggregation of heterogeneous units, which remain major obstacles to their analysis in DSGE models. Last but not least, AB frameworks have proven to be particularly successful in making emerge financially unstable dynamics, along which the procyclicality of leverage and the credit and balance-sheet channels of monetary policy are essential to the formation of credit cycles *à la* Minsky (1986). The resulting emerging boom-and-bust dynamics constitute an ideal testbed for alternative designs of leaning-against-the-wind policies.

In this paper, we build on the class of `Jamel` models (Seppecher, 2012; Seppecher and Salle, 2015; Seppecher, Salle and Lang, 2017; Seppecher, Salle and Lavoie, 2017), as this model has been proven to be capable of producing these unstable financial dynamics. We extent the model developed in Seppecher, Salle and Lang (2017) along several dimensions, in particular by introducing some simpler behavioral rules, endogenous and firm-specific risk premia, prudential constraints and leaning-against-the-wind interest rate rules. Next to a leverage engine that produces a strong investment accelerator and endogenously creates Minskian credit cycles, the model 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.[4] 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 and

[3]We refer here to, for instance, Delli Gatti et al. (2011) for an introduction to this literature. We only give here the general principles.

[4]Other examples include Cincotti et al. (2010), Chiarella and Di Guilmi (2011, 2017) or Dosi et al. (2013).

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 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: interest rates enter the investment decisions of firms and, hence, influence both their risk-taking behavior and the service on their debt.

Overall, the model is a virtual laboratory that mimics a complex world, where to confront different simple policy rules that may have been suggested in the related literature or empirically tried out. Such a virtual platform has the further advantage of being a fully-fledged macroeconomic model, while remaining stylized enough for the emerging cycles to be well-understood and the chain of events from the micro behaviors to the macro patterns to be unraveled in detail. While the study in Seppecher, Salle and Lang (2017) provides such a scrutinized analysis of the model's dynamics, it ignores the major question of their mitigation, or even control, by policies, and the necessary prerequisite of their realism. Those two questions are therefore at the core of this paper, and we address them *via* a policy-oriented exercise using the `Jamel` backbone. Firstly, we dedicate novel efforts to calibrate and validate the model, and provide a detailed confrontation of the model's outcomes with empirical counterparts. We also devote some attention to develop indicators to quantify the costs of the observed crises, and analysis tools to picture the comparison between the different policy scenarios. Secondly, we focus the paper on what type of policy setting may help stabilize the cycles, and analyze the conjugated role of monetary policy through an interest-rate policy rule and prudential regulations.

Our main results can be summarized as follows. We find that adding an objective of financial stability to the monetary policy rule helps dampen the credit-driven boom and bust dynamics in the real side of the economy (both on the goods and the labor markets) 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. Such a stabilizing effect is obtained if the central bank reacts to the leverage or, equivalently, to movements in the firms' net worth. Among all the alternatives that we have considered, this rule functions best because it allows the regulator to react to the developments of the conditions of a financial crisis, not to its expressions. In other words, such a rule is forward-looking in the sense that it contains early warning signals of financial turmoils because it directly monitors the balance-sheets of the private sector and their growing fragility during favorable economic conditions. This provides a first-hand measure of the financial imbalances that build up among leveraged agents during a boom, as typical along credit cycles, and does include predictive power as discussed in, among others, Borio and Drehmann (2011). To the best of our knowledge, our paper is the first to design and propose such a policy rule that formalizes those intuitions.

By contrast, other indicators that we have tried out, including the interest spreads or the credit growth rate, turn out to be too procyclical to convey enough *ex ante* information about financial risk. Furthermore, while the economic performances appear quite sensitive to the coefficient values of the policy rule and the prudential framework under a traditional dual-mandate Taylor rule, the performances obtained under such triple-mandate Taylor rules are more robust across those dimensions. Yet, 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. Finally, maintaining low and stable inflation and promoting financial stability, while mitigating the unemployment costs of recessions seem to be, at least to some extent, conflicting objectives.

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. 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. Section 5 discusses potential conflicting objectives in the mandate of the central bank and their interaction with the prudential framework, and Section 6 concludes.

2. The model

We provide an overview of the architecture of the Jamel 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. A comprehensive exposition of the behavioral rules of the agents, as well as the timing of events and the parameter values are deferred to Appendix AppendixB through a pseudo-code. Appendix AppendixC 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

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 producing a generic good by combining capital (machines) and labor inputs with complementary production factors and fixed production coefficients. 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 which it breaks down and becomes irreversibly unproductive. There is no technical progress, 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.[5] 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 firms and the bank,

[5]See Seppecher, Salle and Lavoie (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.

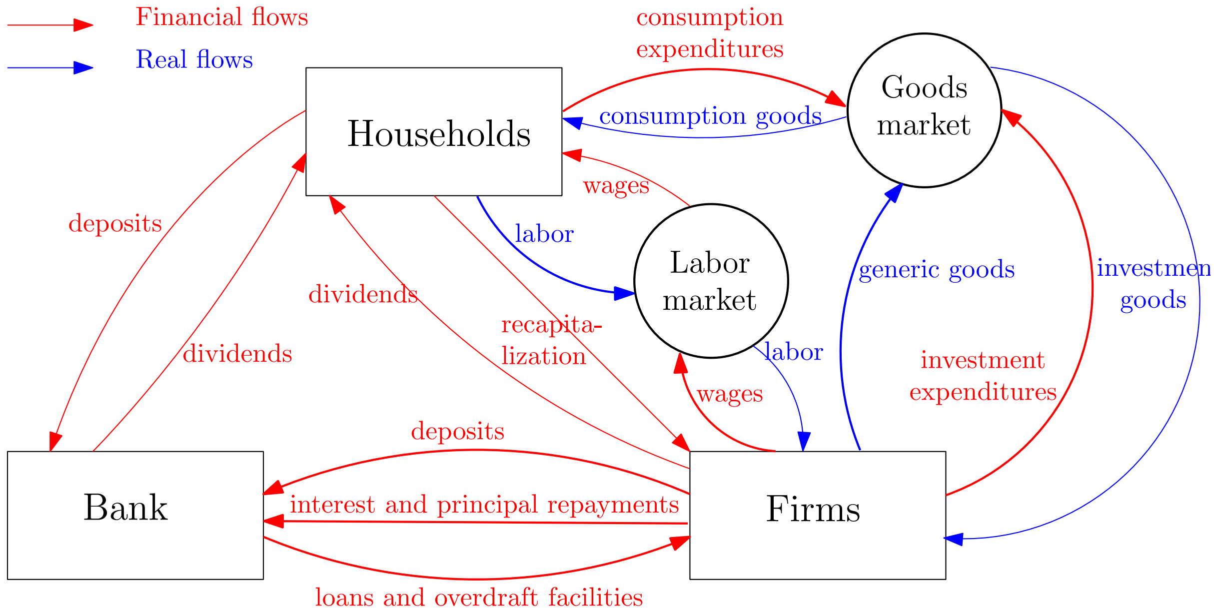


Figure 1: General architecture of the model

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: a financial strategic component, where the decision variable is a leverage target and an effective-demand component that relates to future sale prospects. The leverage targets of the firms endogenously evolve as a result of an evolutionary mechanism rooted in the market selection pressure.

The total number of households remains fixed. The banking sector is aggregated, the single bank hosts deposits of households and firms, and grants loans to the firms to finance their production (through short-term loans) and their investment (through long-term loans). The prevailing interest rate depends 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 prudential policies in the model. 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 by one step till its completion after several periods. The machine then delivers a number of units of goods (given by the productivity in the economy) to be added to the firm's inventories level. Note that the number of employees in each firm cannot 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 as a proxy for the variations in their demand to decide upon the corresponding price *and* quantity adjustments. This twofold decision is necessary as soon as interactions between agents are fully decentralized, and the law of unique price and wage does not hold. 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 proceed by small, stochastic adjustments in the corresponding direction. Additionally, for the pricing decisions, each firm keeps track of a floor price and a ceiling price. Such a price range is dynamically updated so as to materialize the firms' *tâtonnement* process to discover the market clearing price in an ever-changing economy.

Given these behaviors, prices (and wages) 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 supply and demand at the aggregate level. However, the pricing rule of the firms is state-dependent: the more unstable the aggregate price dynamics, the stronger and quicker the price adjustments so as to guarantee more adaptability in more volatile environments. 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 levels of other firms. Large firms tend to be wage makers and adjust their wages 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). Indeed, a firm only goes to the labor market in periods when a contract has to be renewed or the workforce has to be increased. Hence, 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 decides to decrease its labor demand. We note that such a design implies some degree of nominal wage stickiness.

2.2.4. Determinants of investment decisions

Each firm determines whether, and how many machines to invest in, by following a several-step decision process. In the model, each firm has a targeted level of equity (which is equivalent to a leverage target, denoted by $\ell^T_{j,t}$) and decides to invest if, and *only if*, its actual amount of equities is above that target. Hence, the first step is to check whether the amount of entrepreneurial equity does not limit the expansion of the firms (Kalecki, 2010). If this is not the case, the firm will consider investing.

In a second step, the firm is constrained by a *limitation on its debt-service-to-profit ratio*, and computes its corresponding maximum credit capacity or, equivalently, the maximum amount of its investment expenditures, given its leverage target, cash-on-hand and current indebtedness. The firm then randomly samples other firms in the goods market to estimate the price of the generic goods and the corresponding price of a machine. Given its credit constraint and the estimated investment costs, the firm then computes the maximum number of machines that it can invest in.

In a third step, for each possible investment size, the firm compares the expected cash flow with the costs of the investment by using the net present value (NPV) analysis. The expected cash flow integrates the sales objective of the firm, real interest rates and profitability considerations. The sales objective of the firm is determined 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. The higher the greediness factor, the higher the sales expansion objective, and the larger the potential investment. The expected cash flow of each investment also involves a discount factor, taken to be equal to the risk-free interest rate set by the central bank discounted by average past inflation, and the firm's current price and wage levels. The firm eventually chooses the investment size (i.e. the number of machines) that returns 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.[6] 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.

[6]See Seppecher, Salle and Lang (2017) for a detailed explanation of this procedure and analysis of the resulting microeconomic behaviors.

This procedure simply ensures that the cash-on-hand of the firm can never constrain 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. The firms then roughly stay in line with their leverage target throughout the lifetime of the machines.

This leverage target $\ell_{j,t}^T$, together with its maximum credit allowance, dictates the amount of each firm's indebtedness, and therefore its investment behavior. In the model, the leverage targets of the firms evolve through an evolutionary algorithm, whose selection pressure is directly rooted in the market competition: a "bad" strategy would lead the firm to insolvency (i.e. negative profits would exhaust its equity), and hence to bankruptcy. In this case, the bankrupted firm abandons its leverage target and copies a new one from another, surviving firm, as surviving the market competition is a clear indication of the fitness of a leverage strategy. 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, which is another clear sign that the leverage strategy was unfit. 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' leverage strategies, and can be interpreted as control errors, exploration 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. We follow the endogenous money route and assume that *aggregate* credit supply is not limited *per se*, unless (i) the borrowers are not considered credit-worthy by the bank, or (ii) the private agents are not willing to borrow.[7] What ultimately constrains the aggregate credit supply, and hence the credit demand, is monetary policy, through the influence of changes in interest rates on the credit conditions (see McLeay et al., 2014 for an enlightening description of those mechanisms).

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*: the debt service (including interest rate payments and principal repayments on ongoing short and long-run loans) 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

[7] This feature distinguishes our model from most related ABMs in which capital adequacy ratios or exogenous rules constrain the supply of credit, see e.g. Van der Hoog and Dawid (forthcoming); Popoyan et al. (2017), see also Dosi et al. (2015) and the references therein. We believe that our assumption is more consistent with an aggregate banking sector and the focus on interest-rate policy rules. It is also consistent with the results obtained by Teglio et al. (2012) stating the primary role of the credit demand in driving the money stock. Implementing such a credit supply restriction (simulations available upon request) does not alter our results. The reason is that this constraint binds only in deep busts, along which firms are banned from investing given their indebtedness, or are not willing to do so in light of their sales prospects.

endogenous risk-premia into the model, as the classification of the firms into one of those categories endogenously evolves as the result of changes in their leverage targets, their economic decisions and the overall market competition.

2.3.2. Capital adequacy ratio

Following the recent developments in the macroprudential framework induced by Basel II and III, the bank in our model 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. Note that the capital adequacy ratio does not constraint the supply of credit, as previously discussed. 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.[8] Hence, our baseline scenario includes a liquidity-related macroprudential tool that ensures a capital buffer to the bank, as well as a credit-related microprudential tool that restricts the access to credit of leveraged firms.

2.3.3. Foreclosure and firms' bankruptcy

In the event where a firm j has insufficient cash-flow to pay off a loan in due terms, it receives an overdraft facility at a higher interest rate $i_{j,t} + rp$, where the penalty rp is assumed to be the same for all firms. In case of insolvency, the firm goes bankrupt and the bank starts a foreclosure procedure: the bank first erases the amount of debt so as to make assets and liabilities coincide, and then recapitalizes at least partially the firm with the available cash-on-hand of households, who then become the new owners of the firm.[9] If the capital of the bank is not enough to absorb the canceled debt 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

[8] 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-.

[9] This procedure has been vastly simplified with respect to the one used in Seppecher, Salle and Lang (2017).

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.

2.4. 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 ϕ_π, ϕ_y, ϕ_f the reaction coefficients to, respectively, inflation π_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 π^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 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 and Michell, 2017). This is a core mechanism of financial instability hypothesis as exposed by Minsky (1986).

2.5. The households

In the labor market, each household supplies one unit of labor, subject to his reservation wage. His reservation wage remains equal to his current wage as long as 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 up 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.[10] 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.

3. Numerical results from the baseline scenario

3.1. Parameter values

All the parameters of the model are listed in Appendix AppendixA, and Appendix AppendixB gives how they intervene into the agents' behavioral rules. Most parameter values are taken from Seppecher, Salle and Lang (2017), where empirical values or reasonable orders of magnitude are used whenever they are available. If not, we have performed unilateral sensitivity analyses of the model to the parameter values, the results of which we briefly discuss hereafter. In Section 3.2, we proceed 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

[10]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.

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 β 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 and 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 η_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 allowing for the eventual recovery (see Seppecher and 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). 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. Furthermore, the model includes elements of stickiness in the production process: the maximum adjustment of the labor demand reaches 10% in each period (parameter ν_F). We further consider adaptive expectations with a memory of 12 periods.

The households build a buffer equivalent to $\kappa_S = 20\%$ of their average past income. If their available cash-on-hand exceeds this level, they consume no more than half of this surplus in each period ($\mu_H = 0.5$). This precautionary saving behavior is intuitive given the absence of insurance scheme such as unemployment benefits in the model. We set the size of the market exploration to $g = 10$ for both markets, which corresponds to radically decentralized interactions given the number of firms (400) and households (6000). The risk premium parameter Δ 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 ratio of 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, and systematically discard a 1000 period burn-in phase.

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). We also perform such an exercise and show that the baseline scenario of our ABM is able to account for various macro and microeconomic empirical regularities. Note that this is an improvement upon our previous work (Seppecher, Salle and Lang, 2017), where such an exercise was left out of the study.

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

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

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

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. We also report the velocity of money as the ratio of nominal GDP (summed over 12 periods, i.e. a year) to the money stock (i.e. the sum of liabilities of the bank over 12 periods).[11]

A closer look at the macroeconomic simulated data uncovers the main emergent property of the model: 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)

[11]Interestingly, the velocity of money is rather stable on average in our model, and the price level moves, at least partly, as a response to changes in the quantity of money in the economy, independently from the exact specification of the monetary policy rule, in line with the monetarist view. However, movements in the velocity at higher frequencies reveal a strongly counter-cyclical pattern, which is a realistic feature in light of recession episodes over the last 30 years. Furthermore, the quantity of money and its velocity are negatively related in our model, which tends to validate the Keynesian view. All these results are available upon request, but a systematic study of the velocity, in light of the theoretical terms of the debate, is beyond the scope of this paper.

persistent and irregular fluctuations in real variables, including GDP (Figure 2a) or the rate of capacity utilization (Figure 2b).

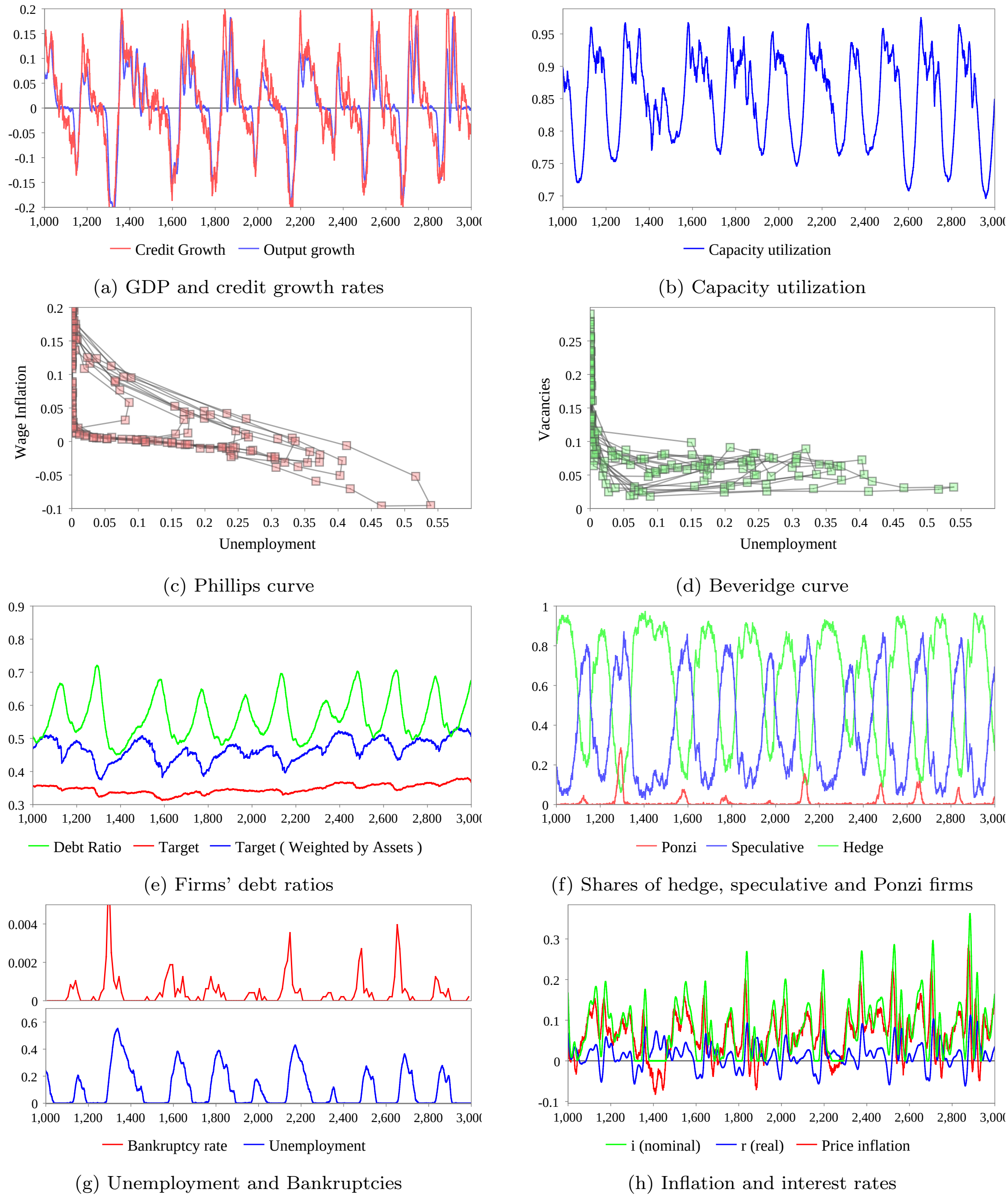
Our model is also able to produce ii) a downward-sloping Phillips curve (Figure 2c); and iii) a downward-sloping Beveridge curve (Figure 2d). As also striking from Figure 2a, iv) GDP growth rates are highly correlated with credit growth (or equivalently with firms' debt), which also corresponds to swings in the leverage behaviors of firms (Figure 2e) and their resulting financial positions (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.[12] Time series display v) considerable persistence, both in GDP (Figure 4a) and in inflation (Figure 4b). A Dickey-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 (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.[13]

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). 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 co-movement between GDP and unemployment is a consequence of our relatively flexible labor market, especially with work contracts of

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

[13] 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) Firms' debt ratios

(f) Shares of hedge, speculative and Ponzi firms

(g) Unemployment and Bankruptcies

(h) Inflation and interest rates

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

fixed duration only.

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 as, in turn, firms build up debt in periods of output expansion. This is further confirmed by xiv) the pro-cyclical and lagging nature of the

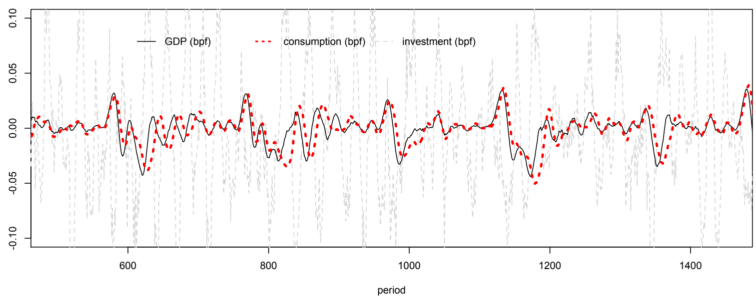
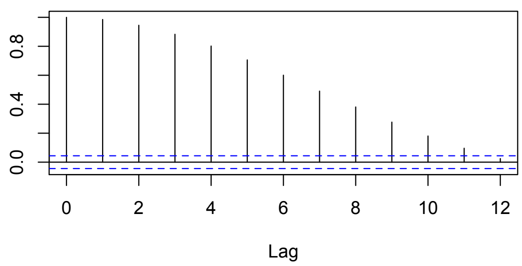


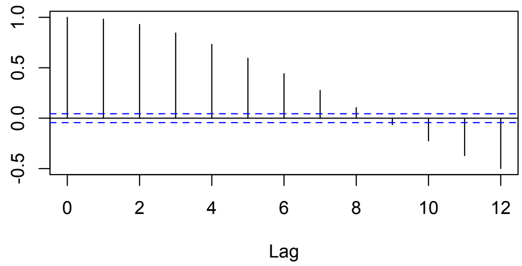
Figure 3: Cyclical co-movements of GDP, consumption and investment, baseline scenario, $t = 1000, ..., 3000$

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 and Di Guilmi, 2011). We further discuss this mechanism below (see in particular Figure 6d).

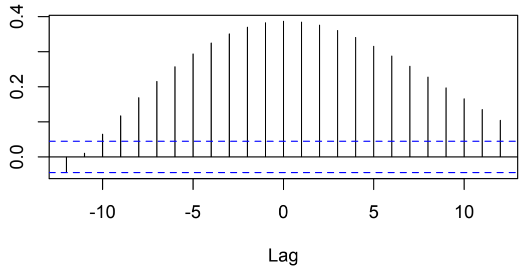
At the industry level, in the absence of technical progress (recall that, in our model, productivity is time-invariant), the number of stylized facts that we can seek to replicate with our model is limited. Yet, we can take a look at the cross-sectional distributions of some firms' characteristics at 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 each case). Figure 5a indicates that the cross-sectional distribution of firms' sizes (measured either by sales, assets or, as displayed, by production capacities) exhibits instead skewness and fat tails. We shall recall that all firms are initially endowed with the same number of machines, so that the heterogeneity in their sizes is an emerging property of the model resulting from their individual 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



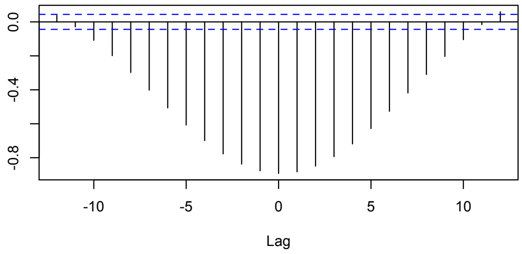
(a) Auto-correlation of GDP



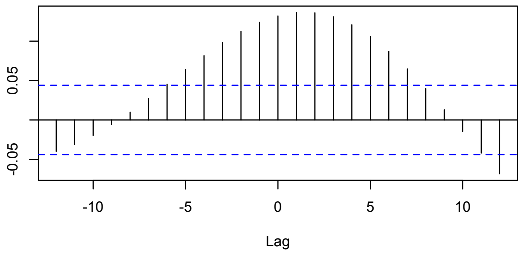
(b) Auto-correlation of inflation



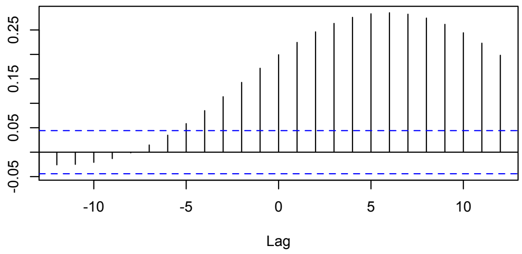
(c) Cross-correlation between consumption and GDP.



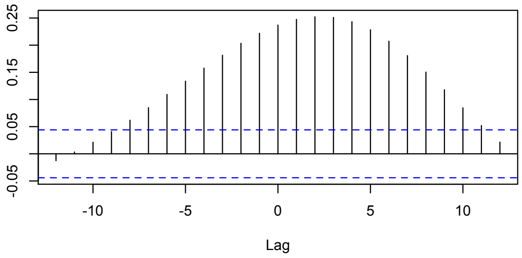
(d) Cross-correlation between unemployment and GDP.



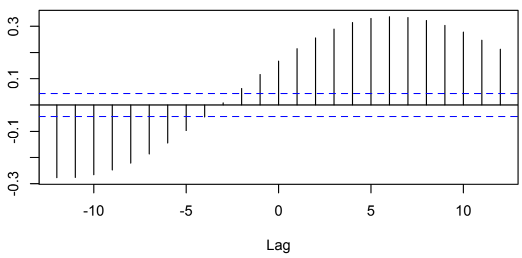
(e) Cross-correlation between inflation and GDP.



(f) Cross-correlation between credit and GDP.



(g) Cross-correlation between bankrupcties and GDP.



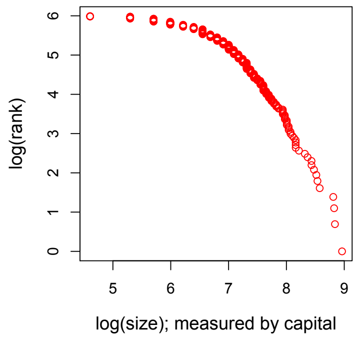
(h) Cross-correlation between doubtful debt and GDP.

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.

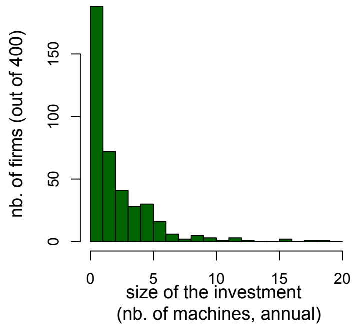
model (see the discussion and references in Dosi et al., 2010).

3.3. A closer look at the dynamics

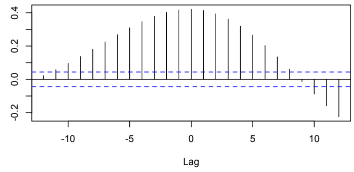
The credit cycles described in Seppecher, Salle and Lang (2017) remain the main emerging property of our model despite the prudential tools that we have introduced here, namely the risk-weighted capital requirement imposed to the bank, and the cap on the debt service imposed to the firms, next to the state-dependent individual risk



(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

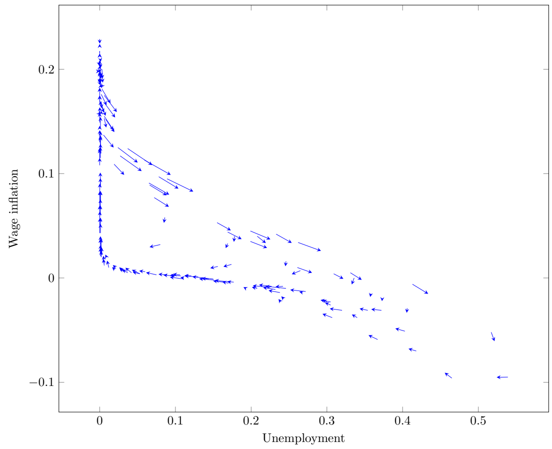
premia. This is as such an interesting outcome: simple restrictions may not be sufficient to completely eliminate those credit cycles and the abrupt recessive episodes that follow the sudden deleveraging phases.

To shed some additional light on those fluctuations, Figure 6 uncovers the cyclical relationships between real and financial variables in the model by the use of vector fields. 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 show the qualitative resemblance among all successive cycles in a simulation. Yet, the depth of the different crises differs and, interestingly, (xix) the model is able to generate both mild and deep downturns. (xx) Crises are also irregular: from Figure 2a, the time span between two crises varies from 160 (between $t = 2350$ and $t = 2510$) to 280 periods (between $t = 1340$ and $t = 1620$). Moreover, notice that the longest gap between two crises follows the deepest crisis (the one between $t = 1150$ and $t = 1340$). This observation is fully in line with a Minskian reading of the cycles in the model: the strongest the downturn, the longer it takes for the agents to "forget the crisis" and take risks again. This risk-taking behavior is governed by the imitation process of the leverage targets during waves of bankruptcies: from Figure 2g, the more the blue curve increases, the more firms "forget" the effects of the previous crisis and increase their leverage again. Those properties of the cycles constitute realistic features that standard DSGE macro models cannot account for, unless fed with exogenous shocks of various amplitudes (see, *inter alia*, Stiglitz, 2011 for a critic of DSGE models in that respect). In our ABM, these are emergent properties of the model.

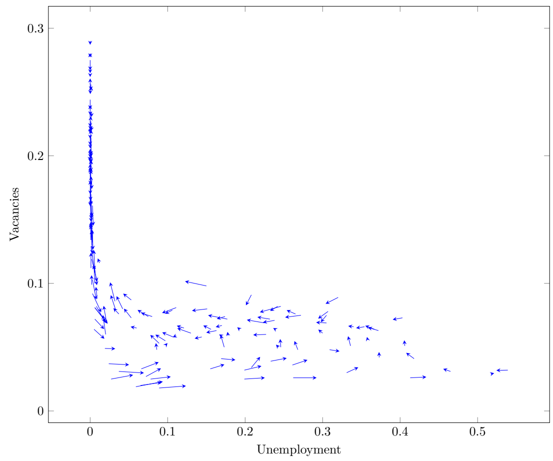
Turning to a more detailed analysis, Figures 6a and 6b give the dynamics along the Phillips and the Beveridge curves. Interestingly, the directions of rotation are the same as found in empirical data. xxi) The Beverdige curve rotates in an anti-clockwise manner, and wages rise slower when approaching full-employment than they fall along a bust (to be compared to Figures 1 and 3 in Daly and 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.[14] By contrast, xxii) the Phillips curve follows a clockwise motion, which is consistent with our assumption of backward-looking expectations of firms and the nominal wage rigidity implied by the fixed-term contracts along upturns (see Tobin, 1980 and the discussion and 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 variables 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,

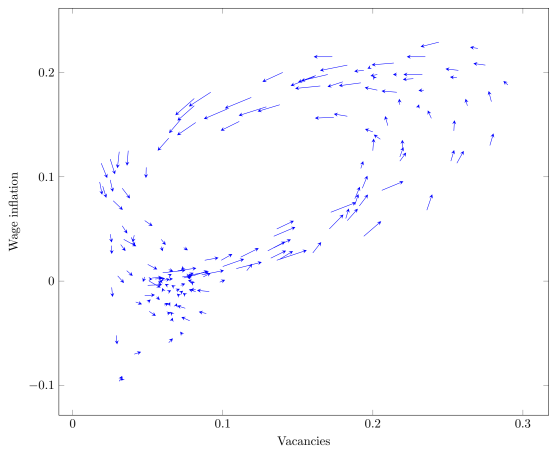
[14] A more elaborate version of the reservation wage updating process allows to circumvent this feature, but without changing any of our qualitative conclusions. We therefore decided to keep this simpler version in the present study.



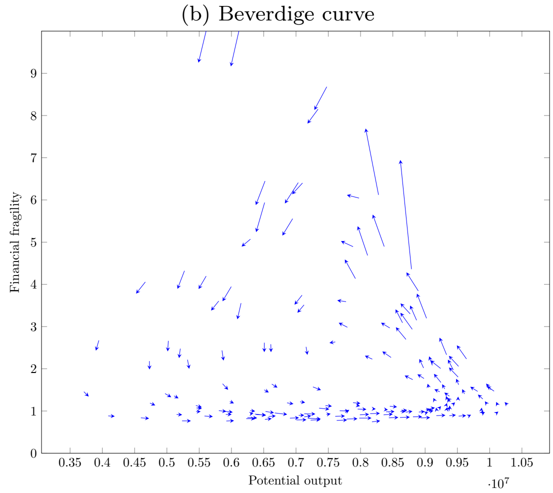
(a) Phillips curve



(b) Beverdige curve



(c) Wage curve



(d) Stockhammer and Michell (2017) curve

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

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 and Krugman, 2012 on that matter, and Ashraf et al., 2017 in an ABM).

Finally, Figure 6d reports the curve used in Stockhammer and Michell (2017) 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. Interestingly, this observation confirms 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 drives the most fragile units out-of-business.

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 which, 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 to aggregate demand – operating both through the counter-cyclical monetary policy and the inflating risk premia applied to increasingly risky firms. 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. An epidemic of bankruptcies along with a strong rise in unemployment and deflationary forces follow, and a Fischerian debt-deflation sets in: firms attempt to deleverage but the burden of their debt increases as prices fall. In our model, as mentioned in Section 3.1, the relative wage flexibility in comparison to prices interrupts the downturn (see also Seppecher and Salle, 2015), firms gradually adopt riskier financial behaviors again, and the cycles start all over again.

Along this chain of events, the interconnection between the real and the monetary sides of the economy, and the dynamics of adaptation of financial behaviors are necessary to the emergence and reproduction of the cycles. This does not imply that disequilibria on the labor market and supply factors are irrelevant to the observed dynamics. For instance, the life-cycle of the capital goods is certainly related to the length of the cycles. However, labor-related, real processes alone would not be sufficient to the emergence of the cyclical patterns.

4. Comparative study of alternative leaning-against-the-wind monetary policy rules

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. (2017) use credit growth, Da Silva and Lima (2016) the credit-to-GDP ratio. Borio and 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 and Di Guilmi (2017) consider the share of Ponzi firms in the economy. Cúrdia and 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 light of the lack of consensual suggestions, we use our model as a policy simulator, and successively consider a wide range of possible indicators of financial fragility (variable $\mathcal{F}_t$), and the corresponding design of the monetary policy rule (reaction coefficient ϕ_f). The scenarios are summarized in Table 2. The values of ϕ_f for which we perform a systematic analysis come from prior trial-and-error explorations of the model's behavior. 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 (while 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). This indicator is related to the degree of aggregate leverage in the economy. The bottom of Figure 2g indicates that the value of this credit 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 this "corridor" or normal-time value. Another way for the central bank to track a credit indicator is to adjust interest rates in reaction to the overall credit growth in the economy. This scenario corresponds to *creditGrowth* in Table 2.

In the third 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 related scenario *changeNetWorth*, the central bank reacts to the changes in the net worth of the firms. 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 discussion).

A fifth scenario, referred to as *spread*, includes in the Taylor rule 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:

$$\tilde{i}_t - i_t \equiv \kappa_{H,t} i_t + \kappa_{S,t} i_t (1 + \Delta) + \kappa_{P,t} i_t (1 + 2\Delta) - i_t \tag{2}$$

with $\kappa_{H,t}, \kappa_{S,t}$ and $\kappa_{P,t}$ the share of (respectively) hedge, speculative and Ponzi firms, as displayed in Figure 2f and i_t the risk-free interest rate. This scenario is equivalent to

Scenario	$\mathcal{F}_t$	ϕ_f
fragility	$\left(\frac{D_t}{\Pi_t} - 2\right)$	0.01
creditGrowth	$\log D_t - \log D_{t-12}$	1
	(yearly growth rate)	2
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

reacting 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 spreads.

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 and Dawid, forthcoming for a similar effort to quantify recessions). The first indicator is the *number of crises*, 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 frictional unemployment, a 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. Another indicator is the *breadth* of the crisis that we compute using the number of unemployed households throughout the crisis divided by the number of households in the economy. In intuitive terms, the breadth of a crisis corresponds to the area under the unemployment curve during a crisis episode. This gives the average number of months of unemployment per household along a 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, as emphasized in the previous section.

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 financial stress during a crisis episode. As credit pro-cyclicality is the main channel through which financial instability affects economic dynamics, we build an indicator of this dimension to discuss the performances of different monetary policy rules: in each simulation, we measure the cumulative value of the cross-correlation coefficients between the detrended series of credit and GDP over ± 12 lags.[15] This indicator is refereed to as *credit cyclicality* in the next section. Finally, in line with the objective of macroeconomic stabilization of central banks, we use the *standard deviations of output growth, inflation and the nominal interest rate* as indicators of macroeconomic volatility.

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 leaning-against-the-wind policy) and in the monetary policy scenarios under consideration. Data are reported for all crises pooled together from all scenarios, identified as explained in Section 4.2. The strong and significant positive correlation between the maximum of financial fragility

[15] We are grateful to a reviewer for this suggestion.

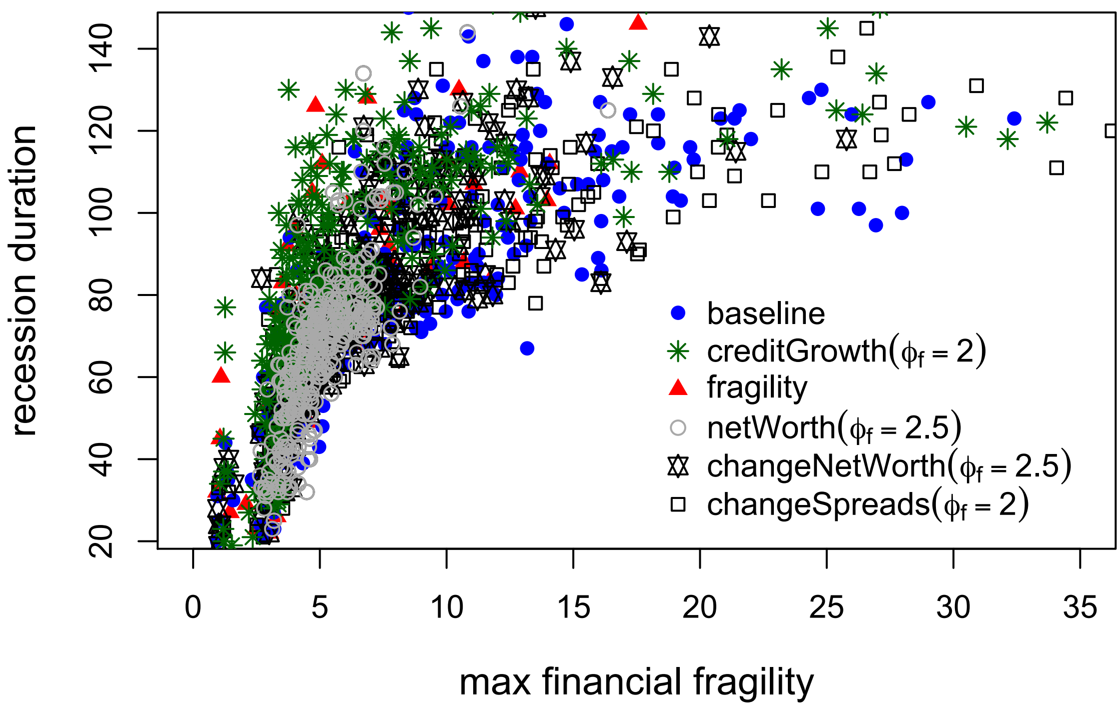


Figure 7: Recession duration against the maximum recorded financial fragility

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 economy.[16] The longest and deepest 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 augmented Taylor rules succeeds in completely breaking this correlation and fully eradicating the employment costs of financial crises once they arise.

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 beyond which further deterioration of the firms' balance sheets does not create significant

[16]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. We do not show them here to avoid redundancy.

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 crisis 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, in our model, the bankruptcy of the whole financial system, aggregated within a bank, causes the simulations to stop. 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. It is nevertheless premature to conclude that reacting to financial risks does not come at the expense of the other objectives of monetary policy. In Section 5 below, we take a closer look at this issue, and shed light on the existing conflicts between the central bank's mandates.

Turning to the policy scenarios, the first scenario, namely *fragility*, clearly delivers the worse performances: more than half of the simulations experience a bankruptcy of the banking system, 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). As a consequence, under this scenario, the rise in interest rates as a response to financial stress hits too late, and worsens the recession. We conclude that the ratio between firms' total debt and their net profits is a poor indicator of growing financial imbalances for the central bank, because it does not contain any early signal of upcoming financial turmoils.

One may be tempted to attribute the bad performances of the *fragility* scenario to the absence of bailout mechanisms during the frequently recorded bankruptcies of the single bank. One may suggest that such a mechanism could give a better chance to that scenario as there could be a trade-off between crisis and post-crisis economic performances. We have conducted additional simulations, results of which are available upon request, where we implement such a bail-out mechanism operating through haircuts on deposits once the bank's capital drops below the required level. While the system can survive more crises and more simulations can complete, the recessions observed in this scenario are the deepest and correspond to the worst economic situation observed in the model. Still, occasionally, a banking crisis is unavoidable, and the simulation stops. This is because the bankruptcy of the bank is not the cause of the systemic crisis, it is its ultimate expression. We conclude that a tradeoff between crisis and post-crisis employment does not materialize in our model. A policy rule that is not able to systematically avoid those extreme events is not desirable. In our model, a banking crisis constitutes a situation that the central bank should try to prevent first and foremost. Hence, the concern of the central bank should be to find a policy rule that is able to steer the economy away from those explosive dynamics at the first place.

Reacting to the credit growth (i.e. scenario *creditGrowth*) achieves significantly better outcomes than under the scenario *fragility*, but the stabilization power of the central bank does not improve significantly compared to the baseline scenario. Increasing the coefficient of reaction to the credit growth rate allows less deep recessions and a weaker credit procyclicality than under the baseline scenario but this comes at the price of longer recessions. The reasons for the disappointing performances of the credit growth indicator are twofold: credit growth is highly correlated with GDP growth that is already contained in the Taylor rule, and credit is not leading GDP strongly enough (see Figure 4f). As a consequence, this additional objective in the Taylor rule is partly redundant, without conveying informative content about upcoming financial imbalances.

Scenario	Nb. of recessions	Duration	Depth	Breadth	Max. Financial fragility	Nb. of bankrupcies	sd. GDP growth	sd. inflation	sd. nom. int. rate	Credit cyclicality	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)	9.54 (0.74)	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)	8.49** (0.79)	18
creditGrowth ($\phi_f = 1$)	9.79 (0.9)	95.6** (11.5)	0.31 (0.03)	22.1 (5)	18.4 (11.3)	12.4 (4.5)	0.012 (0.001)	0.051 (0.007)	0.01** (0.000)	8.17*** (0.72)	1
creditGrowth ($\phi_f = 2$)	9.9 (0.79)	94.5** (9.5)	0.29** (0.02)	20.5 (3.4)	43.5 (115.7)	10.9 (3.2)	0.012 (0.000)	0.047 (0.003)	0.011 (0.000)	7.67*** (0.82)	1
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)	8.15*** (0.58)	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)	7.54*** (0.7)	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)	9.38* (0.8)	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)	9.02*** (0.79)	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)	9.46 (1.06)	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)	9.4 (0.92)	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)	9.52 (0.73)	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)	9.54 (0.64)	2

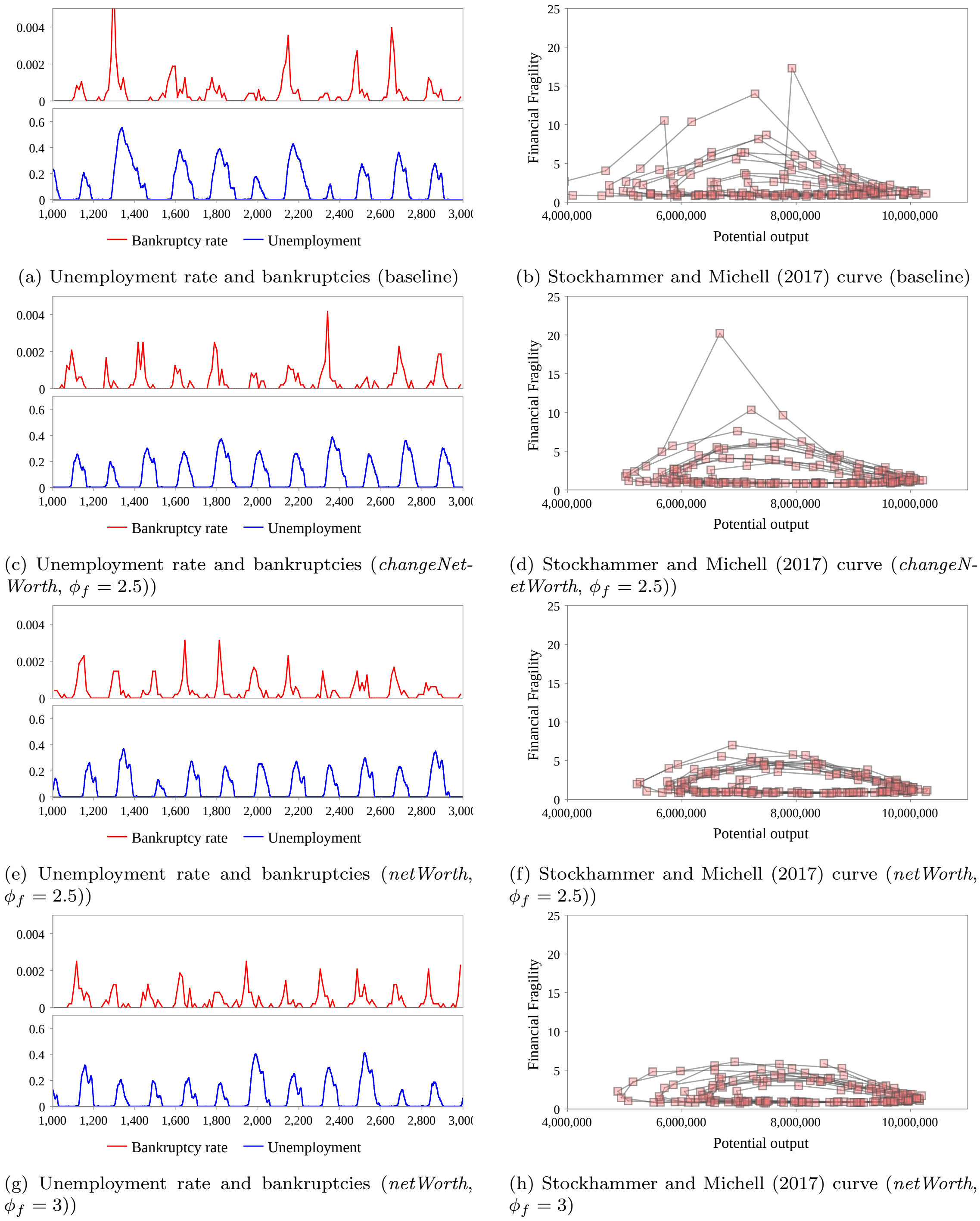
Table 3: Comparative statistics over the monetary policy scenarios, average over 30 replications (standard deviation between brackets)

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 ϕ_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 with GDP, which makes their *ex-ante* information content limited, just like in the case of the *creditGrowth* scenario. As GDP, inflation and spreads co-move, monetary policy is equally constraint by the zero-lower bound when reacting to the spreads as 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 and Di Guilmi (2017): adjusting interest rates to the share of Ponzi firms does not break down the pro-cyclicality of the credit bubble, and the ensuing develerage crisis and debt deflation. We have highlighted here the underlying reasons for such a failure thanks to a full macroeconomic closure.

The most striking improvements upon the baseline scenario 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 credit cyclicality and macroeconomic volatility measured by GDP growth and interest rate volatility – note that the volatility of inflation is higher but the difference is not significant. Importantly in light of the above discussion, in scenarios *netWorth* and *changeNetWorth*, like in the baseline scenario, no systemic crisis is observed in any of the 30 replications.

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 case). It is particularly revealing to look at the indicator of cyclicality of credit. The weakest cyclicality



(a) Unemployment rate and bankruptcies (baseline)

(b) Stockhammer and Michell (2017) curve (baseline)

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

(d) Stockhammer and Michell (2017) curve (*changeNetWorth*, $\phi_f = 2.5$))

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

(f) Stockhammer and Michell (2017) curve (*netWorth*, $\phi_f = 2.5$))

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

(h) Stockhammer and Michell (2017) curve (*netWorth*, $\phi_f = 3$))

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

across all scenarios under study is observed in scenario *netWorth* with $\phi_f = 2.5$. This finding clearly shows that this monetary policy rule has a stabilizing impact on credit bubbles, while fully eradicating bankruptcies of the banking system.

The level of unemployment recorded along recessions remains quite high though, even in this scenario. Eliminating extreme values of financial fragility does help reduce bankruptcies but does not completely eliminate the costs of financial crises. In intuitive terms, 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 ϕ_f do not seem to improve stabilization performances (compare Figures 8g-8h).

In order to explain the good performances of the scenarios *netWorth* and *changeNetWorth*, recall that they prescribe to monitor the balance sheets of the private sector 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 and 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). To the best of our knowledge, our paper is the first to design and propose such a policy rule that formalizes those intuitions.

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, slightly limit GDP volatility and rule out the possibility of banking crises. In the remaining of the analysis, we shall then focus on the scenario *netWorth* in comparison with the baseline simulations.

5. Policies and stabilization: some additional experiments

We shed further light on the potential tradeoffs that can arise between the different mandates of the central bank, in particular between low inflation and financial stability (see, for instance, the discussion in Howitt, 2012). We materialize those potential tradeoffs with “magic squares”. On these figures, each angle measures how the central bank performs with respect to one objective in a given simulation. The closer each dimension to its target, the closer the figure to a perfect square, and the milder the tradeoff between those objectives. Deformations of the squares illustrate the tradeoffs that the central bank faces. We use four objectives: inflation, unemployment, the maximum of the financial fragility index and the procyclicity of credit, as explained in Section 4.2. In the sequel, the leaning-against-the-wind policy refers to the best identified policy scenario in the previous section, namely scenario *netWorth* with $\phi_f = 2.5$.

5.1. Inflation and financial stability: a tradeoff?

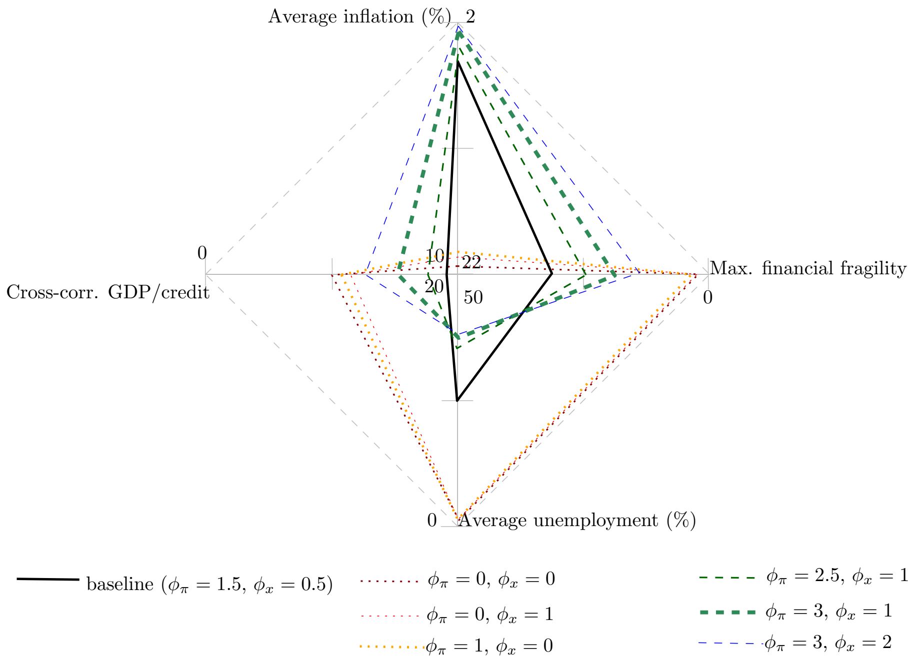
Figure 9 compares a simulation of the baseline scenario (Figure 9a) with one from the leaning-against-the-wind policy (Figure 9b) when the reaction coefficients to inflation ϕ_π and to output growth ϕ_x vary.

Under a simple Taylor rule, Figure 9a reveals a first striking feature. There is a clear tipping point at $\phi_\pi = 1$. As long as $\phi_\pi \leq 1$, i.e. the central bank reacts less than one-to-one to an increase in inflation, the simulated economy is stuck in an hyperinflation regime with near-zero unemployment. This confirms the effectiveness of monetary policy in our model: when $\phi_\pi \leq 1$, the *real* interest rate decreases as a reaction to a rise in inflation, which further feeds investment, and inflation. In our model, powerful wage-price spirals are at play once full employment is reached, which explains the spiraling up of prices, even in the absence of the expectations channel, that would with no doubt reinforce this mechanism.

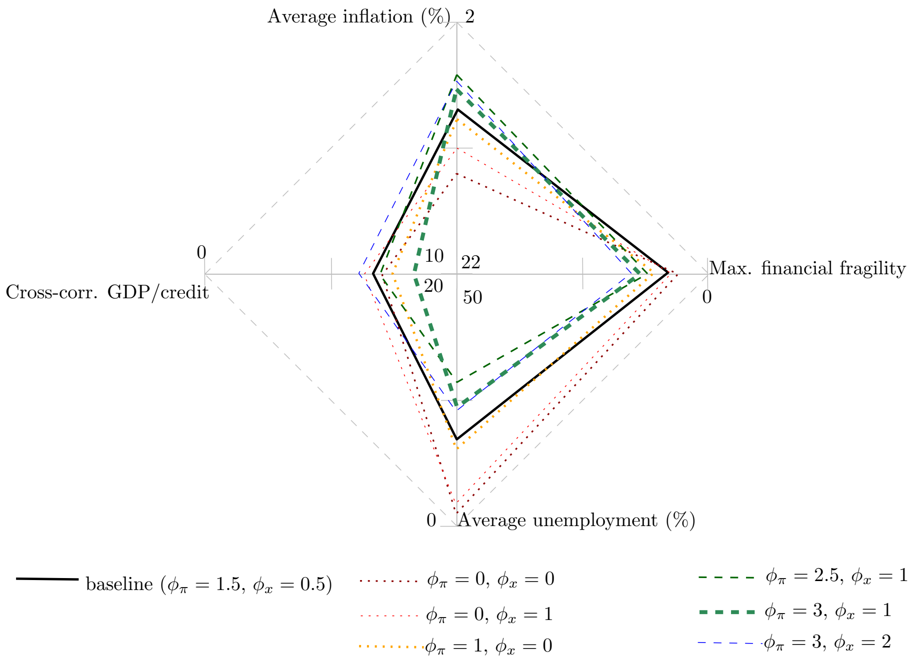
On the contrary, when $\phi_\pi > 1$, the real interest rates increase as a reaction to inflation, and the central bank obtains a much better grip on inflation. Hence, the "Taylor principle" also operates in our model, as widely established in formal macro model (see e.g. Bullard and Mitra, 2002). We do not wish to push the comparison between the two setups much further tough, as they are fundamentally different. What is interesting is that the resulting counter-cyclical real interest rates, while they help calm down inflation, generate in turn credit cycles, along which financial fragility increases during booms, and unemployment peaks along busts. This observation stresses the proximity between our analysis and the extensive description of business cycles in Minsky (1986): in both cases, what causes the sudden stop along a boom is the rise in the real interest rate that penalizes the productive units (firms), starting by the most fragile ones. Therefore, there is a tradeoff between the control of inflation and financial stability in our model. This is the reason why a tighter control of inflation through the interest rate setting rule comes at the price of higher unemployment, as clear from Figure 9a. This observation is fully consistent with the presence of a downward-sloping Phillips curve in the model, and the primary role of debt-deflation dynamics along which inflation is negatively related to unemployment.

Furthermore, the stronger the reaction of the CB (i.e. the stronger ϕ_π, but also ϕ_x), the lower inflation and the better the credit control. To see this, note that the squares become wider along three out of four dimensions (i.e. expect unemployment, on the bottom of the figures) when the reaction coefficients increase.

Figure 9b shows that the tradeoff of the central bank is attenuated if the central bank also leans against the wind by monitoring the networth of firms. To remark this, note that the shapes of the squares are less sensitive to the specific values of ϕ_π and ϕ_x than in Figure 9a. When $\phi_\pi = 0$, the leaning-against-the-wind reaction adjusts nonetheless real interest rates to some extent to inflation. In this case, low unemployment is achieved at the price of a lower inflation than with a simple Taylor rule, but the corresponding inflation rate is still above target. Similarly, higher reaction coefficients allow the central bank to better control inflation, but the marginal benefit of stronger reactions is much lower than in the baseline scenario. Overall, unemployment is lower, financial fragility is lower but inflation is higher under a leaning-against-the-wind policy. Which rule should be adopted depends on the preferences of the central bank.



(a) Baseline scenario ($\phi_f = 0$).



(b) *netWorth* scenario, $\phi_f = 2.5$.

Figure 9: Illustration of the trade-off between monetary policy objectives for various monetary policy rules.

Note: the indicators are measured in each simulation over $t = 1000, ..., 3000$. A perfect square would mean that all objectives are simultaneously achieves. Deformations w.r.t. a perfect square illustrates conflicting objectives.

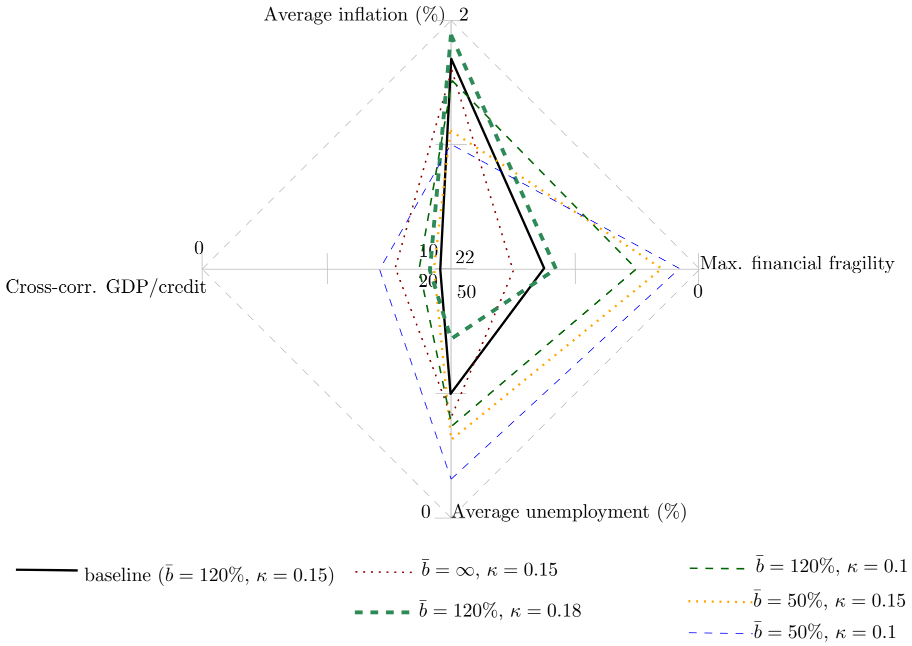
5.2. Monetary policy and prudential regulation

We now vary the cap on the debt-service-to-income ratio $\bar{b}$ and the capital requirement of the bank κ, for a given monetary policy rule, namely $\phi_\pi = 1.5$, $\phi_x = 0.5$ and $\phi_f = 0$ or 2.5. Figure 10 compares the performances of the central bank for various financial regulation arrangements in the baseline scenario (Figure 10a) and in the leaning-against-the-wind scenario (Figure 10b).

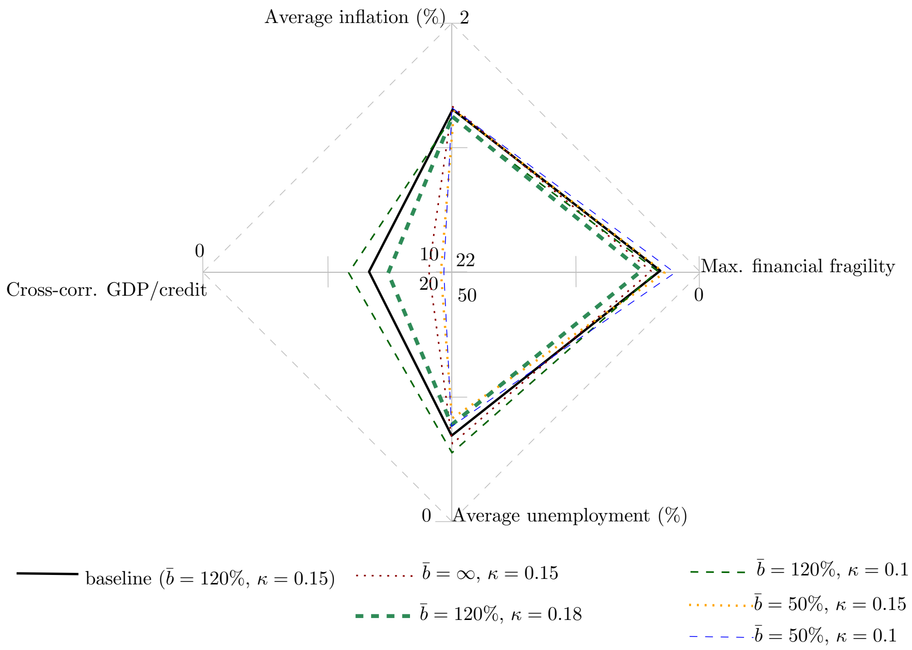
Under the baseline scenario, i.e. under a simple Taylor rule, those prudential parameters have a strong influence on the dynamics, especially on the tradeoff between inflation and unemployment. Increasing the equity to risk-weighted assets ratio allows for a better control of inflation, but at the price of higher unemployment and fragility. This result echoes the one in, *inter alia*, Cincotti et al. (2012) and Van der Hoog and Dawid (forthcoming), and the frequent criticisms addressed to the framework of Basel II: capital adequacy ratios being procyclical, they are counterproductive at stabilizing financial dynamics. Lowering κ produces the opposite effect on unemployment, without much impact on financial stability. Without surprise, removing the cap $\bar{b}$ creates more financial instability. By contrast, tightening this parameter is the most effective tool to promote financial stability, which in turn fosters employment, but this comes at the cost of higher inflation rates.

We note that the central bank can achieve similar results to the one with the leaning-against-the-wind rule with a simple Taylor rule if it jointly tightens credit conditions by lowering the cap on the debt service to income ratio and relaxes capital requirement – to see this, remark the similarity between the baseline scenario in 9b and the dashed blue line in 10a).

If the central bank is already leaning-against-the-wind (see Figure 10b), the effects just discussed persist but are much milder than under a simple Taylor. It seems that the performances of the augmented Taylor rule are rather robust across different specifications of the regulatory framework. To see that, notice that all squares are similar on Figure 10b, by contrast to the variability displayed on Figure 10a. This points towards two comments. First, the leaning-against-the-wind policy is probably partly redundant with



(a) Baseline scenario ($\phi_f = 0$).



(b) *netWorth* scenario, $\phi_f = 2.5$.

Figure 10: Illustration of the effects of prudential regulations. ($\bar{b} = \infty$ means that the cap has been suppressed).

the prudential rules, which could explain the lack of variability of performances across the different scenarios considered. Second, this robustness is undoubtedly a strength of this leaning-against-the-wind policy, because the performances of this policy are rather independent from the empirically-relevant issues of coordination between monetary and prudential policies, and the exact design of the appropriate credit regulation.

6. Elements for conclusion

This paper conducts a comparison of the stabilizing power of a wide range of monetary policy rules to lean against the wind in a complex economy, featuring a Minskyan leverage engine and a Keynesian aggregate demand loop, which give rise to credit cycles followed by debt-deflation 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 first observation tends to suggest that micro- or macroprudential policies *alone* may not be sufficient to fully eliminate financial crises.

The central bank can achieve significant stabilizing benefits with a triple mandate Taylor rule that is augmented by a reaction to the developments of 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*. A fine-tuned prudential framework that restricts in particular the debt service-to-income ratio can achieve similar performances with a simple Taylor rule.

Those conclusions should be discussed along several 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. In the case of the firms' networth, this may be feasible as firms are required to deposit their annual accounts with the central bank once a year. Firms filling bankruptcy throughout the year may provide information at a higher frequency to estimate an aggregate index of the firms' networth. This discussion 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, at least to some extent, so that rules-based policy-making inevitably involves some fine-tuning, which raises the question of the robustness of such policies to model misspecifications. In that respect, the performances of the leaning-against-the-wind policy are more robust to the exact parameter values of the rule and the design of the prudential framework than the ones obtained with a simple, dual-mandate Taylor rule. Thirdly, 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 may not be a panacea, even if augmented with reactions to financial instability or accompanied by prudential regulations. In particular, there seem to be conflicting objectives between the different mandates of the central bank, especially between the level of inflation on the one hand, and the stabilization of credit cycle along with the mitigation of occasionally large employment costs on the other. We believe that this result deserves to be further studied.

Finally, on a more general note, this paper adopts a "minimal model" approach: we present a model that contains the minimal ingredients in order to produce the dynamics and address the research questions in which we are interested. The single-bank design provides us with the considerable advantage of being able to focus on the interplay between the real economy and the banking sector in a way that is fully independent from the inner structure of the banking sector. Admittedly, the resulting framework is somewhat rudimentary – even though it is already more sophisticated than most standard macro frameworks that have been developed to think about the links between financial instability and monetary policy. However, we believe that simplicity can be a virtue, not necessarily a shortcoming, and that a stylized framework is a natural starting point for testing simple policy rules. Indeed, we take the view that implementing policies in a simple framework is a necessary (but clearly not sufficient) test of their effectiveness. It is intuitive to think that if a policy does not work in the simplest model that can be elaborated to think about the dynamics under study, it casts some doubt on how it could potentially work in a more complicated model, not to mention the admittedly much more complex real world.

Along this line of thought, our study brings up an important message. Even within this stylized environment, the instability of the economy seems somehow inherent to the functioning of the complex economy that we have modeled. If central banking is to be conceived as piloting the economy away from those “dark corners”, simple systematic rules do not appear to be always sufficient to the task. Following our reasoning, this observation casts some doubts about how simple rules-based policies could do a better job in the much more complex real-world economy. A natural extension would be to model a third policy dimension, namely the role of government through fiscal intervention in the aftermath of financial crises, besides the Taylor rule and the prudential rules that only act *ex ante* on the behaviors of the agents. This intention is left for future research.

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AppendixA. Parameter values

Parameter	Description	Baseline value
Households		
h	number	6,000
d^r	wage resistance	12 (months)
η_H	wage adjustment parameter	0.05
g	size of the market selection (same for firms)	10
$window$	memory (same for firms)	12 (months)
κ_S	targeted savings rate	0.2 (share)
μ_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)
β	greediness in investment	1.2
δ^P	price flexibility parameter	0.04
δ^W	wage flexibility parameter	0.02
ν_F	production flexibility parameter	0.1
μ_F	proportion of goods to be sold	0.5
κ_d	maximum share of equity to be distribute as dividends	0.2
σ_ℓ	size of individual leverage innovations	0.01
Bank		
κ_b^T	capital adequacy ratio	0.15
b	cap on the debt service ratio	120%
Δ	risk premium parameter	0.1
rp	additional penalty on doubtful debt	0.04 (monthly rate)
ω_H	asset risk weight for hedge debtors	50%
ω_S	asset risk weight for speculative debtors	100%
ω_P	asset risk weight for ponzi debtors	150%
ϕ_π	reaction to inflation (Taylor rule)	1.5
ϕ_y	reaction to output growth (Taylor rule)	0.5
π^T	inflation target	0.02/12 (monthly)
Model		
d^S	length of the simulations	3,000 (months)

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

AppendixB. 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:**

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

   where π_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 from 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 RWA_t as a weighted average of all debts of the firms, where each hedge firm receives a weight ω_H, each speculative firm a weight ω_S, and each Ponzi firm a weight ω_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:**

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

$$\text{else if } (s_{j,t-1} < s^T_{j,t-1} \text{ and } in_{j,t} > in^T_{j,t}) \quad \begin{cases} \overline{P}_{j,t} = P_{j,t-1} \\ \underline{P}_{j,t} = \underline{P}_{j,t-1}(1-\delta^P) \\ P_{j,t} \hookrightarrow \mathcal{U}(\underline{P}_{j,t}, \overline{P}_{j,t}) \end{cases} \tag{B.2}$$

$$\text{else} \quad \begin{cases} \overline{P}_{j,t} = \overline{P}_{j,t-1}(1+\delta^P) \\ \underline{P}_{j,t} = \underline{P}_{j,t-1}(1-\delta^P) \\ P_{t,j} = P_{j,t-1} \end{cases}$$

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:

$$\begin{cases} W_{j,t} = W_{k,t} \\ \overline{W}_{j,t} = W_{j,t}(1+\delta^W) \\ \underline{W}_{j,t} = W_{j,t}(1-\delta^W) \end{cases} \tag{B.3}$$

else:

$$\text{if } (\rho_{j,t-1} > 0) \quad \begin{cases} \overline{W}_{j,t} = \overline{W}_{j,t-1}(1+\delta^W) \\ \underline{W}_{j,t} = W_{j,t-1} \end{cases}$$

$$\text{else} \quad \begin{cases} \overline{W}_{j,t} = W_{j,t-1} \\ \underline{W}_{j,t} = \underline{W}_{j,t-1}(1-\delta^W) \end{cases} \tag{B.4}$$

$$\text{and then} \quad W_{j,t} \hookrightarrow \mathcal{U}(\underline{W}_{j,t}, \overline{W}_{j,t})$$

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 $k_{j,t}$):

$$n^T_{j,t} = (1+\delta^h_{j,t})n^T_{j,t-1} \tag{B.5}$$

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:

$$\delta^h_{j,t} = \begin{cases} \alpha_{j,t}\nu_F & \text{if } 0 \leq \alpha_{j,t}\beta_{j,t} < \frac{in^T_{j,t} - in_{j,t}}{in^T_{j,t}}, \\ -\alpha_{j,t}\nu_F & \text{if } 0 \leq \alpha_{j,t}\beta_{j,t} < \frac{in_{j,t} - in^T_{j,t}}{in^T_{j,t}}, \\ 0 & \text{else.} \end{cases} \tag{B.6}$$

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

$$\begin{cases} \text{if } n_{j,t} > n^T_{j,t} & \text{fires } n_{j,t} - n^T_{j,t} \text{ (on a last-hired-first-fired basis)} \\ \text{else} & \text{posts } n^T_{j,t} - n_{j,t} \text{ job offers.} \end{cases} \tag{B.7}$$

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 $(unemploymentDuration_{i,t} < d^r)$:

$$W^r_{i,t} = W^r_{i,t-1} \tag{B.8}$$

     – else :

$$W^r_{i,t} = W^r_{i,t-1}(1 - \eta_H \cdot \alpha_{i,t}) \tag{B.9}$$

     where $\alpha_{i,t}$ is $\mathcal{U}(0,1)$, and $\eta_H > 0$ and $d^r \geq 0$ are parameters.
   - Else:

$$W^r_{i,t} = W_{i,t-1} \tag{B.10}$$

     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 $W_{j,t} \geq W^r_{i,t}$, 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 $s^T_{j,t}$ goods in the goods market:

$$s^T_{j,t} = \mu_F \cdot in_{j,t} \tag{B.11}$$

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

14. **Investment decision (whether or not to invest):**
Each firm j considers whether or not to invest:
   (a) if $k_{j,t} = 0$, buys $m_{j,t} = 1$ new machine, for a value $I_{m_{j,t}}$ (computed as in Step 14.c below);
   (b) else, if and only if ($E^T_{j,t} > E_{j,t}$ 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 $\max\left(0, \frac{debtService_{j,t}}{grossProfits_{j,t}} - \bar{b}\right)$.
   (c) Only if its maximum credit capacity > 0, the firm will invest. If this is the case, the firm computes its maximum investment $\bar{m}_{j,t}$:
      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. selects a random sample of g suppliers (other firms) to estimate the average price of the goods (costs of the investment);
      iv. computes the maximum number of machines $\bar{m}_{j,t}$ that the firm can afford for $I_{\bar{m}}$.

15. **Investment decision (how many machines to invest in):** If, and only if, $\bar{m}_{j,t} > 0$, the firm chooses how many machines $m_{j,t} \in \{0, ..., \bar{m}_{j,t}\}$ to invest in:
   (a) computes $\tilde{s}_{j,t}$, average of the sales s_j over the past *window* periods;
   (b) computes $s^e_{j,t} = \beta \cdot \tilde{s}_{j,t}$, its sales expansion objective;
   (c) given its sales expansion objective $s^e_{j,t}$, the expected lifetime of a machine d^k, its current price $P_{j,t}$, its 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 $m_{j,t} = 0, 1, .., \bar{m_{j,t}}$:

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

   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.
   (d) chooses the project $m_{j,t}$ with the highest NPV, and adds $\frac{I_{m_{j,t}}}{m_{j,t}}$ per new machine to its assets.

16. **Financing of fixed assets:** If the firm has invested (i.e. $m_{j,t} > 0$ in Step 15):
    (a) borrows (amortized long-run loan) the amount: $\ell^T_{j,t} I_{m_{j,t}}$;
    (b) borrows (amortized short-run loan) the amount: $\max((1 - \ell^T_{j,t}) I_{m_{j,t}} - M_{j,t}, 0)$;
17. **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:

$$C^T_{i,t} = \begin{cases} (1 - \kappa_S)\tilde{Y}_{i,t} & \text{if } M_{i,t} \leq M^T_{i,t} \\ \tilde{Y}_{i,t} + \mu_H (M_{i,t} - M^T_{i,t}) & \text{else.} \end{cases} \tag{B.12}$$

    The budget constraint always gives $C_{i,t} \leq \min(C^T_{i,t}, M_{i,t})$.
18. **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;
19. **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 from an overdraft facility, i.e. a new short-term loan at an higher rate including the risk premium of the bank ($i_{j,t} + rp$).
20. **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 $\ell^T_{j,t+1} = \ell^T_{k,t}$ on a randomly drawn firm k, among all the operating firms in the same sector, independently from their relative profit levels.
    (c) The firm j updates $E^T_{j,t}$ on the base of its new $\ell^T_{j,t+1}$. 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).
21. **Next period**. Unless the bank has become insolvent (i.e. bank insolvency), this process starts all over again for d^S periods.

AppendixC. 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 C.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 C.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 C.7: Flows

Change in the stock of	**Households**	**Firms**	**Banks**	$\boldsymbol{\Sigma}$
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
Σ (Δ Net worth)	$+WB - S + I - AF$	0	0	$+WB - S + I - AF$

Table C.8: Full-integration matrix