Stock Market Dynamics, Leveraged Network-Based Financial Accelerator and Monetary Policy

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Abstract

In this paper we build on the agent based model of Riccetti et al. (2011), adding the presence of the stock market. The stock market values influence the distance-to-default (DD), used to evaluate firms' financial soundness and, thus, to set the interest rates charged by banks to them. The presence of the stock market enriches the positive feedback mechanism tied to the Financial Accelerator, that we now divide in three components: (i) **leverage accelerator** - negative shocks on firms' output make banks less willing to loan funds, hence firms might reduce their investment because of the credit constraint and this leads again to lower output; (ii) **stock market accelerator** - a firm, that has lower profit, has a decreasing capitalization on the stock market, thus the DD reduces and banks ask a higher interest rate, reducing firm's profit and amplifying the leverage financial accelerator; (iii) **network-based accelerator** - the presence of a credit network may produce a propagation of the initial shock and even an avalanche of bankruptcies. In this framework, we find that if the stock market impact becomes too relevant, its volatility could damage the real economy. Moreover, an increase of the stock market volatility is widely influent in worsening the performance of the real economy, because it enlarges the stock market financial accelerator. A very important implication for **monetary policy** is that when the policy rate decreases a short-run expansion of aggregate production follows, but it is partially counteracted by the increasing financial accelerator that enlarges aggregate production volatility and banks financial fragility. This counteracting effect is even stronger if the stock market volatility is affected by the interest rate level, as really happens. Central Banks should consider this effect when deciding monetary policy changes.

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1 Introduction

The current crisis is showing how the business cycle fluctuations can be enlarged by different kinds of self-reinforcing mechanisms. Riccetti et al. (2011) considers two financial accelerator: the "leverage" one and the "network-based" financial accelerator (Delli Gatti et al., 2010). Indeed, the leverage accelerator explains that a negative shocks on firms' output make banks less willing to loan funds, hence firms might reduce their investment and this leads again to lower output in a vicious circle. Moreover, the network-based financial accelerator highlights that the presence of a credit network may produce an avalanche of firms' bankruptcies: the bankruptcy of a firm may bring "bad debt" that affects the net worth of banks, which can also go bankrupt or, if they manage to survive, will react to the deterioration of their net worth increasing the interest rate to all their borrowers (Stiglitz and Greenwald, 2003, p.145), making them incur additional difficulties in servicing debt and thus increasing the weakness of the whole non-financial sector, in another vicious circle.
However, Bernanke and Gertler (1989, 1990) and Bernanke et al. (1999) shows the presence of another positive feedback mechanism, that we will call the "stock market" financial accelerator. Indeed, in this paper we build on the agent based model of Riccetti et al. (2011) adding the presence of the stock market, although in a stylized way. In practice, we set the firms' stock market value by using the earning-per-share (EPS) multiplier, consistent with the market custom founded on the Gordon (1959) model (according to the discounted cash flow theory). The stock market values influence the distance-to-default (DD), a measure of credit risk widely used by many banks and developed in the Moody's KMV Portfolio Manager model. We use a proxy of the DD, based on stock market return and return's variance, to evaluate firms' financial soundness and, thus, to set the interest rates charged by banks to them. Moreover, we add a risk aversion parameter able to increase or reduce the impact of the stock market volatility on firms' DD evaluation.
As, in Riccetti et al. (2011), the firms' financial structure relies upon the Dynamic Trade-Off theory (Flannery and Rangan, 2006), therefore we hypothesize that firms have a "target leverage". This theory implies that a growing firm will decide to increase its leverage level, thus creating in good periods the basis for the subsequent crisis. This model allows us to analyze:

- how a shock on the real side of the economy can be amplified, through a stock market multiplier, further increasing the financial accelerator mechanism and the overall fragility of the system. In other words, the interplay between forward-looking evaluation of firms' future profits provided by the stock market and the interest rate setting due to bank lending attitudes may lead to a boom-bust cycle;

- whether a shock on the financial market may be dangerous for the real economy. Indeed, we investigate the evolution of the economic environment when the stock market multiplier increases - considered as a symptom of a mounting financial market bubble - in order to ascertain if this results in a riskier systemic configuration;

- how banks' risk aversion can influence the economic environment;
- how the central bank can influence the economic cycle modifying the interest rate. Indeed, the interplay between interest rate and stock market evaluation can modify the effectiveness of monetary policy, compared to the case of stock market absence.

The paper is organized as follows: in the next Section we present the characteristics of our model. Then, firms' behaviour is analyzed in Section 3, while Section 4 considers the banking sector. Simulation results are presented in section 5. A sensitivity analysis on two important parameters regarding the stock market is developed in Section 6. In Section 7 we propose an extensions of the baseline model and a monetary policy experiment. Section 8 concludes.

2 Environment

Our economy is populated by households (final consumers and labor suppliers), firms and banks. Firms - indexed by $i = 1, 2, ..., I$ - produce consumption goods. Banks, indexed by $z = 1, 2, ..., Z$, extend credit to firms.

We consider three markets: consumption goods, stock and credit market. We will focus on the last market, making simplifying assumptions for the first and second ones. Moreover, we do not explicitly model the labor market[1].

On the market for consumption goods there are consumers and firms. Prices are exogenously determined: following Greenwald and Stiglitz (1993), we assume that on the market for consumption goods, prices are governed by a random process. We suppose that consumers buy all the output that firms produce at the stochastic price. Prices on good market have the important role of determining profits, which in turn affect the accumulation of net worth and financial fragility.

In the stock market we take firm prices determined by using the earning-per-share (EPS) multiplier. These values influence the evaluation of firms' financial soundness made by banks and, thus, influence the interest rates.

The credit market is the focus of the model, where firms and banks interact. The net worth of firms is the "engine" of fluctuations for the economy: we assume that the scale of production of firms is constrained only by their net worth, then it turns out to be the main driver of fluctuations. A shock to a firm affects the credit relationship between the firm and the bank: if the shock is large enough, the firm may be unable to fulfill debt commitments and

[1]The lack of this market does not change the theoretical framework compared to a model where the labor market is present, workers obtain a fixed slice of aggregate income and entrepreneurs set a mark-up on the labor cost.

may go bankrupt. In a networked economy, the bankruptcy of a firm may bring "bad debt" - i.e. non-performing loans - that affects the net worth of banks, which can also go bankrupt or, if they manage to survive, will react to the deterioration of their net worth increasing the interest rate to all their borrowers. Hence, borrowers may incur additional difficulties in servicing debt thus increasing the weakness of the whole non-financial sector and the number of bankruptcies itself (network-based financial accelerator).
The endogenous evolution of credit interlinkages affects the extent of bankruptcies' diffusion: the bankruptcy of a highly connected agent increases the probability of bankruptcy diffusion across the network. The structure of the network of credit relationships evolves endogenously because in every period each firm looks for the bank with the lowest interest rate.

3 Firms

Firms operates on all the three considered markets.

3.1 Goods market

On the market for consumption goods there are consumers and firms. Prices are determined following Greenwald and Stiglitz (1993): we suppose that consumers buy all the output that firms produce at the stochastic price. The output produced by firm i is Y_{it} and, following Delli Gatti et al. (2010), it is an increasing concave function of its net worth A_{it}. Indeed, we hypothesize that the production function (called "financially constrained output function", because β is less than 1) is:

$$Y_{i,t} = \phi K_{i,t}^{\beta} \tag{1}$$

where $\phi > 1$ and $0 < \beta < 1$ are parameters uniform across firms and K_{it} is the total capital of the i firm at time t, composed by net worth and debt. $Y_{i,t}$ is a function of $A_{i,t}$ given that, following the Dynamic Trade-Off theory for firms' capital structure, we hypothesize that the amount of debt $B_{i,t}$ is a function of the net worth too. According to the Dynamic Trade-off theory, firms have long-run leverage targets, but they do not immediately reach them, instead they adjust toward them during some periods.

The leverage level is set by firms by following an adaptive behavioral rule according to which the current leverage level is equal to the previous level modified by a random percentage increase (decrease) when the expected price pm is larger (smaller) than the interest rate on bank loans $r_{i,t}$:

$$Leverage_{i,t} = Leverage_{i,t-1}(1 \pm adj \cdot random) \tag{2}$$

where adj is a parameter that set the maximum leverage change between the two periods and is multiplied by a random number drawn by a uniform distribution between 0 and 1. The sign is + if $pm_{i,t} > r_{i,t}$ and it is - otherwise. Here pm is set adaptively, that is equal to the price

of the previous period. This level changes among firms and over time given the evolution of pmi, t and $r_{i,t}$. Moreover, the leverage level cannot be set below a 1% level.
We hypothesize that debt last for two periods: every period each firm asks for an amount of debt equal to the difference between the required debt

$$B^{*}_{i,t} = A_{i,t} Leverage_{i,t} \tag{3}$$

and the residual amount of debt $B_{i,t-1}$ made in the previous period (and that will expire in the following period):

$$B_{i,t} = max(B^{*}_{i,t} - B_{i,t-1}, 0) \tag{4}$$

thus:

$$K_{i,t} = A_{i,t} + B_{i,t} + B_{i,t-1} \tag{5}$$

If a firm suffers high losses that, reducing the net worth, make the debt target smaller than the previous debt, then the firm does not ask for new debt. In this way we address four problems. First, we consider that firms prefer multiperiodal debt. Second, it is possible for firms to have two banks to obtain credit (in practice big firms often have syndicated loans or multiple banks). Third, as implied by the Dynamic Tradeoff theory, firms that suffer high losses may present a real debt higher than that implied by the current target (because now the target is lower than the previous period debt); this rigidity may cause financial problems to firms. Fourth, we add another factor able to spread the financial instability in the network.

Firms' profit is given by:

$$Pr_{i,t} = p_{i,t} Y_{i,t} - Rb_{i,t} B_{i,t} - Rb_{i,t-1} B_{i,t-1} \tag{6}$$

where $Y_{i,t}$ is the output, $Rb_{i,t}$ is the interest rate paid on the last loan ($B_{i,t}$), $Rb_{i,t-1}$ is the interest rate paid on the previous period loan ($B_{i,t-1}$), and $p_{i,t}$ is the stochastic gain per unit of output, that contains the stochastic price net of the expenses for producing the output itself (but for financial costs). The rationale is the same explained in Delli Gatti et al. (2010): given the predetermined supply, the relative price is an increasing function of the demand disturbance. A high realization of $p_{i,t}$ can be thought of as a regime of high demand which drives up the relative price of the commodity in question. On the other hand in a regime of low demand, the realization of $p_{i,t}$ turns out to be low and may push the firm to the bankruptcy. In practice $p_{i,t}$ is composed by three parts:

$$p_{i,t} = \alpha + \frac{Div_{t-1} + fc \cdot A_{z,t-1} - A^{new}_{i,t} - A^{new}_{z,t}}{Y_{t-1}} + random_{i,t} \tag{7}$$

where

- α represents firms' expected mark-up;

- $(Div_{t-1} + fc \cdot A_{z,t-1} - A^{new}_{i,t} - A^{new}_{z,t})/Y_{t-1}$ is an aggregate demand component influenced by the business cycle. It increases the aggregate demand if the previous period aggregate dividends Div_{t-1} or costs paid by banks increases and it decreases the demand if agents go bankrupt because part of the total income has to be spent to replace the defaulted firms, $A^{new}_{i,t}$, and banks, $A^{new}_{z,t}$;

- $random_{i,t}$ is the firm specific random component. We assume that the random term is distributed as a Gaussian with zero mean and finite variance ($varp$).

Profits ($Pr_{i,t}$) are a key component of the model for two reasons. First, they determine firms' net worth $A_{i,t}$: $A_{i,t+1} = A_{i,t} + Pr_{i,t} - Div_{i,t}$, where only firms with net worth larger than 1 distribute a fraction div of positive profits as dividends $Div_{i,t}$. The firm goes bankrupt if $A_{i,t+1} < 0$, i.e. if it incurs a loss (negative profit) and the loss is big enough to deplete net worth: $Pr_{i,t} <= -A_{i,t}$; when a firm goes bankrupt, we hypothesize that a new firm enters in the market with a small random net worth. Second, profits determine the earning-per-share (EPS) used in the evaluation of the firms' market value in the stock market, that we will now analyse.

3.2 Stock market

We set the firms' stock market price as a long run value. Thus, we focus on the so-called fundamentalist investors (with a long investment horizon), avoiding chartist traders effects. Then, we use the earning-per-share (EPS) multiplier, that is the technique most used by the fundamentalists, and the accounting value, as representative value of all the other fundamentalist techniques. Indeed, for the sake of simplicity we have adopted a basic price mechanism, without a real modeling of the stock market[2] EPS multiplier practice is based on the discounted cash flow theory, as in the Gordon model, that is the most famous discounted dividend model: the price of an asset is determined by the expected dividend supposed to be generated for all the future history of the firm and discounted with the rate representative of the cost of capital., that is composed by the risk free rate plus a risk premium (often based on the capital asset pricing model). In this model the market value is set in the following way:

$$Amkt_{i,t} = 0.5 \cdot A_{i,t} + 0.5 \cdot \max(Pr_{i,t-1} \cdot moltp, 0) \tag{8}$$

where $moltp$ is the EPS multiplier[3]. The stock market values influence the evaluation of firms' financial soundness made by banks and, thus, influence the interest rates. We hypothesize

[2] We will relax these assumptions in further extensions of the present model, considering the criticism made in the field of behavioral finance and modeled by many agent based models, that shows that deviations from the "fair price" are common and caused simply, for instance, by the presence on the market of chartist traders or by herding behavior.

[3] We use the max function because the value of the profits can be enough negative to make the overall market value negative. This is a simplifying assumption, in fact, for example fundamental analysts put beside EPS multiplier other multipliers in order to prevent negative stock price forecast driven by negative profits.

that the stock market is not used for the initial public offering (IPO) or to issue/buy-back new securities, then it is just a secondary market. Thus, firms can finance themselves only by self-financing and by bank credit.

3.3 Credit market

In this market firms and banks interact. In every period each firm asks for a debt that lasts two periods as explained before. Initially, firm-bank links are set randomly. Afterwards, in every period each borrower observes the interest rates of a fraction BNK of randomly selected banks. We assume, as done in Delli Gatti et al. (2010), that the firm changes bank with a probability ps of switching to the new lender that is decreasing (in a non-linear way) with the difference between r_{old} (the previous bank's interest rate) and r_{new} (the interest rate set by the observed potential new bank). In symbols:

$$ps = 1 - e^{\lambda(r_{new} - r_{old})/r_{new}} \tag{9}$$

In this way, we model the sticky connection between a borrower and its banks, due to the (asymmetric) information on the firm owned by the banks. Parameter $\lambda > 0$ represents the propensity of switching from a bank to another: a higher λ depicts a higher propensity of switching from a bank to another, according to the best interest rate. In this way the structure of the network of credit relationships evolves endogenously due to a decentralized mechanism of interaction. Thus, prices on the credit market (that is, interest rates) have two important roles: (i) influence profits, which affect the accumulation of net worth and financial fragility, (ii) shape the evolving topology of the credit network. Indeed, banks characterized by more robust financial conditions can charge lower prices and therefore attract more new partners. As a consequence, their profits go up and their financial conditions improve, making room for even lower interest rates in the future and attracting more new partners. This self-reinforcing mechanism gives rise to an endogenous evolution of the credit network, that will be characterized by a right-skew distribution for node degree: there will be nodes characterized by a relatively high number of links ("hubs") and nodes with a small number of connections. Higher values of parameters λ or BNK increases the banking sector concentration. We calibrate the value of the parameter λ in order to obtain a banks' degree distribution similar to the real Japanese one at year 2000, thus we set $\lambda = 4$.
Moreover, we add a fixed commission equal to the 1% of the expiring debt if the firm changes bank, as a proxy of the information and administrative costs to change bank. In order to complete the description of the credit market, we need to explain how banks set the interest rate, then we now introduce banks.

4 Banks

4.1 Interest rate setting

As already seen, firms require credit from banks. Indeed, we hypothesize that the stock market is only a secondary market, thus firms can finance themselves only by self-financing and bank credit.
Moreover, each bank sets a different interest rate on loans and these differences imply that firms sometimes change banks to obtain a lower interest rate, following the mechanism explained in section 3.3. We hypothesize that bank z adopts the following rule in setting the interest rate on loans to borrower i:

$$Rbd_{i,t} = rCB_t + f1(A_{z,t} + D_{z,t}) + f2(DD_{i,t}, A_{i,t}) \tag{10}$$

Thus the interest rate is composed by three parts:

1. the policy rate set by the central bank: rCB_t;

2. a term that decreases with the financial soundness of the bank (proxied by the bank's leverage). Indeed, as already said, if the bank is in good shape from the financial point of view, it will be eager to extend credit at more favorable terms to increase its market share. We set this term as follows:

$$f1(A_{z,t}) = [\frac{(A_{z,t} + D_{z,t})}{A_{z,t}}]^{\gamma} - 1 \tag{11}$$

   where $D_{z,t}$ is the amount of deposits that bank z has at time t, calculated as the difference between extended credit and net worth;

3. a term that incorporates a risk premium increasing with borrower's Distance to Default ($DD_{i,t}$), that we will analyze hereafter, and decreasing for bigger firms. In this paper we proxy the DD with a function that reduces it if stock market asset value increases or if stock market volatility decreases. Thus, we set:

$$f2(DD_{i,t}, A_{i,t}) = \gamma \cdot \frac{(B_{i,t} + B_{i,t-1})}{[weight \cdot \frac{Amkt_{i,t}}{\sigma_{i,t}^{1/\psi}} + (1 - weight) \cdot A_{i,t}]} \cdot \frac{1}{(1 + \frac{A_{i,t}}{A_{i,t}^{max}})} \tag{12}$$

   The parameter $weight$ determines how strong is the stock market component in the firm evaluation (and it could be seen as a presence of a mark-to-market mechanism instead of a balance sheet evaluation), while σ is equal to 1 plus the standard deviation of the firm assets market value (calculated on the last TT periods; new firms have the standard deviation set at the highest value among the survival firms) divided by 100, and ψ is a risk propensity parameter: when ψ grows, banks are less risk averse, that is less afraid of market volatility, and reduces the interest rates. Last, $(1 + A_{i,t}/A_{i,t}^{max})$ is a correction to represent that bigger firms obtain lower interest rates (all the other component being equal).

The DD is a widely used market-based measure of corporate default risk. It was introduced in the Portfolio Manager model developed by the KMV society (KMV from the names of the founders: Kealhofer, McQuown and Vasicek) that was later acquired by Moody's. Banks widely use measures like the DD, because this is a simple way to introduce in the firm evaluation a forward looking analysis based on the market ability to incorporate firm prospects in the market price. Indeed, a firm with a high stock market capitalization should easily obtain credit from banks because of the alternative of financing on the stock market, issuing new equities to repay previous debts. This is then a sort of collateral-covenant.
Many authors find that the DD is an effective method to explain differences in credit spreads; for example Campbell and Taksler (2003) find that equity volatility of corresponding stocks explains as much variation in corporate credit spreads as credit ratings do or, in other words, that equity volatility affects loan ratings.
The DD is derived from the structural evaluation model of corporate debt introduced by Merton (1974) and it is based on the two following features: the higher the value of the firm net worth or the lower the volatility of the firm net worth, the further away from default the firm is. The framework is built on an accounting identity: the value of the firm, V, (or the value of its assets) should be equal to the sum of the values of its debt, B, and equity, Amkt. We use V instead of K, because V is a market based value, while K is a balance sheet value:

$$V_{i,t} = Amkt_{i,t} + B_{i,t} + B_{i,t-1}; \tag{13}$$

Because debt is senior to equity, equity holders are residual claimants on the firm: the firm's assets are first used to pay debt holders, and the left part is distributed to shareholders. Thus the value of equity is:

$$E_{i,t} = max(0, V_{i,t} - B_{i,t} - B_{i,t-1}) \tag{14}$$

The payoff to shareholders is equivalent to a call option on the value of the firm with a strike price equal to the face value of debt, also known as default barrier. This formula implies that the higher the value of the firm assets, $V_{i,t}$, relative to the strike price or default barrier, $B_{i,t} + B_{i,t-1}$, the farther away from default the firm is. In the case of the widely used Merton (1974) model, where it is assumed that the asset value of the firm follows a geometric Brownian motion process, the distance-to-default T periods ahead is given by:

$$DD_{i,t} = \frac{ln\frac{V_{i,t}}{B_{i,t}+B_{i,t-1}} + T(\mu_{i,t} - \frac{\sigma^2_{i,t}}{2})}{\sigma_{i,t}\sqrt{T}} \tag{15}$$

where $\mu_{i,t}$ and $\sigma_{i,t}$ are respectively the mean and the volatility of the growth rate of firm asset value $V_{i,t}$. As shown by equation 15, the DD increases when $V_{i,t}$ grows and when the volatility of asset value reduces. As already said, in this paper we compute the growth volatility using the value of $V_{i,t}$ of the last TT periods.

In this model we insert the stock market influence on banks only indirectly, through the distance-to-default mechanism. In fact, universal banks suffer from stock market volatility because they directly invest part of their capital in stocks (trading book). So our findings could be amplified by this channel, as we will investigate in an extended version of the model.

4.2 Banks profit and net worth

Banks' net worth $A_{i,t}$ evolves in the following way:

$$A_{z,t+1} = A_{z,t} + Pr_{z,t} \tag{16}$$

Where $Pr_{z,t}$ are bank z profit at time t, given by:

$$Pr_{z,t} = \sum Rb_{i,t}B_{i,t} + \sum Rb_{i,t-1}B_{i,t-1} - rCB_t \cdot D_{z,t} - fc \cdot A_{z,t} - bad_{z,t}; \tag{17}$$

where $Rb_{i,t}$ is the interest rate paid on $B_{i,t}$ (if firm i has not gone bankrupt), rCB_t is the Central Bank official interest rate, $D_{z,t}$ is the amount of z banks' deposits, fc is a fixed percentual cost paid by all banks depending on bank size (proxied by the net worth), and $bad_{z,t}$ is the z banks's bad debt. In particular, $bad_{z,t}$ is computed as the sum of all the credit lent to firms gone in default in period t, multiplied by the loss given default rate (LGDR), that is 1 less the recovery rate (RR); RR is computed as the ratio between the asset and the debt of the bankrupted firm and decreased by a fixed amount for the legal expenditure LE (that, in the baseline model, we hypothesize equal to 10% of the debt). In this way we insert both the two most important components of the credit risk models: the probability of default (PD) and the loss given default rate (LGDR).

5 Simulations

We analyze our economy by means of computer simulations. We assume that this economy is composed by 500 firms and 50 banks over a time span of 1000 periods. However, we use the first 200 periods to inizialize the simulation and we present and analyse the last 800 periods. At the beginning of the simulation, we set the net worth of each firm and bank to 10. We hypothesize that, when a firm or a bank goes bankrupt, it is replaced by a new one with net worth equal to a random number between 0 and 2 for firms and between 0 and 10 for banks. The parameter used are in Table 1.

We do not perform a validation exercise, given that we have sketched many characteristics of the economic system and we have neglected some others such as the labor market, even if we calibrate parameter values to reproduce some empirical regularities in the simulated data, as already found in Delli Gatti et al. (2010) or Riccetti et al. (2011). For example, even if all firms start from the same conditions, they become rapidly heterogeneous and a right-skew distribution of firms' size emerges. This feature also emerges for banks, which concurrently present a right-skew distribution of the number of borrower firms (the degree distribution of the credit network). Moreover, in Section 6 we will perform some sensitivity analysis, to show

Table 1: *Parameter setting.*

Parameter	Value	Meaning
ϕ	2	see production function eq.1
β	0.8	see production function eq.1
α	5%	expected mark-up, see eq.7
$varp$	0.1	profit variance, see eq.7
div	20%	percentage of profits distributed as dividends
$moltp$	20	EPS multiplier, see eq.8
adj	20%	maximum leverage change allowed to firms in a time period, see eq.2
rCB	2%	central bank monetary policy rate, see eq.10
γ	1%	risk premium parameter, see eq.11 and eq.12
$weight$	1	percentage of stock market component influence on the firm evaluation, see eq.12
ψ	5	risk propensity parameter, see eq.12
TT	5	number of periods to calculate the st. dev. of firm assets market value
fc	0.2	bank operational costs, see eq.17
BNK	20%	percentage of bank observed by each firm in every period
λ	4	propensity of switching from a bank to another, see eq.9
LE	10%	legal expenditure in case of firm bankruptcy, that increases the LGDR

some interesting features.

As already said, our model extends the analysis of Riccetti et al. (2011) by considering stock market dynamics. Now, the mechanism of the Network-based Financial Accelerator is threefold:

1. **leverage accelerator**. A firm that makes less (or negative) profit, lowers its growth (or its activity), reducing both the amount of internal funds and of external finance. Here we hypothesize that the firm asks less credit, but this characteristic could be theoretically coupled with the unavailability of banks to loan funds to a firm with smaller cash flow and smaller value of firm's collateral. Hence the firm reduces its investment, leading to a lower output, a lower profit, and yet again lower investment. In other word there is a leverage cycle that enlarge business fluctuations, as shown in the upper right plot of Fig.2: when net worth increases, leverage increases boosting the production (positive correlation on the left side of the cross-correlogram), but, after a short time positive effect, an increased leverage will take to growing instability that will revert the business cycle (negative correlation on the right side of the cross-correlogram);

2. **stock market accelerator**. A firm, that has lower profit, has a decreasing capitalization on the stock market; thus the distance to default reduces and banks ask a higher interest rate. The increased interest rate reduces the firm's profit, boosting the previous mechanism. Hence, the presence of the stock market amplifies the leverage financial accelerator mechanism, given that the interest rate is set following a profit multiplier.

Moreover, just a small reduction of profits can trigger this financial accelerator[4]. We study the ratio between stock market capitalization and balance sheet net worth (we call it capitalization ratio): when it grows, overall output level grows but after a while the output tends to decrease, because there is an increasing probability of trigger the explained mechanism. In this way we represent the possible creation of a bubble and the subsequent crisis. Indeed, the cross-correlation between the capitalization ratio and the number of bankruptcies shows that a bubble increases the probability of crises: the growth of this ratio is related with following firms and banks defaults rise, as shown in the bottom plots of Fig.1;

3. **network-based accelerator**. A firm could even not be able to pay its debt to banks and goes bankrupt. Its banks record a non performing loan that reduces their net worth. If banks are not financially robust, they could also go bankrupt. Instead, if the loan is relatively small compared to the banks' net worth, they survive the loss; however, even in this case, banks increase the interest rates to other borrowers to cover the loss; the increased interest rates reduce the firms' profits, starting again the leverage financial accelerator or, if other firms go bankrupt, enlarging the network-based mechanism. In both cases, with or without bank defaults, the initial shock spreads across the financial network, with the possibility to create an avalanche of bankruptcies, which amplifies business fluctuations. In our simulations, financial fragility creates quite strong bankruptcies avalanches with the number of defaulted banks in the same period that is in mean equal to the 0.45% of the overall banks number (that is 50), but it ranges from a minimum of 0 to a maximum of 8% of the banks in the economy; moreover, bankruptcies tend to cluster in subsequent periods; the distribution of bank defaults present positive skewness (2.69) and high kurtosis (11.86). However, this propagation could be dampened (or increased) considering the interbank market, that we want to introduce in further extensions of the present model. Banks defaults are triggered by bad debt (firm bankruptcies): correlation coefficient is statistically significant and equal to 54.5% (Fig.2 panel bottom-right). Analyzing the distribution of firm bankruptcies, we observe that they vary from a minimum of 4 (0.8% of overall firms) to a maximum of 28 (5.6%), with a mean of 12.78 and a positive skewness of 0.38.

The first mechanism, as already said, is the leverage financial accelerator; the second mechanism due to the presence of the stock market, that is the innovation of this paper, reinforces the first; the third is the accelerator due to the network.

[4]For example, a firm in year t has a total capital of 20, composed by 10 of net worth and 10 of debt ($K_{i,t} = A_{i,t} + B_{i,t}$), a profit of 3 and, with a multiplier of 20, a market capitalization of 35 ($0.5 \cdot 20 \cdot 3 + 0.5 \cdot 10$); the next year the firm makes again a positive profit of 2 and net worth increases to 12, but the market capitalization decreases from 35 to 26, with a -26% of return that reduces the distance to default and increase the interest rate that banks will charge on following credits: the firm starts to be weaker, even if it is still profitable.

Figure 1: *Cross-correlations between: (i) firms' leverage and firms' defaults; (ii) firms' leverage and banks' defaults; (iii) firms' capitalization ratio (e.g., market values over balance sheet value of firms) and firms' defaults; (iv) firms' capitalization ratio and banks' defaults.*

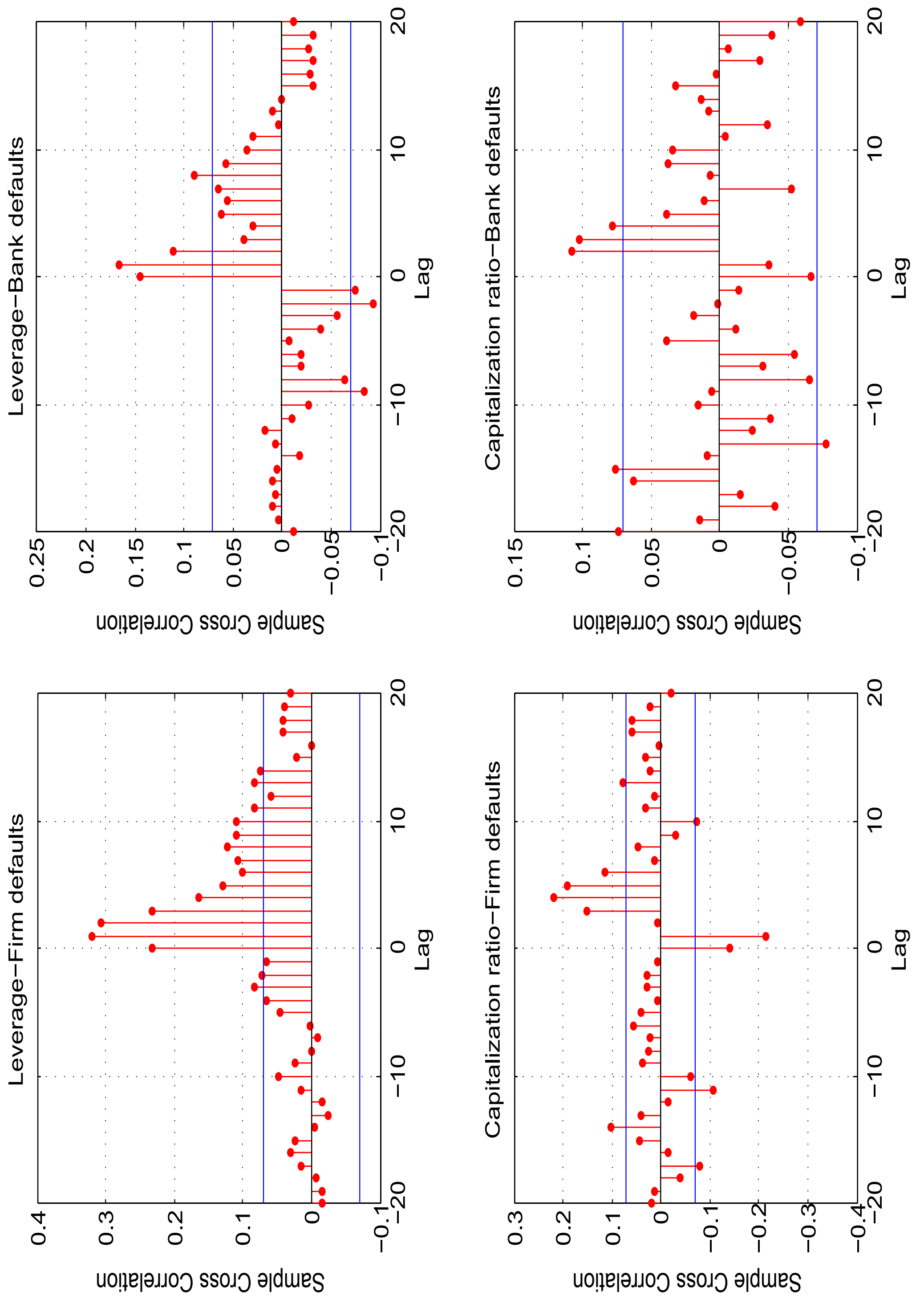
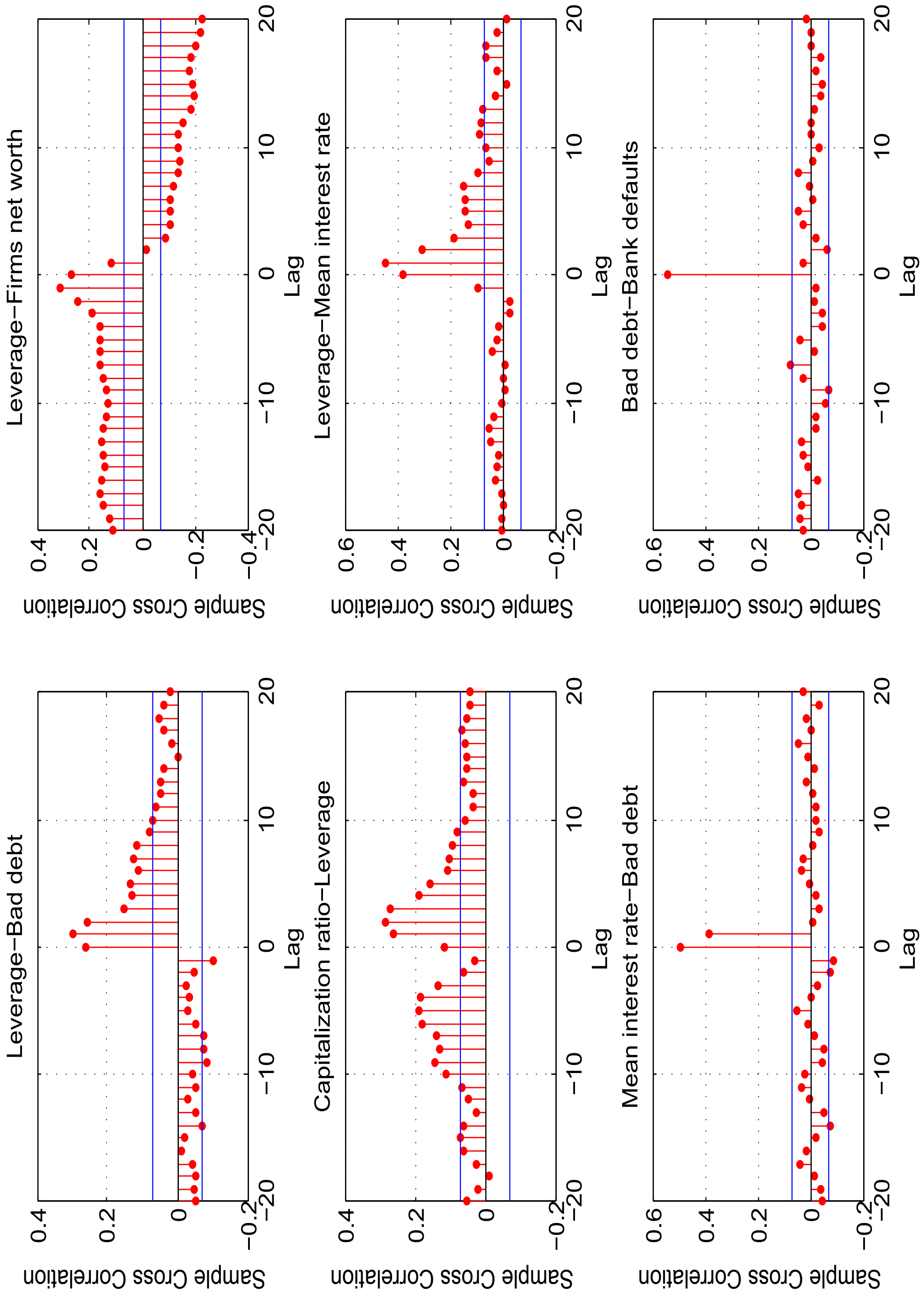


Figure 2: *Cross-correlations between: (i) firms' leverage and bad debt ratio (e.g., total bad debt over total credit); (ii) firms' leverage and firms' net worth; (iii) firms' capitalization ratio and firms' leverage; (iv) firms' leverage and mean interest rate; (v) mean interest rate and bad debt ratio; (vi) bad debt ratio and banks' defaults.*



The first two mechanisms are the trigger of the accelerator, the third makes possible that an idiosyncratic shock creates an extended/global crisis, without the need of a systemic shock. The instability due to the first two accelerators is shown in Figure 1: an increasing firms leverage or an increasing stock market bubble enlarges the number of subsequent firm and bank defaults. We can divide the overall causal sequence in many parts, following Figure 2. The leverage accelerator is described in the two upper plots, that show the already explained leverage cycle: when the economy is growing, that is the net worth increases and the bad debt reduces, firms increase their leverage (because of increased expected profits); the high leverage makes the cycle revert increasing bad debt and decreasing net worth. Indeed, if leverage grows, banks require a higher interest rate (center-right panel), that reduces firms gain and increases bankruptcies (bottom-left plot). Firms bankruptcies, through consequent bad debt, increase the number of bank defaults (bottom-right panel). The leverage cycle can be enlarged by the stock market (forward-looking) fluctuations: when the stock market capitalization increases, this reduces interest rates causing a higher leverage (center-left plot) and thus starting or boosting the leverage accelerator mechanism. In other word, the stock market seems to reinforce the leverage cycle.

Till now, we have presented a model with real shocks to firms, that, reducing profits, start the first two mechanism. Now, we can study:

- how the presence of the stock market in the firms'evaluation done by banks affects the output (parameter *weight*);
- how the stock market volatility affects the real performance of the economy (parameter *moltp*);

For the sensitivity analysis of most of the other parameters we refer to Riccetti et al. (2011). Moreover, in Section 7, we will analyse the influence of the stock market on the monetary policy effectiveness.

6 Sensitivity analysis

In this section we discuss the effects of parameters *weight* and *moltp* changes in terms of the following output variables: the mean aggregate production, the volatility of the aggregate production's growth rate, the average interest rate, the mean firms' leverage, the average aggregate firms net worth, the mean number of firms bankruptcies, the average value of bad debt ratio (the sum of all the debts of the defaulted firms in the period divided by the overall outstanding credit), the average number of bank defaults. These statistics are calculated, for each simulation, on the time series from period 301 to period 1000.

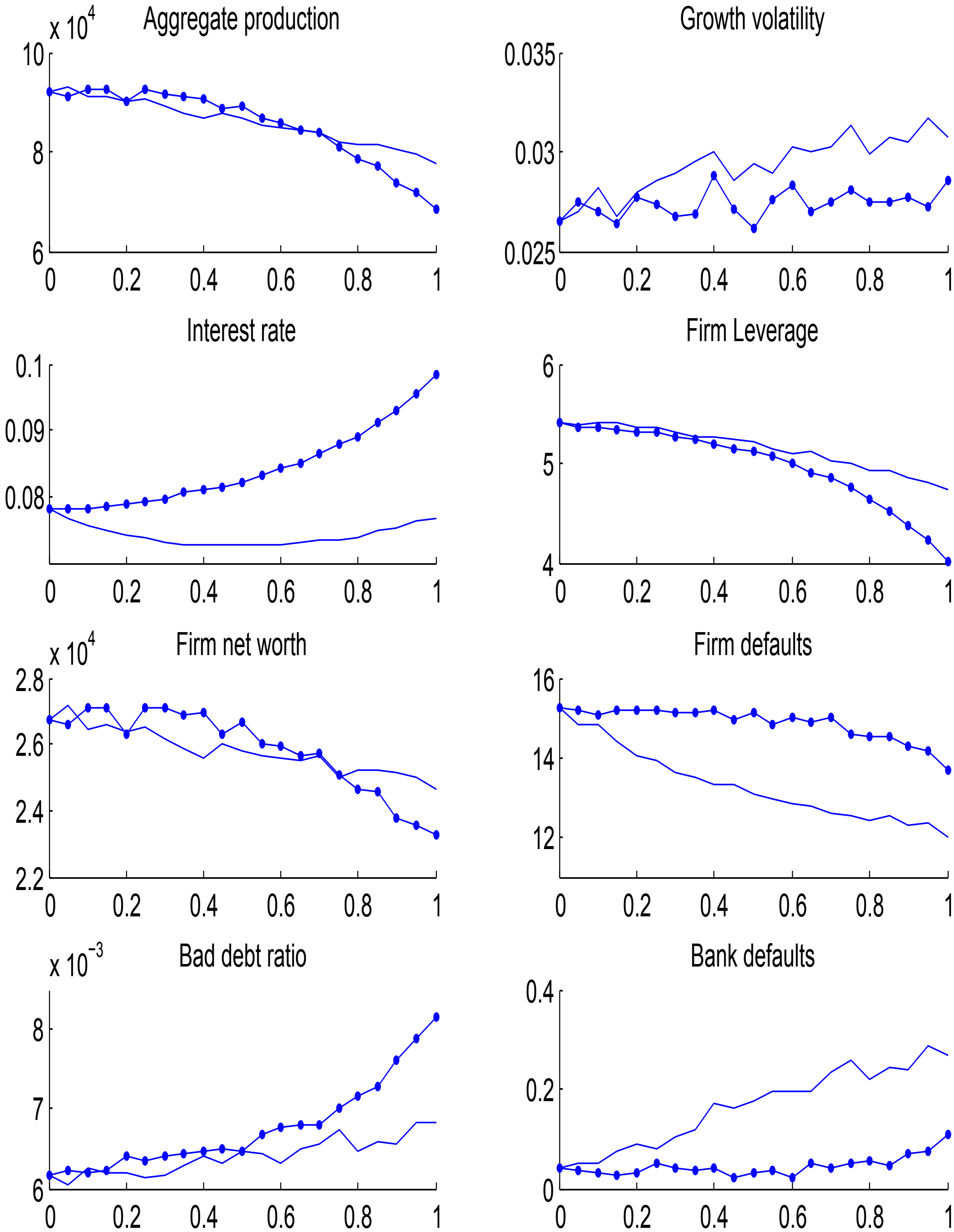
6.1 Parameter *weight*

Parameter *weight* determines the weight of the stock market component in the firm evaluation done by a bank in setting the interest rate. The same simulation is repeated for each value of *weight* between 0 and 1, with step 0.05. Moreover, we study how the risk aversion of banks modifies the output, comparing the sensitivity analyses for two different values of ψ (that is $\psi = 2$ and $\psi = 20$), keeping all the other parameters unchanged (see Table 1). Consider that the risk aversion propensity parameter can represent how confident banks are about the economic cycle and, thus, a lower risk propensity can be associated to a stronger credit constraint phase on credit market. Banks, in this model, can not directly invest in the stock market or in derivatives, thus a higher risk aversion does not reduce the investment in speculative assets, but only applies to the credit market.

As shown in Figure 3, when banks are very risk averse ($\psi = 2$), we find that: (i) the mean aggregate production reaches its maximum for low values of *weight*, that is it slightly increases when the stock market enters in the evaluation of the firm (*weight* equal to 10%-15%), but decreases when this component becomes prevalent; (ii) the volatility of the real aggregate production (measured by its coefficient of variation) tends to increase when the stock market component increases; (iii) banks ask for higher interest rates because the stock market volatility is heavily valued by banks (low ψ); (iv) the mean leverage follows the opposite shape of the interest rate, given that higher rates imply lower target leverage; (v) the average aggregate net worth has the same shape of the aggregate production (that is function of the net worth); (vi) the mean number of firm bankruptcies is stable from $weight = 0$ to $weight = 0.7$, and then it slightly reduces thanks to the leverage reduction; (vii) however, the ratio between the aggregate bad debt (that decreases) and the aggregate extended credit (that reduces even more) increases; (viii) the number of bank defaults remains almost stable till $weight = 0.8$ because the mean interest rate increases and this offsets the higher bad debt ratio, but for $weight > 0.8$ defaults tends to increase following the growth of the bad debt ratio. Summarizing, for low values of *weight*, the stock market does not damage the economy; instead, when the stock market is strongly considered by banks in firms' evaluation, its presence reduces the aggregate production. Indeed, when banks are very risk averse, they react to the stock market fluctuations constraining credit (represented in the model by higher interest rates and then lower firms leverage). This have two consequences: on the one hand it prevents the economy to become too volatile, offsetting the volatility effect caused by the stock market fluctuations; on the other hand, however, it reduces the economic activity.

Instead, when banks are prone to risk ($\psi = 20$), we find that the interest rate is U-shaped: when the stock market enters in the evaluation it helps in reducing the interest rates compared to the case of no stock market influence, but when this influence becomes too relevant and the volatility of the system increases, then firms' stability reduces and banks ask for higher interest rates. As in the previous case: the average aggregate production (and aggregate

Figure 3: *Sensitivity analysis for parameter weight, from 0 to 1 with step 0.05. Dotted lines when* $\psi = 2$ *and solid lines when* $\psi = 20$.



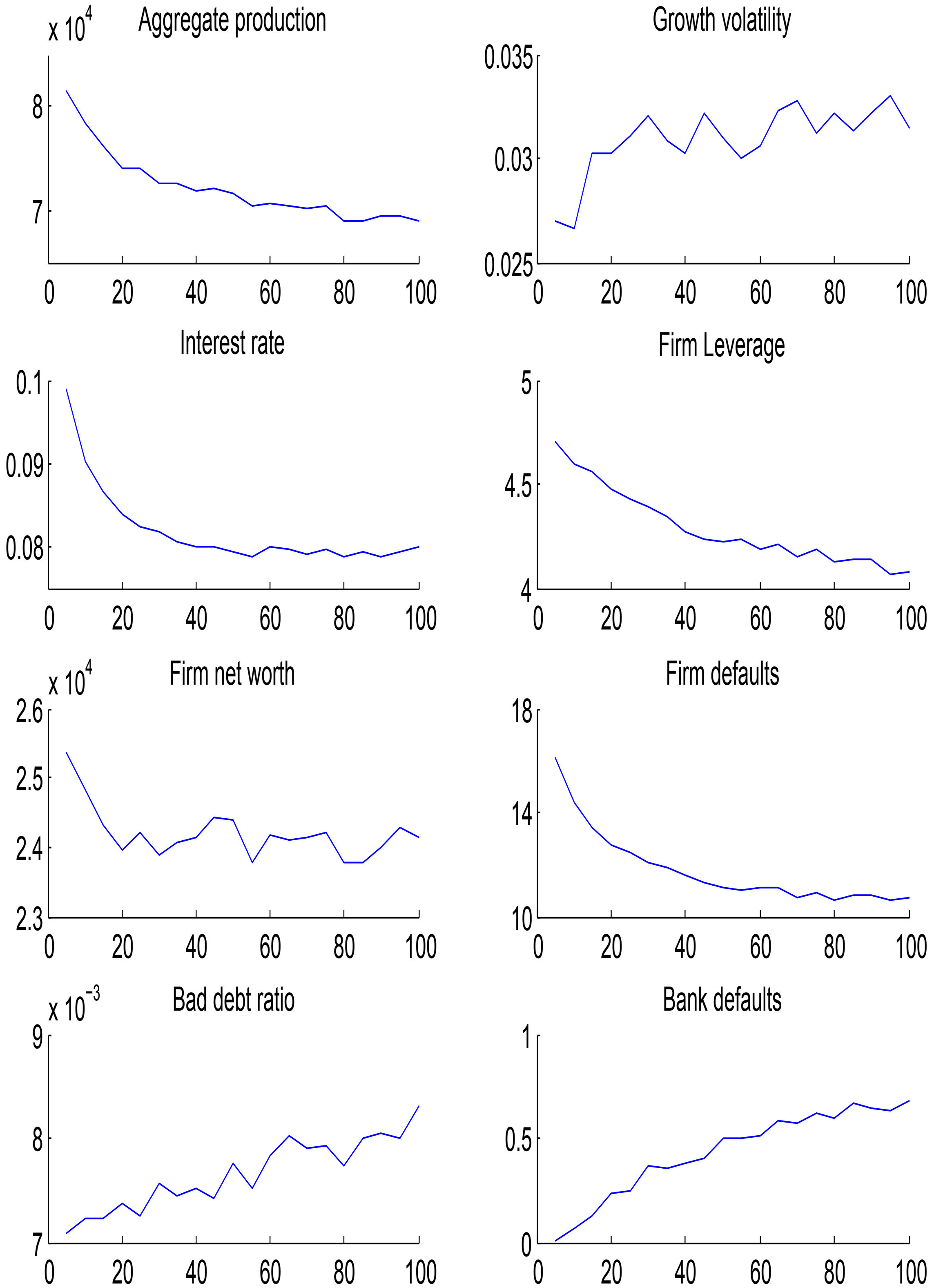
firms net worth) reaches its maximum for very low values of *weight* and then it decreases; firms leverage reduces and this reduces firms defaults; but, again, the bad debt ratio increases because the average net worth of bankrupted firms grows and it increases banks defaults. Differently from the previous case, the low interest rates (representing no credit constraint) keep the leverage more stable and this lowers the aggregate production reduction for high values of parameter *weight*. However, when banks have high risk propensity, a strong influence of the stock market makes the economy more volatile and banks weaker because they do not face the increasing bad debt ratio with growing interest rates.
Summarizing all, we can affirm that a low stock market influence does not damage the real economy, but if the stock market component is too strong, then the aggregate production reduces, the business cycle volatility increases and the banking system becomes weaker.

6.2 Parameter *moltp*

Now we analyse how the parameter *moltp* influences the economy. We replicate the simulation for *moltp* between 5 and 100, with step 5. All the other parameters are set as in Table 1; thus, parameter *weight* is equal to 1 and the stock market volatility widely affects the determination of the interest rate through the DD. The parameter *moltp* has a strong influence in determining how much volatile the stock market is. For example, a high *moltp* can represent a stock market bubble, that increases the market volatility. In other words, a high multiplier increases the stock market capitalization and, thus, the ratio between market capitalization and balance sheet net worth (the capitalization ratio), that also becomes much more volatile. When the EPS multiplier increases, the most important features shown in Figure 4 are: (i) the mean aggregate production reduces; (ii) the volatility of the real aggregate production growth rate rises; (iii) the interest rate firstly falls, given that the stock market increases the firms' value, but then stabilizes, because the stock market bubble makes the firms' value more volatile, reducing the DD[5]; (iv) the mean leverage, even if the interest rate declines, decreases because the overall economy is weaker and the expected profit reduces; (v) firm defaults decrease because leverage decreases, but (vi) bad debt ratio grows because the average size of defaulted firms raises; (viii) bank defaults sharply rise, because of the interest rate fall and of the bad debt ratio growth. Summarizing, when there is a highly volatile stock market the economy is weaker, more volatile and the banking system is more fragile. The increasing economic fragility related to a growing parameter *moltp* has strong monetary policy implications, as we

[5]We repeat the simulation for different values of the risk propensity parameter ψ. The only remarkable difference concerns the interest rate: for $\psi = 2$, the interest rates are higher and are U-shaped when *moltp* increases; instead, when $\psi = 20$, the average interest rates are lower and always decreasing as *moltp* increases. This is obvious: when banks are very risk-prone, the growing market capitalization has an effect on the DD larger than the effect of the growing volatility, thus DD increases, making room for lower interest rates. Instead, if ψ is low, when the stock market grows the DD enlarges, but if it becomes too volatile, the DD reduces because banks negatively evaluate the capitalization volatility.

Figure 4: *Sensitivity analysis for parameter moltp, from 5 to 100 with step 5.*



will see in the next Section.

We conclude that financial shocks, for example a mounting stock market bubble, can create real economic effects enlarging business fluctuations.

7 Varying stock market multiplier and monetary policy experiment

In this section we compare the effect of a monetary policy expansion (the opposite holds for a policy rate tightening), that is a reduction of the central bank interest rate from 3% to 1% at time 601, on the baseline model and on a slightly different model (that we will call "Multiplier" model) in which the stock market multiplier is affected by the interest rate level. In this second model we calculate the EPS multiplier in the following way, that considers 40 periods of future discounted cash flows:

$$moltp_t = \sum_{i=1}^{40} \frac{1}{(1 + rCB_t)^i} \tag{18}$$

Among the causes at the basis of an increase of the stock market multiplier when the monetary policy rate decreases there is, for instance, the low profitability of monetary and bond products that results in a liquidity inflow into the stock market. This is analytically represented in the above formula through a smaller discount rate.
We replicate this comparison for two different level of risk aversion $\psi = 2$ (high risk aversion) and $\psi = 20$ (low risk aversion).
We start with the case of $\psi = 2$, represented in Figure 5. In the baseline model, when the policy rate decreases a short-run expansion of aggregate production follows (and consequently an expansion of firms net worth, as shown in the upper-right plot), driven by a higher leverage (center-left plot). This also increases the stock market capitalization (upper-left plot), triggering the (initially positive) effect of the stock market accelerator. However, after a while, the higher level of leverage and capitalization ratio enlarges the financial accelerator mechanisms, making the economic system more volatile: more firms and banks go bankrupt, reducing the overall wealth. When deciding monetary policy changes, central banks should consider this counteracting effect due to the instability caused by the increased financial accelerator.
This effect is even larger when the stock market multiplier depends on the interest rate. Indeed, the capitalization ratio largely increases (upper-left panel of Figure 5) and this enlarges the stock market accelerator. In other words, when the interest rate reduces, the stock market multiplier increases from 23.1 to 32.8 (while in the baseline model it is fixed at 20) and the stock market becomes more volatile. Thus, the overall benefits on aggregate production (upper-right plot) are even of a minor magnitude: the incorporation of the interest rate into the multiplier partially counteracts the expansive effect of the monetary policy too. It implies

Figure 5: *Monetary policy expansion at time 600. $\psi = 2$. Blu line for the baseline model and gree line for the "Multiplier" model.*

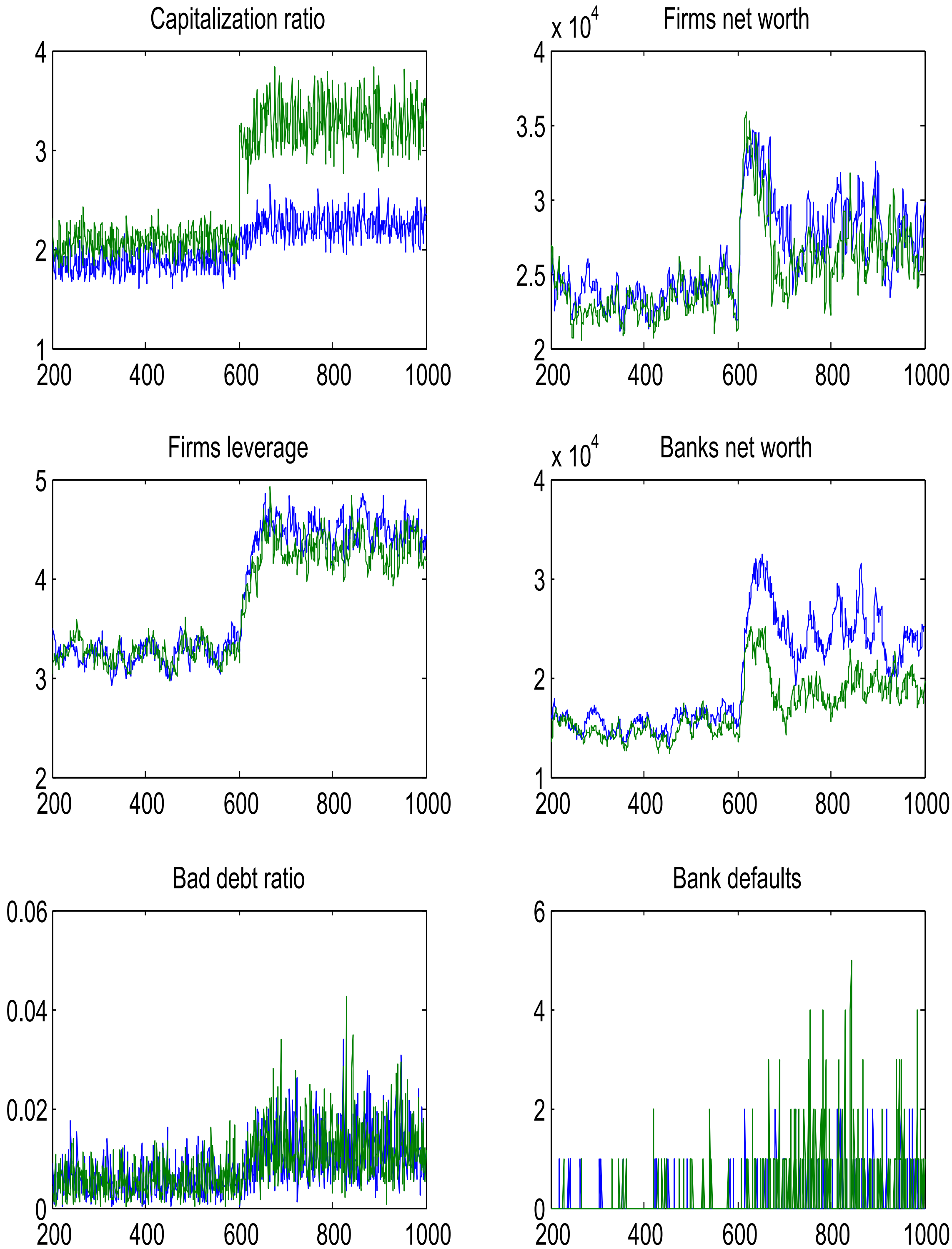
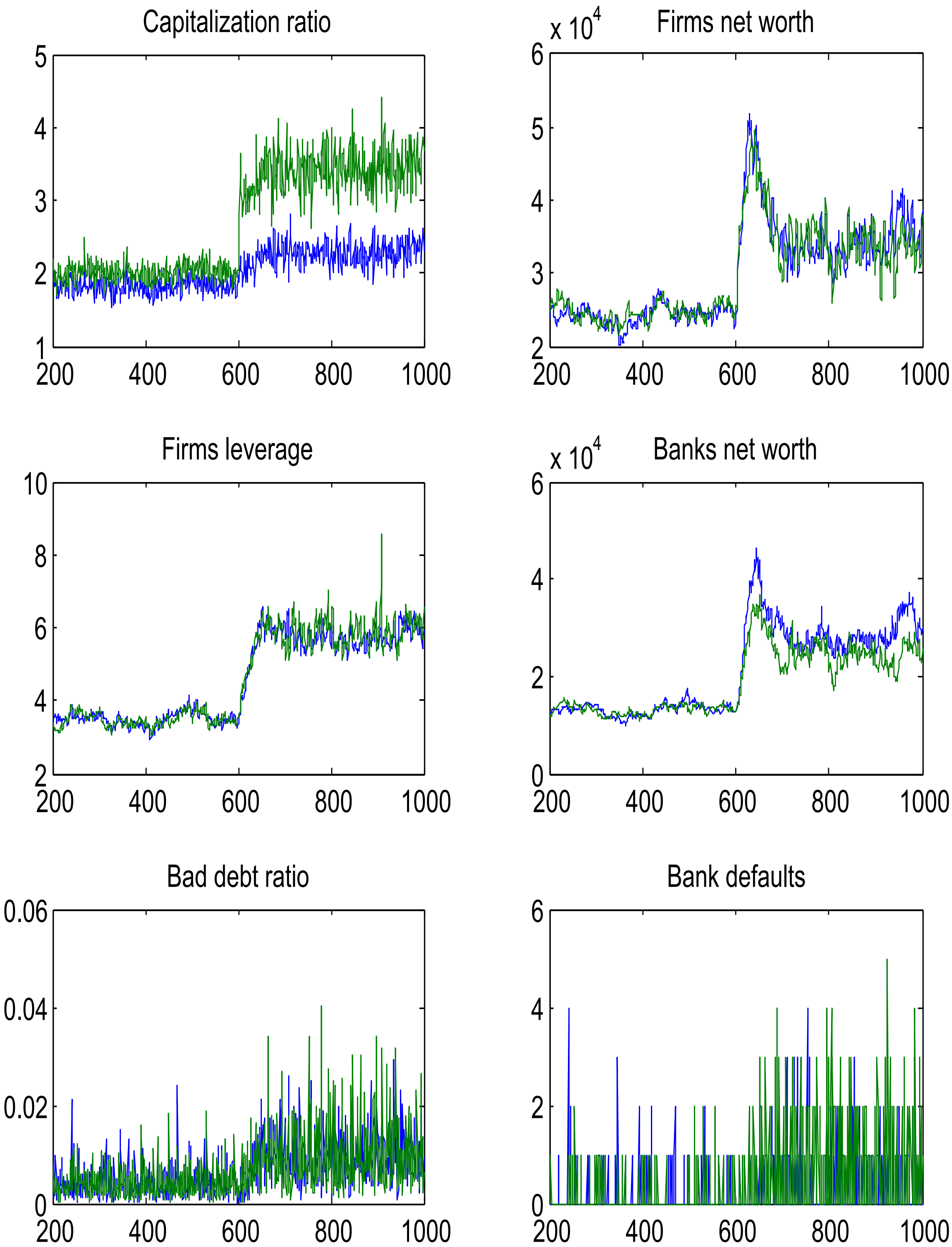


Figure 6: *Monetary policy expansion at time 600.* $\psi = 20$. *Blu line for the baseline model and gree line for the "Multiplier" model.*



a lower net worth and a higher number of defaults for firms and banks. These implications are very relevant for monetary policy decisions.

We repeat the same experiment for very risk-prone banks in the credit market: $\psi = 20$. This result is reported in Figure 6. We obtain the same results of the previous case ($\psi = 2$). The difference are only quantitative: in this case the monetary policy is more effective on the aggregate production (see Table 2) and there is a minor consequence in not considering the impact of the monetary policy on the stock market (that is to use the baseline model, instead of the "Multiplier" one). Thus, if the monetary expansion is done in a small downturn of the business cycle and banks are risk-prone, it can exploit much of its expected positive effects, while if it is done during a big financial crisis, it is probably less useful. However, as Table 2 highlights, when banks are more risk-prone an interest rate reduction also enlarges the economic volatility and the banking system fragility. Probably, it is not a case that the current financial crisis started at the end of a period with very low interest rates, with banks taking increasing risk (not only in the credit market). Moreover, the monetary policy expansion applied after the beginning of crisis could be dampened by the increased risk aversion.

Table 2: *Aggregate variables change as a consequence of a monetary policy expansion ($rCB_{1-600} = 3\%$, $rCB_{601-1000} = 1\%$). We refer to "Baseline" as the baseline model and to "Multiplier" as the model with variable EPS multiplier. The Δ is the difference between the value (average or standard deviation) of the variable calculated in period $t = 601 - 1000$ and the value calculated in period $t = 201 - 600$.*

Variable	Δ Baseline, $\psi = 2$	Δ Multiplier, $\psi = 2$	Δ Baseline, $\psi = 20$	Δ Multiplier, $\psi = 20$
Average aggregare production	+23196	+18212	+50954	+48371
Growth rate volatility	+0.95%	+1.19%	+1.53%	+2.18%
Average leverage	+1.20	+1.02	+2.19	+2.31
Leverage volatility	+0.11	+0.12	+0.30	+0.37
Average bad debt ratio	+0.58%	+0.64%	+0.50%	+0.58%
Average bank defaults	+0.16	+0.43	+0.29	+0.63

8 Conclusions

In this paper we build on the agent based model of Riccetti et al. (2011), adding the presence of the stock market. The stock market values influence the distance-to-default, used to evaluate firms' financial soundness and, thus, to set the interest rates charged by banks to them. The presence of the stock market enriches the positive feedback mechanism tied to the Financial Accelerator, that is now threefold:

1. **leverage accelerator**. Negative shocks on firms' output make banks less willing to loan funds (the same holds for risk averse firms characterized by a capital structure modeled with the dynamic trade-off theory), hence firms might reduce their investment

because of the credit constraint (increased interest rates) and this leads again to lower output;

2. **stock market accelerator**. This is the most important innovation of the paper. A firm, that has lower profit, has a decreasing capitalization on the stock market; thus the DD reduces and banks ask a higher interest rate. The increased interest rate reduces the firm's profit, amplifying the leverage financial accelerator;

3. **network-based accelerator**. Bankruptcies deteriorate banks' financial condition and it leads to higher interest rates to all borrowers (Stiglitz and Greenwald, 2003, p.145), further increasing the weakness of the whole non-financial sector. Thus, the presence of a credit network may produce an avalanche of firms' bankruptcies, in another vicious circle that can make banks go bankrupt too.

The first two mechanisms are the trigger of the accelerator, the third makes possible that an idiosyncratic shock creates an extended/global crisis without the need of a systemic shock.

In this framework, we find some interesting results, besides confirming some already found in Delli Gatti et al. (2010) and Riccetti et al. (2011), such as the emergent right-skew distribution of firms' and banks' size even if all firms start from the same conditions.

An important result is that if banks consider the firms' stock market value in evaluating the distance-to-default, the economy can benefit till the influence of the stock market is limited. If the stock market impact becomes too relevant, its volatility could damage the real economy. When the stock market impact is strong, an increase of the stock market volatility, for instance caused by a stock market multiplier increase, is widely influent in worsening the performance of the real economy, because it enlarges the stock market financial accelerator.

A very important implication for monetary policy is that when the policy rate decreases (the opposite holds for a policy rate tightening) a short-run expansion of aggregate production follows, but it is partially counteracted by the increasing financial accelerator that enlarges aggregate production volatility and banks financial fragility. Central Banks should consider this counteracting effect when deciding monetary policy changes.
This result is even stronger in the simulation in which the stock market multiplier is affected by the interest rate level, as really happens. Indeed, when the stock market multiplier increases as a consequence of an interest rate decrease, the effects on aggregate production is of a minor magnitude due to the even stronger stock market financial accelerator. Thus, the incorporation of the interest rate into the multiplier also counteracts the expansive effect of the monetary policy on the real economy. Moreover, an interest rate reduction can enlarge stock market values, but it could be useless for the real economy, lowering the relative profitability of the credit market compared to the stock market, and thus shifting funds from real economy to financial speculation (that can also increase the banking system fragility). We aim to further develope the influence of portfolio choices on the real economy in future works.

References

[1] Bernanke B., Gertler M. (1989) "Agency costs, net worth and business fluctuations", *American Economic Review*, 79: 14-31.

[2] Bernanke B., Gertler M. (1990), "Financial fragility and economic performance", *Quarterly Journal of Economics*, 105: 87-114.

[3] Bernanke B., Gertler M., Gilchrist S. (1999), "The financial accelerator in a quantitative business cycle framework", in: Taylor J., Woodford M. (Eds.), *Handbook of Macroeconomics*, Vol. 1, North Holland, Amsterdam, 1341-1393.

[4] Campbell J.Y., Taksler G.B. (2003), "Equity Volatility and Corporate Bond Yields", *Journal of Finance*, 63: 2321-2349.

[5] Delli Gatti D., Gallegati M., Greenwald B., Russo A., Stiglitz J.E. (2010), "The financial accelerator in an evolving credit network", *Journal of Economic Dynamics and Control*, 34(9): 1627-1650.

[6] Flannery M.J., Rangan K.P. (2006), "Partial adjustment toward target capital structures", *Journal of Financial Economics*, 79(3): 469-506.

[7] Gordon M.J. (1959), "Dividends, earnings and stock pricings", *Review of Economics and Statistics*, 41(2): 99-105.

[8] Greenwald B., Stiglitz J.E. (1993), "Financial market imperfections and business cycles", *Quarterly Journal of Economics*, 108: 77-114.

[9] Merton R.C. (1974), "On the Pricing of Corporate Debt: the Risk Structure of Interest Rates", *Journal of Finance*, 29: 449-470.

[10] Riccetti L., Russo A., Gallegati M. (2011), "Leveraged Network-Based Financial Accelerator", *Working paper series of the Department of Economics and Social Sciences, Università Politecnica delle Marche*, http://193.205.135.133/dea/quaderni/pdf/371.pdf.