REPORT FOR PRUDENTIAL REGULATION IN AN ARTIFICIAL BANKING SYSTEM – REPLY TO THE REFEREE REPORT

We appreciate the reviewer's thoughtful and thorough review of our paper. Responses to individual comments are given below. The reviewer's comments have resulted in substantial improvements to the manuscript.

I – Explanation of Modelling Assumptions

1. Why does (productive) capital K not matter for the equity ratio in eq. 5?

The model's underlying code does take into account productive capital in the equity ratio. As correctly pointed out by the referee, equation 5 must be amended to reflect this. This revision will be incorporated in the final version of the paper.

2. What are the initial conditions when simulating following the protocol as laid out on p. 11. E.g. what is X_0^e 0 in eq. 9?

The initial conditions used in the simulations (i.e., the calibrated model parameters) are displayed on Table 3 of the paper (page 29). X_0^e represents the initial amount of external demand and is set to 56 000.

3. Before eq. 10 it is said that demand is equally distributed among all firms. Why do you introduce heterogeneous firms in the first place?

Although internal demand is equally distributed among all firms, external demand is firm specific (please refer to page 11 of the paper). This fact, in association with several other firm specific aspects of the model (e.g., the bank to which the firm is connected), validates the need for heterogeneous firms.

4. What is the rationale for eq. 12 and 13? Please provide a thorough discussion. They are hard to grasp.

Equation 12 establishes the loan amount required by company e from bank b:

$$BL_*^{e,b} = \begin{cases} \varphi\left(1 - \frac{\overline{BL_{t+1}^e}}{E[\pi_{t+1}]}\right) \times \max\left(\frac{E[D]_t^e}{\phi} - S_t^e, 0\right) & for\ E[\pi_{t+1}] > 1 \\ 0 & otherwise \end{cases} \quad (1)$$

The rationale behind this mechanism can be explained on this way:

- Companies are assumed to be rational, which means that they will only ask for a loan if they expect to have profits during the next step ($E[\pi_{t+1}]$ must be higher than 1).
- If the previous condition is satisfied, companies determine how much external funding they should ask for. At each point in time, firms will try to produce as much as their expected demand ($E[D]_t^e$). They will only require bank financing if the amount of capital they have (S_t^e) is less than the amount of capital required

$\left(\frac{E[D]_t^e}{\phi}\right)$. The second term of equation 12 $\left(\max\left(\frac{E[D]_t^e}{\phi} - S_t^e, 0\right)\right)$ establishes the amount of credit that the company would request to the bank if it did not take into account any risk considerations. However, since borrowing entails the risk of default, each company takes into account its probability of failure when submitting a loan application. It does this by comparing its expected profits ($E[\pi_{t+1}]$) with its debt servicing costs ($\overline{BL_{t+1}^e}$). If the firm expects its next profits not to be enough to pay back its installments, it will ask for less loan. The lower the coefficient φ (a proxy for risk aversion), the more the loan application amount is reduced. This "financial fragility" and risk aversion aspect is reflected in the first term of equation 12 $\left(\varphi\left(1 - \frac{\overline{BL_{t+1}^e}}{E[\pi_{t+1}]}\right)\right)$.

Equation 13 defines the amount of credit to be granted by the bank:

$$BL_t^b = \begin{cases} 0 & for\ ER_t^b < ER_{min}^b \vee ER_t^i < ER_{min}^i \vee CO_t^b \leq 0 \\ \min\left(BL_*^b, \frac{(ER_t^b - ER_{min}^b) \times RWA_t^b}{RW}, CO_t^b\right) & for\ (ER_t^b - ER_{min}^b) \times RWA_t^b < BL_*^i \times RW^l \times ER_{min}^b \wedge ER_t^i > ER_{min}^i \\ \min(BL_*^i, CO_t^b) & for\ (ER_t^b - ER_{min}^b) \times RWA_t^b > BL_*^i \times RW^l \times ER_{min}^b \wedge ER_t^i > ER_{min}^i \end{cases} \quad (2)$$

The rationale behind this mechanism can also be explained as:

- The bank grants no loans whenever:
  - Its capital ratio (ER_t^b) is below minimum requirements (ER_{min}^b);
  - The capital ratio of the borrower (ER_t^i) is below minimum requirements (ER_{min}^i);
  - The bank has no liquidity surpluses (CO_t^b) to underwrite the loan.
- If the three premises described above are fulfilled, the bank may grant the loan. However, the amount granted is limited by:
  - The amount of cash holdings the bank has;
  - Its capital buffer ($\left(ER_t^b - ER_{min}^b\right) \times RWA_t^b$), which may be inferior to the loan's capital consumption ($BL_*^i \times RW^l$).

  Indeed, it may be the case that the total amount of financing required by the company is superior to the banks liquidity surplus or ability to leverage. In such cases, the amount granted must be rationed ($\min\left(BL_*^b, \frac{(ER_t^b - ER_{min}^b) \times RWA_t^b}{RW}, CO_t^b\right)$).
- If the three premises described above are fulfilled and the bank's capital buffer (i.e., the amount of capital in excess of minimum requirements) is above the loan's capital consumption, the bank grants the minimum between the requested amount and its liquidity surplus.

5. It could be helpful to point out that the deposit interest rate (eq. 14) decreases with excess demand for credits.

It is our understanding that by "excess demand for credits" the referee means a lower difference between outstanding deposits and loans ($\sum_{i=1}^{I} BD^i + \sum_{e=1}^{E} BD^e - \sum_{i=1}^{I} BL^i - \sum_{e=1}^{E} BL^e$).

Should this be the case, it is important to clarify that, contrary to what is stated in the remark, the deposit interest rate does not decrease with excess demand for credits. To see this, please note that a higher amount of bank loans reduces the equation's denominator, which implies that more credit actually increases the deposit interest rate.

This result is expected because, as in every market, a higher amount of credit translates into increased demand for deposits (since these are necessary for banks to sustain their lending activity), which in turn implies that depositors must be remunerated at higher prices.

6. What is S_t^e in eq. 16? In general, a table featuring all parameters and (!) variables with their mathematical symbols could be helpful to guide the reader.

As stated in equation 11 and detailed in the associated explanation (please refer to page 12 of the paper), S_t^e represents the production capacity of each firm and is a function of capital (K) and capital productivity (ϕ).

As stated in the answer to question 2, a Table containing an exhaustive list of parameters is available on page 29 of the paper. A Table containing the list of variables will be added to the final version of the paper.

7. The discussion of eq. 17 features the parameter N which is not included in the respective equation. What is B? Does M in this equation represent maturity?

As correctly identified by the reviewer, the paper inaccurately refers to parameter N instead of parameter I (i.e., the number of consumers in the economy). The final version of the paper will be amended in accordance.

As stated in the answer to question 2, a Table containing an exhaustive list of parameters is available on page 29 of the paper. As per its content, B represents the number of banks in the economy and M stands for the standard maturity of loans granted.

8. In the end of section 2.7 it is said that consumers sell land. What is land and how is it modeled exactly. There is no other reference up to that point in the paper.

As correctly identified by the reviewer, the paper inaccurately refers to land instead of referring to bonds. The final version of the paper will be amended in accordance.

9. Eq. 24 seems inconsistent with equation 19. Equation 25 seems inconsistent with eq. 16. Please explain.

In our opinion, the equations in analysis are not inconsistent. To explain why this is the case, it is important to note that this model is based on a choreographed protocol that restricts the decisions made by the agents and forces them to initiate action sequentially.

This means that each step of a simulation run is composed by 11 stages that are processed consecutively. As such, the assessment of the banks' financial position is only undertaken after the assessment of the financial position of companies and consumers, which is naturally the logical sequence since banks can only assess their position after ascertaining whether their clients have been able to make their payments.

This feature of the model means that, at the stage where consumers' income is computed (equations 19), it is not possible to know whether the revenue generating capacity of the consumer's bank is enough to fulfill the totality of its commitments. Interest revenue is

thus added to the consumer's net worth after the computation of the bank's financial position (equation 24).

In a similar fashion, at the stage where firms' cash inflow is computed (equations 16) it is not possible to know whether the revenue generating capacity of the company's bank is enough to fulfill the totality of its commitments. Interest revenue is thus added to the firm's net worth after the computation of the bank's financial position (equation 25).

These explanations are provided as footnotes in the paper. Nevertheless, we acknowledge that the current wording does not provide enough clarity. As such, the terms of equations 16 and 19 that refer to interest income from deposits ($r_d \times BD_t$) will be removed in the final version of the paper.

10. The modeling of the financial market trading (section 2.10) is highly unusual and hard to grasp. Maybe, the authors want to incorporate a simple and well-used model such as e.g. Westerhoff (2008).

The modeling of the financial market trading closely follows Takahashi and Okada (2003). This specification is particularly insightful because it successfully captures the emergence and burst of asset bubbles (e.g., the collapse of the housing market), one of the key drivers behind the recent financial crisis.

Although we strongly believe the current structure is perfectly aligned with the purposes of our analysis, we acknowledge the merits of the model described in Westerhoff (2008) and consider that its implementation would constitute an interesting avenue for future model extensions.

11. The combination of eq. 33 and 34 seems flawed. Is P_t recursively defined by itself?

As correctly pointed out by the reviewer, the paper inaccurately refers to P_t instead of referring to P_{t-1}. The final version of the paper will be amended in accordance.

II – Discussion of Results

1. I think the analysis provided in section 3.1 which completely shuts down the banks is not very insightful. As stated on p. 31f the presence of a capital depreciation rate implies that without banks firms will run out of productive capital and thus are doomed to fail without a supply of credit as provided by the banks. Please discuss this more thoroughly.

The comparison between economic performance with and without banks provided in section 3.1 is insightful because it proves that financial institutions:

- Significantly facilitate investment through credit, thus allowing firms' to increase their production capacity and promote economic growth;
- Significantly alleviate the effect of shocks by sustaining firm's productive capital during economic downturns.

These conclusions would not be obvious without this analysis because there are cases where firms can sustain (or increase) their productive capital without credit supply. This happens whenever firms are able to generate excess cash flow, thus accumulating enough deposits to self-sustain their capital expenditures. In these cases, it could not be concluded *a priori* that firms were doomed to fail without credit supply: as long as demand (which may be subject to random shocks) is sufficient to support sales, firms do not require external financing.

However, this is not the average behavior we see in the model because, usually, every simulation run contains randomly generated economic downturns in which demand decreases continuously for several time periods, giving rise to long phases where firms cannot accumulate deposits.

2. The aggregate growth seems to be superimposed on the model by assuming exogenous growth of consumption and exports (driving the demand for goods). Please discuss.

The aggregate growth pattern we observe in the model is the result of two different but complementary effects:

- The exogenous growth of external demand. As in Tedeschi et al. (2012), and taking into account considerations of simplicity, this variable (which is firm specific) is assumed to grow at a pre-defined growth rate that is affected by random shocks;
- The endogenous growth of internal demand. Since both the income and the net worth of consumers tends to increase with time, so does the level of consumption.

As correctly pointed out by the reviewer, the endogenous growth of internal demand is only possible because, at inception, exogenous growth of external demand is assumed. However, it is important to point out that this simplifying assumption in no way hampers the conclusions of the model. This is because:

- Nefarious economic events (e.g., consumer, firm or bank bankruptcies) still have a direct negative impact on total demand (and thus GDP) through:
    - Their impact on the net worth and income of consumers, which reduces internal demand;
    - Their impact on exports, since new firms (being smaller than existing ones) do not have enough productive capital to fully replace the supply that was made available by the defaulting companies they replace;
- Our performance metric is the GDP output gap (i.e., the difference between potential GDP if all demand was met and actual GDP).

3. I am not entirely convinced that the capital share (as depicted in fig. 7) will ever increase in time. I think this results from the increasing returns (see fig. 8). I have the feeling that the rate of rate of return should converge to the capital productivity $\phi = 0.1$ (cf. table 3) in the long run implying a long-run stationary functional distribution.

The capital share does tend to increase in time. To see why, please note that:

- There is no wage adjustment process in the model (i.e., wages are fixed);

- The number of consumers (and thus the number of workers) is fixed.

Because GDP tends to increase in time, the ratio between the compensation of employees and the total income generated by the economy tends to decrease. In other words, because the share of income devoted to labor is fixed, the fact that total economic income tends to increase with time implies that the share of income devoted to capital must increase.

4. **It seems that (at least in the baseline scenario) a defaulting bank is replaced by some exogenous institution that can always and perfectly meet the demand for credit. I think this is a strong assumption in particular regarding the analysis which concerns Zombie-banks. The assumption presented in section 3.4 seems more reasonable. I think a more thorough discussion of this issue is necessary.**

First, let us start by clarifying that the statement according to which "defaulting banks are replaced by some exogenous institution that can always and perfectly meet the demand for credit" seems not entirely accurate.

In the event of bankruptcy, credit institutions are assumed to enter resolution. As part of this process, non-performing loans are foreclosed. After all the non-performing loans are foreclosed, the capital position of the bank is assessed. Losses are first and foremost absorbed by equity capital. Depositors are bailed-in whenever equity capital is negative.

Only after the bail-in does the recapitalization of the bank using foreign funds takes place. Since only healthy assets are now left in the bank, this does not constitute a farfetched scenario. The amount of the recapitalization is equal to the maximum between the endowment initially given to all banks and the amount of capital needed for the bank to display a capital adequacy ratio 12% in excess of minimum requirements.

This process means that, under the baseline scenario:

- A bank default has economic costs (i.e., depositor bail-in and the consequent impact in internal demand);
- The new entrant will not always and perfectly meet the demand for credit because it will always be limited by the capital buffer it owns.

Nevertheless, we also agree with the referee's opinion that, in the baseline scenario, the assumption that banks can be recapitalized through foreign investment, thus creating a credit institution that can finance economic activity from the onset, could be signaled as one of the reasons why our model reveals improved economic performance with risky banks.

This is the reason why we endogenized the cost of bank failures. Like before, depositors of failed banks are still bailed-in, thus absorbing the losses of the institution and raising its capital to zero. Under the setting presented in section 3.4, however, depositors further see a part of their deposits being converted into equity so that the new institution complies with minimum capital requirements.

In this revised setting, risky banks are still clearly the best performer within the scenarios in analysis. This result thus suggests that the benefits of increased credit availability are able to surpass the costs stemming from a higher probability of bank failures.

Because the changes of section 3.4 corroborate the results of the baseline scenario, we do not see in which way an additional discussion could be of help regarding this topic.

As stated in the paper's conclusion, we see the pertinence of this argument with respect to firms (whose bankruptcy costs are not fully endogenized) and consider that its implementation would constitute an interesting avenue for future model extensions.

5. **I find the point raised in section 3.2 interesting. Is there a trade-off between the *default* of firms as compared to banks?**

The results of our model do not point towards a straightforward link between the *default* of firms as compared to banks, suggesting a more intricate relationship between both variables.

To see this, please note that the default rate of firms does not seem to reveal monotonic behavior. When compared to the "regular banks" scenario, the default of firms is shown to increase in both the "safe banks" and the "risky banks" setting. If there was a direct trade off, we would not expect this phenomenon to take place (i.e., we would expect the default rate of firms to increase[1] in the "safe banks" scenario and decrease in the "risky banks" setting).

6. **In the discussion of the inflection point p. 33 and fig. 9ff. The authors infer anon-linear behavior out of three observations (low, middle and high) only. This is not very convincing.**

We have mentioned the existence of non-linear behavior because the results show that the variables in analysis do not move in a tandem (e.g., when compared to the "regular banks" setting, firm defaults increase in both the "safe" and "risky banks" scenarios). Nevertheless, we agree with the referee's opinion that 3 observations may not be enough to make such a statement. The final version of the paper will be amended in order to avoid any excessive inference**.**

7. **In general, I would be interested in the role of debt for consumers. In the paper, there are two forms of loans: productive loans to firms and consumer loans. The literature discussing the recent financial crisis has emphasized the role of private debt (f. e.g. Mian and Sufi (2010)). I have the impression that the positive role of banks emphasized in the paper comes from the fact that they provide loans to the productive sector. On the other hand, excessive leverage of private households is identified as a main driver in the literature that tries to explain the financial crisis. Can private households turn bankrupt in the model at hand?! I do not find a reference to this in the protocol on p. 11.**

Private households can also turn bankrupt in the model at hand. As described on page 16 of the paper, banks will liquidate debtors (consumers or companies) as soon as they miss BPM^i payments. In this process, credit institutions take over any bond still owned by the debtor[2] and immediately try to sell it on the market. Consumers who have been liquidated

[1] Or remain relatively constant, given that the banks' default rate is virtually the same in both the "safe" and "regular banks" scenario.

[2] Note that the debtor will not have any asset at this point, since all deposits/cash have already been used to try and pay off its debts.

see their outstanding debt forgiven and start the next step with a debt-free financial situation.

In the current structure, consumers take on credit in order to invest in the financial asset. As such, and despite households' debt being smaller than firms' outstanding loans, the impact of credit to consumers also plays a part in the results of our model.

Naturally, we see the interest in further analyzing the role of debt for consumers and consider that pursuing this objective would constitute an interesting avenue for further research.

III – Minor Remarks

We thank the reviewer for these remarks. The suggested amendments will be incorporated in the final version of the paper.

IV – References

Takahashi, I., Okada I., 2003. Monetary policy and banks' loan supply rules to harness asset bubbles and crashes. Multi-Agent-Based Simulation III. Springer Berlin Heidelberg, 89-105.

Tedeschi, G., Mazloumian, A., Gallegati, M., Helbing, D., 2012. Bankruptcy Cascades in Interbank Markets. PLoS ONE 7 (12): e52749. doi:10.1371/journal.pone.0052749.