Linking Economic Modeling and System Dynamics: A Basic Model for Monetary Policy and Macroprudential Regulation

Klaus Dieter John

Chemnitz University of Technology

Thueringer Weg 7, D-09107 Chemnitz, Germany

Fon +49 371 531 34198 / Fax +49 371 531 33969

john@wirtschaft.tu-chemnitz.de

Abstract

The financial crisis shifted the focus of monetary policy. Whereas before the crisis the main goal of using monetary policy instruments was to keep the inflation rate low after the crisis policy makers put much emphasis on stabilizing the financial system. The economic literature has started to elaborate on the issue of macroprudential regulation only recently. Financial turbulences, by their very nature, constitute a complex dynamic phenomenon. Hence, an analysis employing tools of system dynamics should help to improve our understanding of the underlying feedbacks. In order to link economic reasoning and the systems approach a model of financial behavior developed by Stein is introduced and used to create building blocks for a basic dynamic simulation model.

Keywords: Financial crisis, monetary policy, macroprudential regulation.

JEL classification: G01, G18

1. Introduction

The financial crisis of 2007/08 and its consequences (e.g., the world economic crisis of 2008/2009, the debt crisis of Greece, Portugal, Ireland, Spain, and Italy) shifted the focus of monetary policy. Whereas before the crisis the main goal of using monetary policy instruments was to keep the inflation rate low (and, perhaps, support economic growth), after the crisis policy makers put much emphasis on stabilizing the financial system. Part of this change in policy was the acknowledgment of the potential problem of systemic risk. This aspect, namely that the actions of one agent in the financial markets has effects on other agents and the stability of the financial system as a whole, had been widely neglected before the crisis.

This observation is true not only for monetary (and economic policy in general), but it is also true for monetary economics research and monetary economics teaching.[1] The crisis made it clear that monetary policy cannot limit its role on fostering price stability. Central banks also have to play an important role in fostering the stability of the financial system as a whole, and there is a need to develop appropriate policy tools (Clement 2011: 59). This task has been recognized in the economic literature only recently (see, e.g., Angelini et al. (2011) and Hoogduin (2010)). Another important contribution to this strand of literature is the paper of Stein (2011). Stein develops a macroeconomic model to address several aspects of macroprudential regulation. A central purpose of his model is to analyze the systemic feedbacks of a money-issuing institution in a simple framework and to show that unregulated private banks have an incentive to issue too much short-term debt. This in turn makes the financial and economic systems vulnerable to financial crises. The Stein model has many virtues: inter alia, it emphasizes the systemic feedback of one single bank on the financial system as a whole, it allows for the evaluation of different policy measures, and it is quite accessible. But it is a typical economic model in the sense that, in the end, it is a static optimization model: In an unrealistic way it asks too much from the agents and it does not allow for analyzing the dynamics of the actions and feedbacks.

A financial crisis is *per se* a complex dynamic phenomenon which involves feedbacks between many different agents. Hence it seems promising to contribute to the analysis of the financial system and its vulnerability to crises by using a System Dynamics approach without ignoring the recent developments in economic modeling. To the best of our knowledge, so far there is no System Dynamics literature that explicitly deals with this problem.[2] Therefore this paper wants to serve as a basic stepping stone to transform monetary economic models analyzing the financial crises into dynamic models that allow for a richer analysis of the feedbacks in the financial system.

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[1] Stein (2011: 1) points to a survey article of Goodfriend (2007) in the Journal of Economic Perspectives that supports this view. But also a glance at the leading textbooks and reference books published before the crisis underlines the focus on price stability (see e.g., Mishkin 2007, Howells and Bain 2002, Walsh 2003, and Woodford 2003).

[2] Recent work that deals with the financial and economic crisis from a system dynamics view includes John (2010), Zavrl (2010), Lewis (2011) and Yamaguchi (2011). But all these papers focus on other aspects.

The rest of this paper is organized as follows. In the next section we lay the economic foundation by introducing the main structure of the model of Stein (2011). At the end of this section we will review this model critically from a System Dynamics viewpoint. In the following section we develop a dynamic model that tries to keep the spirit of the Stein model but improves on some of its shortcomings with respect to feedbacks and dynamic behavior. Our contribution is of a more qualitative type although we present some results of a preliminary simulation analysis. But we did not put much emphasis on empirically supported relations and parameter values. (Basically, we refer to the parameter values Stein (2011: 20, 25, 30) used in his examples.)

2. An economic framework for monetary policy and macroprudential regulation

In this section the model proposed by Stein (2010) is briefly introduced and the main results are given. The Stein model can be classified as a one good, three sectors economy static optimization model. The single good of the economy can either be consumed or saved and invested. The three sectors the model encompasses are households, private banks, and patient investors. The model explicitly takes care of time but does it in a fashion that qualifies it as a static model. It makes use of three time periods which serve only as a means to structure the decision making stages of the agents with respect to time. In the following these periods are labeled t_0, t_1, and t_2, respectively.

We start the exposition of the model by explaining the assumptions regarding the household sector. The model assumes that households derive utility from consumption in t_0 and t_2. In addition, they derive utility from monetary services. These ideas are captured in the following utility function:

(1) $$U = C_0 + \beta E\left(C_2\right) + \gamma M$$

As equation (1) reveals households are assumed to have linear preferences. Moreover, it is assumed that households have an exogenously given endowment of the single good. In t_0 the representative household has to decide which amount of this endowment it will consume and which part it will save. The model also assumes that the household is not able to invest its savings directly. Instead, savings are invested via banks which issue financial assets in return. (As will be made clear in more detail below, banks issue two types of financial claims: one that is risky and one that is riskless in the sense that banks guarantee the repayment. To simplify matters, we will call the first type of financial asset just "bonds", and the second (riskless) type we will call (private) money.) The proceeds of these assets are consumed in t_2. The parameters β and γ fix the (equilibrium) return rates of bonds and money. We will denote the gross real return of bonds by R^B and the gross real return of money by R^M. The (equilibrium) values of these rates are given by

$$R^B = \frac{1}{\beta}, 0 < \beta < 1$$

and

$$R^M = \frac{1}{\beta + \gamma}, \quad 0 < \beta + \gamma < 1$$

As Stein (2011: 7-8) points out the assumption of linear preferences of the households is not necessary for the results derived from the model but helps to illuminate a distinguishing feature of the model: The linear preferences imply a constant spread between the return on bonds and the return on money. Specifically, the spread does not depend on the quantities of bonds and money. Consequentially, the policy of the central bank does not alter the real rates of returns of the assets but changes the composition of bonds and money. In effect, the return rates are constants.

We now turn to the description of the behavior of banks. Banks lack own initial endowment. They collect the savings of the households and issue in turn long-term or short-term financial claims (bonds or money). They invest the collected funds in physical projects. The proceeds of this investment are uncertain because it may be the case that under bad circumstances the investment yields an output of zero. Therefore, if they finance the collected savings long-term by issuing bonds this debt cannot be riskless (because of the possible zero return on the investment). This statement does not hold in full for short-term financed funds because the model assumes that banks have the possibility to sell a part of their investment to patient investors. When doing so they have to accept a discount which depends on the volume of fire-sales of the banking sector as a whole.

Formally, the model can be described as follows: At t_0 the banks collect savings from the household sector and invest the amount of I into physical projects. At t_2 the economic situation may be good (with probability p) or bad (with probability $1-p$). If the economic situation is good the output of the investment I is given by a concave function

$$Q = f(I) > I$$

If the economic situation is bad then the expected output is $\lambda I \leq I$ with probability q or zero with probability $(1-q)$. Hence, the expected output is given by

$$E(Q) = q\frac{\lambda I}{q} + (1-q) \cdot 0 = \lambda I$$

At t_1 all actors learn what the state of the economy in t_2 will be and banks have the opportunity to sell any fraction of their physical investment I to a patient investor. As we just have seen the expected output of the investment is λI. The patient investors are only willing to buy physical assets from the banks at a discount k on this expected value.

Specifically, it is assumed that if the banks sell a fraction δ of the invested real capital I to patient investors they will receive a return for this amount in t_1

$$k\delta\lambda I,\ \ 0<k<1.$$

For the unsold fraction of the investment they get an *expected* return of

$$(1-\delta)\lambda I.$$

It is important to note that k is an endogenous variable because it is determined by the total asset sales of the banking sector as a whole.

In the case a bad economic situation is revealed at t_1 a bank has the possibility to sell a part of its real investment to patient investors. This feature of the Stein model allows private banks to create riskless short debt ("private money"). But there is an upper bound and private money creation is only in so far possible as "the amount issued is not too large" (Stein 2011: 11). Stein (2011: 10) argues as follows: If a bank finances a fraction m of its investment I by issuing riskless short-term papers that carry a rate of return R^M then it has a definite obligation of paying the households a sum of $mIR^M =: M$. But in the bad economic situation the obligation can only be fulfilled if the bank is able to raise the respective amount by selling some of its real investment to the patient investors such that the proceeds from this "fire sale" are equal to the obligations resulting from the short-term debt. Hence, it must be true that

$$k\delta\lambda I = mIR^M,\ \text{or}$$
$$m = \frac{k\lambda}{R^M}\delta$$

The fraction of fire sales must be between zero and one. Hence, an upper bound of riskless short-term debt (and creation of private money) is given for $\delta = 1$ by:

$$m^{\max} = \frac{k\lambda}{R^M}$$

Hence, the creation of riskless short-term debt is limited by the constraint that the fraction of "money financed" investment m must not exceed this upper bound (collateral constraint):

$$m \le m^{\max} \tag{2}$$

We turn now to the behavior of patient investors (Stein 2011: 13-15). In the model of Stein patient investors have an initial endowment of W that they invest in real projects. They can be seen as second type of intermediary for the real proceeds of investment projects go to the households at t_2. The initial endowment of the patient investors is treated as an "unconditional war chest" because there is no way for the investors to alter this endowment when the information about the state of the economy is available at t_1.

They can use their resources for two purposes at t_2: Either they can invest in real projects or they can buy real investment projects from banks which have to sell these projects in order to satisfy the collateral constraint. The latter is only relevant in a bad economic situation which forces banks to fire sale assets in order to be able to repay the short-term debt M. The "production function" of the real investment of the patient investors is given by $g(.)$ which is assumed to be a concave function. In equilibrium, the patient investors must be indifferent between investing one marginal unit into a real project and buying one marginal unit of the existing real assets of the banks. This is only the case if the marginal returns of both possibilities are the same:

(3) $$\frac{1}{k} = g'(W - M)$$

Eq. (3) determines the fire sales discount k. In a bad economic situation an increase in the short term financing of real investment projects by banks leads to an increase in fire sales to patient investors which in turn leaves less funds for the latter to invest into new real projects. Given the concaveness of $g(.)$, the marginal product of such investment increases. Hence, in equilibrium the increased fire sales will only be absorbed if the discount is larger (i.e. k is smaller).

This is one of the key features: In its decision making process the single bank treats k as exogenously given, whereas, in fact, k is endogenously determined by the banking sector as a whole (via its choice of M).

After the exposition of the model structure Stein (2011: 15-23) turns to the bank's optimization problem which he contrasts with the optimization problem of a benevolent social planner. His main finding from this exercise is that banks may finance their real investment projects by a higher fraction of short-term debt than the social planner would do. This is the case if the spread between the returns on short-term debt and long-term debt is high enough to make the collateral constraint (2) binding. As we will not refer to these results below we will not delve further into the details of the calculations. Instead, we will take the basic aspects of the preceding exposition and use them as building blocks for a simulation model. This will not only shed more light on virtues and shortcomings of the Stein model but it will also allow us to investigate the dynamics of the problem more thoroughly.

3. A basic dynamic model for analyzing private money creation and macroprudential regulation

Stein (2011: 1-5) claims quite a broad scope for his model: First, he demonstrates how unregulated private money creation may potentially lead to excessive short-term financing - an externality which makes the financial system vulnerable to costly crises. Second, he argues that "conventional" commercial banks can be regulated appropriately by conventional monetary policy tools in order to avoid this externality whereas the regulation of "shadow banks" requires other policy measures. Third, he wants to show that monetary policy can control financial and real activities even in a new classical setting with frictionless price adjustment. The scope of our reasoning is much narrower: We limit ourselves to the development of a dynamic model which incorporates some ideas of the Stein model and leave the question how to regulate financial markets for future work. The main purpose of this undertaking is to make a suggestion how to link economic reasoning, specifically the reasoning of the model introduced in the preceding section, with a system dynamics perspective. We do that because we believe that the systems perspective can add extra insights to the conventional economic models. At the same time we believe that in order to be recognized by professional economists it is important to stay as close as possible to the economic modeling approach.

The Stein model has the following characteristic properties:

- highly aggregated
- makes use of representative agents
- random driven events
- simultaneous equations approach
- optimization behavior of agents
- fully flexible adjustment, equilibrium
- static
- feedback important - but not intensively discussed

The Stein model is a highly aggregated model because the behavior of economic agents is summarized in three sectors (households, banks, patient investors). Moreover, the agents in each group are treated alike by using the concept of representative agents. This kind of modeling deviates from the modeling used in most areas of system dynamics as prominent textbooks witness.[3] From our viewpoint to keep the aggregated approach, even when modeling financial markets from a systems perspective, has advantages: Because it stays close to the conventional macroeconomic approach the ideas of the model are easier to grasp for economists without prior exposition to system dynamics. Moreover, the macro models developed from scratch with a systems perspective in mind are rich in detail but, for that, sometimes hard to understand.[4]

[3] See e.g. Sterman (2004), Maani and Cavana (2007), Warren (2008), and Morecroft (2007)
[4] See e.g. Yamaguchi (2004, 2005, 2006, 2007, 2008)

The Stein model involves random events in two places. First, the state of the economy (which is revealed by a public signal at t_2) is treated as a random variable. Second, the return on real investment of banks in the bad state is treated as a random variable. But, in fact, random events are only important in so far as banks have no perfect foresight when making their decisions. Moreover, the way random events are modeled is rather arbitrary. Decision making units just have to wait until time t_1 to observe the public signal about the state of the economy at t_2. They do not try to gather information that allows them to anticipate what the state at t_2 will be. This ambiguity justifies putting randomness aside for the moment. Instead of including a random process to determine which state prevails at t_2 we concentrate on the bad state which is linked with fire sales of real assets.

The equations describing the Stein model form a simultaneous system. The Vensim software we use below to construct a computable simulation model reports an error when trying to simulate such a model. In principle, it is possible to solve simultaneous equations iteratively within Vensim. But from a methodological viewpoint the simultaneity error points to a missing causality in the model relations. We take care of that point by not calculating the (optimal) equilibrium values of the simultaneous equation system. Instead, we formulate a causal system and provide (arbitrary) initial values. An additional justification for this approach lies in the fact that in reality no agent would ever be able to calculate equilibrium values in the way the banks in the Stein model do it.

A similar critique holds for the optimization procedure of the Stein model. In that model the banks get perfect information at t_1 what the economic situation will be at t_2. Given this information they calculate the optimal level of *m* and *I*. After that calculation they are able to implement the optimal solution immediately. In a complex real world such a sequence of decision and behavior is almost impossible. More realistic is the assumption of changing boundary conditions, not precisely known functional dependencies, and inexact parameter values. In a dynamic environment this framework makes some kind of adaptive behavior more plausible than optimization.

In the Stein model households are only in so far important as the supposed linear preferences pin down fixed interest rates of short-term lending and long-term lending $\left(R^M, R^B\right)$. The patient investors are also of limited importance. Their supposed production function pins down the fire sales discount k. The central actors of the model are the banks. For this reason we concentrate on this sector and put the other sectors outside the model boundaries for the time being.

With respect to our remarks on the relevance of static optimization we refrain from modeling the banks as optimizing agents. Instead, we assume that banks try to close the gap between a desired profit and the actual profit. As we want to build a dynamic model we have to distinguish between stocks and flows. For simplicity, we assume that banks compare desired accumulated profits and accumulated actual profits when deciding about measures to close the gap.[5] If desired profits are higher than actual profits the banks have two instruments to increase the actual profits: First, they can increase their investment of real assets. Second, they can change the composition, i.e. short-term and long-term financing of these assets. The involved feedbacks are shown in Fig. 1.

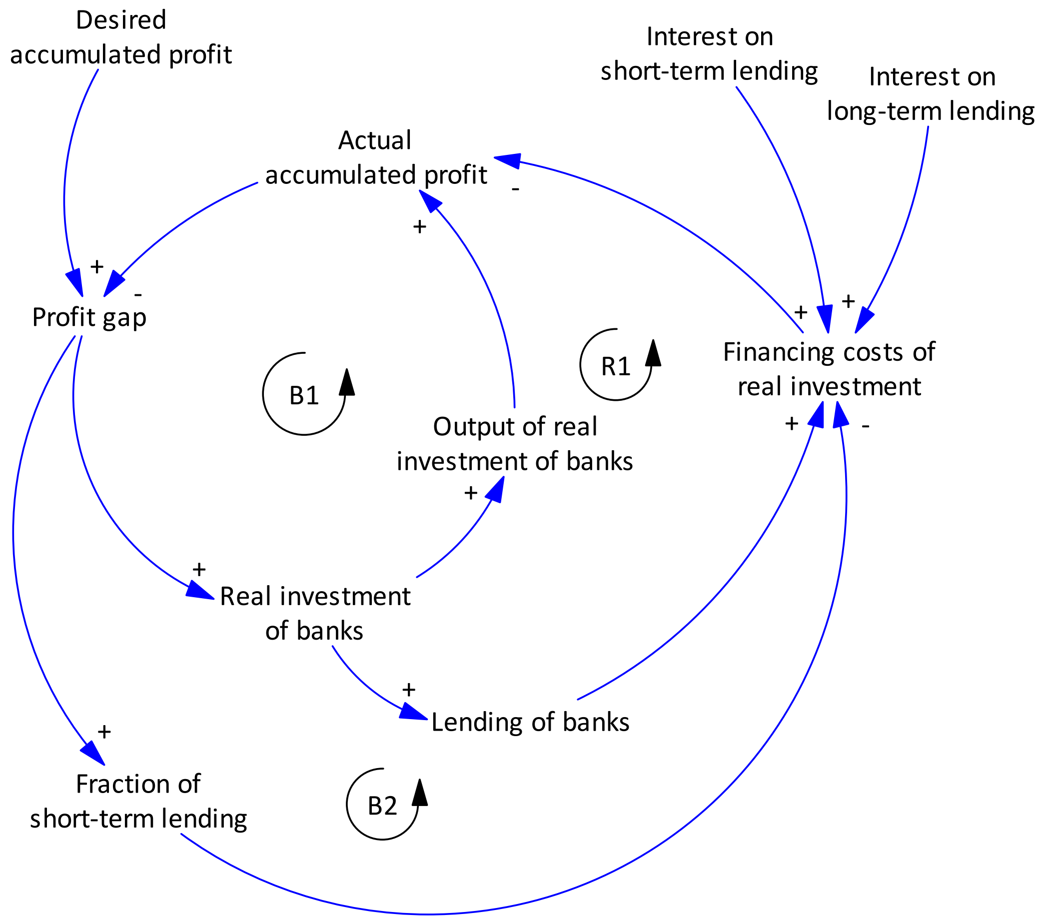

Figure 1

There are two balancing loops and one reinforcing loop (labeled B1, B2 and R1, respectively) which are interpreted as follows:

B1: An increase in the profit gap induces ceteris paribus an increase in real investment of banks which in turn leads to higher output and higher profits; the increase in profits decreases the profit gap.

B2: An increase in the profit gap induces an increase in the fraction of short-term lending because this is a cheaper form of finance (compared to long-term financing). The higher proportion of short-term financing lowers ceteris paribus the financing costs of real investment and, thus, increases profits; the increase in profits decreases the profit gap.

[5] Certainly, this assumption is unrealistic; but it has no relevance for the qualitative behavior of the variables.

R1: An increase in the profit gap induces ceteris paribus an increase in real investment of banks which in turn leads to higher lending of banks. A higher volume of lending increases the financing costs, lowers the actual profits and increases the profit gap.

Next, the ideas developed in the CLD of Figure 1 are translated into a stock and flow diagram (see Figure 2).

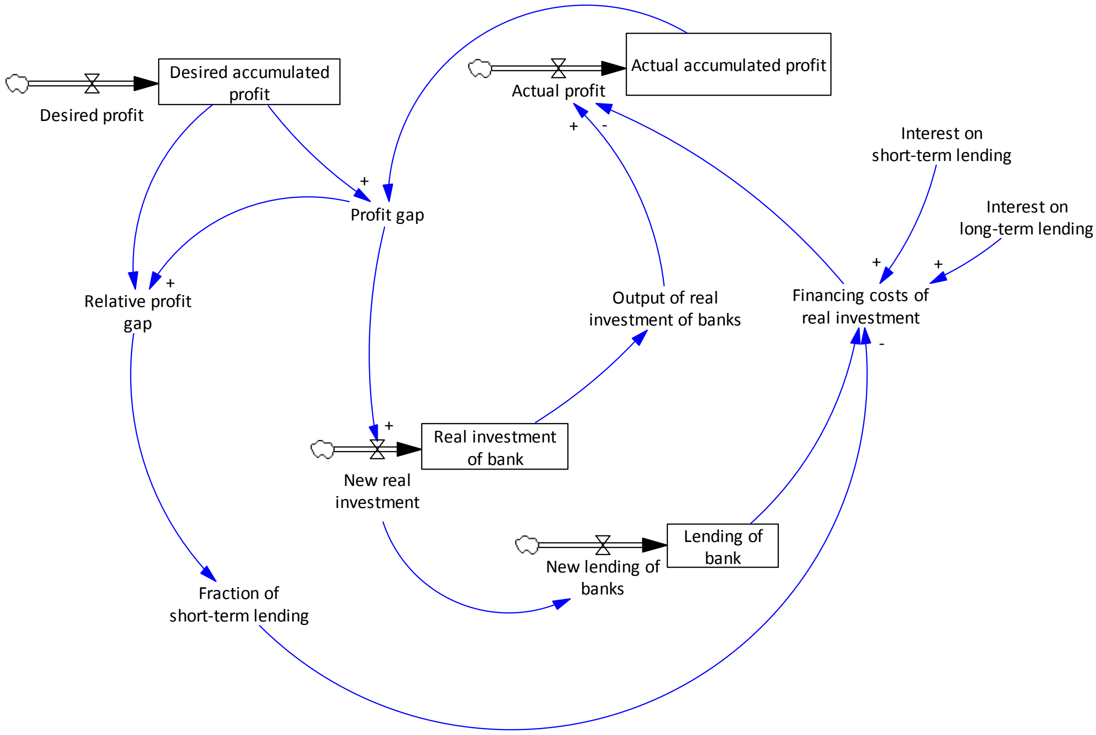

Figure 2

There are four stocks: desired and actual accumulated profit, real investment (real assets) of banks, and the lending of banks. To turn this stock and flow representation into a working simulation model we have to make several assumptions with regard to functional forms and parameter values. As stated above, this model is not meant to describe a specific real economy. Hence, we can choose functional forms and parameter values quite arbitrarily. The fraction of short term lending is calculated via a lookup function using the relative output gap as input. The production function is concave (we use a standard Cobb-Douglas-Function).

To give an intuition of the model we show in the following figures some simulation results which reflect different values of the short term interest rate (which is equivalent to a spread reduction because we keep the long-term rate at 0.06). In particular, the runs reflect short-term rates of 0.01, 0.02, and 0.03.

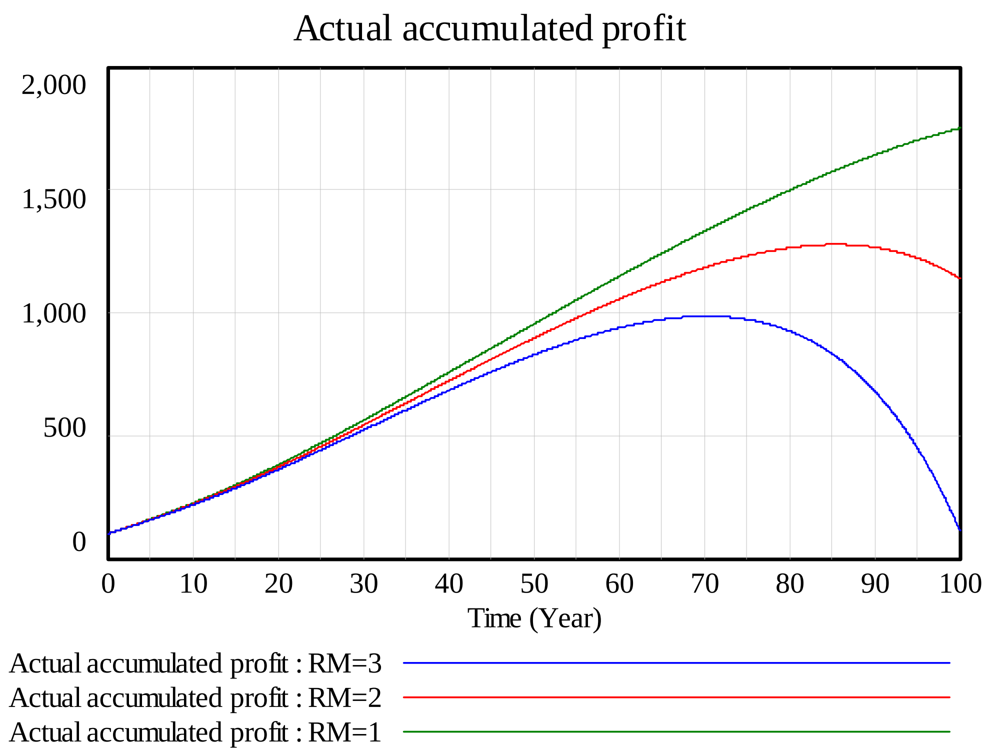

Figure 3

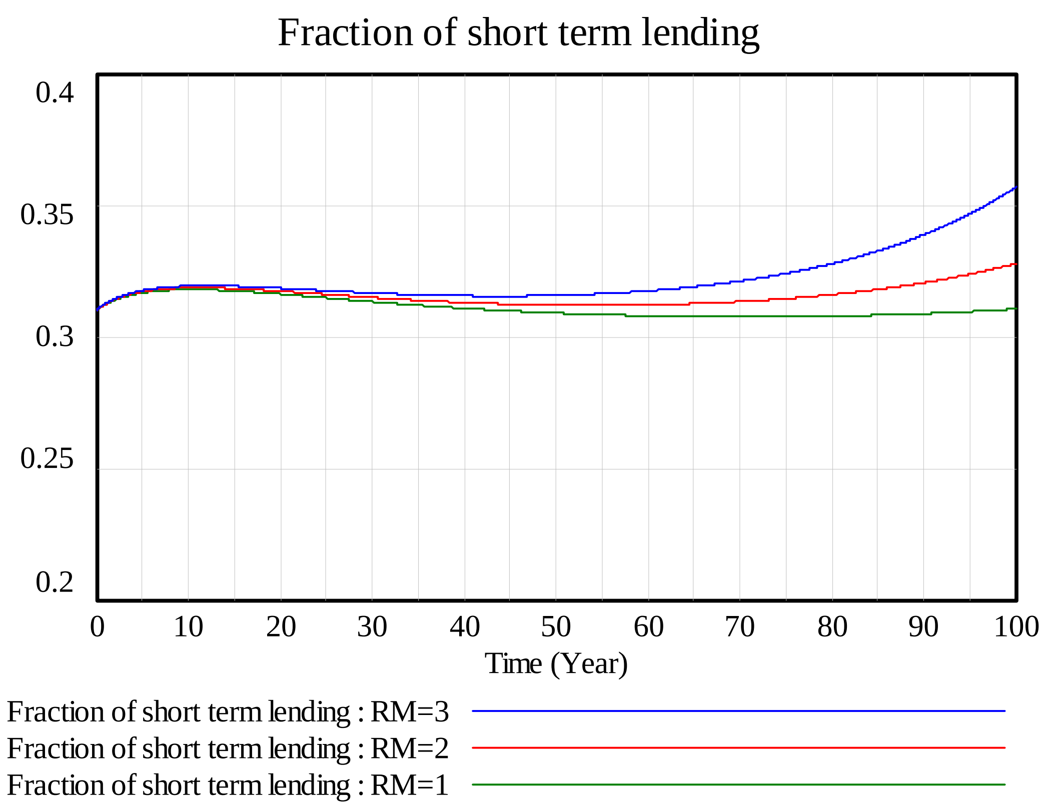

Figure 4

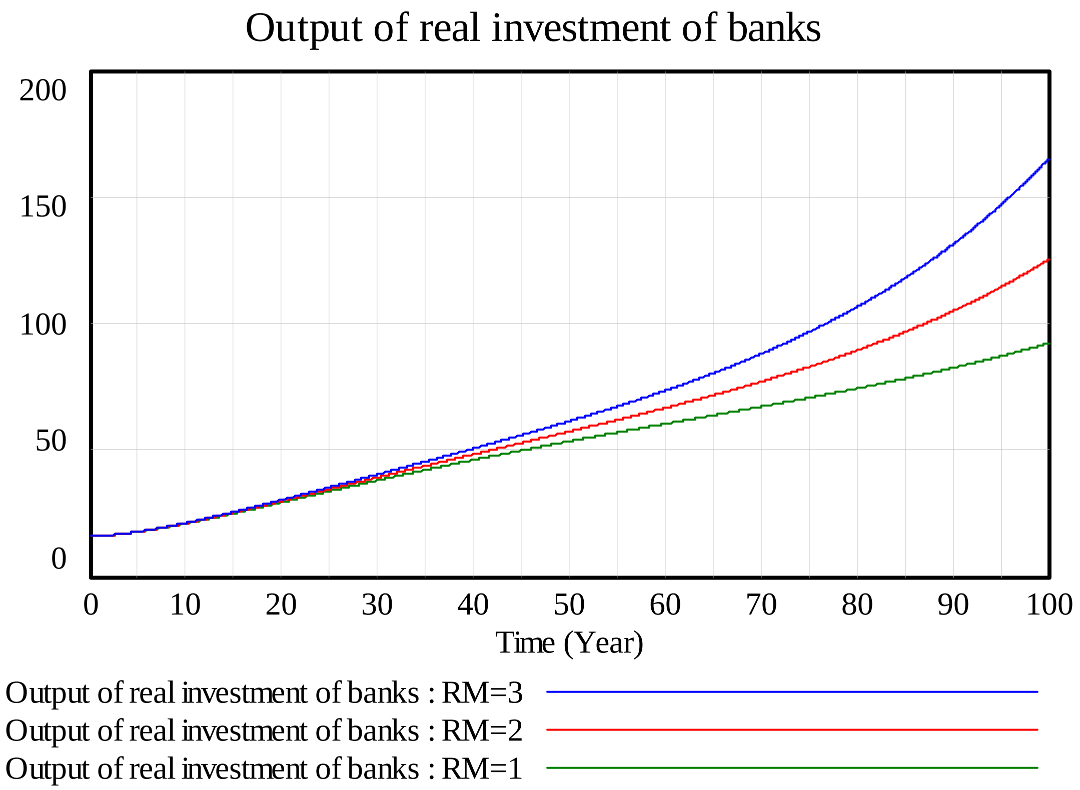

Figure 5

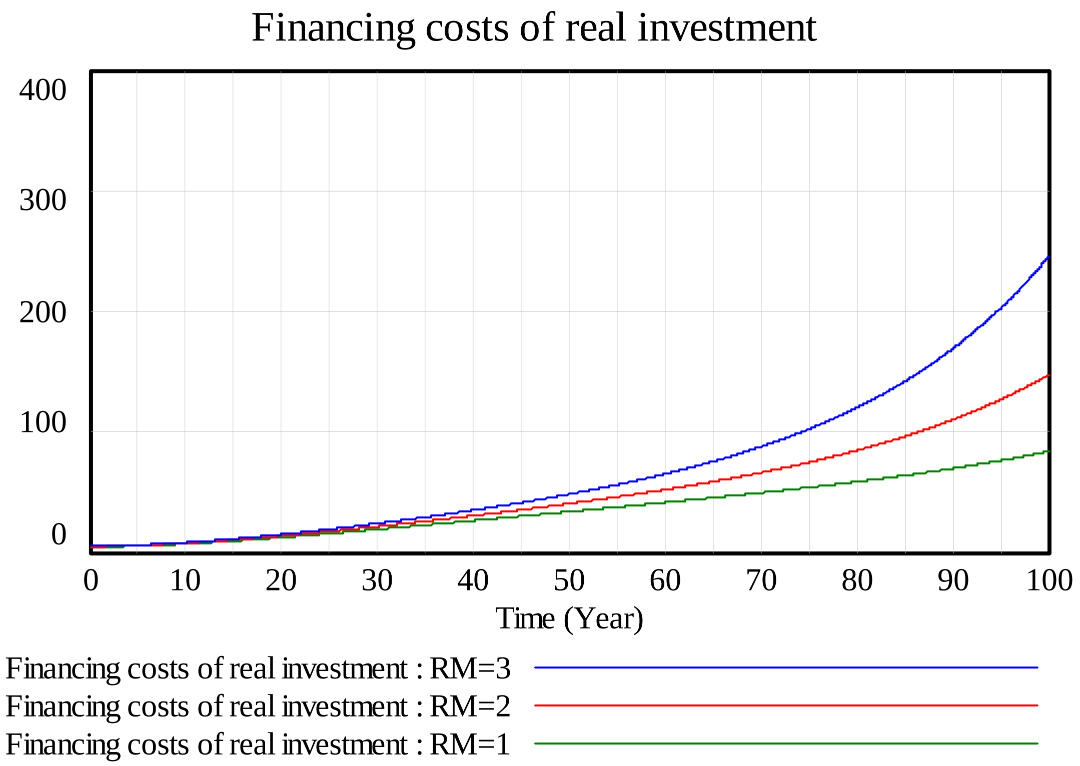

Figure 6

Fig. 3 shows the actual accumulated profit. Initially the profit is increasing. But after a couple of periods the accumulated profit starts to decline. The decline starts the earlier the smaller the spread between short-term lending and long-term lending is. The following figures reveal the reason for that behavior: In trying to bring the actual profit closer to the desired profit the banks increase investment and lending. At the same time they shift from long-term to short-term financing of their investment. From Fig. 4 we see that even the simple dynamics of our model keep the fraction of short-term lending away from increasing monotony. Interestingly, the increase in short-term lending is the more pronounced the higher the short-term interest rate is. At a first glance, this is a counterintuitive result. The driving force behind this result is the attempt to counteract the higher costs of financing investment by employing more investment and by shifting to (still) cheaper short-term financing. As Fig. 5 shows, the output increases. But the increase in output is overcompensated by the increasing financing costs in the long run. That is why the profit turns negative and accumulated profits fall in the end.

These first results of our model are promising. To us, it seems worthwhile to extend the model along the outlined ideas. Especially, the incorporation of the effects of a higher proportion of short-term financing on fire sales should yield interesting results. Without going into details, we refer to Fig. 7 which shows a preliminary version of a stock flow diagram making a suggestion on how to proceed.

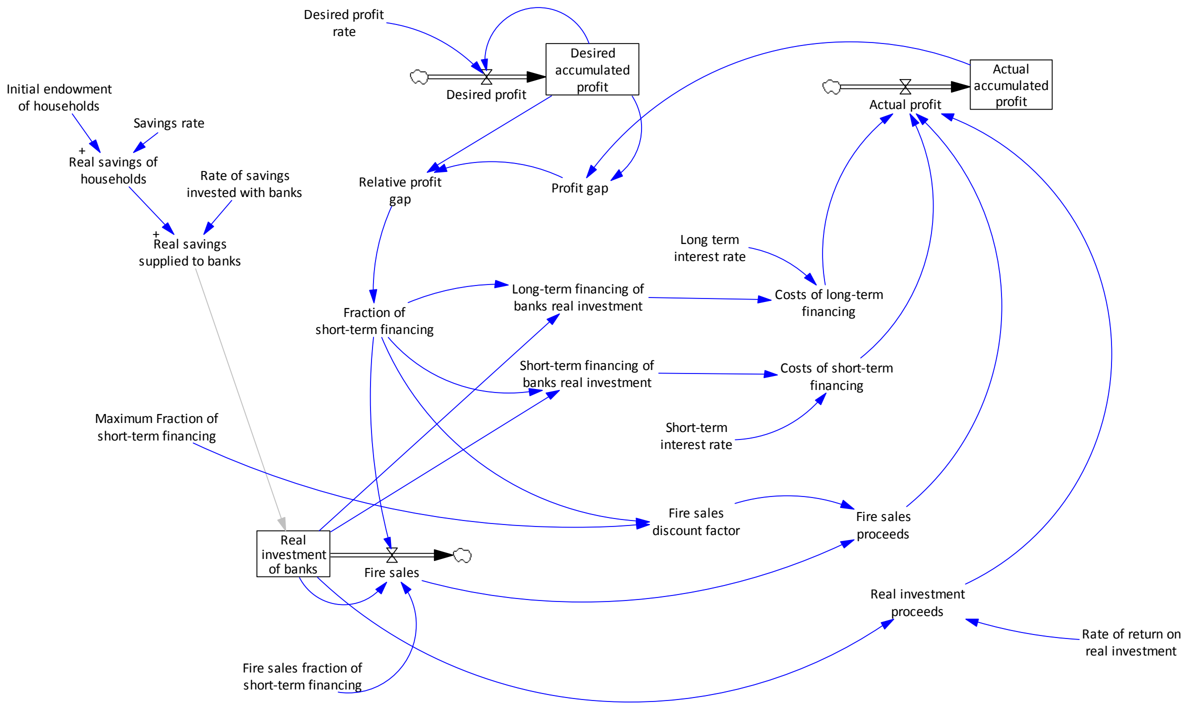

Figure 7

4. Conclusion

This paper started with emphasizing the idea that the now arising economic models of financial crises, monetary policy and macroprudential regulation should be improved by adding true dynamics. Therefore, it seems promising to link system dynamics thinking with economic modeling. We did so by introducing an economic model recently proposed by Stein. Thereafter, we developed a basic dynamic simulation model in order to show how the ideas incorporated in the Stein model may be translated into a system dynamics framework. Definitely, our model is not (yet) suited to answer specific questions about the conduct of monetary policy and macroprudential regulation. But we believe it to be a starting point for further development that in the end may contribute to answer such questions.

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