Policy experiments in an agent-based model with credit networks

Tiziana Assenza, Alberto Cardaci, Domenico Delli Gatti, and Jakob Grazzini

Abstract

In this paper the authors build upon Assenza et al. (Credit networks in the macroeconomics from the bottom-up model, 2015), which include firm-bank and bank-bank networks in the original macroeconomic model in Macroeconomics from the bottom-up (Delli Gatti et al., Macroeconomics from the Bottom-up, 2011). In particular, they extend that framework with the inclusion of a public sector and other modifications in order to carry out different policy experiments. More specifically, the authors test the implementation of a monetary policy by means of a standard Taylor rule, an unconventional monetary policy (i.e. cash in hands) and a set of macroprudential regulations. They explore the properties of the model for such different scenarios. Their results shed some light on the effectiveness of monetary and macroprudential policies in an economy with an interbank market during times of crises.

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1 Introduction

In a recent contribution, Assenza et al. (2015a) extend the macroeconomic agent-based model introduced in *Macroeconomics from the Bottom Up* (Delli Gatti et al., 2011) with the inclusion of firm-bank and bank-bank credit networks. The motivation for that work relies on the need to investigate the emergence of financial fragility, by exploring aspects that are related to network effects and the spillovers across markets that result from micro-interactions that reverberate at the macroeconomic level. Indeed, interbank markets are one of the most important elements of the financial system and they represent the focus of the implementation of monetary policies (Allen et al., 2009)

In this paper we go a step further in this direction: we build upon Assenza et al. (2015a) and extend that framework with some modifications – from the inclusion of the public sector, to a more detailed specification of the consumption function – with the ultimate goal of evaluating the impact of different policy experiments in the presence of an interbank market. In particular, we deal with different scenarios.

First, with run model simulations under a baseline calibration with a fixed nominal interest rate. Eventually we introduce a central bank operating via a standard Taylor Rule that targets inflation and we compare this scenario with the introduction of an unconventional monetary policy which is implemented by providing households with *cash in hands*. In particular, we investigate which of the two types of monetary policies is more effective in times of crisis, using the baseline scenario as the reference. Our framework also allows for the analysis of different types of macroprudential policies thus contributing to the hotly debated issue of macroprudential regulation Hanson et al. (2011); Shin (2011). More specifically, we act on two factors, representing the maximum bank leverage and the required liquidity ratio, in order to assess whether different regulatory scenarios significantly change the dynamics of the system in terms of stability and emergence of financial crises.

The paper is organized as follows. Section 2 introduces the main elements of novelty of our model compared to the previous Assenza et al. (2015a). Section 3 describes the main results of our computer simulations. Finally, Section 4 concludes.

2 The environment

The basic set-up of our model replicates the one reported in Assenza et al. (2015a), which extends the macroeconomic model described in Macroeconomics from bottom-up (Delli Gatti et al., 2011) by including a credit network of the firm-bank and bank-bank types, similar to Delli Gatti et al. (2010). As such, in this section we only focus on the extensions to that framework, thereby describing the main elements of novelty.[1] In particular, these include the introduction of a class of bankers; the modification of the consumption function; the introduction of some elements of friction in the labour market; the presence of a public sector with a government that issues bonds and a central bank that operates under a Taylor Rule. Let us analyse each of the aspects individually.

2.1 Bankers and bank dividends

The model introduces a class of bankers. Each of the bankers owns one bank and, as such, benefits from the distribution of dividends. In particular, each bank retains a portion $(1 - \phi_b)$ of its profits, while distributing a share ϕ_b to the corresponding owner.

2.2 Consumption function

The model features a consumption function defined as follows:

$$C_{t,h} = c_y(1 - \tau)y_{t,h} + \max[c_w - \phi_r R_t, 0]D_{t-1,h} \tag{1}$$

According to Equation 1, each individual consumes a portion c_y of her disposable income, $(1 - \tau)y_{t,h}$, where τ represents the tax rate on income. Additionally, households consume a portion of their wealth, $D_{t-1,h}$, which depends on the level of the real interest rate that negatively affects the individual propensity to consume out of wealth.

Individual income corresponds to the sum of wages for workers, firm dividends for capitalists and bank dividends for bankers.

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[1]For the full specification of the algorithms and rules of behaviour of the other parts of the model, see Assenza et al. (2015a).

2.3 Labour market

The labour market features two main elements of novelty compared to the previous version of the model. First, workers' wage ($w_{t,h}$) is determined endogenously in the labour market, as a function of unemployment. In particular, at each time t, the workers' wage in the previous period is updated by a factor that multiplies the difference between the target level of unemployment, U, and the current value of unemployment, U_t, by a sensitivity factor, ξ. As such, the higher the difference between U and U_t, the higher the current wage at time t.

$$w_{t,h} = w_{t-1,h}(1 + \xi(U - U_t)) \tag{2}$$

The second new aspect introduced in the labour market deals with the presence of an element of friction in the search and matching mechanism. In particular, in the previous version reported in Assenza et al. (2015a), any unemployed worker who finds a vacancy at a firm is automatically matched thus filling the vacancy and interrupting the searching process. However, in our framework, the matching process does not occur automatically. Rather, there is a probability associated with it, so that unemployed workers who find a vacancy may have to keep on looking for one if the matching does not occur at the first try.

2.4 Public sector

The model features a public sector composed by a government and a central bank.

In each period the government sets a desired level of public spending, G_t^d, as described in Equation 3. The evolution of the desired public spending is related to the level of public debt relative to GDP, as we assume that the government has to meet a specific target ratio. In particular, G_t^d equals its value in the previous period multiplied by a positive scaling factor, ϕ_t^G, if the public debt-to-GDP ratio in the previous period, PD_{t-1}, is less or equal to its target value, $\overline{PD}$.

$$G_t^d = \begin{cases} G_{t-1}^d(1 + \phi_t^G) & \text{if } PD_{t-1} \leq \overline{PD} \\ max[G_{t-1}^d(1 - \phi_t^G), 0] & \text{if } PD_{t-1} > \overline{PD} \end{cases} \tag{3}$$

Notice that the scaling factor ϕ_t^G is a function of the relative distance, ϵ_t, between the actual value of the public debt-to-GDP ratio and its target level. In particular, the larger such distance, the greater the value of ϕ_t^G and, as a consequence, the stronger the adjustment in the

level of desired public spending. Additionally, ϕ_t^G oscillates within two boundaries, ϕ_{min}^G and ϕ_{max}^G, defined in the parametrisation of the model.

$$\phi_t^G = \phi_{min}^G + \frac{\phi_{max}^G - \phi_{min}^G}{1 + \frac{1}{|\epsilon_t|}} \tag{4}$$

$$\epsilon_t = \frac{PD_t - \overline{PD}}{\overline{PD}} \tag{5}$$

The government collects taxes on income based on an exogenous tax rate. If the amount of collected taxes is not enough to finance desired government spending and the repayment schedule, the government enters the bond market to find the necessary external finance. As such, bond supply, BS_t, in each period equals the sum of desired government spending, G_t^d, and the balanced owed on the existing public debt, rep_t, net of tax revenues, T_t.

$$BS_t = max[G_t^d + rep_t - T_t, 0] \tag{6}$$

The demand side in the bonds market features banks. In particular, for simplicity, we assume that banks want to convert a fixed share of their liquidity into bonds. The functioning of the market is based on a simple search and match mechanism: banks are sorted randomly so that banks obtain the desired amount of bonds, as long as the supply is still positive. In case the market is short of demand, the central bank can operate as a lender of last resort. This indeed occurs only when all the commercial banks have obtained the desired amount of loans and the residual government supply is still positive.

Bonds correspond to a multi-period repayment schedule for the government, which is based on the nominal interest rate set by the central bank, for simplicity.

The central bank operates under a standard Taylor Rule, thus determining the nominal interest rate, i_t, as a function of the target interest rate, $\bar{i}$, the actual interest rate in the previous period and the inflation gap, that is the difference between the current inflation rate, π_t and the its target level, $\bar{\pi}$. As shown in Equation 7, these factors are multiplied by three sensitivity parameters, respectively α_1, α_2 and α_3.

$$i_t = \alpha_1 \, \bar{i} + \alpha_2 \, i_{t-1} + \alpha_3 \, \phi_p(\pi_t - \bar{\pi}) \tag{7}$$

Also notice that the central bank has a minimum and maximum nominal interest rate that define the limits of oscillation of the actual interest rate, so that $i_t \in [i_{min}, i_{max}]$, where i_{min} and i_{max} are exogenously calibrated.

3   Simulations

We investigate the macro and micro features of the model described in this paper by means of computer simulations. Simulations are implemented under the parameter vector and the initial conditions reported in Assenza et al. (2015a). Table 1 reports the value of the new parameters introduced in our extension of the model. At this stage we do not want to replicate any empirical regularities, rather the choice of the parameter vector is based on the need to rule explosive dynamics and unrealistic patterns.

Parameter	Value
c_y	0.9
c_w	0.2
τ	0.05
ϕ_r	0.05
ξ	0.001
α_1	0.1
α_2	0.9
α_3	0.1
ϕ_p	0.01
$\bar{\pi}$	0.02

Table 1: Model calibration.

Our simulations are implemented by means of Monte Carlo (MC) repetitions with 50 different random seeds in each scenario. Eventually we compute the cross-simulation mean of the key variables for each scenario. The model runs for 10000 periods representing one week each. Results are eventually represented and discussed in quarters. In all the simulations we drop the first 100 periods in order to get rid of transients.

We proceed as follows: first, we analyse model dynamics in the baseline scenario, thereby discussing the main factors that drive the system on the brink of a crisis. Eventually, we are going to compare the different policy implementations introduced in the other scenarios.

The baseline scenario consists in the simulation of the model under the calibration specified above. In this case, however, the Taylor Rule is not active, so that the central bank fixes a constant nominal interest rate equal to 2%.
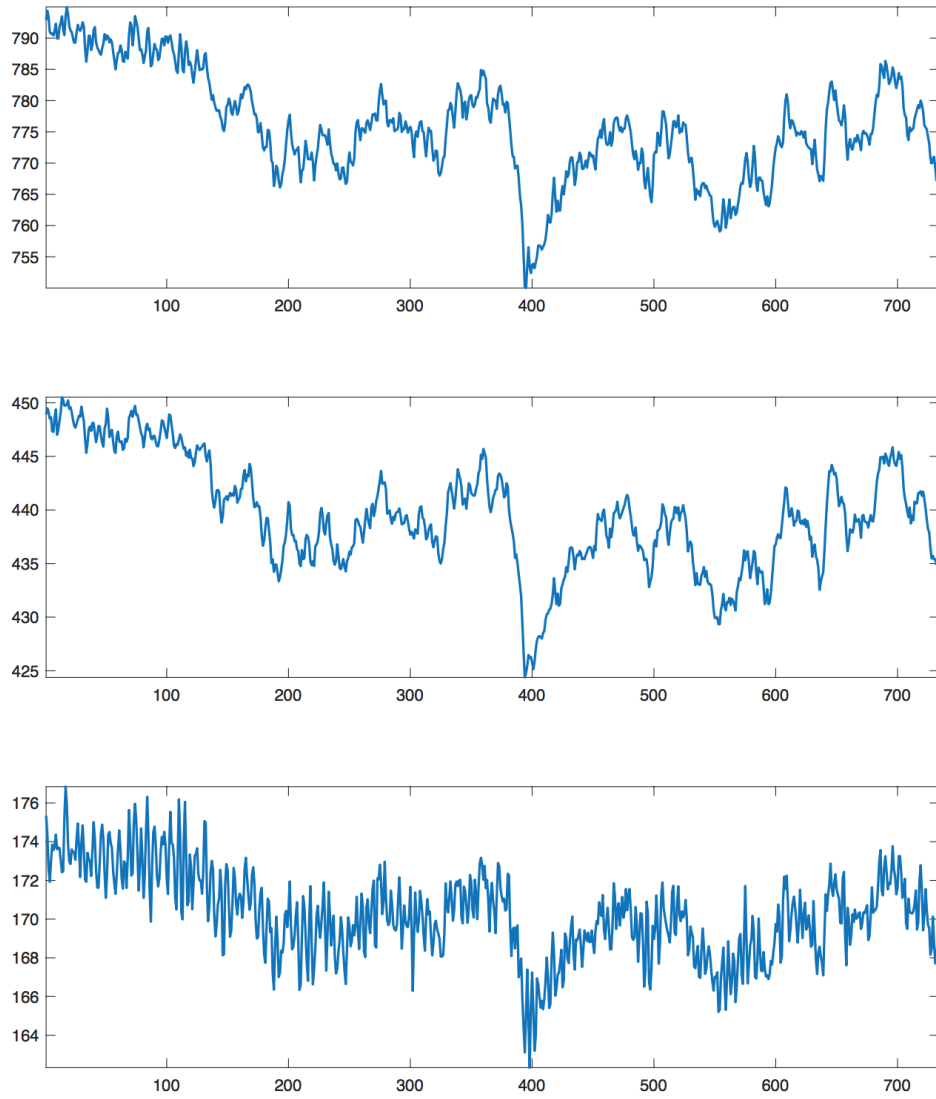
Figure 1: Production (top), consumption (middle) and government spending (bottom) in the baseline
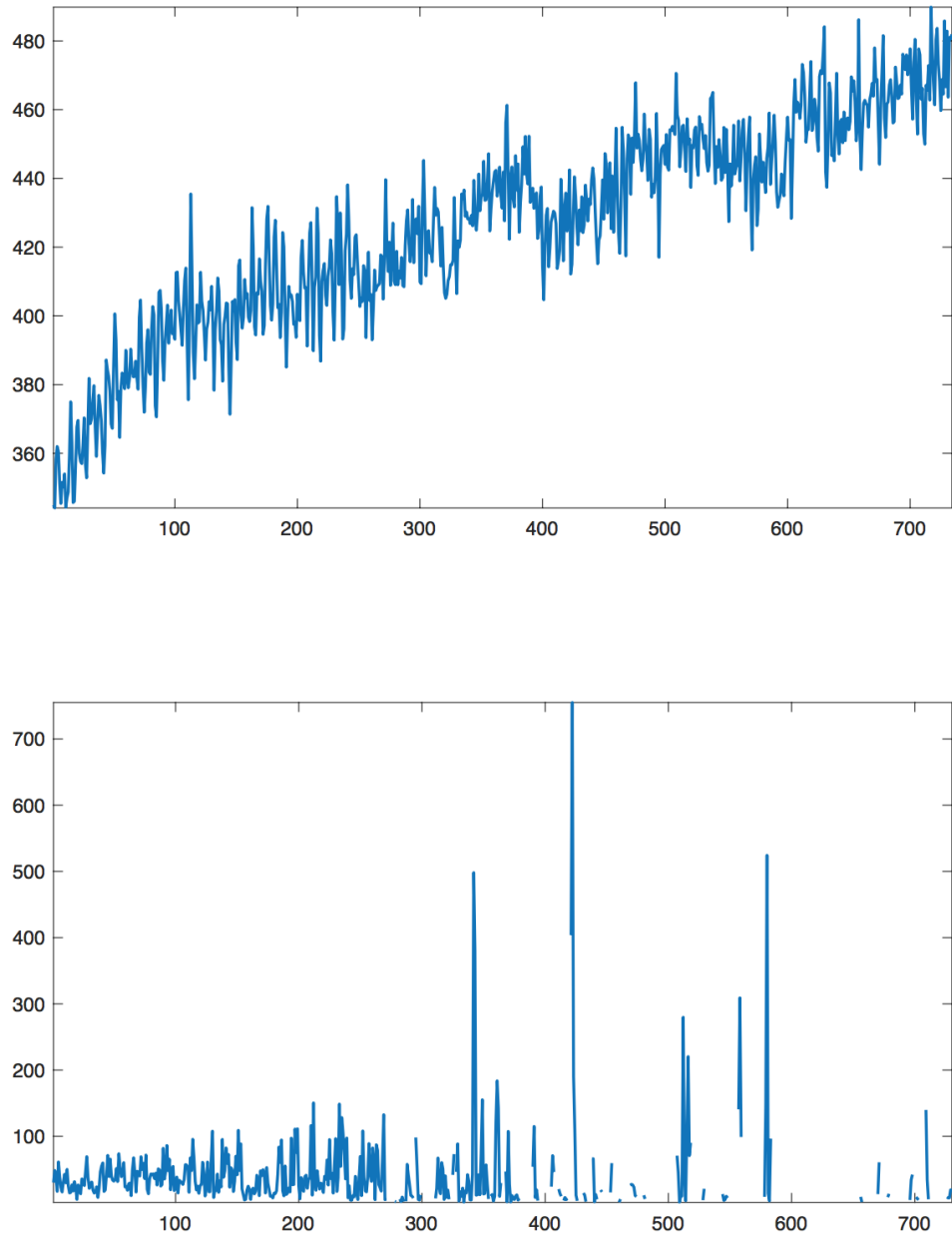
Figure 2: Total credit issued by the banking sector (top) and overall amount of loans issued in the interbank market (bottom).
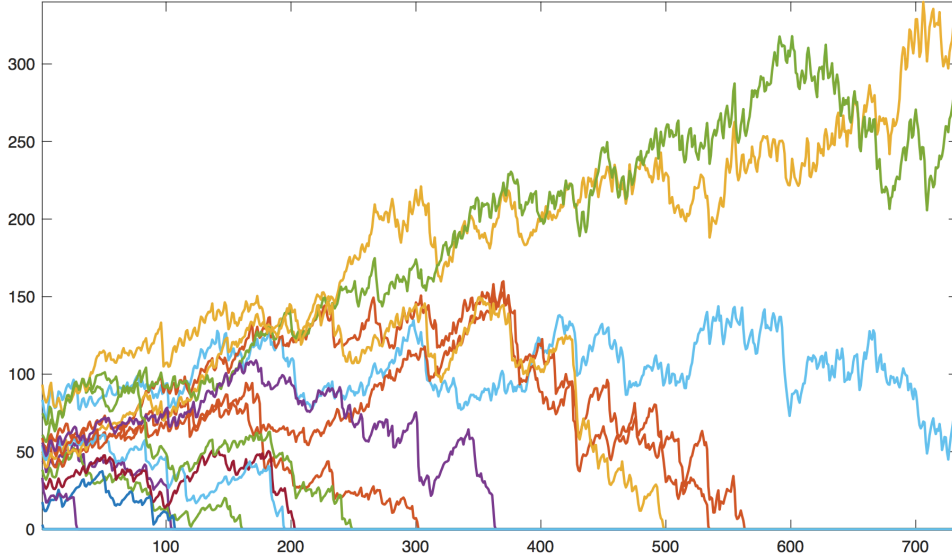
Figure 3: Total bank equity for each bank b.

Compared to the first work described in Assenza et al. (2015b), the modifications that we have implemented play a major role in affecting model dynamics. In particular, in the previous version of the model, the economy moved along a stationary path with two sizeable endogenously determined episodes of recession. Our results, instead show that production moves with a more irregular pattern characterised by minor oscillations along a constant trend, indicating the emergence of some booms and busts, as well as a major episode of crisis around period 400, lasting about 40 quarters which correspond to 10 years (Figure 1). In this phase, the contraction of the economy also corresponds to a fall in private consumption as well as government spending.

The amount of credit being issued by the banking sector also experiences a contraction during the period of crisis, as shown in the top panel in Figure 2. It is also worth pointing out that the interbank market is now much more active compared to the previous version of the model. In particular, banks seem to interact with each other in the interbank market especially right before the crisis and during the turning point at the end of the recession, when the amount of loans exchanged in the interbank market peaks at roughly more than 700 (Figure 2, bottom panel).

Some other interesting dynamics take place in the banking sector. Figure 3 shows the evolution over time of the equity of each bank b. There are two relevant aspects. First, the banking sector experiences the default of 14 out of 20 banks before the emergence of the major crisis at around period 400. In particular one of the big banks (in terms of equity) goes bankrupt slightly before the beginning of the crisis. This phenomenon may be partly responsible for the

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decline in total credit and the exacerbation of the crisis. In a way, our finding identifies the pivotal role of some banks in driving model dynamics to the crisis. By adopting the terminology by the (Financial Stability Board, 2011), such banks in our model may be defined as Systemically important financial institutions (SIFIs): they are financial institutions whose distress, because of their size, complexity and systemic interconnectedness, causes significant disruption to the wider financial system and economic activity.

The second aspect is the strengthening of the surviving banks in the market, as their equity grows remarkably over time.

Let us now analyse the impact of the different monetary policies, as well as the introduction of the macroprudential regulations described above. We have four different scenarios: TR, CH, Prud-E and Prud-L.

In the TR scenario, the Taylor Rule is activated and the nominal interest rate evolves endogenously as described in Equation 7. In the CH scenario, the central bank still operates under the Taylor Rule specified above. However, any time a long recession hits the economy, the central bank also provides households in the economy with an amount of money equal to the 0.01% of nominal GDP, until the recession stops and the economy gets back on a recovery path. This is an unconventional monetary policy of the cash-in-hands type. In the Prud-E scenario, the maximum leverage ratio of the banking system changes endogenously in order to tighten the limit on the banking borrowing capacity. The change in the maximum allowable leverage ratio is triggered by recessionary episodes. Finally, in the Prud-L scenario, the required liquidity ratio of the banking system changes endogenously in order to increase the required amount of liquidity that each commercial bank has to hold. Also in this case the change in the required liquidity ratio is triggered by any recessionary event. Notice that in both Prud-E and Prud-L, the central bank still operates under the Taylor Rule.

Our analysis looks at the stability of the system from different perspectives.

A first aspect consists in the comparison of the different scenarios based on the number of bank defaults, the number of crises and the average crisis duration (in quarters). Each of these values is computed across the 50 MC simulations. In particular, a crisis includes a recession and a recovery, where the recession is defined as any time the rate of growth is negative and production falls below its corresponding exponential moving average for more than 25 periods (corresponding roughly to 2 quarters).

These values allow to have an intuitive picture of the effectiveness of the monetary and

macroprudential policies implemented in the various scenarios.

	Number of bank defaults	Number of crises	Average crisis duration
Baseline	16	4	12
TR	17	3	8
CH	16	3	11
Prud-E	16	3	12
Prud-L	16	4	12

Table 2: Scenario comparison in terms of number bank defaults, number of crises and crisis duration in quarters.

Our results suggest that the economy has a similar performance across the scenarios regarding the number of bank defaults (Table 2). However, the TR, CH and Prud-E scenarios seem to be more stable compared to the other two scenarios, as the number of economic crises amounts to 3 compared to 4 in the other cases. The major element of difference, however, can be found in the average duration of the crises: the number falls to 8 quarters in TR, while reaching 12 quarters in the baseline, Prud-E and Prud-L. To put it simply, it seems that the conventional monetary policy implemented via a simple Taylor Rule represents the most effective policy response in order to reduce the length of the crises in the economy. Hence, in line with Delli Gatti and Desiderio (2015), we find that the standard Taylor Rule is quite successful as an effective macro-stabilization tool. More specifically, TR represents the most stable scenario in our simulations.

	Average real GDP	Variance	Coefficient of variation
Baseline	777.53	92.96	0.012
TR	786.83	29.99	0.006
CH	779.91	64.49	0.011
Prud-E	778.51	75.86	0.011
Prud-L	778.52	79.97	0.011

Table 3: Scenario comparison in terms of GDP levels and variations.

This result is confirmed also by the analysis of the dynamics of production in the different scenarios. In particular, Figure 4 shows the time series of real GDP in the baseline compared to TR and CH. It is possible to notice that production is, on average, higher in TR compared to CH. Indeed, the average real GDP is 786.83 in TR and 779.91 in CH, with a coefficient of variation of 0.006 and 0.011 respectively.

Table 3 also shows that the average level of real GDP in the baseline is 777.53, with a coefficient of variation of 0.012. These values confirm the positive stabilising effect of the
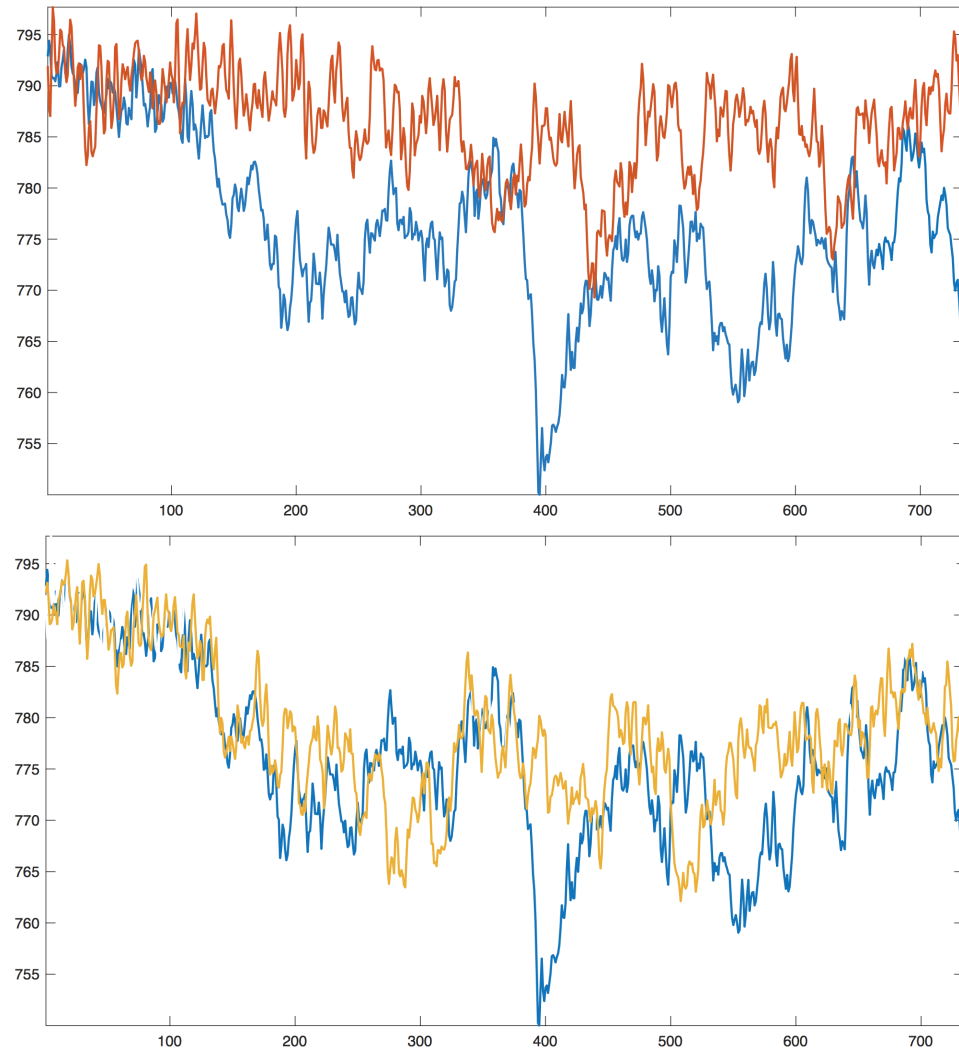
Figure 4: Production in the baseline (blue), in TR (red) and CH (yellow).

introduction of the Taylor Rule compared to the baseline and the unconventional monetary policy. Also, there seems to be no sizeable distinction between the two macroprudential policies, especially by looking at the average real GDP as well as its corresponding coefficient of variation.

4 Conclusions

Our paper introduces some extensions to the recent model developed in Assenza et al. (2015b). In particular, we include an improved specification of the consumption function, some frictions in the labour market and a public sector with a government operating in a bonds market and a central bank. Our extensions significantly modify the main results obtained by Assenza et al. (2015b). In particular, the interbank market now has a much more active role in our artificial economy. Additionally, the dynamics of the macro time series such as production and aggregate consumption show a much different pattern, characterised by minor oscillations and the presence of a major episode of crisis. Moreover, the inclusion of the public sector, and the better specification of some mechanisms in the banking sector, allow us to test different policy scenarios by means of computer simulations. In particular, we compare the implementation of a monetary policy under a standard Taylor Rule with an unconventional policy of the cash-in-hands type. Our results highlight the slightly better performance of the economy under the first type of policy, as the model shows a lower number of crisis and a shorter duration of the recessionary events. A further element of our work consists in the analysis of two macro-prudential policies implemented via a modification of the maximum allowable leverage ratio and the required liquidity ratio of the banking sector. The former seems to be more effective than the latter in terms of frequency of crises. However, no difference seems to emergence as far as the duration of the crises is concerned. In particular, the policy acting on the required liquidity ratio determines no modifications compared to our baseline scenario.

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