Appendix A

ODD: Macroeconomy from the bottom up: Studying the implications of a monetary authority's behavior in a macroeconomic agent-based model with a central bank.

ODD Template

The model description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al. 2010).

Introduction

Since the last financial-economic crises the economist has a new challenge: generate tool robust enough to resist time of crises. In difficult times the conventional tool of analysis had demonstrated limited support to the policymakers. Hommes (2015) had shown us that the atomistic optimizing agents underlying existing models do not capture the behaviors during a crisis period. Their point is, we need a better way to deal with heterogeneity among agents. This brings us an alternative motivation for economic choices based on behavioral economics draws on psychology to explain decisions made in a time of crisis circumstances, which need to be modeled into the agent-based framework.

The model we work on here could find as origins from Brock and Hommes (1997), Brock and Hommes (1998), going thru Gatti at al. (2011), and it is close to Assenza et al. (2015). In Assenza et al. (2015) you can find the core of our model, in its works they generating a macroeconomic agent based model with credit and capital. That means one virtual economy which has a consumption market, has a job market and also has a capital goods market. This model is capable of reproducing stylized facts, such as the series of GDP, unemployment, and series of prices. The interesting thing is, this model had created endogenously crises; which here will mean a sequence of time when GDP shrinks abruptly and induce a high level of unemployment. But, so far, the model has no government and no monetary authority. We include the figure of the monetary authority.

Purpose

We inserted a monetary authority into a Macroeconomic Agent-Based Model with Capital and Credit and verify the interaction between the central bank and the rest of the economy, thus offer a tool for policymaker simulate monetary policies.

Entities, state variables, and scales

- *Agents*. We use agents to represent the minimal unit of a behavior of the members at this economy; they will represent the participants of the productive, consumption, and the financial sector of an economy.
- *Spatial units*. The patches of the grid will be occupied by only one firm per patch. There will be as many patches as a number of firms.
- *Environment*. The households can transit among the patches freely. The position of the firms is constant during all the experiment; they do not change their address. All the patches have the same characteristics. Each period will represent a quarter, the simulations may be running for an arbitrary number of periods.
- *Collectives*. We will divide our agents into three types: (i) the first one, will be the firms, responsible for the production in this economy; (ii) the householders, among them there will be the workers and the owners of the firms; (iii) the financial sector, we will stylize the financial sector in a way which will a commercial bank, and a monetary authority – which will manage the basic interest rate of our economy.

AGENTS

Production sector

The firms will be divided into two groups: (i) producers of consumption goods; and (ii) the producers of capital goods. The first one is absolved by the households, and the second one is buying for the firms which produce consumer goods.

Financial sector

One commercial bank will receive the deposit of the households and firms. The bank will not charge for this service, but he will charge the firms that need for credit. The bank receives the deposit of the agents into this economy and supplies the credit market. There is a minimal rate (risk-free interest rate); this rate is decided by a central bank. The central bank does not make any contact with the productive sector or the households; it only controls the minimal interest rate.

Households

The households of this economy are divided into two groups: the workers; and the capitalists. The workers sell their workforce in the job market to the firms, receive wages, and use the wages to buy goods into the consumption market. The capitalist is the owners of the firms and the bank. Each firm has only one owner. Each capitalist has the same share of the bank.

Information

The available information is limited; any agent has access to see complete information. The firm which produces consumption goods will know the level of price practiced in their sector and the quantities demanded from their clients. The firms which produce capital goods will know the level price of their sector and also the quantities demanded from their clients. These will be the information available during the decision process of the firms.

The households can visit a restricted number of firms per period. They will have as information the prices of the firms visited, and the quantities ready to sale by these firms. At the moment to decide how much and from whom to buy this will be the set of information used by the households.

The bank will need to decide whether to offer or not a loan and what rate to use in each transaction. For that, the bank will measure the financial health of the firm, this means, find out how much leveraged the firm has. The bank will know how much money the firm has deposited with it, and the bank will know how much credit the firm had taken before. As all this information is available for each firm individually; the bank can construct a risk for the entire market.

The central bank has a concern about production and about the prices movement – inflation. It will decide what to do with the free interest rate based on his observation of these two variables.

Process overview and scheduling

Time will be a discrete variable where each period will represent a quarter. In each period the firm will decide how much to produce and what price to use. The households will decide how much to consume, if do not consume all the income within the period they will save their remaining money – they made a deposit in the bank.

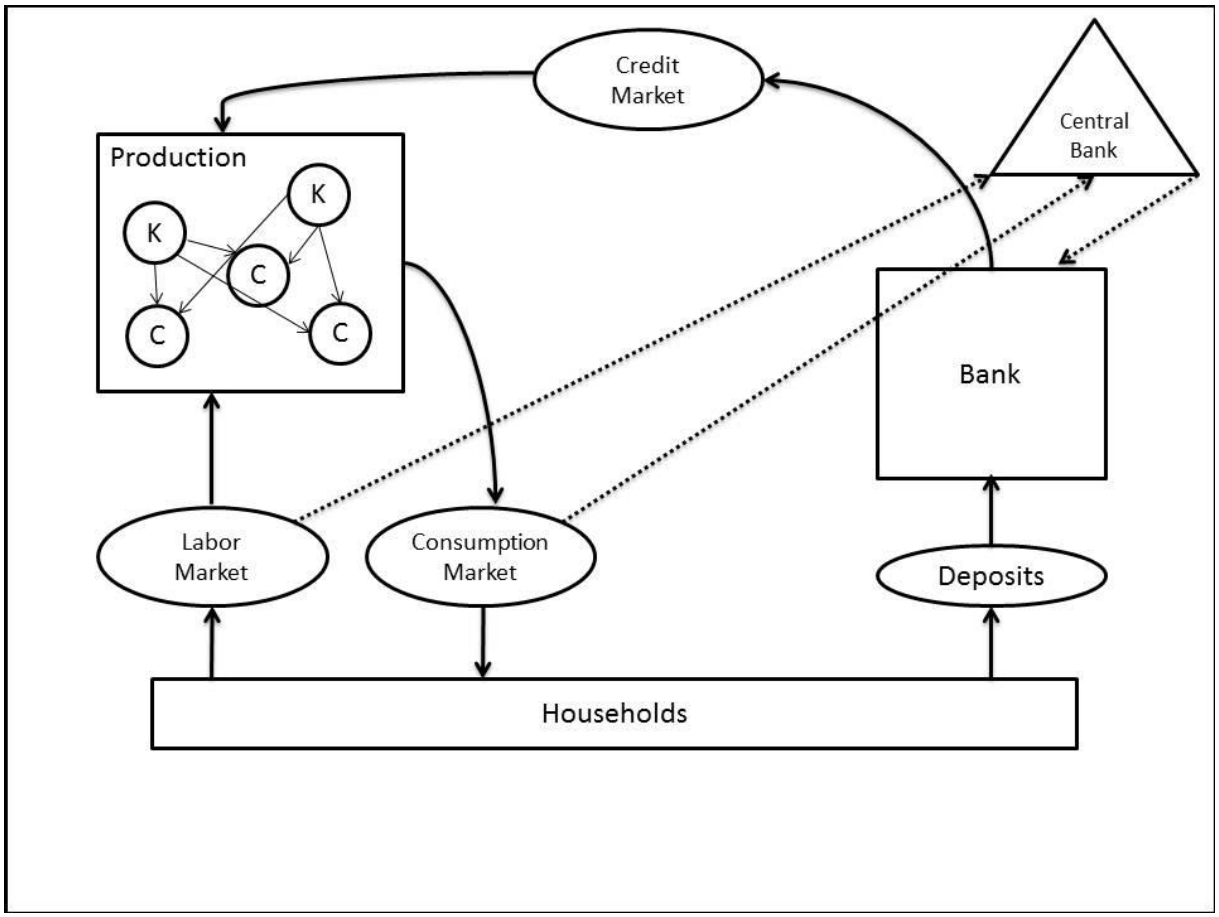

Figure 1: Agents and markets; production sector with firms that produces capital goods (K) and consumptions goods (C)

Job market

The unemployed workers will visit a restricted number of firms trying to find a job position. The wages are homogenous, so the worker will accept the first job offer they receive. The productivity is homogenous among the workers, and through the time, then the firms will contract the first worker to apply for their vacancy position.

Consumption market

The households have a certain amount of money that need to consume for each period, they will visit a restricted number of firms and try to buy their goods at the firm with the lower price. In that case, the firm with the better price will not have the enough quantity for the household, so the households will buy in the next firm. When there are not enough goods in all firms visited the household will save money.

Capital market

The consumption firms will need to combine labor and capital in a way to produce goods. The capital and the labor are perfect complements (a Leontief production function). The consumption firm will visit the capital producer's firms and try to buy for the lower price, similar to the behavior of the households in the consumption market.

Credit market

Sometimes the firms will need to access the credit market. Doing so, the firms will ask the bank for a loan. The bank will measure if it has enough available money for that firm which is asking for a loan, and the bank will also decide which interest rate he will apply for that loan. For the formation of the interest rate, the bank will use this set of information together with the free interest rate – which is determined by the central bank.

Design concepts

Basic principles. The macroeconomy we simulated here emerge as a result from the behavior of individuals which are trying to maintain their consumption level through the time. That comes from the permanent income life circle hypothesis, which means, the individual will consume not only in a base in their income of the moment, but will also consider their expectation of the entire life wealth. The firm will have some monopolistic power; so, some firms may have extraordinary profit performances, at the same time some other firms may be in trouble times. The limitation of information is a key fact that induces these situations described before. As the economy will not be run at full capacity, sometimes in a period of crises, we have space for some adjustments. The introduction of a monetary authority into the model comes in this direction.

Emergency. The individual errors at the forecast formation may drag some firms at difficult financial times, it will be transmitted to the others firms by the credit market. As a result of a positive feedback, we will be able to see a series of investment with abrupt interruptions. This occurs because the bank uses the risk of the market to decide whether or not conceive credit. So, one particular firm could be in a good financial health situation, but see their credit go restricted because the environment is not in a good time. The series of GDP and employment which emerge are also affected by these circumstances and will also show abrupt movements.

Adaptation. The households will use an adaptation rule to decide how much to consume each period. The idea is the household will measure the wealth of their entire life, not only the revenue of the period, at moment to decide how much to consume. So, in each period the household will reformulate their knowledge of their own fortune (the amount deposited at the bank plus the revenue of the period). The firms will adapt their quantity produced and their price practiced; increasing or decreasing their production they will affect the job market (hiring of firing workers).

Objectives. The central bank tries to keep the unemployment level low, but at the same time, it would like to avoid big changes at the level price. The households will consume the goods using a hole of thumbs to decide how much to consume in each period. The firms will try to have profit, for that they try to sell their production and update their prices goods, as well adjust their labor's demands.

Learning. Not applied. The rules will be the same for all the experiment.

Prediction. The households, when behaving as consumers, think the proximate future is a continuous of the recent past, their rule of thumb for consuming will not change over time. That means, if he has a job at this time, for example, it will behave as it also has a job in the next period – what may not be true.

Sensing. The households can see the prices and the quantity available at the firms they visit. The consumer goods' production firms can see the price and the quantity available at the firms they visit trying to buy capital goods.

Interaction. The households interact with firms by opportunism, each period they can visit and buy from different firms, there is no such thing as fidelity's behaviors. The firms will interact with each other in an indirect way into their own sector. They will compete by price and by quantity. Since the households have no fidelity, firms have a difficult job trying to formulate their forecast; the competition will happen using the information of the previous period. The bank has a direct interaction with the firms, receiving and conceiving financial services.

Stochasticity. When the firms need to chance their prices, up or down, we used a stochastic way to do so. The firm will raffle the number from a uniform distribution every time it needs to create a new price and then charge the new price with a small variation using this mechanism.

Collectives. For the point view of the bank, there are two groups. The consumer goods' firm production and capital goods' firm. The bank will use these two collectives to generate a risk market, which increases with the number of firms in financial difficulty into each sector.

Observation. The series of GDP, price, and unemployment rate can be exported and analyzed. The credit market behavior can also be exported, via the quantities of loans conceive and denied, the connection with the GDP is a key to understanding the crises. These data may be collected by the end of the simulations

Initialization

We start with 200 consumptions firms and 50 capital firms, each firm uses a position of the grid. The bank and the central bank will use arbitrary positions, their address will coincide with one of the others firms. So, the grid has 250 patches. Will exist 250 capitalists, and they will be linked with one unique firm each one. The total of workers is 3,000.

The initial conditions and the parameters are disposals at Table 1, these parameters were settled using real data from the FRED's database from Federal Reserve among the years of 1955 to 2013. Taylor's parameters are described as in Taylor (1993). Details can be found at the Assenza at al. (2015).

Table 1: Parameters and initial conditions.

Parameters	Description	Value
T	Number of periods	3000
H	Number of workers	3000
F_c	Number of consumptions firms	200
F_k	Number of capital goods firms	50
Z_e	Number of firms visited by unemployed workers	5
Z_c	Number of consumptions firms visited by a consumer	2
Z_k	Number of capital goods firms visited by a C-Firm	2
ε	Memory parameter, human wealth	0.96
τ	Dividend payout ratio	0.20
χ	Fraction of wealth devoted to consumption	0.05
r	Initial risk free interest rate	0.01
ρ	Quantity adjust parameter	0.90
η	Price adjust parameter (random variable)	U(0,0.1)
μ	Bank gross mark-up	1.20
α	Productivity of labor	0.50
κ	Productivity of capital	1/3
γ	Probability of investing	0.25
ζ	Bank's loss parameter	0.002
θ	Installment on debt	0.05
δ	Depreciation of capital	0.02
ν	Memory parameter (investment)	0.50
$\overline{\omega}$	Desire capacity utilization rate	0.85
w	Wage	1.00
D_1^f	Initial liquidity of all firms	10
K_1	Initial capital	10
Y_1^c	Initial production (consumptions firms)	5
Y_1^k	Initial production (capital goods firms)	2

E_1^b	Initial equity of the bank	3000
E_1^h	Initial households' personal assets	2
r^*	Natural interest rate	0.01
π^*	Desire inflation for the monetary authority	0.01
α_π	Taylor' rule parameter for inflation	0.50
α_Y	Taylor' rule parameter for product	0.50

Submodels

At the consumption market the workers and the capitalists will behavior at the same way. Their sources of income will be:

$$Y_{c,t} = \begin{cases} w\,,\ if\ he\ is\ a\ worker\ with\ job\ contract, \\ \tau\pi_{f,t-1},\ if\ he\ is\ capitalist\ receiving\ dividends. \end{cases} \quad (1)$$

$Y_{c,t}$ *is the actual income,* $Y_{c,t} \in (0,\infty) \subset \mathbb{R}$;

w *is the wage,* $\omega \in (0,\infty) \subset \mathbb{R}$;

τ *is the dividend ratio,* $\tau \in (0,1) \subset \mathbb{R}$;

π *is the profit of the period,* $\pi \subset \mathbb{R}$.

The households have a limited rationality, they will use a rule of thumb to decide how much to consume. First, he estimates their own lifetime wealth, $\bar{Y}_{c,t}$, as a proxy of their own future income, that means, he expected in the future their wealth will be similar then nowadays. For that, they will use this adaptive rule:

$$\bar{Y}_{c,t} = \varepsilon\bar{Y}_{c,t-1} + (1-\varepsilon)Y_{c,t}, \quad (2)$$

$\bar{Y}_{c,t}$ *is the lifetime wealth estimative,* $\bar{Y}_{c,t} \in (0,\infty) \subset \mathbb{R}$;

ε *is the memory parameter,* $\varepsilon \in (0,1) \subset \mathbb{R}$.

If the household has no income in determined period he still consumes. In this situation he will decrease his savings. Also, will occur decrease in the agent's savings account when the consumptions of the period are bigger than the income:

$$D_{c,t} = D_{c,t-1} + Y_{c,t} - C_{c,t}, \quad (3)$$

$D_{c,t}$ *is the savings,* $D_{c,t} \in (0,\infty) \subset \mathbb{R}$;

$C_{c,t}$ *is the total consumption of the period,* $C_{c,t} \in (0,\infty) \subset \mathbb{R}$.

Each household will visit a number Z_c of firms by period. They will try to consume the goods for the lower price. The firms each produce consumptions goods will need labor and capital, at the beginning of period the firm will check their own position $(P_{i,t}, Y_{i,t})$, it is their set of prices and quantities practiced at previous period. The $P_{i,t}$ represent the last price used. The firm also know their real quantity sold $Q_{i,t}$. As the sales just occur after the firm take their production levels choice, it may happen a queue of clients unsatisfied or an undesirable storage of goods at the end of the period. The goods of the consumption market will be perishables ones, so the stock that did not had sold will go to waste, i.e., they will not be available to be sale in the next period. So, the firm will try to find the correct level of production. For that the firm will use two pieces of information: the current level of price practiced in their sector; and their own forecast error, it is, the difference between their expectation of sales and the real sales.

$$\Delta_{(i,t)} = Q^{e}_{i,t} - Q^{d}_{i,t}, \tag{4}$$

$\Delta_{i,t}\ is\ the\ forecast\ error, \quad \Delta_{i,t} \subset \mathbb{z}$;

$Q^{e}_{i,t}\ is\ the\ actual\ produtcion\ , \quad Q^{e}_{i,t} \subset \mathbb{N}$;

$Q^{d}_{i,t}\ is\ the\ quantity\ demanded, \quad Q^{d}_{i,t} \subset \mathbb{N}$.

$$P^{c}_{t} = \frac{1}{Q}\sum_{i=1}^{N} Q^{d}_{i,t}\ P^{c}_{i,t}, \tag{5}$$

$P^{c}_{t}\ is\ the\ level\ price\ in\ the\ consumption\ sector, \quad P^{c}_{t} \in (0,\infty)\ \subset \mathbb{R}$;

$P^{c}_{i,t}\ is\ the\ price\ in\ i^{th}\ firme, \quad P^{c}_{i,t} \in (0,\infty)\ \subset \mathbb{R}$;

$Q^{d}_{i,t}\ is\ the\ level\ quantity\ sold\ by\ i^{th}\ firme, \quad Q^{c}_{i,t} \subset \mathbb{N}$;

$Q\ is\ the\ total\ quantity\ sold, \quad Q \subset \mathbb{N}$.

$$Q^{e}_{i,t+1} = Q^{d}_{i,t} - \rho\Delta_{i,t} \ \ if\ \ \{\Delta_{i,t} \leq 0\ and\ P^{c}_{i,t} \geq P^{c}_{t}\}\ or\ \{\Delta_{i,t} > 0\ and\ P^{c}_{i,t} <\ P^{c}_{t}\}, \tag{6}$$

$\rho\ is\ the\ quantity\ adjust\ parameter, \quad \rho \in (0,1) \subset \mathbb{R}$.

$$P^{c}_{i,t} = P^{c}_{i,t}\left(1 + \eta_{i,t+1}\right)\ if\ \left\{\Delta_{i,t} \leq 0\ and\ P^{c}_{i,t} < P^{c}_{t}\right\}\ and\ \left\{\Delta_{\mathrm{i,t}} > 0\ and\ P^{c}_{i,t} \geq P^{c}_{t}\right\}, \tag{7}$$

$\eta\ is\ a\ price\ adjust\ paramer, \quad \eta \in U(0{,}0.1) \subset \mathbb{R}$.

The firm will produce using labor and capital available:

$$\hat{Y}_{i,t} = \min\left\{\alpha N_{i,t},\ \kappa K_{i,t}\right\}, \tag{8}$$

$\hat{Y}_{i,t}\ is\ the\ actual\ production\ of\ the\ i^{th} firm$;

$K_{i,t}\ is\ the\ capital\ in\ use\ by\ the\ i^{th} firm, \quad K_{i,t} \in (0,\infty) \subset \mathbb{R}$;

$N_{i,t}\ is\ the\ number\ used\ by\ the\ i^{th} firm, \quad N_{i,t} \subset \mathbb{N}$;

$\alpha\ is\ the\ productivity\ of\ labor, \quad \alpha \in (0{,}1) \subset \mathbb{R}$;

$\kappa\ is\ the\ productivity\ of\ capital, \quad \kappa \in (0{,}1) \subset \mathbb{R}$.

The capital which is in use by the firm will suffer depreciation; the firm will need to invest, by new capital goods, in a way to keep their level of production.

$$K_{i,t+1}\left(1 -\ \delta\omega_{i,t}\right)K_{i,t} + I_{i,t}\ , \tag{9}$$

$\delta\ is\ the\ depreciation\ of\ capital, \quad \delta \in (0{,}1) \subset \mathbb{R}$;

$w_{i,t}\ is\ the\ capacity\ utilization\ by\ the\ i^{th} firm, \quad w_{i,t} \in (0{,}1) \subset \mathbb{R}$;

$I_{i,t}$ *is the investiment made by* i^{th}*firm,* $I_{i,t} \in (0,\infty) \subset \mathbb{R}$.

There are fluctuations into the firm's demand; the firm will not be in a situation that he is using their full capacity. That means the firms will be looking for the long run at the moment to target their desire amount of capital, doing so:

$$\overline{K}_{i,t-1} = \nu\overline{K}_{i,t-2} + (1-\nu)\omega_{i,t-1}K_{i,t-1}, \tag{10}$$

$\overline{K}_{i,t}$ *is the long run desire capital by the* i^{th}*firm,* $\overline{K}_{i,t} \in (0,\infty) \subset \mathbb{R}$;

ν *is the memory of investiment parameter,* $\nu \in (0,1) \subset \mathbb{R}$.

When the firm knows their long run desire capital the firm will be able to calculate their level of investment:

$$I_{i,t}^{r} = \frac{\delta}{\gamma}\,\overline{K}_{i,t-1}, \tag{11}$$

γ *is the probability to invest,* $\gamma \in (0,1) \subset \mathbb{R}$.

Just readjusting, we can rewrite the law of capital as:

$$K_{i,t+1} = \left(\frac{1}{\bar{\omega}} + \frac{\delta}{\gamma}\right)\overline{K}_{i,t-1} - \delta\omega_{i,t}K_{i,t}, \tag{12}$$

$\bar{\omega}$ *is the long run desire capacity utilization,* $\bar{\omega} \in (0,1) \subset \mathbb{R}$.

Then the quantity of labor can be finding. The firm does not know a priori if she will have all that labor, the firm will open some vacancies at the job market and hope to same free worker to apply.

$$K_{i,t+1}^{*} = \omega_{i,t+1}^{*}K_{i,t+1} \tag{13}$$

$\omega_{i,t+1}^{*}$ *is the desired capacity to be use by the* i^{th}*firm,*

$$N_{i,t+1}^{*} = \min\left\{ K_{i,t+1}^{*}\frac{\kappa}{\gamma}\ ,\ K_{i,t+1}\frac{\kappa}{\gamma}\right\}. \tag{14}$$

The Equation (14) shows us the quantity of labor will be need. When the capital available is restrict, $K_{i,t+1}\frac{\kappa}{\gamma}$, the quantity of labor will depend of that. If there is abundant capital the firm will use only a portion of that, then the quantity of labor is relative to that.

So far, we are talking about the decision process of the firms which produces goods for the consumption market. The firm that produces capital goods has a different job. They will not use the combination of labor and capital; they will only use labor into their production process. Also, as their product is capital goods they will be able to storage their unsold production. Whit that in mind we may construct their rules for decision of prices and quantities:

$$Q_{j,t+1}^{k} = \left(Q_{j,t}^{k} + \Delta_{j,t}^{k}\right)(1-\delta^{\kappa}) \tag{15}$$

$\Delta_{j,t}^{k}$ *is the variation of stock of the* j^{th}*firm,* $\Delta_{j,t}^{k} \subset \mathbb{R}$;

δ^k *is the depreciation of capital in stock,* $\delta^k \in (0,1) \subset \mathbb{R}$.

Their rule for price formation is similar to the firms into the consumption market:

$$P_{j,t}^K = P_{i,t}^K\left(1+\eta_{j,t+1}\right) \; if \; \left\{\Delta_{j,t}^k \leq 0 \; and \; P_{j,t}^K < P_t^k \right\} \; and \left\{\Delta_{j,t}^k > 0 \; and \; P_{j,t}^K \geq P_t^k\right\} \quad (16)$$

An adaptive rule, considering the forecast error and the current stock, will guide their productions decisions:

$$Q_{j,t}^* = Q_{j,t}^K - \rho\Delta_{j,t}^k \quad if \quad \left\{\Delta_{j,t}^k \leq 0 \; and \; P_{j,t}^K \geq P_t^K\right\} or \; \{\Delta_{j,t}^k > 0 \; and \; P_{j,t}^K < \; P_t^K\}, \qquad (17)$$

$$Q_{j,t}^K = \alpha N_{j,t}. \qquad (18)$$

As we can see in Equation (18) the production into the capital goods sector will depends only by the level of labor. The labor productivity is the same in both sector and time independent. To need for new workers, or necessity to dismiss some, the firm look at their desire production, $Q_{j,t+1}^*$, and for the productivity of labor, α:

$$N_{j,t+1}^* = \frac{Q_{j,t+1}^*}{\alpha}. \qquad (19)$$

Will be times when the expectation will not be realize, the firms my see difficult to honor their bills (pay the wages and for investments). Their assets will be deposit at the bank, and will be the bank that may help the firms at the time of short money. We can define the need for financial help as the gap between the expenses of the period and the revenue. The Equation (20) resume that for a firm that product consumption goods. The firms which produce capital goods will differ because they don't need to invest, so we can resume that in Equation (21).

$$F_{i,t}^C = \max\{wN_{i,t} + P_{t-1}^K I_{i,t} - D_{i,t-1}, \; 0\}, \qquad (20)$$

$F_{i,t}$ *is the finciancial gap of the* i^{th}*firm,* $\quad F_{i,t} \subset \mathbb{R}$;

$D_{i,t}$ *is the assets of the* i^{th}*firm,* $\quad D_{i,t} \subset \mathbb{R}$.

$$F_{j,t}^K = \max\{\, \omega N_{j,t} - D_{j,t-1}\,, \; 0\}, \qquad (21)$$

Once the bank has this information he will move on in their job to measure the risk of the firm. The next step is the look at the leverage ratio of the firm that will expose the dimension of the financial problem of firm. When the firm is in perfect financial the leverage ratio tends to zero, that means, the firm are working only with their own money. Otherwise, when the firm has little assets their leverage ratio tends to one.

$$\lambda_{f,t} = \frac{L_{f,t-1}+F_{f,t}}{E_{f,t-1}+L_{f,t-1}+F_{f,t}}, \qquad (22)$$

λ *is the leverage ratio,* $\quad \lambda \in (0,1) \subset \mathbb{R}$;

L *is the accumulated debt,* $\quad L \in (0,\infty) \subset \mathbb{R}$;

E *is the equity or assets,* $\quad E \in (0,\infty) \subset \mathbb{R}$.

In an ideal situation, when the firm has no doubt about the return a loan, the bank would target this minimal gross rate:

$$R = \left(1 + \frac{r}{\theta}\right), \tag{23}$$

$R\ is\ the\ gross\ rate, \quad R \in (0,1) \subset \mathbb{R};$

$r\ is\ the free\ interest\ rate, \quad r \in (0,1) \subset \mathbb{R};$

$\theta\ is\ the\ installment\ on\ debt, \quad \theta \in (0,1) \subset \mathbb{R}.$

Likely the bank will find the firms with no ideal situation, then the bank will need to evaluate the risk of the loan do not return. He will calculate the risk for each firm individually. For that the bank will use the leverage ratio of the market to construct a logistic regression ($\phi_{f,t}$) and the leverage ratio of the firm to measure the time life expectance of a firm, $T_{f,t}$. When the firm has low leverage ratio their time life tend to infinity and their situation tends to ideal situation describe above.

$$T_{f,t} = \frac{1}{\phi_{f,t}\lambda_{f,t}}, \tag{24}$$

$\phi_{f,t}\ is\ a\ logist\ regression\ for\ mesuare\ market\ risk, \quad \phi_{f,t} \subset \mathbb{R}^{+};$

$T\ is\ the\ expected\ survival\ time, \quad T \subset \mathbb{R}^{+}.$

The gross rate applied to a particular firm will then depend on that set of information: the time life expectance of the firm, which also depends of the market risk, the free interest rate practiced at the moment by the monetary authority, and the installment on debt:

$$R_{f,t} = \left(\theta + r_{f,t}\right)\frac{1-(1-\theta)^{T_{f,t+1}}}{\theta}, \tag{25}$$

If we reorganize the equation above, and resume $\Xi = 1 - (1 - \theta)^{T_{f,t+1}}/\theta$, we have:

$$r_{f,t} = \mu\left(\frac{1+\frac{r}{\theta}}{\Xi} - \theta\right), \tag{26}$$

$\mu\ is\ the\ bank's\ markup, \quad \mu \in (1,\infty) \subset \mathbb{R}.$

After all, the bank will apply a markup and find their interest rate applicable for the firm in Equation (26). The bank needs now decide how much credit will be available for the firm. He already known the current stock of loan ($L_{f,t-1}$) and also know their new need for loans. The bank has a limit of acceptable loss, ζE_t^b, and he will only conceive new credit when this loss limit is not exceeded:

$$\phi_f\left(\Delta L_{f,t} + L_{f,t-1}\right) \leq \zeta E_t^b, \tag{27}$$

$\zeta\ is\ the\ bank\ loss\ parameter, \zeta \in (0,1) \subset \mathbb{R}.$

The monetary authority will use a simple Taylor rule to formulate the free interest rate. For this he will need to know the potential gross domestic product of this economy. As the labor productivity is known and constant this job could be done:

$$\bar{Y} = \alpha H, \tag{28}$$

$\bar{Y}\ is\ the\ potential\ GDP;$

α *is the productivity of labor,* $\alpha \in (0,1) \subset \mathbb{R}$;

H *is the total of workers,* $H \subset \mathbb{N}$.

The current inflation level is described as the difference between the current and the previous level of price:

$$\pi_t = \frac{P_t - P_{t-1}}{P_{t-1}}, \tag{29}$$

π_t *is the actual inflation.*

Then the monetary authority has the tools to apply the following Taylor rule:

$$r_t = \pi_t + r^* + \alpha_\pi (\pi_t - \pi^*) + \alpha_Y (Y_t - \bar{Y}), \tag{30}$$

r_t *is the current free interest rate*;

r^* *is the natural interest rate,* $r^* \in (0,1) \subset \mathbb{R}$;

α_π *is a paramenter,* $\alpha_\pi \in (0,1) \subset \mathbb{R}$;

α_Y *is a parameter,* α_Y *in* $(0,1) \subset \mathbb{R}$;

Y_t *is the current groos domestic product.*

The information use by the monetary authority is also known by the other agents of this economy, except by the parameters of Taylor's rules. This is our first attempt to include a monetary policy in the model. The desire inflation is taken as fixed at the first moment, we may ease this assumption in the future. Also the parameter of Taylor rule – each one could indicate if the monetary authority is more inclined to regulate inflation or support production – could verify other sets of value to them.

References:

C. Hommes, G. Iori, et al., Introduction special issue crises and complexity, Journal of Economic Dynamics & Control 50 (2015) 1–4.

D. D. Gatti, S. Desiderio, E. Gaffeo, P. Cirillo, M. Gallegati, Macroeconomics from the Bottom-up, volume 1, Springer Science & Business Media, 2011.

Gertler, Mark, Nobuhiro Kiyotaki, and Andrea Prestipino. Wholesale Banking and Bank Runs in Macroeconomic Modelling of Financial Crises. No. w21892. National Bureau of Economic Research, 2016.

V. Grimm, U. Berger, D. L. DeAngelis, J. G. Polhill, J. Giske, S. F. Railsback, The odd protocol: a review and first update, Ecological modelling 221 (2010) 2760–2768.

T. Assenza, D. D. Gatti, J. Grazzini, Emergent dynamics of a macroeconomic agent based model with capital and credit, Journal of Economic Dynamics and Control 50 (2015) 5–28.

Taylor, J. B. (1993). Discretion versus policy rules in practice. In Carnegie-Rochester conference series on public policy (Vol. 39, pp. 195-214). North-Holland.

W. A. Brock, C. H. Hommes, A rational route to randomness, Econometrica: Journal of the Econometric Society (1997) 1059–1095.