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MNB Working Papers 5

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An agent based Keynesian model with credit cycles and countercyclical capital buffer*

(Hitelciklusok és anticiklikus tőkepuffer egy ágens alapú keynesi modellben)

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Budapest, May 2017

Published by the Magyar Nemzeti Bank

Publisher in charge: Eszter Hergár

Szabadság tér 9., H-1054 Budapest

www.mnb.hu

ISSN 1585-5600 (online)

*We would like to thank Balázs Világi for his useful help and comments. All remaining errors are our responsibility.

Contents

Abstract

In this paper, we have developed an agent-based Keynesian macro model that features a detailed representation of a banking system, besides households and firms, and in which fiscal, monetary and macroprudential policy regulators also operate. The banking system generates longer credit cycles on the time series compared to the business cycle, and also fosters growth through lending, but deepens the recession during crises by decreasing credit supply. Macroprudential authority uses countercyclical capital buffer requirements to decrease the procyclicality of the banking system. According to our results, this policy instrument is effective in enhancing financial stability, while in recessions, the decrease in GDP is less with countercyclical capital buffer requirements than without any macroprudential rule. However, there is a trade-off between financial stability and economic growth.

JEL: E12, E32, E44, G18, G21.

Keywords: agent based model, credit cycle, business cycle, countercyclical capital buffer.

Összefoglaló

Tanulmányunkban egy olyan ágens alapú keynesi makromodellt fejlesztettünk, amely a háztartásokon és vállalatokon felül egy részletesen kidolgozott bankrendszert tartalmaz, továbbá amelyben központi bank, fiskális hatóság és makroprudenciális politikai szabályozó is működik. A bankrendszer az üzleti ciklusnál hosszabb hitelezési ciklusokat idéz elő az idősorokban, a hitelezésen keresztül támogatja a növekedést, válság esetén azonban mélyíti a recessziót a hitelkínálat csökkentésével. A makroprudenciális hatóság anticiklikus tőkepufferráta alkalmazásával próbálja csökkenteni a bankrendszer prociklikus viselkedését. Eredményeink szerint ez a szabályozói eszköz hatékonyan hozzájárul a pénzügyi stabilitás erősítéséhez, mivel recessziós időszakokban kisebb a GDP visszaesése anticiklikus tőkepufferráta használata mellett, mint a nélkül. Ugyanakkor a nagyobb stabilitás némileg kisebb mértékű növekedéssel párosul.

1 Introduction

The global crisis shed light on the significant impact of the financial intermediary system on macroeconomic developments. The banking system provides a part of the funds required for the investments and other expenditures of corporations and households, thus it fosters growth. However, the asset price bubbles arising from irrational expectations lead to the excessive opening of the output gap, while the stress events of the financial system may give rise to deep recession. Consequently, lending developments are also instrumental in the assessment of the economy's cyclical position. Therefore, the financial intermediary system also impacts fiscal and monetary policy decision-making; moreover, there is increasing focus on measuring, monitoring and regulating banks' systemic risks and their macroeconomic impact, i.e. macroprudential policy.

Macroprudential policy aims to ensure the stability of the banking system (i.e. the sector's adequate capital and liquidity position) by preventing the accumulation of systemic risks. Regulators have numerous instruments intended to ensure financial stability based on various criteria. In terms of solvency, the countercyclical capital buffer is one of the most important of such instruments. In essence, the countercyclical capital buffer requires banks to form an additional capital buffer during periods of excessive credit expansion, which they can then release during recessions. This enables banks to cover the losses caused by the crisis from the released capital, which allows them to avoid restraining their lending activity.[1]

Parallel to the new macroprudential measures to be introduced, a natural need arises for investigating the expected effects of the new instruments and for analysing the possible ways of harmonising them with monetary and fiscal policy. Since these tools were mostly introduced after the crisis, empirical research can only be conducted under very limited conditions in the absence of a sufficient sample size. Therefore, relatively few studies have addressed such topics using econometric tools. In terms of the impact of the countercyclical capital buffer and other capital increases, most papers focus on measuring the credit cycle and early warning indicators, but are less capable of capturing the expected real economic impact (exceptions include: Edge and Meisenzahl (2011) and Jiménez et al. (2012)).

Another modelling solution could be the use of mainstream DSGE models. There is an increasing number of DSGE models incorporating financial intermediation. While early models (for example Smets and Wouters (2003)) used a rather simple representation of the financial sector, later financial frictions got more emphasis (Lombardo and McAdam (2012), Brzoza-Brzezina et al. (2013), Bonciani and Roye (2016), Palek and Schwanebeck (2017)). There are many attempts to make models with macroprudential orientation. For example, Gertler et al. (2012) investigate the perceptions of fundamental risk and how macroprudential policy may help offset the incentives for risk-taking. Brzoza-Brzezina et al. (2015) present a macrofinancial model for the euro area, in which the macroprudential authorities may lower the amplitude of credit and output fluctuations by regulating the loan-to-value ratio. Falagiarda and Saia (2017) modeled LTV ratios and the procyclicality of lending and the effect of macroprudential regulation on business cycle fluctuations and financial stability. Still, macroprudential instruments address problems regarding systemic risks which may concern a high degree of heterogeneity, irrational expectations and persistent disequilibrium as well. For instance, it is important for macroprudential policy to ensure that the model contains long credit cycles (of up to 30 years) that can be generated endogenously; in other words, sustained imbalances should also appear in the economy, otherwise the role of the countercyclical capital buffer would become meaningless. The study published in 2015 by Jakab and Kumhof (Jakab and Kumhof (2015)) attempted to generate long-term credit cycles in a DSGE framework, but its amplitude was relatively small and they needed many independent shocks for the build-up phase.

Since modelling the main aspects of macroprudential policy is hampered by strict limitations in the case of DSGE models we have opted for an agent-based approach in this paper. (For a detailed comparison of DSGE and agent-based models, see Fagiolo and Roventini (2017).) In these models, instead of maximising utility or profit economic agents are rationally limited following behavioural rules of thumb. Nevertheless, they may have an ability to learn (as is the case with evolutionary economic models in general, e.g. Nelson and Winter (1982)). Agent-based models are increasingly common in every field of economics, as they can be flexibly shaped, capable of modelling complex systems and nonlinear connections (see Tesfatsion and Judd (2006)

[1] For a more detailed description of the countercyclical capital buffer, see: Drehmann et al. (2010), Detken et al. (2014) and Hosszú et al. (2015).

and LeBaron and Tesfatsion (2008)). Some agent-based models focus exclusively on the banking system without examining macroeconomic integration (Poledna et al. (2014)), while some macro models do not include financial intermediary system (Lengnick (2013)). However, an increasing number of models attempt to investigate the banking sector integrated into the macro economy (e.g. Cincotti et al. (2010)).

Among the models focusing on the banking system, Lenzu and Tedeschi (2012) examine the development of the interbank market, focusing on the systemic risks carried by endogenously emerging interbank networks. In Delli Gatti et al. (2011), contrary to DSGE models, the cycle is not driven by factor productivity shocks, but by changes in demand, which spread through the macro economy via the bankruptcy of certain companies. While macroprudential instruments may contribute to increasing financial stability, a more stable environment is often paired with lower lending and thus lower output. We are able to model the impact of macroprudential instruments on output if we factor in the relationship between lending and output, with financial accelerator getting an emphasis during economic cycles (Bernanke et al. (1999)). The financial accelerator effect comes into play when banks restrain lending to corporations during negative business cycles; corporations, in turn, produce less which causes an even greater slump in lending and hence, a deceleration in output. Delli Gatti et al. (2010) developed a network-based financial accelerator model in which the bankruptcy of a few highly leveraged corporations generated an even greater downturn. This model was supplemented by Riccetti et al. (2013) with multi-period loans and subsequently, with corporations' market capitalisation (Riccetti et al. (2016)). Popoyan et al. (2015) presents an agent-based model that can be specifically applied to the investigation of macroprudential policy and addresses macroprudential and monetary policy interactions as well.

In the agent-based model proposed by Dosi et al. (2006), technological progress gives rise to endogenous business cycles within the economy. Expanding the model in multiple steps (Dosi et al. (2008), Dosi et al. (2010), Dosi et al. (2013)), a model was created (Dosi et al. (2015)) in which technological progress and innovation are placed on Schumpeterian foundations, corporations take out loans for production and investment and corporate defaults also affect banking sector activities. Monetary and fiscal policy decisions are also featured in the model with an impact on cycle developments. We found the macroeconomic assumptions of the model plausible and its conclusions pertaining to business cycles confirm numerous stylised facts. For these reasons, we took this model as a basis for building our own and adopted numerous components of its building blocks. Since our goal was to include macroprudential issues in our analysis, we attempted to enable our model to generate credit cycles longer than the business cycles. Accordingly, we represent the banking sector in more detail in our model than in the original one and we also altered a number of other behavioural rules to ensure more persistent results. Moreover, we examined the impact of the countercyclical capital buffer in our model and found that this policy instrument can mitigate the procyclical behaviour of the banking sector and hence, facilitate a more stable economy. However, at the same time, it exerts a slightly negative impact on economic growth.

This paper is structured as follows: our model is presented in Section 2. Section 3 features a description of the evolution of cycles and our findings with respect to the length of the cycles. Next we present the impact of the countercyclical capital buffer on GDP. Finally, in Section 4 we summarise our main findings and address further developments to the model.

2 The model

In a closed economy, two types of products are produced: capital goods and consumer goods. Capital goods are utilised by the consumption-good sector, while consumption goods are purchased by households. Agents require money both for production and for purchase. Money is made available through the banking system. Firms and households are heterogeneous, while the banking sector is represented by a single commercial bank. There are three additional agents within the economy alongside firms, households and the commercial bank: the central bank, the government and the macroprudential authority. The central bank acts as lender of last resort. The government collects tax on profits and provides benefits to unemployed households. The macroprudential authority supervises banks: it ensures financial stability by imposing capital requirements. Firms and households hold their money in deposits, while in the lack of sufficient deposits, firms can contract credit from the bank in the form of working capital loans to fund the labour expenditures of production, or investment loans to expand their capital stock or replace a part of their capital stock with more efficient capital goods. The economy is fuelled by fiat money: the money supply is backed by corporate loans and government bonds. The economy rests on Keynesian foundations: firms determine their output based on the observed demand, while households define their consumption based on their wealth and income. However, if the bank does not grant credit to a firm (based on its own discretion or due to the presence of various prudential rules), the shortage of credit may affect production, investment and – through lower output (income) – demand. Corporate bankruptcies may also generate losses for the bank which may even lead to the bank's default.

2.1 THE TIMELINE OF EVENTS

The model consists of consecutive periods. Each period corresponds to a quarter. The sequence of events is the following in each period:

1. Nominal wages are set for the given period. The macroprudential authority determines the countercyclical capital buffer rate.
2. Consumption-good firms set their prices.
3. The technology of capital-good firms sustains an idiosyncratic shock; the firms determine the price of the capital produced by them and send out the price and the technological characteristics of their capital goods to the consumption-good firms in contact with them.
4. The bank determines the volume of loans that can be still disbursed and ranks the firms based on their creditworthiness (profitability).
5. Consumption-good firms define how much to produce during the period and how much to invest for the purposes of capacity increase and replacement (productivity increase). Based on corporate deposits and the amount of money necessary for production and investment, firms submit their loan applications to the bank.
6. The bank grants loans to the firms in consideration of its credit constraints. Loans are granted on the basis of the predefined corporate ranking: firstly, the bank disburses the working capital loans required for production during the given period. This is followed by investment loans also based on the ranking.
7. Production: if consumption-good firms received only a portion of the loan amount for which they applied, they first try to achieve the targeted production level and use only the remaining liquidity for investment. They convey their investment demand to the capital-good firms with which they are in contact. Capital-good firms and consumption-good firms hire the required number of employees and pay wages then the goods produced are placed in inventory. After production, a part of the capital of consumption-good firms is depreciated. The government pays unemployment benefits to the unemployed.
8. Consumption: the market share of consumption-good firms evolves, while households determine their consumption expenditures. Households distribute their consumption expenditures among the various firms based on their market share,

but in the case of excess demand, they may even purchase from firms with excess, ignoring market share. Firms purchase and put into operation capital goods and replace the necessary quantity.

9. End-of-period cash flows:

    a) Firms pay their taxes to the government. Interests are paid in a predefined order. Firms pay interest on their closing stock of loans for the previous period and on their working capital loans for the period. The bank receives interest on its closing stock of government bonds for the previous period. It pays interest on its closing stock of deposits for the previous period and on its central bank loan for the previous period (if any).

    b) Firms try to repay their working capital loans, and finally they also repay a specific portion of their closing stock of investment loans for the previous period.

    c) The government bails out the bank if the bank's equity is insufficient and it fails to comply with regulatory requirements.

    d) Firms pay dividends to households.

    e) The bank pays its taxes to the government and then pays dividends to households.

    f) At the end of the period, we record the debt owed by the individual agents and their interest payment obligations for the next period based on the prevailing interest rates.

2.2 BEHAVIOURAL RULES OF AGENTS

2.2.1 CAPITAL-GOOD FIRMS

Capital-good firms produce the required capital goods for consumption-good firms. Each unit of capital goods is sufficient for producing one unit of consumption goods during a given period (quarter), but labour is also necessary for operating the capital good. Each capital good has a labour intensity parameter which indicates the units of labour necessary for producing the consumption good using the capital good. Below, however, we use the reciprocal value of this; in other words, we examine the number of consumption goods produced by one unit of labour in a given period, using the given type of capital (output productivity). The technology of producing the capital good can be captured by investment productivity, which shows the number of capital goods that could be produced by each unit of labour in a given period. Accordingly, the technology of a capital-good firm can be described by output productivity and investment productivity. For the sake of simplicity, the proportion of the two parameters is constant (r_{PI}) and identical for each firm; the value of each parameter, however, can be different.

Every year, capital-good firms develop their technology independent of each other at no cost. This practice is carried out as follows: the technology of individual firms sustains an idiosyncratic shock ($e_{i,t}$) in each period, which increases output productivity and investment productivity by the same degree. $e_{i,t}$ derives from a truncated normal distribution, with an expected value and variance of 0.005 and 0.001, respectively. Moreover, with a probability of 0.03, the technology of one capital-good firm endures a shock (u_t), the expected value and variance of which is 0.07 and 0.01, respectively.

In addition to development, with a probability of ς, all capital-good firms may copy a technology: if a firm has an opportunity to copy, it selects a random company and adopts its technology of the previous period provided that the given technology is more efficient than its own. Due to the time lag, the best technology cannot be immediately learned. Copying makes the spread of a more efficient technology possible and so fosters technological development. It is due to copying that major u_t shocks ultimately give rise to business cycles.

Each consumption-good firm is linked to a single capital-good firm; in other words, it can order capital goods from a single company. In each period, capital-good firms notify their consumption-good partner of the price and the output productivity of the capital good the partner can purchase. Each capital-good firm sells its goods at its own unit cost.

Capital-good firms do not accumulate inventories; they produce on demand and their customers pay for the goods in advance. Since there is no need for them to hire labour in advance, they do not have any financing issues: they are able to produce the necessary quantity using the sums paid by consumption-good firms.

2.2.2 CONSUMPTION-GOOD FIRMS

Consumption-good firms produce using their capital and labour. Their stock of capital goods is heterogeneous: different vintages may have different output productivity (but each capital good still allows the production of one unit of a consumption good). In the course of production (in the case of incomplete capacity utilisation), capital goods are utilised evenly; in other words, it is not the most efficient vintage that is used for production first. Consequently, in terms of production the technology of individual firms is not associated with decreasing returns to scale.

Firms define their prices in view of the prevailing wages of the given period: they consider the average unit of labour required for the production of a consumption good and apply a predefined markup on their unit costs of production. The target price markup of the consumption-good industry is μ_C. If a firm's markup is above this level, it adjusts its markup according to the following autoregressive process:

$$\mu_{i,t} = (1-\rho)\mu_C + \rho\mu_{i,t-1} \tag{1}$$

The only exception is if, due to the investments of the previous period, the productivity growth of the firm is greater than r^{tr}_{AL}. In this case the firm will raise the price of the previous period by the increase in wages (which is greater than the increase in its labour costs) and accordingly, its actual markup will be higher than the one recorded in the previous period. It can do so because, thanks to the major productivity gains, it may have acquired an advantage over its competitors. So, a significant increase in productivity first increases the markup then it reverts towards the target value through autoregressive adjustment. As a result, the impact of investments on profitability peters out over time and the productivity growth transpiring in the economy passes through to real wages.

At the beginning of the period, firms define their production and investment plans. Firms adjust both their production and investment to the empirically observed demand ($D^e_{i,t}$). Empirically observed demand is computed as the exponentially weighted average of the previous n_D periods' actual demand (D_i):

$$D^e_{i,t} = \frac{D_{i,t-1} + \alpha_D D_{i,t-2} + \dots + \alpha_D^{n_D-1} D_{i,t-n_D}}{1 + \alpha_D + \dots + \alpha_D^{n_D-1}} \tag{2}$$

In addition to the quantity meeting the empirically observed demand, firms intend to hold reserves at a rate of ι, and implement surplus production in proportion to their productivity gains. Accordingly, the intended output ($Q^p_{i,t}$) of firm i for period t is expressed by the following formula:

$$Q^p_{i,t} = D^e_{i,t}\left(1 + \eta\left(\frac{AL_{i,t}}{AL_{i,t-1}} - 1\right) + \iota\right) \tag{3}$$

where $AL_{i,t}$ is the firm's average output productivity and η is the adjustment coefficient associated with the productivity gain. The reason why a firm wishes to produce more due to a productivity gain is that it signals the productivity growth of the economy in advance, and higher aggregate productivity generates higher demand over time.

Firms may invest to expand their capacity (capital accumulation) and to boost their efficiency (vintage replacement). Their demand for new capital goods is the sum of these two needs. Accumulation demand is the difference between a firm's intended output and its capital stock, irrespective of the price of the capital good. To define the replacement demand, a firm decides for each vintage of its capital, whether it wishes to replace the given stock. The firm will replace a vintage if it can achieve an efficiency improvement greater than b.

The firm must pay in advance for capital goods and labour, before it begins to sell its newly produced goods. The firm quantifies the amount of money necessary in function of its intended output and investment. If it lacks sufficient deposits, it can turn to the bank with a credit demand corresponding to the difference. If the firm's deposits are insufficient to cover its planned labour cost, it will apply for the difference in the form of a working capital loan, and its remaining credit demand will be regarded an investment loan, to be used for purchasing capital goods. If it does not receive sufficient credit from the bank, it will prioritise production over investment, i.e. it will invest only as much in capital goods as it can purchase after paying the wages required for production.

In the course of production, every vintage of a firm's capital is depreciated at a rate of δ.

Prior to consumption, we define market share for each individual firm. Current market share ($ms_{i,t}$) depends on the firm's market share in the previous period and on the relative price of the firm's product, according to the following formula:

$$ms_{i,t} = ms_{i,t-1}\left(1 + \chi\frac{\overline{p_t} - p_{i,t}}{\overline{p_t}}\right) \tag{4}$$

where $p_{i,t}$ is the offered price of company i in period t, and $\overline{p_t}$ is the average price in period t weighted with the market shares of the previous period. Therefore, if a firm offers its product at a price lower than the average, its market share will increase. The rate of the increase is determined by χ.

In making their consumption decisions, households define the amount to be spent on consumption, rather than the number of goods they wish to purchase. Individual firms receive portions of households' funds dedicated to consumption in proportion to their market share. However, if the stock of a certain firm is insufficient to satisfy demand, consumers will attempt to spend the remaining money at randomly chosen firms. Unsold stocks are scrapped.

After consumption, firms pay taxes on their pre-tax profit to the government at a rate of tr^C; their profit is the difference between the revenue generated by product sales and the cost of labour, less interest paid on investment loans; investment costs do not decrease the tax base. The working capital loan received during a given period is immediately paid back along with interest. In the case of investment loans, however, interest is only paid on the closing stock of the previous period. For investment loans, firms repay a c proportion of the closing stock of the previous period every year. Meanwhile, the firms also strive to keep the growth rate of their outstanding borrowing below n_1 and to ensure that their outstanding borrowing is below an n_2 proportion of their production cost. Thus, it may happen that a firm repays more than a c proportion if its deposit stock is positive. If a firm fails to pay interest or meet its debt payment obligation, it will go bankrupt. After eliminating its deposits, it will retain its capital stock without the payment obligation.

After tax, interest and loan repayment, if the firms have sufficient deposits, they pay dividends to households defined as a d proportion of their after-tax profit.

2.2.3 HOUSEHOLDS

Households hold all their money in bank deposits used for payments when making purchases. Households receive wages from firms for their work, interest from the bank on their deposits, potentially unemployment benefits from the government, and may also obtain dividends from the bank and firms. Wages are subject to an income tax of tr^H proportion, which is transferred by households to the government.

At the beginning of each period, nominal wages grow at a rate of g_w; however, the growth in real wages varies in function of the changes in the price markups of individual firms. On balance, the average growth of real wages corresponds to productivity growth in the long run.

Each household offers one unit of labour. Firms employ households randomly, and a household may be employed by multiple firms, but overall, no household can be employed at a greater rate than one unit of labour. Households employed at a rate of less than one unit are entitled to receive unemployment benefits, granted directly by the government. The unemployment benefit amounts to ϕ proportion of the household's wages, and a pro-rated portion is also due to part-time employees.

In each period, households spend ψ proportion of their permanent income on consumption. In each period, consumers calculate their permanent income as the mean of the previous n_H periods' nominal income (Y). The nominal income of a given period includes the wages, unemployment benefits, interests and dividends received in the given period. Accordingly, the consumption expenditure of household i in period t (consumption function) is calculated as follows:

$$C_{i,t} = \psi \frac{Y_{i,t-1} + \alpha_H Y_{i,t-2} + \cdots + \alpha_H^{n_{H-1}} Y_{i,t-n_D}}{1 + \alpha_H + \cdots + \alpha_H^{n_{H-1}}} \tag{5}$$

2.2.4 BANKS

Households and firms keep their savings in the bank in the form of deposits; the bank, in turn, may grant loans to consumption-good firms to finance wages and a portion of their investments (capital-good firms and households may only place deposits and do not take out loans). Lending generates new deposits; in other words, the amount of money is endogenous: money supply depends on the bank's credit supply and on credit demand. The liabilities side of the bank's balance sheet comprises the bank's equity, corporate and household deposits and central bank funds. The assets side includes corporate loans, government bonds and the reserves held at the central bank.

The bank's credit supply is regulated by the required capital adequacy ratio. In accordance with the solvency criterion, the bank's maximum credit supply in period *t* is:

$$TCS_t = \frac{TOF_{t-1}}{\tau_t^{CCB}} \tag{6}$$

where TOF_{t-1} is the closing capital stock of the previous period and τ_t^{CCB} is the regulatory capital adequacy requirement together with the countercyclical capital buffer ($\tau_t^{CCB} = \tau + CCB_t$) determined by the macroprudential authority.

The bank ranks the firms based on their return on income ((total revenue-labour cost-tax)/total revenue) and satisfies credit demand in this order: it grants loans for wages before satisfying credit demand for investment purposes. Due to this differentiation, if firms face credit constraints during a recession, they first put off investments, while production decreases to a lesser extent. Depending on credit purpose, we distinguished between loans according to maturity: loans taken out for wages were considered to be working capital loans that firms must repay together with interest during each period. By contrast, investment loans are long-term loans for which a given percentage of the principal debt must be repaid during each period (along with interests).

The bank deposits reserves with the central bank corresponding to *rr* proportion of the deposit portfolio and holds the remainder of its liquid assets in government bonds.

In the model all interest rates are fixed and defined relative to the base rate (*r*). The interest rate spread on corporate loans is μ^C (regardless of risk level), while the interest rate on deposits and government bonds is μ^D and μ^G, respectively.

The bank's profit is the balance between interest income and interest expenditure and credit losses. The bank pays to the government a bank levy on its profit at a rate of tr^B, and pays dividends on its after-tax profit to households. The rate of dividends is determined by the bank's solvency position. The bank has a capital adequacy ratio target (τ_t^{max}) to be achieved relative to the total loan portfolio after the new disbursements. If the bank has more capital at the end of the period than what would be required to achieve (τ_t^{max}), it pays out the difference as dividend. Otherwise, it does not pay dividend at all. The capital adequacy ratio target is the sum of τ_t^{CCB} and τ^P. Retained earnings increase the bank's capital.

If the bank's capital adequacy ratio drops below τ_t^{CCB}, the government recapitalises the bank to the extent required for its compliance with regulatory requirements. Doing so the government may prevent that the decrease in the credit supply further deepen the recession.

2.2.5 FISCAL, MONETARY AND MACROPRUDENTIAL POLICY

The expenditures of the government consist of the following items: transfer of unemployment benefits, payment of interests on government bonds, potential recapitalisation of the commercial bank. Revenues are composed of the taxes collected from firms, households and the bank.

At this time, the central bank does not pursue an active monetary policy; it is not engaged in inflation targeting and it maintains the base rate unchanged. It is included in the model primarily for accounting purposes.

The macroprudential authority defines the level of the countercyclical capital buffer for each period.

2.3 DIFFERENCES IN COMPARISON TO THE BASELINE MODEL

In order to receive a framework suitable for analysing the credit cycle and the countercyclical capital buffer, we executed the following main changes on the baseline model:

1. For a coherent modelling of the financial intermediary system, we accounted all financial transactions in the balance sheets of the banking sector.

2. We disregarded monetary policy and kept the base rate constant.
3. We distinguished between short-term and long-term loans.
4. Both the bank and the firms pay dividends to households and households set their consumption level based on their permanent income.
5. We also altered the consumption and investment functions. While in the baseline model market agents based their decisions on the last empirically observed value of income and demand, we considered the exponentially weighted historical observations of these variables. This rule moderates the volatility of time series significantly.
6. Technology: technological development is exogenous and irrespective of investment size. In each period, capital-good firms are affected by idiosyncratic shocks ($e_{i,t}$), which are derived from a truncated normal distribution with an expected value of 0.005 and a variance of 0.001. Moreover, with a probability of 0.03, the technology of one capital-good firm endures a shock (u_t), the expected value and variance of which is 0.07 and 0.01, respectively. These additional shocks may put the business cycles into motion.
7. Our model also includes the macroprudential authority, i.e. the entity determining the countercyclical capital buffer rate. The regulation was integrated into the model in line with the Basel III requirements (see: Detken et al. (2014)). The value of the capital buffer (CCB_t) for the given period is set by the authority on the basis of the credit gap of the previous period (GAP_{t-1}), quantified in accordance with the following formula:

$$CCB_t = \begin{cases} 0\%, & \text{if } GAP_{t-1} \leq 2\% \\ 2.5 * (GAP_{t-1} - 2\%)/8\%, & \text{if } 2\% < GAP_{t-1} \leq 10\% \\ 2.5\%, & \text{if } 10\% < GAP_{t-1} \end{cases}$$

The credit gap is the deviation from the credit-to-GDP trend calculated by a one-sided Hodrick-Prescott filter. However, the capital buffer is released (the value of CCB_t is reduced to 0%) if a decline of at least 5 percentage points is observed in the value of the credit-to-(trend) GDP ratio. This is because the capital buffer must be formed during the positive phase of the credit cycle and must be released during crisis periods, and the credit-to-GDP gap signals the onset of the crisis with a lag. A decline in the amount of outstanding loans, however, can signal the beginning of a recession even in case of a positive credit gap if the bank reduces the loans granted due to the losses incurred. In our model, defaulted loans disappear from the bank's balance sheet after one period, thus the credit-to-GDP ratio could signal effectively a crisis on time. (In a real economy, this ratio reacts much slower, because the relevant decrease of non-performing loans could take many periods.)

3 Results

In this section, firstly we present the evolution of the cycles and subsequently examine the lengths of the cycles generated by the model. Finally, we quantify the effect of the countercyclical capital buffer. In our model, each business cycle begins with a major, positive technological shock (u_t). Firms replace a portion of their capital goods (invest) in an effort to improve their technology. As a result, unemployment decreases with a parallel increase in consumption and the credit stock and firms, in turn, expand their capacities (through further investment). Although the technological shock does not affect all capital-good firms immediately, they may learn the new technology from each other, thus it spreads gradually. Since consumption-good firms are in contact with different capital-good firms, some consumption-good firms may replace their capital earlier than others (they are the first innovators in the sector). Such firms may be able to achieve higher profits and larger market share than the others. The firms need credit for their investment, therefore by accumulating long-term credit, they may get indebted. However, there may be some firms among the followers (i.e. the firms replacing their capital at a later point) that are unable to generate sufficient profits for the repayment of their loans because of overestimating the demand for their products. Firms with less advanced technology or more debt go bankrupt. If too many firms fail to repay their loans simultaneously, the resulting bankruptcies lead to recession and a deep economic downturn may give rise to a financial crisis. However, a macroeconomic recesssion does not cause automatically financial crisis. The impact of bankruptcies on the bank depends on the level of firms' indebtedness. If low number of firms go bankrupt or the credit amount of defaulted firms is low, loan losses of the bank would be covered by the capital buffer. Thus, macroeconomic crises are more frequent than financial crises. If a relevant amount of highly indebted firms go bankrupt, the deterioration of the bank's capital is much higher, therefore the bank diminishes dramatically its credit supply, which leads to a financial crises as well.

3.1 THE LENGTH OF THE CREDIT AND BUSINESS CYCLES

Figure 1
Credit and business cycles

(Note: the trend-cycle decompositions were calculated by HP filter. Credit cycle: the cycle of credit-to-GDP (λ = 400,000, BCBS (2010)). Business cycle: the cycle of logarithm of real GDP (λ = 1,600, Hodrick and Prescott (1997)). Source: authors' calculations.)

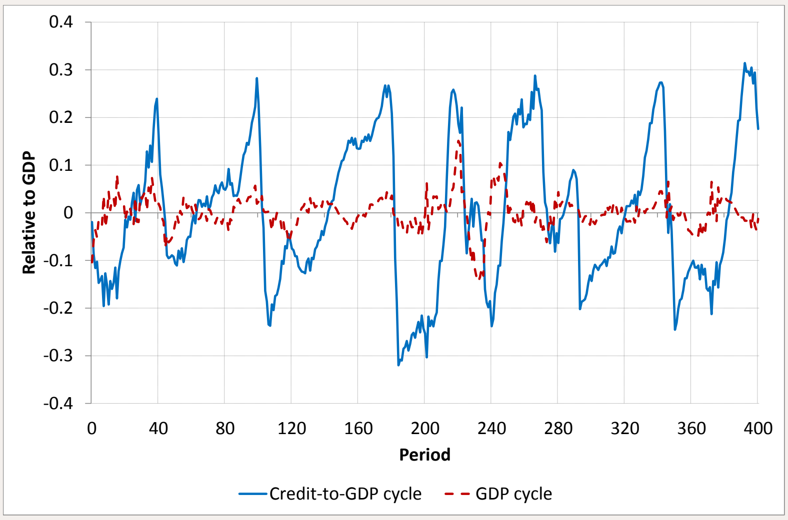
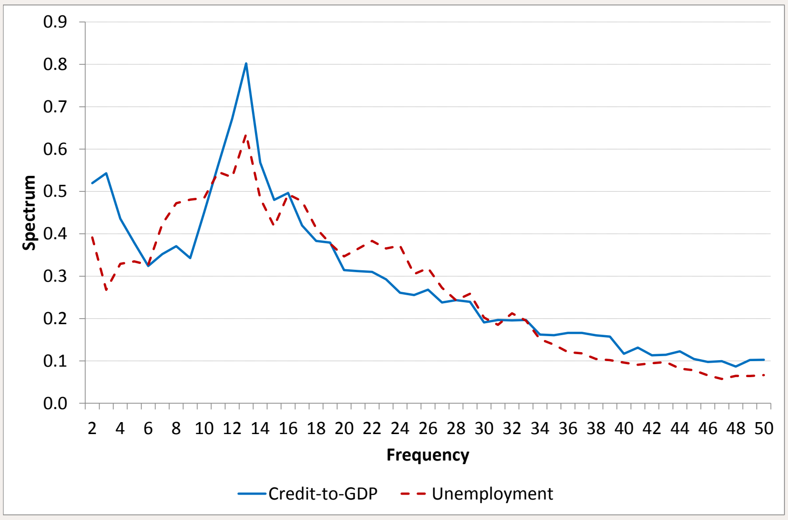


Figure 1 presents two cycle time series simulated by the model (each period is considered to be a quarter). The credit-to-GDP gap measures the credit cycle, while the GDP gap corresponds to the business cycle (both time series were calculated by the Hodrick-Prescott Filter).[2] Based on the figure, the duration of the business cycles generated by our model is 6 to 10 years and the length of the credit cycles thus generated is two to three times longer. Therefore, the model successfully reproduces the relevant empirical values (for the empirical estimation regarding the length of the credit cycle see: Drehmann et al. (2012) and Borio (2014)).

We ran 200 independent simulations for more accurate investigation; each run consisted of 800 periods. We calculated the periodogram of credit-to-GDP and unemployment for each individual simulation; Figure 2 presents the median of these periodograms. A periodogram is based on Fourier-transformation of the original time series. The advantage of it is that this methodology does not need any ex ante assumptions regarding the lengths of the cycles contrary to any trend-cycle decomposition procedure. Each time series can be decomposed to the sum of cycles of various lengths. The periodogram shows which cycle lengths are the most typical in the given time series. The values of the horizontal axis correspond to different cycle lengths; lower values indicate longer cycles (the values of the axis and cycle lengths are inversely proportional to each other). In this case, for example, the value 5 corresponds to the 40-year cycle, while the value 10 designates 20 years. The values of the vertical axis indicate the importance of the cycles in the original time series; i.e. higher values designate more dominant cycles.[3] In the case of the credit cycle (computed from the credit-to-GDP ratio), the most important cycle lengths range between 10 and 65 years. As regards the business cycles (derived from unemployment), the most typical cycle lengths are 7 to 25 years. Accordingly, the periodogram returns the same result based on multiple independent simulations; i.e. that credit cycles are significantly longer than business cycles in our model.

Figure 2
Periodogram of the standardised credit-to-GDP and unemployment
(Source: authors' calculations.)



3.2 THE IMPACT OF THE COUNTERCYCLICAL CAPITAL BUFFER REQUIREMENT

In order to measure the effect of the countercyclical capital buffer rules, we ran half of the 200 simulations assuming that the macroprudential authority applied this policy instrument, while in the other half of the simulations it did not. Table 1 indicates

[2] The λ parameter used for the calculation was determined in accordance with the method used in the relevant literature: its value was 400, 000 in the case of the credit cycle and was set at 1, 600 in the case of the business cycle. The former assumes cycles of around 30 years, while the latter can be applied to cycles lasting for 6 to 8 years.

[3] For a more detailed and more accurate description about periodograms, see, for example, Shumway and Stoffer (2016).

GDP growth in both cases. As a result of the countercyclical capital buffer, average yearly GDP growth was 0.02 percentage points lower, which is a small difference. The second row compares GDP growth rates in the periods when the credit gap was higher than 10 percentage points; i.e. when the countercyclical capital buffer rate (if applied) took its highest value. In such periods, under active macroprudential policy the bank is required to accumulate a capital buffer. Consequently, compared to runs where no such capital buffer requirements are in place, the bank pays less dividend to households, which lowers consumption and GDP. This channel, however, decelerates GDP growth only slightly (each year by 0.09 percentage points). The last row shows the effect of the capital buffer rate in recession periods (after a 5-percentage point-drop in the credit-to-GDP ratio, when the bank is permitted to use the formerly accumulated countercyclical capital buffer). If the bank holds a releasable capital buffer, it can use the buffer to cover its credit losses without decreasing its credit supply. If the bank has no capital buffer, the downturn in lending – and hence, GDP – will be greater than warranted by the demand. Based on the simulations, this channel has a great and significant effect: in the absence of a countercyclical capital buffer imposed by the macroprudential authority, the drop in GDP would be higher by 0.54 percentage points. Our findings are consistent with the expectations of the literature on the countercyclical capital buffer (BCBS (2010), Drehmann and Gambacorta (2012)): the countercyclical capital buffer exerts a greater impact in recession periods than in periods of excessive credit expansion, i.e. during the build-up of systemic risks. According to our findings, therefore, imposing regulations regarding the rate of the countercyclical capital buffer may improve the financial stability of the economy which, in turn, can diminish the procyclical behaviour of the banking system. However, there is a minor trade-off between financial stability and economic growth.

Table 1
The impact of CCB on average yearly GDP growth (per cent)

Review period	with CCB	without CCB
Total sample	3.36	3.38
With a credit gap above 10%	3.60	3.69
In recession	-4.65	-5.19

4 Conclusions

In our paper, we aimed to enhance the model developed by Dosi et al. (2015), primarily by elaborating the banking system in greater detail. Our model was capable of reproducing many properties of the actual developments, and from a macroprudential perspective, it is particularly important that our time series contained credit cycles longer than business cycles. This allowed us to examine the effect of an important macroprudential instrument, the countercyclical capital buffer. In periods of excessive credit growth the capital buffer requirement slightly restrained GDP growth, while in recessions it exerted a significant positive impact on output. On balance, imposing a countercyclical capital buffer rate strengthens financial stability and reduces the procyclicality of the banking sector, but at the same time, it slightly restrains growth.

Our model can be enhanced further in several regards. Since it includes financial cycles as well as detailed bank balance sheets, it can be supplemented with additional macroprudential policy instruments (it could be extended to examine the liquidity coverage ratio, the net stable funding ratio and – with the inclusion of interbank funds and exposures – the capital requirements pertaining to systemically important financial institutions). The inclusion of the real estate market and permitting household lending would also support the analysis of housing market bubbles and, in this context, the payment-to-income ratio and the loan-to-value ratio. Finally, with the addition of a non-resident sector, external trade and the flow of foreign bank funds could also be modelled.

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Appendix A Parameters

Table 2
Parameters

Parameter name	Symbol	Value
Number of capital-good firms, consumption-good firms, households	N_K, N_C, N_H	200, 200, 10
Rate of technological development (excluding extraordinary shocks)	$E(e)$	0.005
Standard deviation of technological development	σ^e	0.001
Probability of an extraordinary technological shock	pr^u	0.03
Expected value of extraordinary technological shock	$E(u)$	0.07
Standard deviation of extraordinary technological shock	σ^u	0.01
Probability of technology copying	ς	0.3
Consumption-good firms' price markup target	μ_C	0.5
Autoregressive parameter of corporate price markup dynamics	ρ	0.9
Productivity growth threshold for endogenous price markup	r_{AL}^{tr}	0.01
Number of periods considered for the calculation of observed demand	n_D	8
Basis of weighting in the calculation of observed demand	α_D	0.99
Adjustment coefficient associated with productivity growth	η	1
Planned rate of reserves	ι	0.1
Rate of efficiency growth generating capital replacement	b	0.2
Ratio of output and investment productivity	r_{PI}	8
Depreciation rate	δ	0.02
Coefficient of the effect of relative price on market share	χ	0.025
Rate of loan repayment	c	0.015
Maximum growth rate of corporate credit	n_1	0.02
Maximum ratio of corporate credit to production costs	n_2	3
Firms' dividend payment rate	d	0.5
Rate of nominal wage growth	g_w	0.005
Share of consumption in permanent income	ψ	0.9
Number of periods considered for the calculation of permanent income	n_H	8
Basis of weighting in the calculation of permanent income	α_H	0.99
Reserve requirement	rr	0.02
Base rate (annualised value)	r	0.04
Interest rate spread on corporate loans	μ^C	200 bp
Interest rate spread on deposits	μ^D	-360 bp
Interest rate spread on government bonds	μ^G	-40 bp
Capital requirement (excluding CCB)	τ	0.08
Maximum capital buffer	τ^P	0.03
Minimum decline in credit-to-GDP ratio for the release of CCB	θ	0.05
Ratio of unemployment benefits to wages	ϕ	0.4
Corporate tax rate	tr^C	0.1
Income tax rate	tr^H	0.1
Rate of bank levy	tr^B	0.2

We tried to use the same parameter values as in Dosi et al. (2015), but in some cases we needed to alter them due to the changes we applied (e.g. technological progress and a different representation of the banking sector). To reduce computational time, we significantly decreased the number of households and it did not make significant difference since the findings of the model are not driven by household heterogeneity. We increased the number of capital-good firms because using the original number would have resulted in a faster spread of the additional technological shock and thus shorter business cycles. In the benchmark model investment accounted to 1-2 per cent of total GDP while we managed to have it around 20 per cent. Thus, in our model consumption-good firms need to have a higher markup to cover investment costs. We distinguished corporate tax rate from bank levy, the latter being twice as much. The reason is that insolvent banks are recapitalised by the government while defaulting firms are not.

MNB Working Papers 5

An agent based Keynesian model with credit cycles and countercyclical capital buffer

Budapest, May 2017